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Evaluating Transient Stability in Twin Machine Arrangement through Swing-equation

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Abstract

The steadiness in a connected to each other power system shows their capabilities for coming back into their steady or normal functions when different type of disturbances are presented. The structure of connections among each other tends to enlarge in size repeatedly and expanding across large geographical regions. Due to this it expected to be gradually more and more complicated to keep synchronism among the variety of parts under the power system. Recent made power systems are having so many generating units those are connected to each other with increasing loads. In this paper focus is made above one machine system's steadiness i.e. twin-machine stability.

Key words: *Stability, Swing-Equation, Synchronous-machine etc.*

1. Introduction

Engineer's capability shows the complete operation in the field of power system to get consistent and non-interrupted complete operation to provide consistent and uninterrupted service for the loads connected. Whatever the power supply is available is not sufficient as per reliability. Generally, constant voltage as well as frequency should be maintained all the way through the loads every times [1]. To achieve the demand in load, synchronous type generators have to be operating in parallel with required capacity for reliable service. In general condition, Synchronous machines will not fall out of step. Synchronizing services must be maintained in steps to vary the speed of the machine up and down. Certain condition will came where synchronizing services in the machines will not sufficient where a small variation inside the system requirements can affect the synchronism of the machines. The different conditions may be due to unexpected load, unusual network fault, fault in the equipments, fault in the line, fault in the generating devices etc.

The preservation of power network is the most need in steady electrical services. The connection between load points and the generation points are down through the transmission of high voltage. Any type of obstruction inside the network will affect the power flow towards load. In general all the power systems are connected to each other which tend to gather ideas on the huge geographical map so that all neighboring stations must be connected.

During operations each occasion when variation in loads takes place and can be overcome by the adjustment in the generation unit. Equilibrium state may be affected due to failure in synchronism as there may be growing oscillation in the transmission line which tends to lost in transmission time and subsequently tripping. These problems can be overcome by maintaining the stability in the power system.

2. Swing equation in Power system

2.1 Concept of Stability

It is the ability of the power system to build up some forces to restore the same or more as compared to the disturbing forces for to preserve the equilibrium state. When a power system is functioning with a load in a steady state form and problem is formulated then new adjustment is necessary in the voltage angle of connected synchronous machines [4]. Due to this, an unbalanced condition may occur between load and the system generation which tends to establish a new functioning condition in the steady state by the new set of arrangements in the voltage angles. It is expected to be creation of disturbances in generator loss, line loss or fault in both conditions. It may cause to changes in random or small load during normal functions. From the previous state to new adjustment state the duration taken is called transit time. The performance of the system at this time will establish stability of the system and will be named as dynamic performance of the system. It is important to maintain stability in synchronism by the synchronous machine after completing the transit time.

Here the system can be considered as stable if the response related to oscillation of power system in the transit time is damped and the new steady functioning approach is finalized in a finite duration. For stability system oscillations must be damped and also oscillators are stable in a mathematical approach. The cause is said to be practical as the system which is a continuously oscillating is not at all necessary for both user and supplier of electric energy. Hence it is necessary to accept practical requirements for considerable functioning aspects. The main problem in stability comes in the approaches of synchronous machine whenever a trouble occurs. So for better analysis, the problem related to stability is separated to steady state and transient state stability [2].

2.2 Concept of Swing equation

In general operating procedure, the ensuing magnetic field and the comparative place of the axis of rotor is set where there exist two different angle between them called torque and power angle [6]. If any type of problem is created which tends to disturb the acceleration of rotor with regard to air gap mmf of synchronous rotation where a concern motion in the state starts. To describe this in mathematically a equation is derived named as swing equation.

Standard operation of Synchronous machine:

For description, a synchronous generator is taken with its speed of synchronous ωsm and Te as electromagnetic torque. In general operating procedure, the torque due to mechanical action Tm is same as Te. When a disturbance occurs tends to vary the torque Ta which is the difference between mechanical torque and electromagnetic torque i.e. $Ta=Tm-Te$ ($Ta>0$ if improve in acceleration, $Ta<0$ if reduction in acceleration).

By considering the law of rotation for the above,

$$J\frac{d^2\theta_m}{dt^2} = T_a = T_m - T_e$$

Where, J is defined as the combined moment of inertia of generator and prime mover, θm is defined as rotor's angular displacement with regards to stationery position frame on the stator, $\theta m = \omega smt + \delta m$, ωsm is defined as the angular velocity constant.

