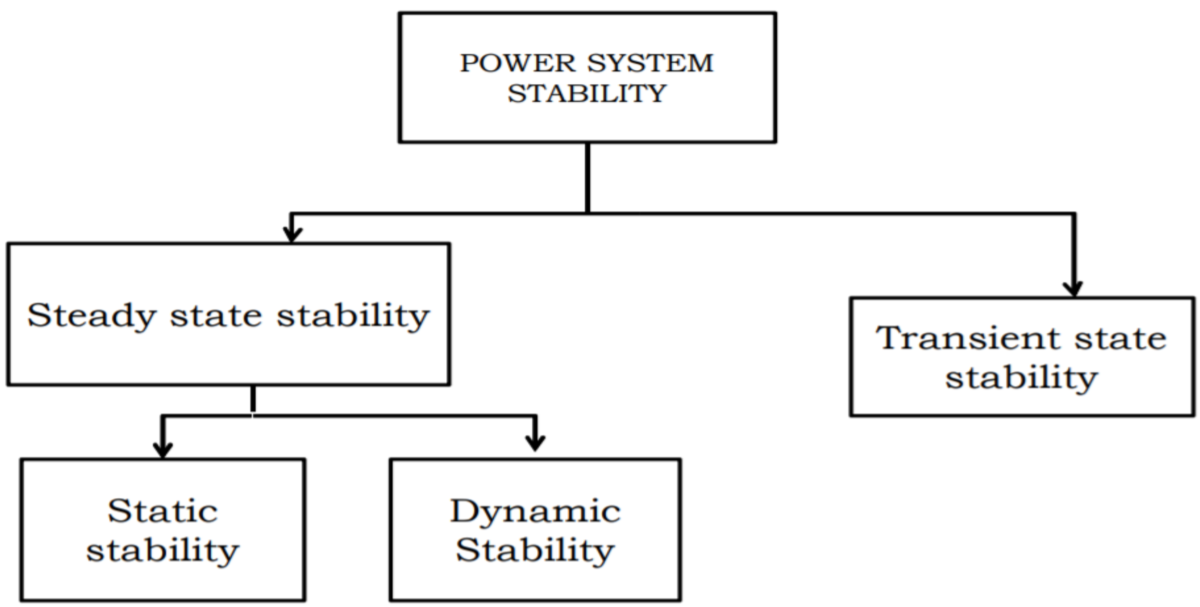
TRANSIENT ANALYSIS OF MULTI MACHINES

POWER SYSTEM STABILITY

- Power System is a very large complex network consisting of synchronous generators, transformers, switch gears etc.
- A large power system consists of a number of synchronous machines (or equipment or components) operating in synchronism.
- When the system is subjected to some form of disturbance, there is a tendency for the system to develop forces to bring it to a normal or stable condition.
- The term stability refers to stable operation of the synchronous machines connected to a power system when they are subjected to sudden disturbances.
- Depending on the nature and magnitude of disturbances the stability studies can be classified in to the following types
  1. Steady state stability
  2. Transient stability



Steady state stability

- It is defined as the ability of a power system to remain stable (i.e., without losing synchronism) for small disturbances (gradual changes in load).
- It is basically concerned with the determination of the upper limit of machine loading without losing synchronism, provided the loading is increased gradually.
- In this we concentrate on restricting the bus voltages close to their nominal values.
- We also ensure that phase angles between two buses are not too large and check for the overloading of the power equipment and transmission lines. These checks are usually done using power flow studies.
- It can further be classified into
    - Static stability
    - Dynamic stability
- Static stability
    - It refers to the stability of the system that obtains without the aid of automatic control devices such as governors and voltage regulators.
- Dynamic stability
    - The ability of a power system to maintain stability under continuous small disturbances.
    - It involves the response to small disturbances that occur on the system, producing oscillations. The system is said to be dynamically stable if these oscillations do not acquire more than certain amplitude and die out quickly. If these oscillations continuously grow in amplitude, the system is dynamically unstable. The source of this type of instability is usually an interconnection between control systems.
    - In other words, It refers to artificial stability given to an inherently unstable system by automatic control devices. It is concerned with small disturbances lasting for 10 to 30 sec.

Transient stability

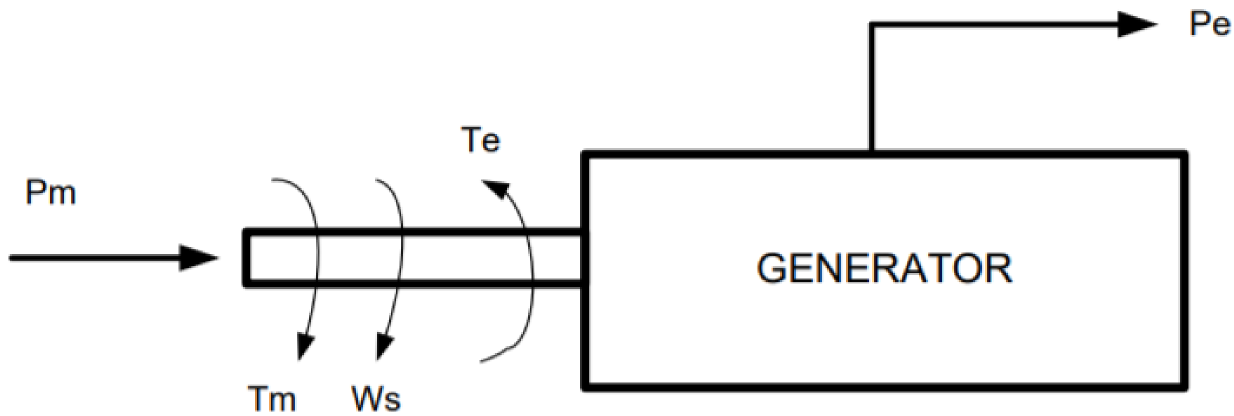
- It involves the study of the power system following a major disturbance.
- The objective of the transient stability study is to ascertain whether the load angle returns to a steady value following the clearance of the disturbance.
- It is defined as the ability of a power system to remain stable for large disturbances. (such as sudden change in loads, loss of generations, excitations, transmission facilities, switching operations and faults)
- Transient stability is a fast phenomenon usually evident within a few seconds.
- If the system experiences a shock by sudden and large power changes and violent fluctuations of voltage occurs. Consequently machines or groups of machines may go out of step. The rapid application of the large disturbances is responsible for the loss of stability, otherwise it may be possible to maintain stability if the same large load is applied gradually. Thus, the transient stability limit is lower than the steady state limit.

