TRANSIENT STABILITY ANALYSIS OF A MULTIMACHINE POWER SYSTEM USING MATLAB

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Abstract: MATLAB, is a registered trademark of Math works, is a high level programming language which uses *matrices* as the basic numerical entities (rather than *scalars*, as in the low-level programming languages such as BASIC, FORTAN, PASCAL and C). MATLAB allows us to *directly* manipulate matrices-such as adding, multiplying, inverting matrices and solving for eigen values and eigenvectors of matrices. MATLAB contains a library of many useful functions-both basic functions and specialized mathematical functions with an advanced facility for plotting and displaying the results of computations in various graphical forms. Instead of issuing individual MATLAB commands, we can group a set of commands to be executed in MATLAB *program*, called an M-file. MATLAB software is increasingly being used as a basic program in many areas of research. As such, it also holds great trend in the area of power system. In this paper I have taken a multi-machine power system example to demonstrate the features and scope of a MATLAB program for transient stability analysis. A program has been developed which can work as a basic structure for advanced and detailed study.

Keywords: MATLAB, power-system modeling, program, transient stability.

1. Introduction

The stability of power systems has been and continues to be of measure concern in the system operation. Modern electrical power system have grown to a large complexity due to increasing interconnections, installations of large generating units and extra- high voltage tie-lines etc. 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 disturbances [1].This complicates the analysis of transient stability considerably. Repeated analysis is required for different disturbances that are to be considered. In the transient stability studies, frequently considered 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 a maximum acceleration of the connected machine [3].

If the perturbation does not involve any net change in power, the machines should return to their original state. If an unbalance between the supply and demand is created by a change in load, in generation, or in network conditions, a new operating state is necessary[2]. In any case, all interconnected synchronous machines should remain in synchronism if the system is stable, i.e., they should all remain operating in parallel and at the same speed. If the oscillatory response of a power system during the transient period following a disturbance is damped and the system settles in a finite time to a new steady operating condition, we say the system is stable.

"Power system stability is the ability of an electric power system , for a given initial operation condition, to regain a state of operation equilibrium after being subjected to a physical disturbance , with most system variables bounded so that practically the entire system remains stable**."**

Following a sudden disturbance on a power system rotor speeds, rotor angular differences and power transfer undergo fast changes whose magnitudes are dependent upon the severity of disturbance. For a large disturbance, changes in angular differences may be so large as to cause the machines to fall out of step. This type of instability is known as *transient instability* and is a fast phenomenon usually occurring within 1s for a generator close to the cause of disturbance. There is a large range of disturbances which may occur on a power system, but a fault on a heavily loaded line which requires opening the line to clear the fault is usually of a greatest concern. The tripping of a loaded generator or the abrupt dropping of a large load may also cause in- stability [4].

The effect of short circuit (faults), the most severe type of disturbance to which a power systems is subjected, must be determined in nearly all stability studies. During a fault, electrical power from near by generators is reduced drastically, while power from remote generators is scarcely affected. In some cases, the system may be stable even with a sustained fault where as other systems will be stable only if the fault is cleared with sufficient rapidity. Whether the system is stable on occurrence of a fault depends not only on the system itself but also on the type of fault, location of fault, rapidity of clearing and method of clearing , i.e., whether cleared by the sequential opening of two of more breakers or by simultaneous opening and whether or not the faulted line is reclosed. The transient stability limit is almost always lower than the steady state limit, but unlike the latter, it may exhibit different values depending on the nature, location and magnitude of disturbances [5].
Modern power systems have many interconnected generating stations, each with several generators and many loads. The machines located at anyone point in a system normally act in unison. It is, therefore, common practice in stability studies to consider all the machines at one point as one large machine. Also machines which are not separated by lines of high reactance are lumped together and considered as one equivalent machine. Thus a multimachine system can often be reduced to an equivalent few machine system. If synchronism is lost, the machines of each group stay together although they go out of step with other groups. Qualitative behavior of machines in an actual system is usually that of a two machine system. Because of its simplicity, the two machine system is extremely useful in describing the general concept of power system stability and the influence of various factors on stability. It will be seen that a two machine system can be regarded as a single machine system connected to infinite system. Stability study of a multimachine system must necessarily be carried out on a digital computer.