Swing equation can be obtained in terms of M (inertial constant),

$$M\frac{d^2\delta_m}{dt^2} = P_m - P_e$$

The interlink between δ (electrical power angle), δm (mechanical power angle), mechanical and electrical speed,

$$\delta = \frac{p}{2}\delta_m\,,\;\; \omega = \frac{p}{2}\omega_m$$

where, pole number is defined by letter P.

Swing equation can be obtained in terms of δ (electrical power angle),

$$\frac{2}{p}M\frac{d^2\delta}{dt^2} = P_m - P_e$$

The above equation can be modified into per unit system,

$$\frac{2H}{\omega_s}\frac{d^2\delta}{dt^2} = P_{m(pu)} - P_{e(pu)}\,,$$

$$where\ M = \frac{2H}{\omega_s}$$

where, inertia constant is defined by the letter H.

2.3 Arithmetical solution to stability for steady-state

It is the tendency of power system to maintain synchronism during the little turbulence and proceeds to its original state and maintaining the stability during this period will not exaggerated with various types of control efforts [1].

Let us take the swing equation,

$$\frac{Hd^2\delta}{\pi f_0 dt^2} = P_{m(pu)} - P_{e(pu)} = P_m - P_{max}sin\delta$$

$$P_s = P_{max}cos\delta_0$$

Through this let us bring in a small disturbance $\Delta\ \delta$, derivation $\delta=\delta 0+\Delta\delta$, simplifying the nonlinear function of power angle δ and analyzing stability for steady-state by swing equation. The swing equation in terms of $\Delta\delta$ can be derived as,

$$\frac{H}{\pi f_0}\frac{d^2\Delta\delta}{dt^2} + P_m cos\delta_0\Delta\delta = 0$$

Concept of damping torque:

A torque due to induction will be created at rotor due to non-similar angular velocity among the field in air gap and

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rotor tends to reduce the dissimilar velocities. The concept of damping power through damping torque is,

$$P_d = D\frac{d\delta}{dt}$$

By implementing the damping power into swing equation we get the equation,

$$\frac{H}{\pi f_0}\frac{d^2\Delta\delta}{dt} + D\frac{d\Delta\delta}{dt} + P_s\Delta\delta = 0$$

$$\frac{d^2\Delta\delta}{dt^2} + 2\zeta\omega_n\frac{d\Delta\delta}{dt}\omega^2{}_n\Delta\delta = 0$$

Now the solution can be taken for swing equation,

$$\frac{d^2\Delta\delta}{dt^2} + 2\zeta\omega_n\frac{d\Delta\delta}{dt} + \omega^2{}_n\Delta\delta = 0$$

Considering the ancestry of the swing equation,

$$\Delta\delta = \frac{\Delta\delta_0}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin(\omega_d t + \theta)$$

$$\delta = \delta_0 + \frac{\Delta\delta_0}{\sqrt{1-\zeta^2}}e^{-\zeta\omega_n t}\sin(\omega_d t + \theta)$$

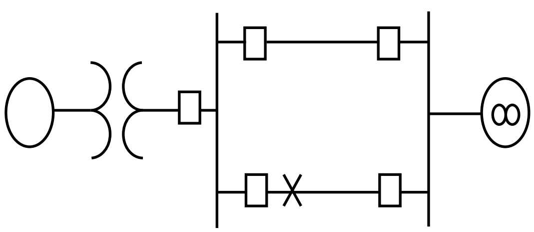

Figure-1: Layout diagram for Steady State Problem

2.4 Arithmetical solution to stability for Transient-state

This type of stability will be considered under severe disturbances in the machine. It is the strength of mind to clarify if the machine is maintaining synchronism under maximum disturbances. The disturbances may occur due to introduction of generation loss, large load loss and fault in the system or unexpected application of load [2]. Almost in every disturbance, it is not allowed for oscillations of such magnitude that creates linearization and it is required to solve the swing equation with nonlinear state.

To solve the system with arithmetical analysis of transient stability requires coupled of differential equations with non linear state [3]. Actually there is no analytical solving method exists. But, there are several methods are available for solving those differential equations approximately by arithmetical approaches through arithmetical computation methods through simulations in digital form. The most common use of such type of approaches to solve the swing equation is:

- Point by point approach
- Euler modified approach
- Runge-Kutta approach

During the investigation of this paper, two different approaches has been examined i.e. Euler modified approach and Point-by Point approach.