Power system stability mainly concerned with rotor stability analysis. For this various assumptions needed such as:

- For stability analysis balanced three phase systems and balanced disturbances are considered.
- Deviations of machine frequencies from synchronous frequency are small.
- During short circuits in the generator, dc offset and high frequency current are present. But for analysis of stability, these are neglected.
- Network and impedance loads are at steady state. Hence voltages, currents and powers can be computed from the power flow equation.

SWING EQUATION

- The differential equation that relates the angular momentum M, the acceleration power Pa and the rotor angle δ is known as SWING EQUATION.
- In other words, the behavior of a synchronous machine during transients is described as the swing equation.
- Solution of the swing equation will show how the rotor angle changes with respect to time following a disturbance. The plot of δ (load angle) Vs t (time) is called the SWING CURVE.
- If δ increases continuously with time the system is unstable and if δ starts decreasing after reaching a maximum value it is said that the system will remain stable.
- Once the swing curve is known, the stability of the system can be assessed.



The figure above shows Flow of power in a synchronous generator

- We know

$$\delta = \theta_e - \omega_s t$$

- Swing equation is given by

$$\frac{H}{\pi f} \cdot \frac{d^2\delta}{dt^2} = (P_i - P_e)\ \text{pu}$$

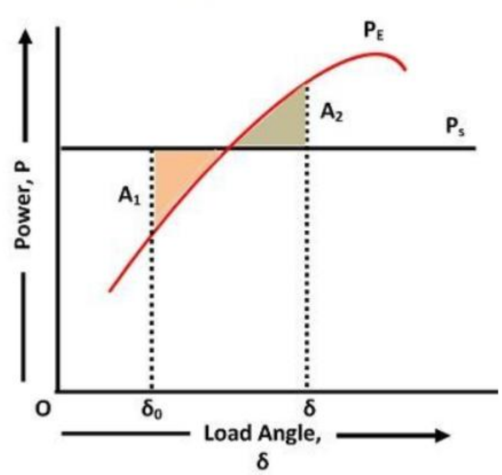
Where **δ** is power angle of synchronous machine
θe is electrical angular position of the rotor
Ws synchronous speed
Pe is electromagnetic power corresponding to electromagnetic torque Te

Pi is input torque

- It describes the rotor dynamics for a synchronous machine. Damping must be considered in dynamic stability study.
- **Multi Machine System**
  In a multi machine system a common base must be selected.
  Let ,
  G machine = machine rating (base)
  G system = system base
  Now the swing equation can be written as..
  $$\left(\frac{H_{system}}{\pi f}\right)\frac{d^2\delta}{dt^2} = (P_i - P_e) \text{ pu on system base}$$
  Where,
  $$H_{system} = \frac{G_{machine}}{G_{system}}.H_{machine}$$ = machine inertia constant in system base

EQUAL AREA CRITERIA

- It is a simple graphical method to analysed the transient stability of a system
- The stability of a single machine connected to an infinite bus can be studied by the use of equal area criterion.
- This principle does not require the swing equation for the determination of stability conditions.
- The stability conditions are recognized by equating the areas of segments on the power angle diagram between the p-curve and the new power transfer line of the given curve.
- The principle of this method consists on the basis that when δ oscillates around the equilibrium point with constant amplitude, transient stability will be maintained.



- The condition for the transient state stability is given by the equation
  $$\int_{\delta_0}^{\delta} P_a d\delta = 0$$
- The area A1 represents the kinetic energy stored by the rotor during acceleration.

- The area A2 represents the kinetic energy given up by the rotor to the system, and when it is all given up, the machine has returned to its original speed.
- The area under the curve PA should be zero, which is possible only when PA has both accelerating and decelerating powers, i.e., for a part of the curve PS> PE and for the other PE> PS.
- For a generation action, PS> PE for the positive area and A1> PS for negative areas A2 for stable operation. Hence the name equal area criterion.

