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Implementation of Point-By-Point Method for Interconnected Power System Network Stability Analysis

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Abstract

The stability of power system networks pertaining to two machine systems can be determined by Equal Area criterion method. In a power system network consisting of two machines namely Synchronous generator and Synchronous motor, as both machines equal size, equal moment of inertia, equal swing, the two-machine system can be considered as equivalent to single machine system and solution of single machine system can be also determined by Equal Area criterion method. However, the solution of interconnected power system network can be determined by point-by-point method.

Keywords: Power System Network, Step by Step method, Critical Clearing Angle

INTRODUCTION

The transient stability analysis requires the solution of a system of coupled non-linear differential equations. In general, no analytical solution of these equations exists. Multi-machine systems transient stability is analysed mostly by solving its swing equation for the machines and algebraic equations for the network by adopting suitable numerical method. However, techniques are available to obtain approximate solution of such differential equations by numerical methods, and one must therefore resort to numerical computation techniques commonly known as digital simulation.

If one generator goes out of step (loses synchronism), it may lead to a system-wide blackout. Swing equations are used to describe rotor dynamics during a disturbance [1].

This focuses on transient stability in power systems- how a power grid behaves after major disturbances (like faults or line failures) and whether it can return to normal operation. Single Machine System: A generator connected to a large power network (called an “infinite bus”). MATLAB was used to simulate different fault clearing times (e.g., 0.125s vs. 0.5s). Longer fault clearing times led to instability. Multi-Machine System: A 3-generator, 6-bus power system was modelled. Simplifications are made (e.g., constant voltage sources, neglecting damping, and constant power inputs). Key electrical equations and swing equations are solved step-by-step. Simulink is used to create subsystems for each generator and simulate both pre-fault and post-fault conditions [2].

Various assumptions were made (like neglecting governor action). Mathematical models used included bus admittance matrices and swing equations. Simulations showed that faster fault clearing leads to stability, and delays can cause system instability [3]. The modelling explains how to mathematically predict and analyse the behaviour of a power system (like a generator or multiple generators) when a sudden fault (like a short circuit) occurs [4]. This investigates how Distributed Generation (DG)—like solar, wind, and battery storage affects the stability of a power system during faults. The test system used is the IEEE 39-Bus System, which is a standard model used in power system studies. Energy Storage System (ESS): Acts as a buffer to improve stability by supplying or absorbing power quickly during faults

MATHEMATICAL MODELLING

The Equal Area Criterion (EAC) is a classical method used in transient stability analysis of power systems. It provides a graphical way to determine whether a generator will remain in synchronism after a disturbance, such as a fault. Originally developed for single-machine infinite bus (SMIB) systems, the EAC can also be extended and applied to multi-machine systems by reducing the system to equivalent two-machine models. The system conditions before the fault occurs, and the network configuration both during and after its occurrence, must be known in any transient stability study

The equal area criterion cannot be used directly in systems when three or more machines are represented. Although the physical phenomena observed in the two machine problems are basically the same in the multimachine case, the complexity of the numerical computations increases with the number of machines considered in a transient stability study. When a multi-machine system operates under electromechanical transient conditions, intermachine oscillations occur through the medium of the transmission system connecting the machines. A typical frequency of such oscillation is of the order of 1-2 Hz, and this is superimposed upon the nominal 50-Hz frequency of the system.

To use EAC in this case, the system is typically reduced:

- Select one generator and compare it with a group of other generators or the rest of the system modelled as an equivalent machine (or infinite bus).
- Apply the EAC between two equivalent machines.

When many machine rotors are simultaneously undergoing transient oscillations, the swing curves reflect the combined presence of many such oscillations. To ease the complexity of system modelling, and thereby the computational burden, the following additional assumptions are commonly made in transient stability studies:

1. The mechanical power input to each machine remains constant during the entire period of the swing curve computation.
2. Damping power is negligible.
3. Each machine may be represented by a constant transient reactance in series with a constant transient internal voltage.
4. The mechanical rotor angle of each machine coincides with ⍰, the electrical phase angle of the transient internal voltage.
5. All the loads may be considered as shunt impedances to ground with values determined by conditions prevailing immediately prior to the transient conditions.

The swing equations are nonlinear in nature. Formal solutions of such equations cannot be explicitly found. Even in the case of a single machine swinging with respect to an infinite bus, it is very difficult to obtain literal-form solutions, and computer methods are therefore normally used. To examine the stability of a two-machine system without solving the swing equation, a direct approach is possible as discussed in figure 1.