The swing equation can be modified into the form of state variable as,

$$\frac{d\delta}{dt} = \Delta\omega$$

$$\frac{d\Delta\delta}{dt} = \frac{\pi f_0}{H}P_a$$

By implementing Euler's modified approach,

$$\left.\frac{d\delta}{dt}\right|\Delta\omega^p{}_{i+1} = \Delta\omega^p{}_{i+1}\ \ where\ \Delta\omega^p{}_{i+1} = \Delta\omega_i + \left.\frac{d\Delta\omega}{dt}\right|\delta_i\ \Delta t$$

$$\left.\frac{d\Delta\omega}{dt}\right|\delta^p{}_{i+1} = \frac{\pi f_0}{H}P_a\Big|\delta^p{}_{i+1}\ \ where\ \delta^p{}_{i+1} = \delta_i + \left.\frac{d\delta}{dt}\right|\Delta\omega_i\,\Delta t$$

After this, the correct values will be calculated by taking the average value of both the derivatives.

$$\delta^c{}_{i+1} = \delta_i + \left(\frac{\left.\frac{d\delta}{dt}\right|\Delta\omega_i + \left.\frac{d\delta}{dt}\right|\Delta\omega^p{}_i}{2}\right)\Delta t$$

$$\Delta\omega^c{}_{i+1} = \Delta\omega_i + \left(\frac{\left.\frac{d\Delta\omega}{dt}\right|\delta_i + \left.\frac{d\Delta\omega}{dt}\right|\delta^p{}_i}{2}\right)\Delta t$$

The above equation can be implemented through the design using Simulink.

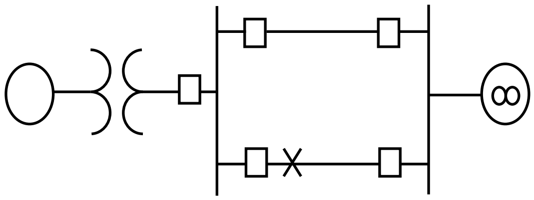

Figure-2: Design diagram for of Transient-State Stability

3. Twin-machine system

The consideration of Twin-machine system will be same as in the case of single-machine system. The conditions that can be followed for the case of twin-machine system are:

- A constant voltage E will be determined for every synchronous machine at the back of Xd by neglecting and flux changes and saliency.
- Power to the input side will made constant.
- All loads will be made corresponding admittances to ground by applying pre-fault bus voltages.
- All effects due to synchronisation and damping will be ignored
- The value of $\delta mech$ must be same to δ.
- Particular station machines will be swing jointly which is known to be coherent and all coherent system machines will be considered as a single-machine.

Approach to twin-machine system:

Towards the solution, examining starting flow of power, considering magnitude of starting bus voltage and determining the bus voltage,

$$I_i = \frac{S^*{}_i}{V^*{}_i} = \frac{jQ_i}{V^*{}_i},$$

$$E'_i = V_i + jX'_i I_i$$

By taking into calculation for equivalent admittance of load,

$$y_{io} = \frac{P_i - jQ_i}{|V_i|^2}$$

The equation for system nodes,

$$\begin{bmatrix} 0 \\ I_m \end{bmatrix} = \begin{bmatrix} Y_{nn} & Y_{nm} \\ Y^t{}_{nm} & Y_{mm} \end{bmatrix} \begin{bmatrix} V_n \\ E'_m \end{bmatrix}$$

This gives the output power of machine in terms of mechanical and electrical during steady-state before the disturbances occurs. Conventional transient stability consideration is related to the application of fault for three-phase. It gives,

$$P_{ei} = P_{mi} = R_e\{\acute{E}_i, I_i\} = \sum_{j=1}^{m} . \left| \acute{E}_i \right\| \acute{E}_j \left\| Y_{ij} \right| cos\left(\theta_{ij} - \delta_i + \delta_j\right)$$

Calculating the swing equation for the system with twin-machine,

$$\frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} = P_{mi} - \sum_{j=1}^{m} . \left| \acute{E}_i \right\| \acute{E}_j \left\| Y_{ij} \right| cos\left(\theta_{ij} - \delta_i + \delta_j\right) = P_{mi} - P_{ei}$$

Where, Y_{ij} gives the admittance matrix for faulted minimized elements.