2. Multi-Machine Stability

Modern power systems are interconnected and operate close to their transient and steady state stability limits. In large interconnected systems, it is common to find a natural response of a group of closely coupled machines oscillating against other groups of machines. These oscillations have a frequency range of 0.1 Hz to 0.8 Hz. The lowest frequency mode involves all generators of the system. This oscillation groups the system into two parts - with generators in one part oscillating against those of the other part. The higher frequency modes are usually localized with small groups oscillating against each other. Unfortunately, the inter-area oscillation can be initiated by a small disturbance in any part of the system. These small frequency oscillations fall under the category of dynamic stability and are analyzed in linear domain through the liberalization of the entire interconnected systems model.

Inter-area oscillations manifest wherever the power system is heavily interconnected. The oscillations, unless damped, can lead to grid failure and total system collapse. Multimachine equations can be written similar to the one-machine system connected to the infinite bus. In order to reduce the complexity of the transient stability analysis, assumptions are made as follows-

- Each synchronous machine is represented by a constant voltage source behind the direct axis transient reactance. This representation neglects the effect of saliency and assumes constant flux linkages.
- The governor’s actions are neglected and the input powers are assumed to remain constant during the entire period of simulation.
- Using the prefault bus voltages, all loads are converted to equivalent admittances to ground and are assumed to remain constant.
- Damping or synchronous powers are ignored.
- The mechanical rotor angle of each machine coincides with the angle of the voltage behind the machine reactance.
- Machines belonging to the same station swing together and are said to be *coherent.* A group of coherent machines is represented by one equivalent machine.

The machine currents prior to disturbance are calculated from

$$I_i = \frac{S_i^*}{V_i^*} = \frac{P_i - jQ_i}{V_i^*} \tag{1}$$

i=1,2,3……,m where m is the number of generators.

V_i is the terminal voltage of the ith generator P_i and Q_i are the generator real and reactive powers.

To include voltages behind transient reactances, m buses are added to the n-bus power system network. Nodes n+1,n+2,…,n+m are the internal machine buses, ie., the buses behind the transient reactances.

$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \\ I_{n+1} \\ \vdots \\ I_{n+m} \end{bmatrix} = \begin{bmatrix} Y_{11} & \cdots & Y_{1n} & Y_{1(n+1)} & \cdots & Y_{1(n+m)} \\ Y_{21} & \cdots & Y_{2n} & Y_{2(n+1)} & \cdots & Y_{2(n+m)} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ Y_{n1} & \cdots & Y_{nn} & Y_{n(n+1)} & \cdots & Y_{n(n+m)} \\ Y_{(n+1)1} & \cdots & Y_{(n+1)n} & Y_{(n+1)(n+1)} & \cdots & Y_{(n+1)(n+m)} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ Y_{(n+m)1} & \cdots & Y_{(n+m)n} & Y_{(n+m)(n+1)} & \cdots & Y_{(n+m)(n+m)} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_n \\ E'_{n+1} \\ \vdots \\ E'_{n+m} \end{bmatrix}$$

$$\boldsymbol{I}_{bus} = \boldsymbol{Y}_{bus}\boldsymbol{V}_{bus} \tag{2}$$

Where $I_{bus}$is the vector of the injected bus currents and V_{bus} is the vector of bus voltages measured from the reference node. To simplify the analysis, all nodes other than the generator internal nodes are eliminated using the *Kron* reduction formula. To eliminate the load buses, the bus admittance matrix is portioned 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 are zero. The generator currents are denoted by the vector $\mathbf{I_m}$ and the generator and the load voltages are represented by the vectors $\mathbf{E_m}$'and$\mathbf{V_n}$, respectively. Then

$$\begin{bmatrix} \mathbf{O} \\ \boldsymbol{I}_m \end{bmatrix} = \begin{bmatrix} \boldsymbol{Y}_{nn} & \boldsymbol{Y}_{nm} \\ \boldsymbol{Y}_{nm}^t & \boldsymbol{Y}_{mm} \end{bmatrix} \begin{bmatrix} \boldsymbol{V}_n \\ \boldsymbol{E}'_m \end{bmatrix} \tag{3}$$