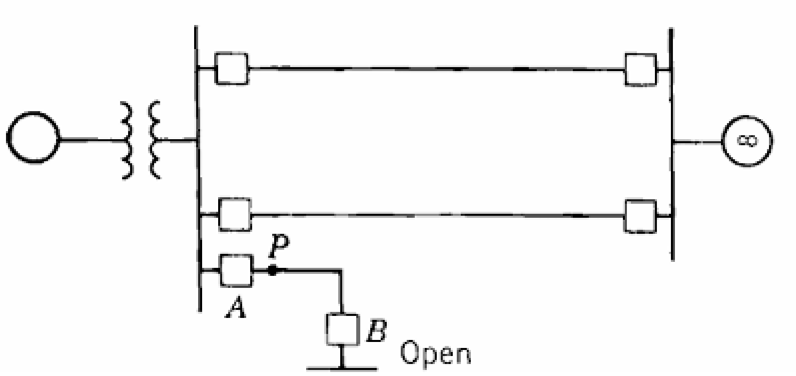

Figure 1: One-line diagram of the system with the addition of a short transmission line

Initially, circuit breaker A is considered to be closed while circuit breaker B at the opposite end of the short line is open. At point P close to the bus a three -phase fault occurs and is cleared by circuit breaker A after a short period of time. Thus, the effective transmission system is unaltered except while the fault is on. The short circuit caused by the fault is effectively at the bus, and so the electrical power output from the generator is zero until the fault is cleared. The physical conditions before, during, and after the fault can be understood by analysing the power-angle curves.

The generator is operating initially at synchronous speed with a rotor angle and the input mechanical power P_m equals the output electrical power P_e. When the fault occurs at t=0, the electrical power output is suddenly zero while the input mechanical power is unaltered. The difference in power must be accounted for by a rate of change of stored kinetic energy in the rotor masses. This can be accomplished only by an increase in speed which results from the constant accelerating power P_m.

The equal-area criterion is a very useful means for analysing stability of a system of two machines, or of a single machine supplied from an infinite bus. However, the computer is the only practical way to determine the stability of a large system. Because the equal-area criterion is so helpful in understanding transient stability.

However, if the fault is at the end of one of the lines, opening breakers at both ends of the line will isolate the fault from the system and allow power to flow through the other parallel line. When a three-phase fault occurs at some point on a double-circuit line other than on the paralleling buses or at the extreme ends of the line, there is some impedance between the paralleling buses and the fault. Therefore, some power is transmitted while the fault is still on the system.

The single line-to-ground fault occurs most frequently, and the three-phase fault is the least frequent. For complete reliability a system should be designed for transient stability for three-phase faults at the worst locations, and this is virtually the universal practice.

By determining swing curves for various clearing times, we can find the length of time permitted before clearing a fault. Standard interrupting times for circuit breakers and their associated relays are commonly 8,5,3 or 2 cycles after a fault occurs, and thus breaker speeds may be specified. Calculations should be made for a fault in the position which will allow the least transfer of power from the machine and for the most severe type of fault for which protection against loss of stability is justified.

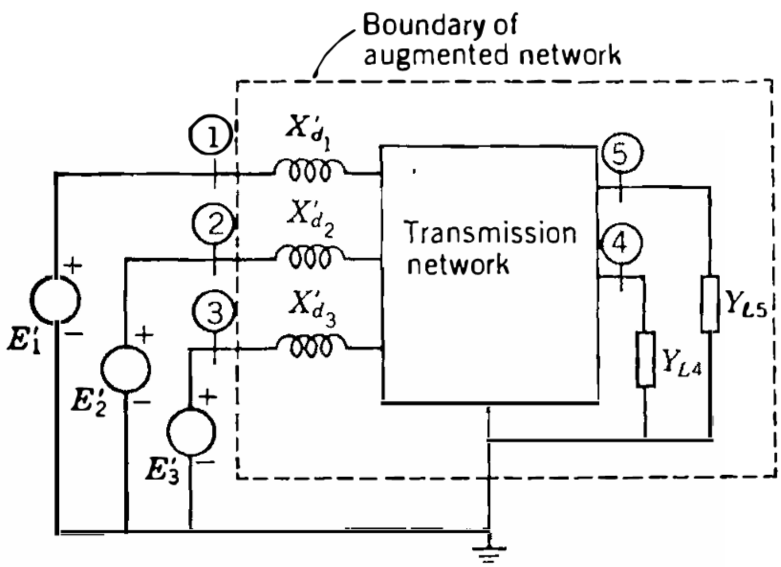

Figure 2: Multi-machine system model

A number of different methods is available for the numerical evaluation of second-order differential equations in step-by-step computations for small increments of the independent variable. The more elaborate methods are practical only when the computations are performed on a computer. The step-by-step method used for hand calculations is necessarily simpler than some of the methods recommended for computers. In the methods for hand calculation the change in the angular position of the rotor during a short interval of time is computed by making the following assumptions:

1. The accelerating Power P_a computed at the beginning of an interval is constant from the middle of the preceding interval to the middle of the interval considered.
2. Throughout any interval the angular velocity is constant at the value ω computed for the middle of the interval.