Single machine, infinite bus system Model:

We know,

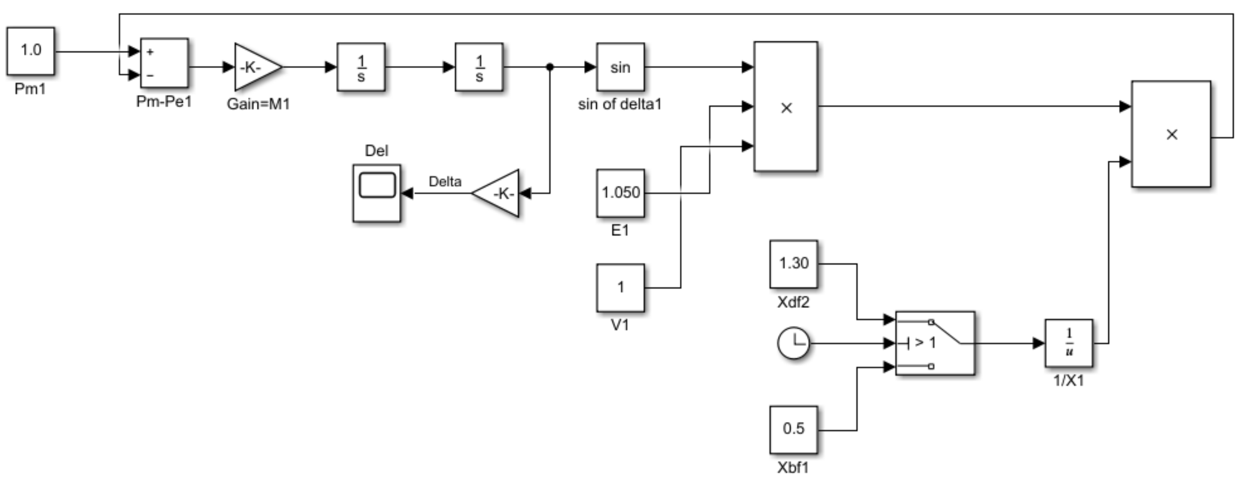
$$\left(\frac{H_{system}}{\pi f}\right)\frac{d^2\delta}{dt^2} = (P_i - P_e) \text{ pu on system base}$$

Using this equation, we have made a simulation for a single machine, infinite bus system. Here, the value of Pm is taken as constant whereas the value of Pe is fed back after a series of operations with Pm. The values considered in the model are as follows:

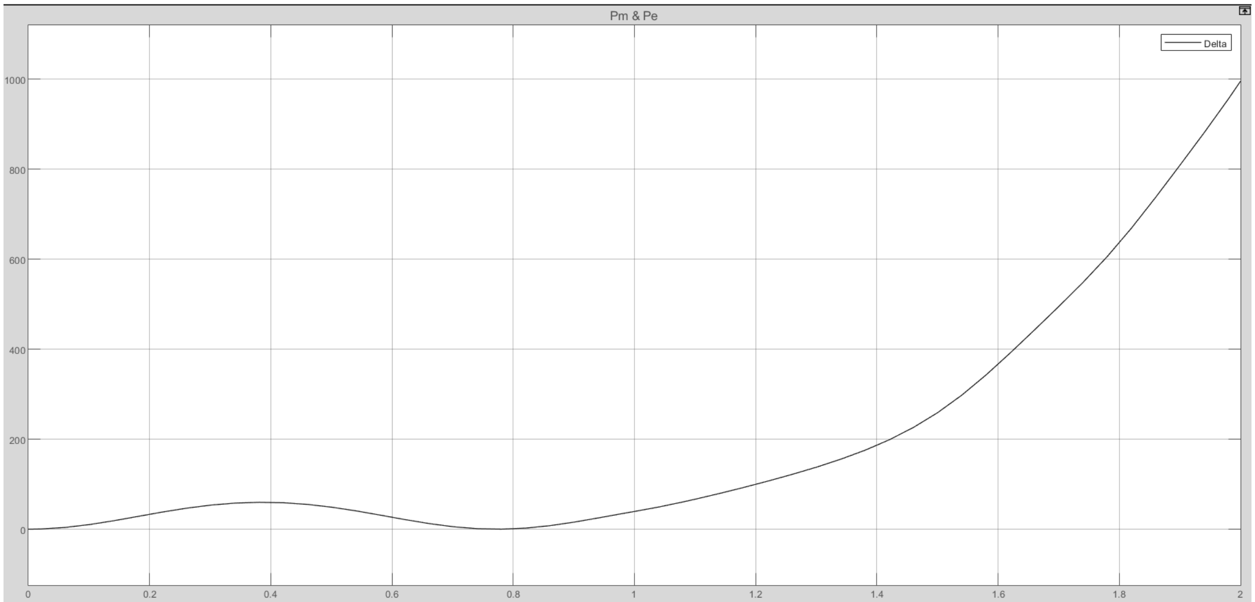
1. Pm = 0.9
2. M=3.14*50/2.52
3. E = 1.1
4. V = 1