The voltage vector $\mathbf{V_n}$ may be eliminated by substitution as follows-

$$\mathbf{O} = \boldsymbol{Y}_{nn}\boldsymbol{V}_n + \boldsymbol{Y}_{nm}\boldsymbol{E}'_m \tag{4}$$

$$I_m = Y_{nm}^t V_n + Y_{mm} E'_m \tag{5}$$

From (4)

$$\boldsymbol{V}_n = -\boldsymbol{Y}_{nn}^{-1}\boldsymbol{Y}_{nm}\boldsymbol{E}'_m$$

Substituting into (5), we have

$$\boldsymbol{I}_m = \left[\boldsymbol{Y}_{mm} - \boldsymbol{Y}_{nm}^t\boldsymbol{Y}_{nn}^{-1}\boldsymbol{Y}_{nm}\right]\boldsymbol{E}'_m$$

$$= Y_{bus}^{red} E'_m \tag{6}$$

The reduced admittance matrix is

$$\boldsymbol{Y}_{bus}^{red} = \boldsymbol{Y}_{mm} - \boldsymbol{Y}_{nm}^t\boldsymbol{Y}_{nn}^{-1}\boldsymbol{Y}_{nm} \tag{7}$$

The reduced bus admittance has the dimensions ($m \times m$), where m is the number of generators.

The classical 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 $V_k = 0$. This is simulated by removing the *k*th row and column from the prefault bus admittance matrix. The new bus admittance matrix is reduced by eliminating all nodes except the internal generator nodes. The generator excitation voltages during the fault and postfault nodes are assumed to remain constant. The electrical power of the *i*th generator in terms of the new reduced bus admittance matrices are obtained and the swing equation with damping neglected for machine *i* becomes

$$\frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} = P_{mi} - \sum_{j=1}^{m}\left|E_i'\right|\left|E_j'\right|\left|Y_{ij}\right|\cos\left(\theta_{ij} - \delta_i - \delta_j\right) \qquad (8)$$

Where Y_{ij} are the elements of the faulted reduced bus admittance matrix, and H_i is the inertia constant of machine *i* expressed on the machine rated MVA S_{Gi} ,then H_i is given by

$$H_i = \frac{S_{Gi}}{S_B} H_{Gi} \qquad (9)$$

Showing the electrical power of the *i*th generator by P_e^f and transforming (8) into state variable model yields

$$\frac{d\delta_i}{dt} = \Delta\omega_i \qquad (10)$$

$$\frac{d\Delta\omega_i}{dt} = \frac{\pi f_0}{H_I}\left(P_m - P_e^{\ f}\right) \qquad (11)$$

Where $i = 1,2,\ldots m$

Illustrative system example

The power system network of an electric utility company is shown where the load data, voltage magnitude, generation schedule, and the reactive power limits for the regulated buses are collected. Bus 1, voltage is specified as $V_1 = 1.025\angle 0^0$ is as the slack bus. The line data containing the series resistance and reactance in per unit, and one-half of the total capacitance in per unit susceptance is on a 100-MVA base .A three-phase fault occurs on any of the line near any of the bus, and is cleared by the simultaneous opening of breakers at both ends of the line. A Matlab program has been developed to perform the transient stability analysis and the system stability is studied when the fault is cleared at a certain time.