The accelerating power is calculated at the beginning of each interval and the solution progresses until enough points are obtained for plotting the swing curve. Greater accuracy is obtained when Δt is small. A value of $\Delta t = 0.05s$ is usually satisfactory.

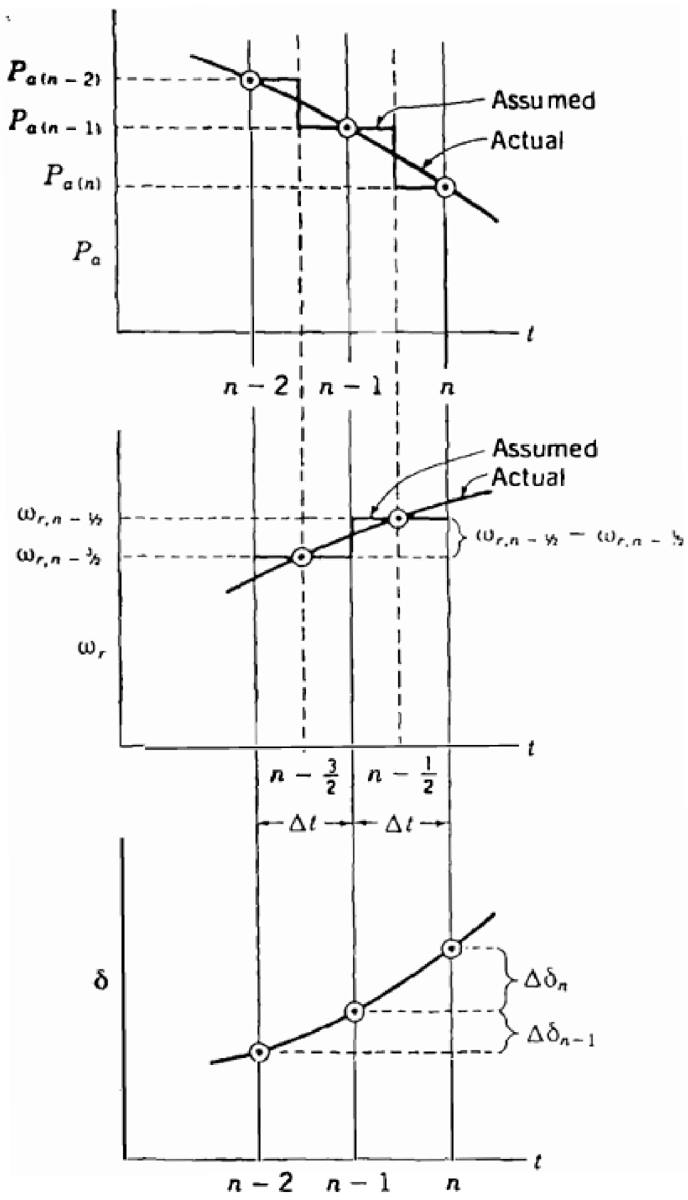

Figure 3: Actual values of P_a, ω_r as functions of time.

The occurrence of a fault causes a discontinuity in the accelerating power P_a, which has a zero value before the fault and a nonzero value immediately following the fault. Discontinuity occurs at the beginning of the interval when t=0. Reference to fig.3 shows that our method of calculation assumes that the accelerating power computed at the beginning of an interval is constant from the middle of the preceding interval to the middle of the interval being considered. When the fault occurs, we have two values of P_a at the beginning of an interval, and we must take the average of these two values as the constant accelerating power.

Two factors which indicate the relative stability of a generating unit are

1. The angular swing of the machine during and following fault conditions

2. The critical clearing time.

It has been seen that transient stability is greatly affected by the type and location of a fault, the following method of improving the transient stability limit of a power system.

- Increase of system voltages, use of AVR.
- Use of high-speed excitation systems.
- Reduction in system transfer reactance.
- Use of high-speed reclosing breakers. Modern tendency is to employ single-pole operation of reclosing circuit breakers.

Reducing transfer reactance is another important practical method of increasing stability limit. Incidentally this also raises system voltage profile. The reactance of a transmission line can be decreased

(i) By reducing the conductor spacing.
(ii) By increasing conductor diameter.

REALIZATION OF PROPOSED METHOD

MATLAB is a high-performance language for technical computing. The name MATLAB stands for matrix laboratory. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical users include Math and computation algorithm development data acquisition modelling, simulation, and prototyping data analysis, exploration, and visualization scientific and engineering graphics user application building. It allows you to solve many technical computational problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar no interactive language such as C or FORTRAN.

CONCLUSION

As the power system network is by default interconnected, point by point method is proved to be an effective method to determine the transient stability. In this method, the changes in position of rotor with respect to stator can be determined for every 0.05second and the new rotor angle has been determined based on which the transient stability has been determined.

Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship and publication of this article.

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