

Transient Stability Analysis of Multi Machine System

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Abstract: *The stability of an interconnected power system is its ability to return to normal or stable operation after having been subjected to some form of disturbance. Transient stability analysis has recently become a major issue in the operation of power systems due to the increasing stress on power system networks. This problem requires evaluation of a power system's ability to withstand disturbances while maintaining the quality of service. This paper introduces a method as an accurate algorithm to analyze transient stability for single and multi machine system.*

Keywords: Transient Stability, algorithm, multi machine.

1. Introduction

Power system stability is a very important aspect to supply continuous power. It is defined as that property of a power system that enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance. One of the stability problems is maintaining synchronous operation or synchronism especially that power system rely on synchronous machines.

The power system is routinely subjected to a variety of disturbances. Even the act of switching on an appliance in the house can be regarded as a disturbance. However, given the size of the system and the scale of the perturbation caused by the switching of an appliance in comparison to the size and capability of the interconnected system, the effects are not measurable. Large disturbance do occur on the system. These include severe lightning strikes, loss of transmission line carrying bulk power due to overloading. The ability of power system to survive the transition following a large disturbance and reach an acceptable operating condition is called transient stability.

Power systems are subjected to a wide range of disturbances, small and large. Small disturbances in the form of load changes occur continually; the system must be able to adjust to the changing conditions and operate satisfactorily. It must also be able to survive numerous disturbances of a severe nature, such as a short circuit on a transmission line or loss of a large generator. A large disturbance may lead to structural changes due to the isolation of the faulted elements. At an equilibrium set, a power system may be stable for a given (large) physical disturbance, and unstable for another. It is impractical and uneconomical to design power systems to be stable for every possible disturbance. The design contingencies are selected on the basis that they have a reasonably high probability of occurrence. Hence, large-disturbance stability always refers to a specified disturbance scenario. The response of the power system to a disturbance may involve much of the equipment. For

instance, a fault on a critical element followed by its isolation by protective relays will cause variations in power flows, network bus voltages, and machine rotor speeds; the voltage variations will actuate both generator and transmission network voltage regulators; the generator speed variations will actuate prime mover governors; and the voltage and frequency variations will affect the system loads to varying degrees depending on their individual characteristics. Further, devices used to protect individual equipment may respond to variations in system variables and cause tripping of the equipment, thereby weakening the system and possibly leading to system instability. If following a disturbance the power system is stable, it will reach a new equilibrium state with the system integrity preserved i.e., with practically all generators and loads connected through a single contiguous transmission system. Some generators and loads may be disconnected by the isolation of faulted elements or intentional tripping to preserve the continuity of operation of bulk of the system. Interconnected systems, for certain severe disturbances, may also be intentionally split into two or more "islands" to preserve as much of the generation and load as possible. The actions of automatic controls and possibly human operators will eventually restore the system to normal state. On the other hand, if the system is unstable, it will result in a run-away or run-down situation; for example, a progressive increase in angular separation of generator rotors, or a progressive decrease in bus voltages. An unstable system condition could lead to cascading outages and a shutdown of a major portion of the power system.

In this paper first stability of single machine system is analyzed and then transient stability of three machine six bus system is done for various fault location and fault clearing time.

2. Single Machine System

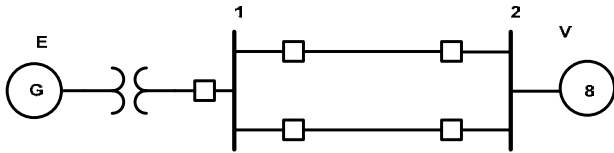


Figure 1. A single machine system connected to infinite bus

A single machine system connected to infinite bus through double circuit lines considered. The generator transient reactance is 0.35pu. Each transmission line has a reactance of 0.2 p.u. For the above said system stability analysis is done and swing curve is obtained using MATLAB code.