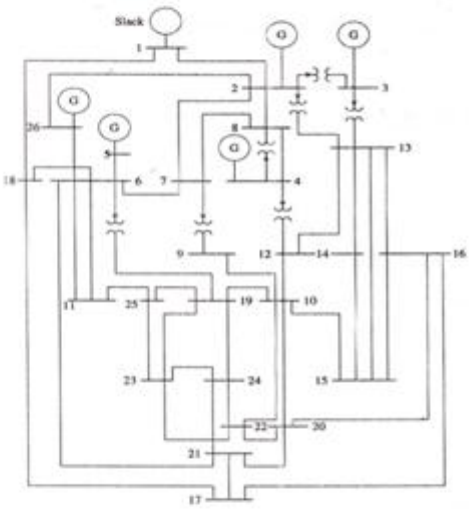

Fig 1.A 26- bus power system networks.

3. Matlab Results

System responses are found for different values of fault clearing time. The phase angle differences of each machine with respect to the slack bus are found out. The program also obtains a plot of the swing curves which show that the phase angle differences after reaching a maximum value, decreases and the machines swing together. Hence, the system is found to be stable.

For another fault clearing time the machine phase angle decreases or increases without limit. Thus the system is unstable. Suppose the faulted bus no. is 16, assuming the fault to be cleared by opening a line [16,17] within 0.3s,0.35s,0.4s and the system stability is checked.

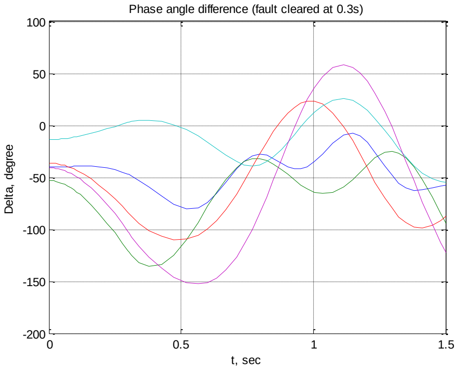

Fig 2 Plots of angle differences for machines att$_c$=0.3s.

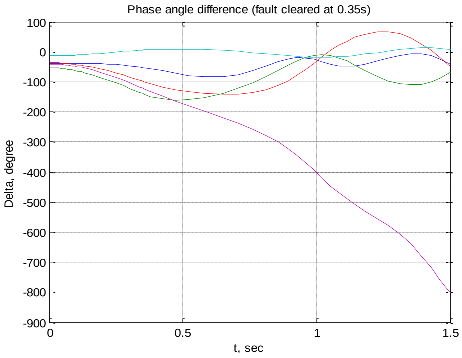

Fig 3 Plots of angle differences for machines att$_c$=0.35s.

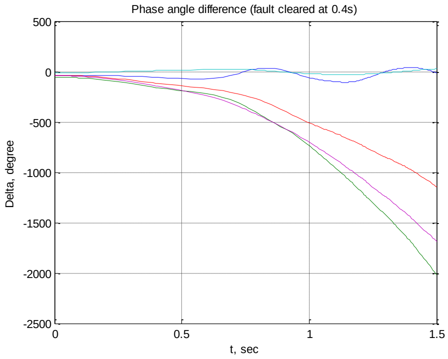

Fig 4 Plots of angle differences for machines at t$_c$=0.4s.

4. Prospects of The Future Work

It is clear from the above study that Matlab offers a wide perspective for programming and analysis of various power system networks. The features of Matlab are easy to understand and implement. In the present study, a 26 bus model of a multi-machine system was considered. However, it explains very well the principles and the scope of the tool, typically for the study of the transient stability in a power system. The other factors such as effects of excitation, turbine, speed governor or any control measure, can be easily realized through Matlab program. Furthermore, the optimization and application of ANN and fuzzy logic can be implemented through Matlab in transient stability studies.

5. Conclusions

A complete study for transient stability of a multi-machine power system was developed using Matlab. Thus Matlab programming is not only best suited for an analytical study of a power system network, but it can also incorporate the state-of- the- art tools for a detailed study and parameter optimization. The program is very user friendly, with tremendous interactive capacity. For a transient stability study the program facilitates fast and precise solution of non linear differential equation viz. the swing equation. The user can easily select and modify the solver type, step sizes, tolerance, simulation period, output options etc. Any parameter can easily be modified through simple Matlab commands to suit the changes in the original power system network due to a fault.

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