Mathematically the model for state variable of swing equation is,

$$\frac{d\delta_i}{dt} = \Delta\omega_i\,, \quad i = 1, K, n$$

$$\frac{d\Delta\omega_i}{dt} = \frac{\pi f_0}{H_i}(P_{mi} - P_{ei})$$

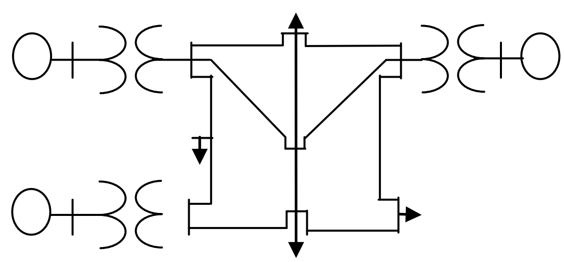

Figure-3: Layout diagram for stability of Twin-machine

4. Simulation through Simulink

For suitable verification and simulation, data of an electrical organization related to a power system network is utilized. Different data values are rightfully considered for the simulation such as schedule of generation, regulated bus's reactive power limits and load data etc. Slack bus is cautiously considered with a particular value of system's bus-1. Other data like gendata, line data, bus data, mailer, accuracy and basemva are also suitable adopted in the form of matrix. The total simulation process through Simulink is examined by MATLAB software.

Figure-4: Simulation result for Twin-machine Stability with Fault cleared at0.4 sec.

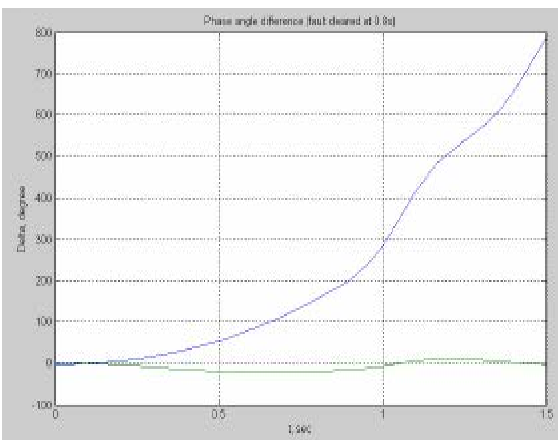

Figure-5: Simulation result for Twin-machine Stability with Fault cleared at 0.8sec.

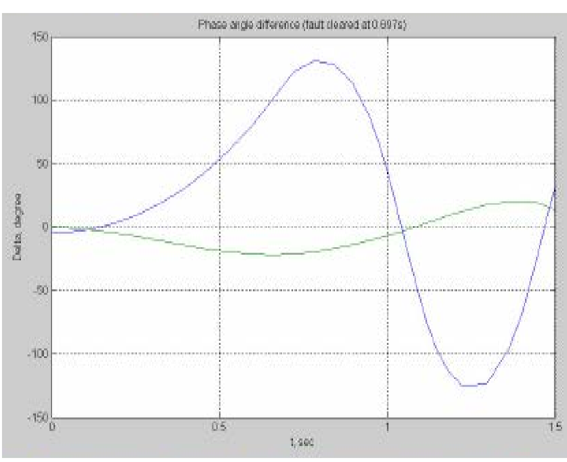

Figure-6: Simulation result for Twin-machine Stability with Fault cleared at 0.697sec.

Result Analysis

After taking suitable data for validating the system with Simulink, the obtained result can be analyzed as:

Differences in various phase angles when it reaches the maximum of *δ21=123.90* and *δ31=62.950* which will decrease where the machines swing jointly. It was observed that, the system appears stable condition when fault is cleared in *0.4* sec. From the swing curves in the figure it was observed that, phase angle of second machine rises with no boundary. At this stage the system is said to be unstable at *0.5* sec. fault cleared. Further the process of simulation is continued to repeat for fault cleared time *0.45* sec. and it was found that the system is critically stable.

Conclusion

The stability of a power system is severely targeted using transient analysis with the type of system fault and location of the occurred fault. Due to this a power system forecaster must go through deeply into the study of stability for solving the type and location of the fault. Hence, a twin-machine arrangement may be consistently reduced to a single-machine arrangement with a infinite bar connection. If there is a arrangement of huge multi-machine then the arrangement is separated into sub-systems with an external sub-system to restrict the need of time and memory of the computer. The modelling of sub-system is done and the rest of the external sub-system can be carried out through estimated modelling. The final conclusion based on quality upon stability of the system drawn from the twin-machine arrangement or corresponding single-machine arrangement with infinite bus structure can be extended without difficulty into a multi-machine arrangement. It can be observed that, the transient state stability is very much affected by location and area of fault.

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