2.1 Result for fault clearing time of 0.125sec

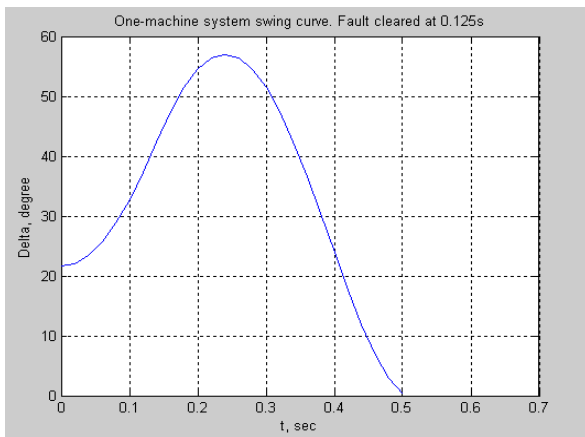


Figure 2. Swing Curve of SMIB for fault clearing time of 0.125 sec

2.2. For fault clearing time of 0.5 sec

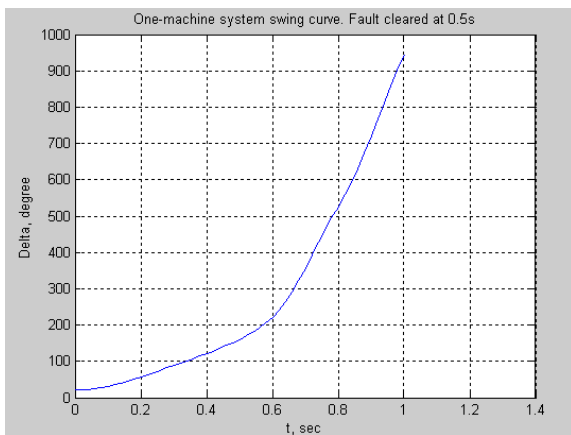


Figure 3. Swing Curve of SMIB for fault clearing time of 0.5 sec

3. Multi machine Transient Stability Analysis

3.1 Assumption in Multi machine stability analysis

1. All Asynchronous power is neglected.
2. Each synchronous machine is represented by a constant voltage source behind the transient reactance.
3. The governor's action is neglected and the input powers are assumed to remain constant.

4. Using the pre-fault bus data, all loads are converted to equivalent admittances to ground and are assumed to remain constant.
5. The mechanical rotor angle of each machine coincides with the angle of the voltage behind the machine reactance
6. Machine belonging to same station swing together and are said to be coherent. A group of coherent machine is represented by one equivalent machine.

3.2 Mathematical model for Multi machine system

Before stability analysis certain preliminary computations are to done:

1. All system data are computed on common base-100 MVA
2. All loads are converted as constant equivalent impedances.
3. Voltage behind the transient reactance is calculated.

The machine currents prior to disturbance are calculated from

$$I_i = \frac{S_i^*}{V_i^*} = \frac{P_i - jQ_i}{V_i^*} \quad i = 1, 2, \dots, m \quad (1)$$

Where

m is the number of generators

V_i is the terminal voltage of the i_{th} generator

P_i and Q_i are the generator real and reactive powers.

All unknown values are determined from the initial power flow solution. The generator armature resistances are usually neglected and the voltages behind the transient reactances are then obtained by

$$E^* = V_i + jX_d' I_i \quad (2)$$

All loads are converted into constant admittance by using relation

$$Y_{l0} = \frac{S^*}{|V_i|^2} = \frac{P_i - jQ_i}{|V_i|^2} \quad (3)$$

The nodal equation for the system is

$$I_{bus} = Y_{bus} V_{bus} \quad (4)$$

Where

I_{bus} is the vector of the injected bus currents

V_{bus} is the vector of bus voltages measured from the reference node

The diagonal elements of the bus admittance matrix are the sum of admittances connected to it, and the off-diagonal elements are equal to the negative of the admittance between the nodes. The reference is that additional nodes are added to include the machine voltages behind transient reactances. Also, diagonal elements are modified to include the load admittances. To simplify the analysis, all nodes other than the generator internal nodes are eliminated using Kron reduction formula. To eliminate the load buses, the bus admittance matrix is partitioned such that the n buses to be removed are represented in the upper n rows. Since no current enters or leaves the load buses, currents in the n rows

is zero. The generator currents are denoted by the vector I_m and the generator and load voltages are represented by the vector E'_m and V_n , respectively. Then, Equation in terms of sub matrices, becomes

$$\begin{bmatrix} 0 \\ I_m \end{bmatrix} = \begin{bmatrix} Y_{nn} & Y_{nm} \\ Y_{nm}^t & Y_{mm} \end{bmatrix} \begin{bmatrix} V_n \\ E'_m \end{bmatrix} \quad (5)$$

The voltage vector V_n may be eliminated by substitution as follows.