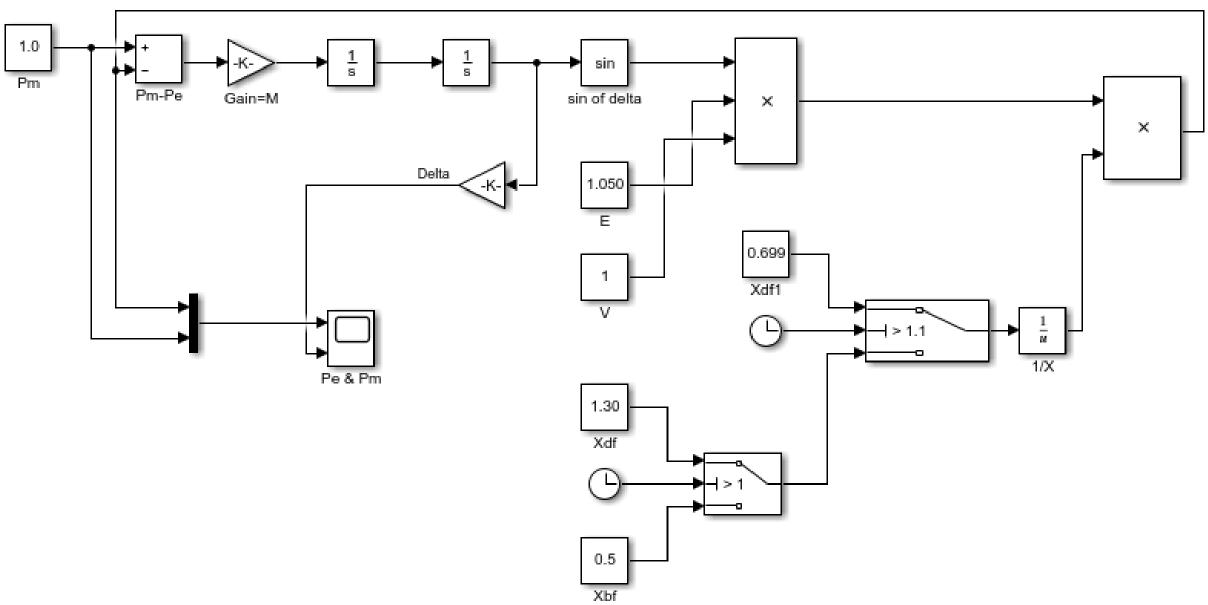
Simulation:

A.

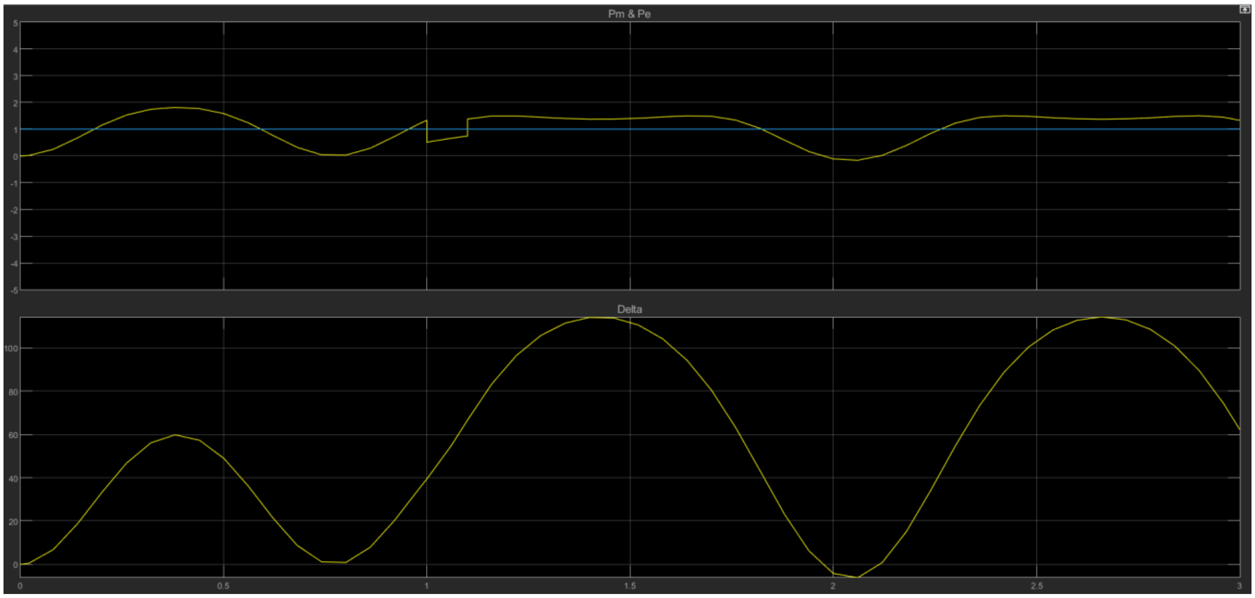


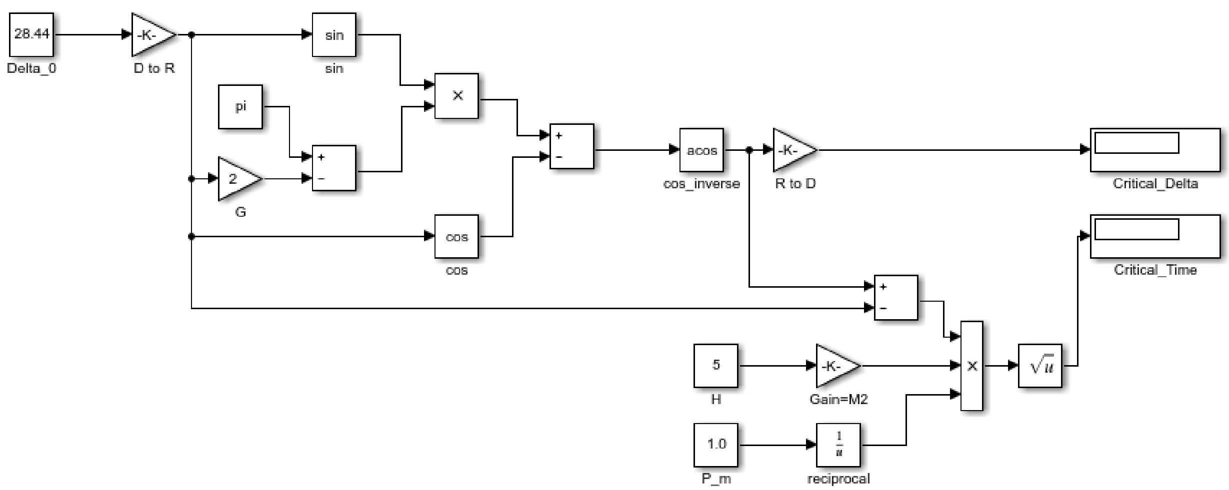
RESULT: Change in rotor angle, with respect to time when both pre fault and post fault is considered:



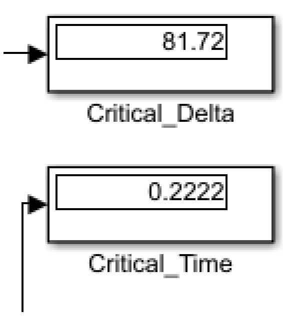


RESULT: The graph of variation in Pm and Pe:



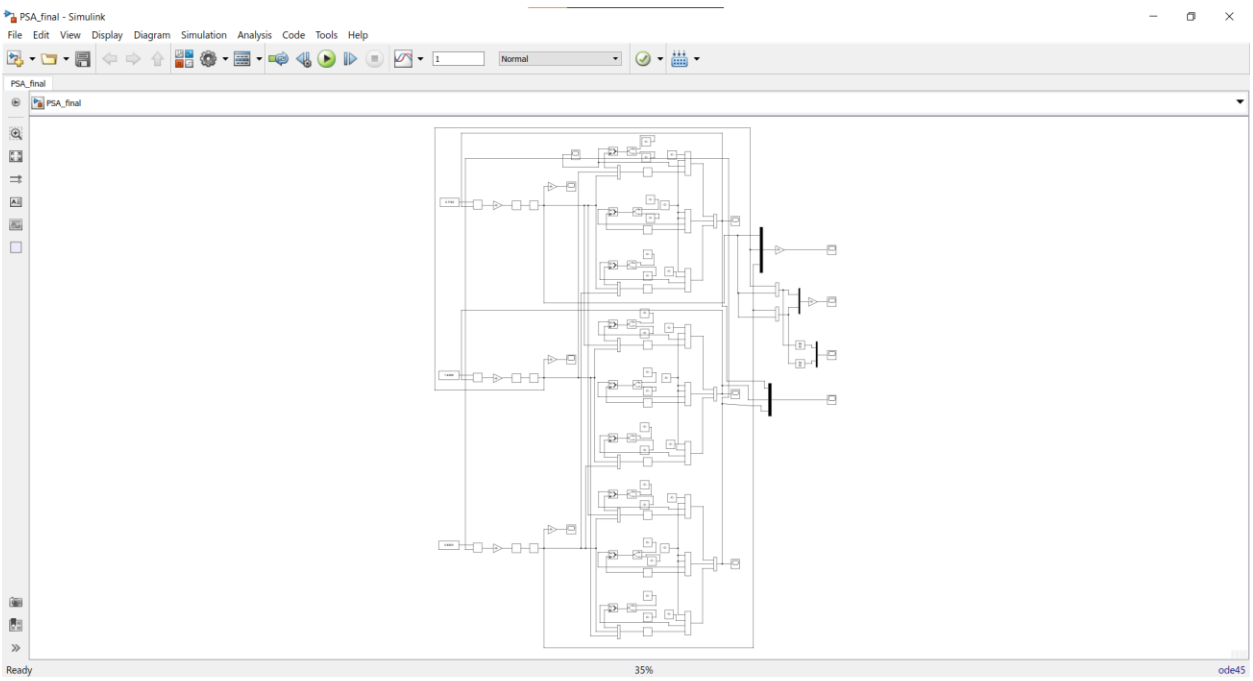


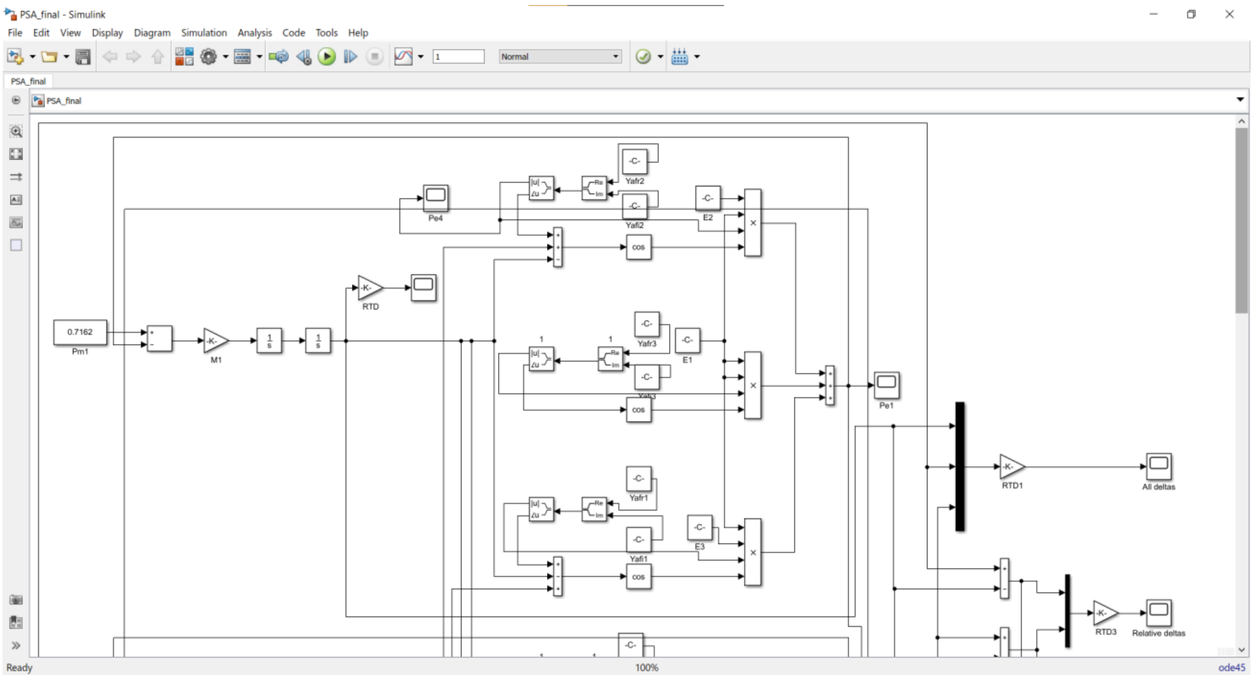
Result: Calculation of Critical delta and critical time, beyond which if the value of rotor angle increases, the system would become unstable:



Classical system model

The complete 3-generator system, given in Fig. above, has been simulated as a single integral model in Simulink. The mathematical model given above gives the transfer function of the different blocks. Fig. below shows the complete block diagram of a classical system representation for transient stability study. The model also facilitates the choice of simulation parameters, such as start and stop times, type of solver, step sizes, tolerance and output options etc. The model can be run either directly or from the MATLAB command line or from an m-file program. In the present study, the fault clearing time, the initial values of parameters as well as the changes in network due to fault, are controlled through an m-file program in MATLAB.

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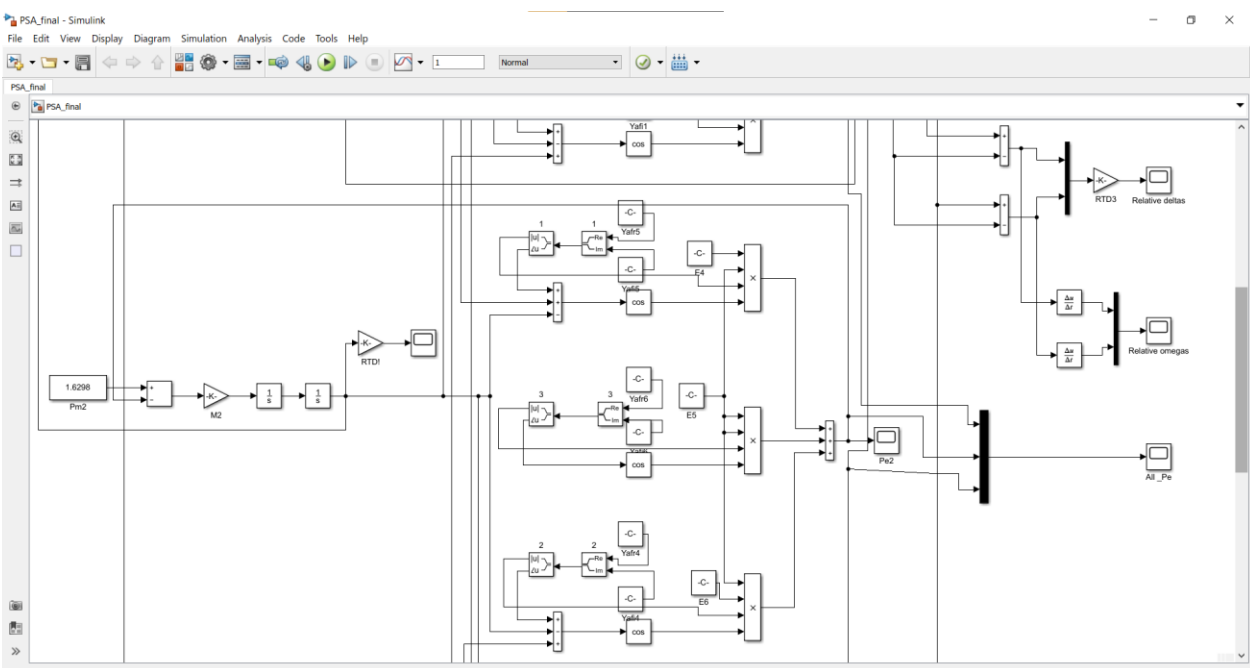
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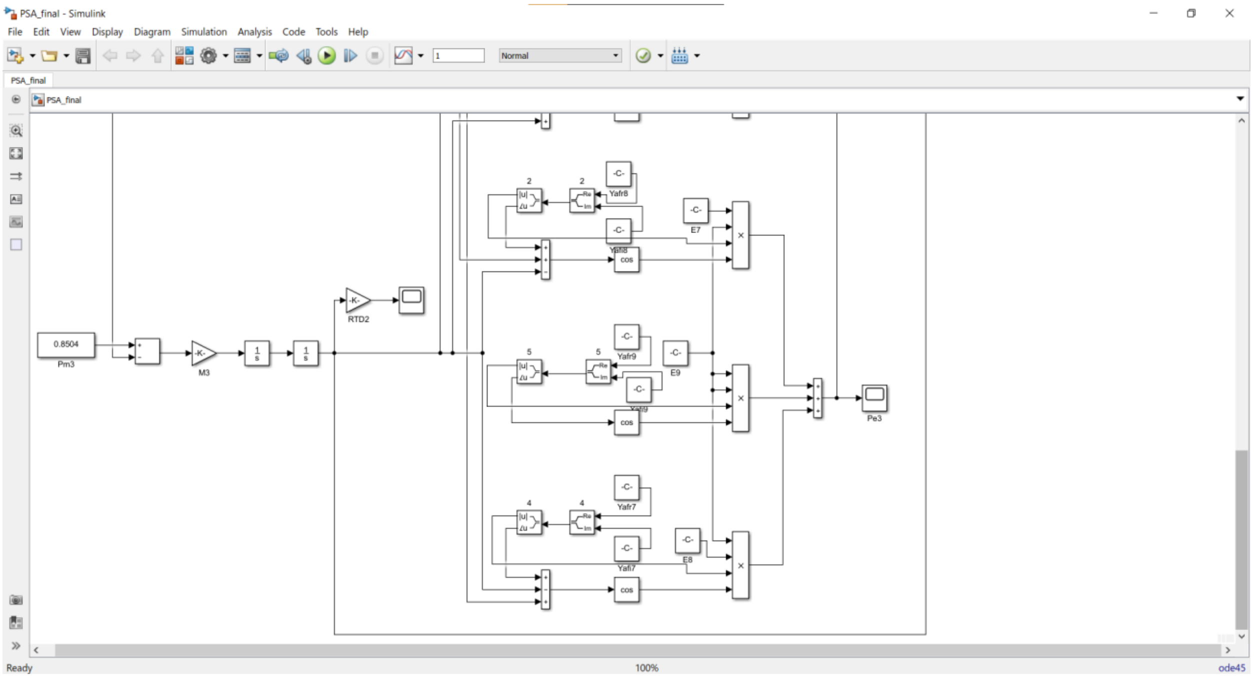


