Question # 3 (10 marks)

A synchronous machine with inertia constant $H = 5.0$ second is delivering a steady-state power of 2.0 pu to a 60 Hz power system representing an infinite bus at voltage 1 pu. The internal voltage of the machine is 1.1 pu and the transfer reactance between the machine and system is 0.22 pu. A three-phase fault occurred at a point in the system. The power-angle equation during fault is $P_e^{During} = 3.0 \sin(\delta)$ pu. The fault was cleared after 0.325 seconds returning the system to its original status.

a) Write the power-angle equation before fault (substitute all known quantities). Then calculate the initial rotor angle.

b) Write the swing equation for the machine during the fault (substitute all known quantities).

c) Taking a time interval of 0.05 seconds, perform a step-by-step solution procedure to compute the swing curve of the machine for a period of 0.5 seconds after fault occurrence.

d) If the electrical power output during fault was reduced to zero, what would be the value of rotor angle after 0.2 seconds.

e) Comparing the results from c) and d) above, which case is worse from the stability point of view

Question # 5 (10 marks)

The set of measurements fed to the state estimator for a given power system, with 3 states, are as follows:
$z_1 = 0.92$, $z_2 = 1.02$, $z_3 = 0.605$, $z_4 = 0.598$, $z_5 = 0.305$.

The variances of the measurement errors are:
$\sigma_1^2 = \sigma_2^2 = (0.01)^2$, $\sigma_3^2 = \sigma_5^2 = (0.02)^2$, $\sigma_4^2 = (0.015)^2$

The state estimates at the end of a state estimation stage are as follows:
$\hat{x}_1 = -0.1762$, $\hat{x}_2 = 0.9578$, $\hat{x}_3 = 0.9843$

The system model $\mathbf{h}(\mathbf{x})$ representing measurements as functions of states has the following values:
$h_1 = 0.9578$, $h_2 = 0.9843$, $h_3 = 0.3240$, $h_4 = 0.6610$, $h_5 = -0.0430$

The coefficient matrix of the system model at the solution point is given by

$$H_x = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -0.6610 & -3.8761 & 4.4303 \\ -3.7125 & 0.6901 & 0.6716 \\ -0.6610 & 3.7863 & -3.7719 \end{bmatrix}$$

Use the following table for $\chi^2_{k,\alpha}$ distribution to determine whether there are any bad data in the above five measurements, and which measurement would be rejected if any. Use a value of $\alpha = 0.01$.

	α					α			
k	0.05	0.025	0.01	0.005	k	0.05	0.025	0.01	0.005
1	3.84	5.02	6.64	7.88	6	12.59	14.45	16.81	18.55
2	5.99	7.38	9.21	10.60	7	14.07	16.01	18.48	20.28
3	7.82	9.35	11.35	12.84	8	15.51	17.54	20.09	21.96
4	9.49	11.14	13.28	14.86	9	16.92	19.02	21.67	23.59
5	11.07	12.83	15.09	16.75	10	18.31	20.48	23.21	25.19

Q5

$$e = z - h = \begin{bmatrix} 0.92 \\ 1.02 \\ 0.602 \\ 0.598 \\ 0.305 \end{bmatrix} - \begin{bmatrix} 0.9578 \\ 0.9843 \\ 0.324 \\ 0.661 \\ -0.043 \end{bmatrix} = \begin{bmatrix} -0.0378 \\ 0.0357 \\ 0.281 \\ -0.063 \\ 0.348 \end{bmatrix}$$

$$f = \sum_{i=1}^{5} \frac{e_i^2}{\sigma_i^2} = \sum_{i=1}^{5} e_i^2 w_i$$

$$w_i = \begin{bmatrix} 10000 & 0 & 0 & 0 & 0 \\ 0 & 10000 & 0 & 0 & 0 \\ 0 & 0 & 2500 & 0 & 0 \\ 0 & 0 & 0 & 4444.44 & 0 \\ 0 & 0 & 0 & 0 & 2500 \end{bmatrix}$$

$$f = (-0.0378)^2(10000) + (0.0357)^2(10000) + (0.281)^2(2500) + (-0.063)^2(4444.44) + (0.348)^2(2500) = 544.83$$

$X^2_{K,\alpha}$

$$K = \# z - \# x = 5 - 3 = 2$$

$$\alpha = 0.01$$

$$X^2_{2,0.01} = 9.21$$

$$f > X^2_{2,0.01}$$

$\therefore$ There is at least one bad data

$$\text{Standrized error} = \frac{\hat{e}_i}{\sqrt{R'_{ii}}}$$

$$R' = [I - H(H^T W H)^{-1} H^T W] W^{-1}$$

$$R' = \begin{bmatrix} 0.0000438 & & & & \\ & 0.0000502 & & & \\ & & 0.0001877 & & \\ & & & 0.0000077 & \\ & & & & 0.0002223 \end{bmatrix}$$

$$\text{Standrized error} = \frac{\hat{e}_i}{\sqrt{R'_{ii}}} = \begin{bmatrix} -5.711 \\ 5.038 \\ 20.51 \\ -22.703 \\ 23.34 \end{bmatrix} \rightarrow \text{Badest measurement}$$

$\therefore Z_5$ rejected