$$0 = Y_{nn}V_n + Y_{nm}E'_m \quad (6)$$

$$I_m = Y_{nm}^tV_n + Y_{mm}E'_m \quad (7)$$

On substitution (7) becomes

$$I_m = Y_{bus}^{red} E'_m \quad (8)$$

$$Y_{bus}^{red} = Y_{mm} - Y_{nm}^t Y_{nn}^{-1} Y_{nm} \quad (9)$$

The electrical power output of each machine is expressed by

$$P_{el} = \sum_{j=1}^m |E'_i| |E'_j| |Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (10)$$

Prior to disturbance the mechanical power and electrical power are same

$$P_{ml} = P_{el} = \sum_{j=1}^m |E'_i| |E'_j| |Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (11)$$

The swing equation for multi machine system is

$$\frac{H_i}{\pi f} \frac{d^2 \delta}{dt^2} = P_{ml} - \sum_{j=1}^m |E'_i| |E'_j| |Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (12)$$

Where

Y_{ij} are the elements of the reduced bus admittance matrix during fault .

H_i is the inertia constant of machine i expressed on common base.

For transient stability analysis we have to solve two state equations,

$$\frac{d\delta_i}{dt} = \Delta\omega_i \quad (13)$$

$$\frac{d\omega_i}{dt} = \frac{\pi f}{H_i} (P_m - P_e) \quad (14)$$

Transient stability study is based on the application of a three-phase fault. A solid three-phase fault at bus k in the network results in $V_k = 0$. When the fault is cleared, which may involve the removal of the faulty line, the bus admittance matrix is recomputed to reflect the change in the networks. Next the post fault reduced bus admittance matrix

is evaluated and the post fault electrical power of the i_{th} generator shown is readily determined from (10). Using the post fault power the simulation is continued to determine the system stability, until the plots reveal a definite trend as to stability or instability. Usually the slack generator is selected as the reference machine is plotted. The solution is carried out for two swings to show that the second swing is not greater than the first one. If the angle differences do not increase, the system is stable. If any of the angle differences increase indefinitely, the system is unstable.

4. Test System Configuration

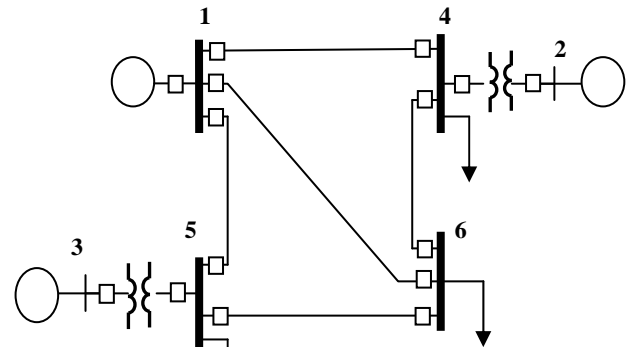


Figure 4. Three machine six bus test system

Table 1. Load Data

Bus No.	Load (MW)	Load (Mvar)
1	0	0
2	0	0
3	0	0
4	100	70
5	90	30
6	160	110

Table 2. Line data including transformer data

From Bus	To Bus	R (p.u.)	X (p.u.)	B/2 (p.u.)
1	4	0.035	0.225	0.0065
1	5	0.025	0.105	0.0045
1	6	0.400	0.215	0.0055
2	4	0.000	0.035	0.0000
3	5	0.000	0.042	0.0000
4	6	0.028	0.125	0.0035
5	6	0.026	0.175	0.0300

Table 3. Generation Schedule

Bus No.	Voltage mag	Generation (MW)	Mvar Limits	
			Minimum	Maximum
1	1.06	---	---	---
2	1.04	150	0	140
3	1.03	100	0	90

5. Simulation

Based on the procedure discussed above a MATLAB program is developed for transient stability analysis of the system under test. The program allows the analysis of transient stability of multi machine system subjected to

balanced three phase fault. The machines phase angle and swing curves are obtained.