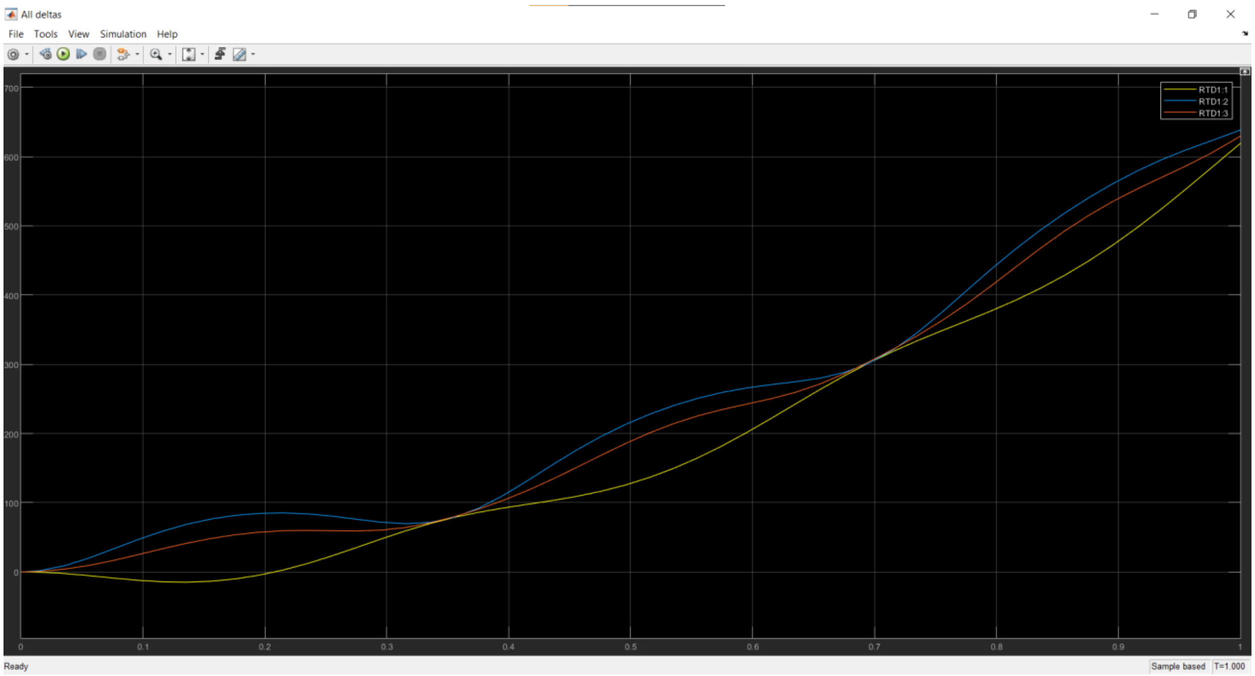
Fig. Complete classical system model for transient stability study.