Table 5. Analysis results of 3 Machine 6 bus systems

No	Faulted bus no.	Removed Faulty line	Clearing time (sec)	Phase angle difference characteristic	Analysis Result
1	5	1-5	0.2	Fig 5	Stable
2	5	1-5	0.5	Fig 6	Unstable
3	4	1-4	0.2	Fig 7	Stable
4	4	1-4	0.5	Fig 8	Unstable

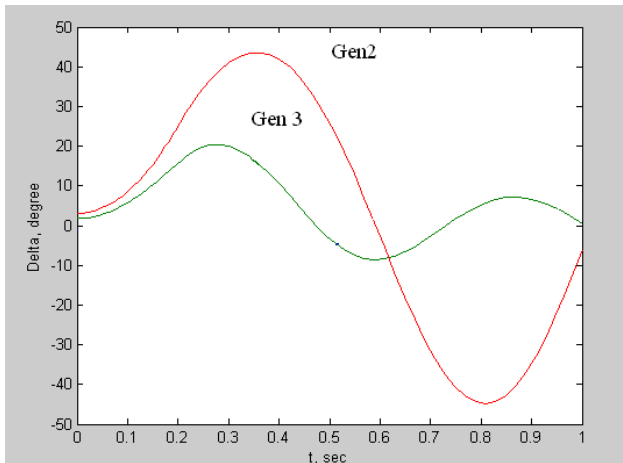


Figure 5. Three phase fault on line 1-5 fault clearing time is 0.2 sec system is stable

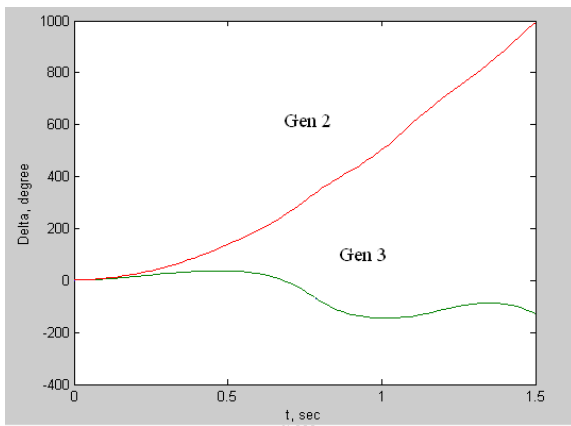


Figure 6. Three phase fault on line 1-5 fault clearing time is 0.5 sec system is unstable

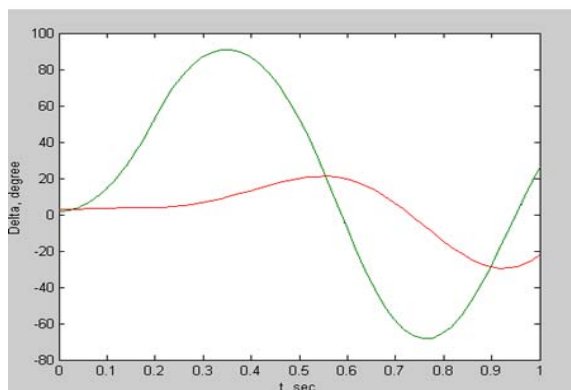


Figure 7. Three phase fault on line 1-4 fault clearing time is 0.2 sec system is stable

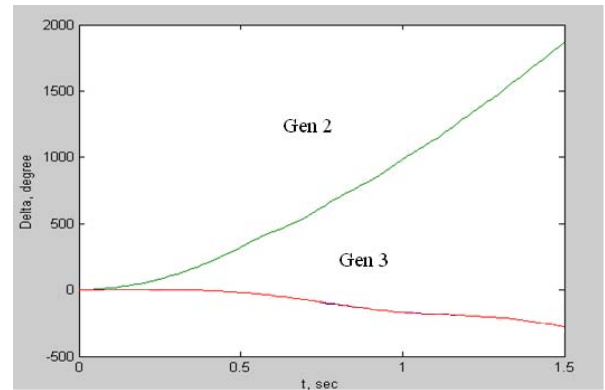


Figure 8. Three phase fault on line 1-4 fault clearing time is 0.5 sec system is unstable

6. Conclusions

In this paper the stability analysis of single machine connected to infinite bus and 3 machine six bus systems has been studied. Through analysis it can be determined whether the system is stable or unstable for a particular fault clearing time when subjected to a three phase fault. It can be seen from the phase angle characteristic that the relative swing between the generator phase angles is less when the fault clearing time is less. As the fault clearing time is increased to 0.5 seconds the system becomes unstable as phase angle of the generator 2 goes on increasing without the limit. In order for the system to be unstable the fault should be cleared within minimum time for system stability.

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