Simulation results

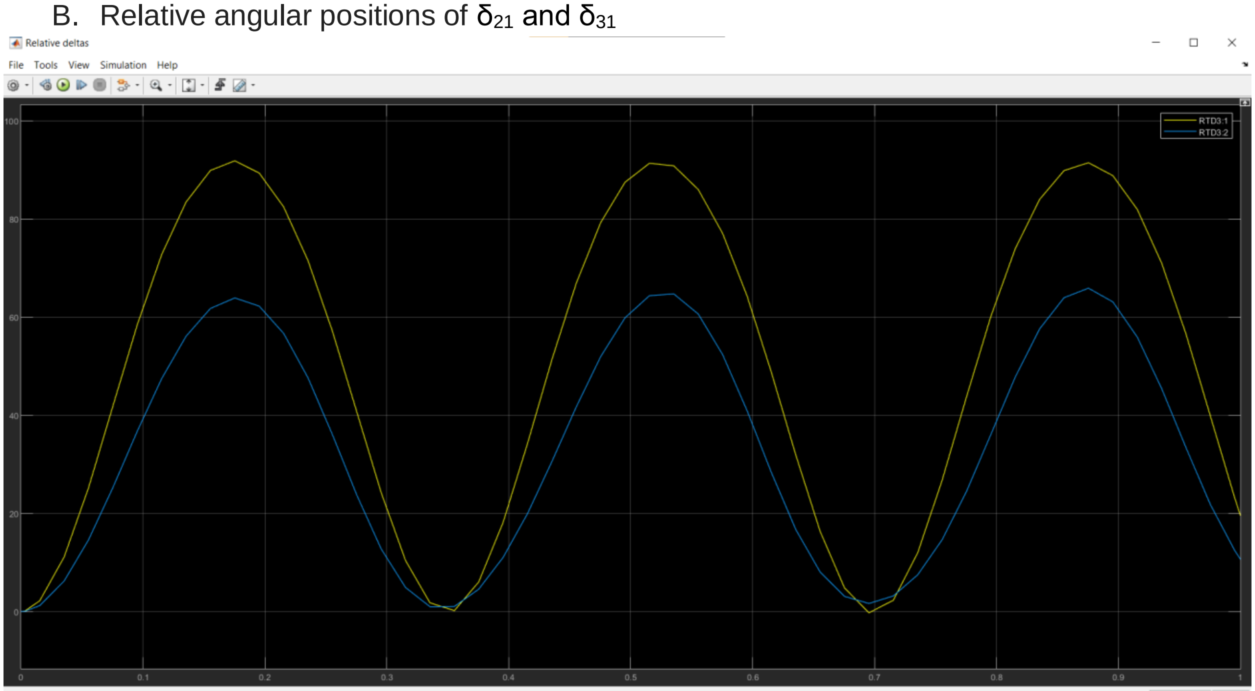
System responses are given for different values of fault clearing time (FCT). Figs A and B show the individual generator angles and the difference angles (with= gen. #1 as reference) for the system with FCT 0.1 s, whereas Figs C and D show the rotor angular speed deviations and accelerating powers for the same case.

The results show that the power system is stable in this case.

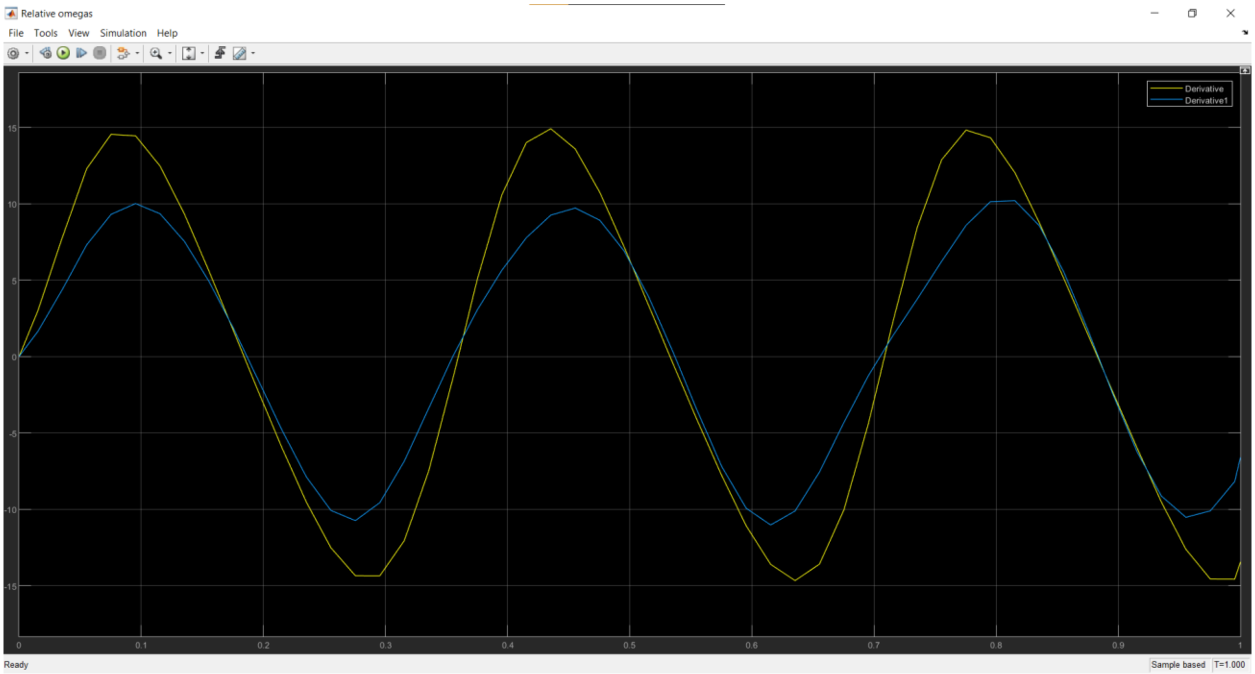
A. Angular position of individual generators



B. Relative angular positions of δ_{21} and δ_{31}



C. Relative angular velocities ω_{21} and ω_{31}



D. Generator accelerating powers