QUESTION BANK

1. A cylindrical rotor generator delivers 0.5 pu power in the steady-state to an infinite bus through a transmission line of reactance 0.5 pu. The generator no-load voltage is 1.5 pu and the infinite bus voltage is 1 pu. The inertia constant of the generator is 5 MW-s/MVA and the generator reactance is 1 pu. The critical clearing angle, in degrees, for a three-phase dead short circuit fault at the generator terminal is

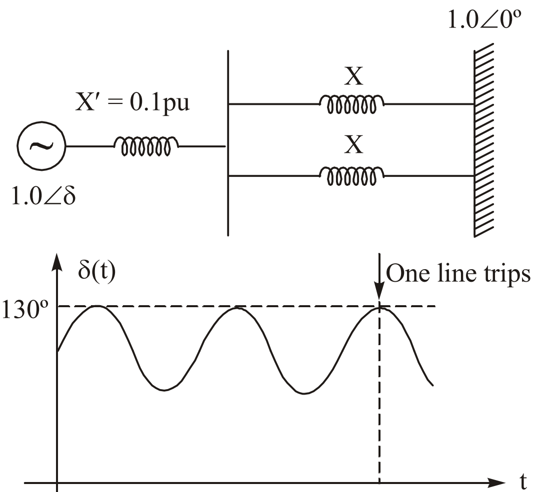
(a) 53.5 (b) 60.2
(c) 70.8 (d) 79.6

2. A 500 MVA, 21 kV, 50 Hz, 3-phase, 2-pole synchronous generator having a rated p.f. 0.9, has a moment of inertia of 27.5×10^3 kg–m^2.

The inertia constant (H) will be

(a) 2.44 (b) 2.71
(c) 4.88 (d) 5.42

3. Consider a synchronous generator connected to an infinite bus by two identical parallel transmission lines. The transient reactance X′ of the generator is 0.1 pu and the mechanical power input to it, is constant at 1.0 pu. Due to some previous disturbance, the rotor angle (δ) is undergoing an undamped oscillation, with the maximum value of δ(t) equal to 130º. One of the parallel lines trip due to relay maloperation at an instant when δ(t) = 130º as shown in the figure. The maximum value of the per unit line reactance, X such that the system does not loss synchronism subsequent to this tripping is



(a) 0.87 (b) 0.74
(c) 0.67 (d) 0.54

Common Data Questions 4 & 5:

A generator feeds power to an infinite bus through a double circuit transmission line. A 3-phase fault occurs at the middle point of one of the lines. The infinite bus voltage is 1 pu, the transient internal voltage of the generator is 1.1 pu and the equivalent transfer admittance during fault is 0.8 pu. The 100 MVA generator has an inertia constant of 5 MJ/MVA and it was delivering 1.0 pu power prior of the fault with rotor power angle of 30º. The system frequency is 50 Hz.

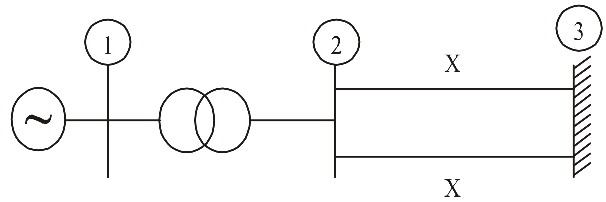
4. The initial accelerating power (in pu) will be

(a) 1.0 (b) 0.6
(c) 0.56 (d) 0.4

5. If the initial accelerating power is X pu, the initial acceleration in elect deg/sec, and the inertia constant in MJ-sec/elect deg respectively will be

(a) 31.4 X, 18 (b) 1800 X, 0.056
(c) X/1800, 0.056 (d) X/31.4, 18

6. A generator with constant 1.0 p.u. terminal voltage supplies power through a step-up transformer of 0.12 p.u. reactance and a double- circuit line to an infinite bus bar as shown in the figure. The infinite bus voltage is maintained at 1.0 p.u. Neglecting the resistances and susceptances of the system, the steady state stability power limit of the system is 6.25 p.u. If one of the double-circuit is tripped, then resulting steady state stability power limit in p.u. will be



(a) 12.5 p.u. (b) 3.125 p.u.
(c) 10.0 p.u. (d) 5.0 p.u.

7. A generator delivers power of 1.0 p.u. to an infinite bus through a purely reactive network. The maximum power that could be delivered by the generator is 2.0 p.u. A three-phase fault occurs at the terminals of the generator which reduces the generator output to zero. The fault is cleared after t_c second. The original network is then restored. The maximum swing of the rotor angle is found to be δ_{max} = 110 electrical degree. Then the rotor angle in electrical degrees at $t = t_c$

(a) 55 (b) 70
(c) 69.14 (d) 72.4

8. A generator feeds power, to an infinite bus which is maintained at 1 pu, through a double circuit transmission line. A $3-\phi$ fault occurs at the middle point of one of the lines. The transient internal voltage of generator is 1.1 pu and equivalent transfer reactance during fault is 1.2 pu. If mechanical input is maintained constant at 1 pu and rotor angle was 30º. The initial accelerating power is

(a) 0.54 pu (b) 0.46 pu
(c) 0.32 pu (d) 0.63 pu

9. Three 50 Hz generating units operate in parallel within same generating station, have ratings

G_1: 11 kV, 200 MVA, 0.8 pf, 5 MJ/MVA

G_2: 11 kV, 500 MVA, 0.9 pf, 10 MJ/MVA

G_3: 11 kV, 100 MVA, 0.8 pf, 8 MJ/MVA

The equivalent inertia constant on 500 MVA base is

(a) 7.7 MJ/MVA (b) 13.6 MJ/MVA
(c) 23 MJ/MVA (d) 10 MJ/MVA

10. A constant load of 300 MW is supplied by two 200 MW generators, 1 and 2, for which the respective incremental fuel costs are

$$\frac{dC_1}{dP_{G1}} = 0.1P_{G1} + 20$$

$$\frac{dC_2}{dP_{G2}} = 0.12\,P_{G2} + 15$$

with power P_G in MW and costs C in Rs/h. Determine (a) the most economical division of load between the generators, and (b) and saving in Rs/day there by obtained compare to equal load sharing between machines.

11. The transient stability of the power system can be effectively improved by

(a) Excitation improved by
(b) Phase shifting transformer
(c) Single pole switching of circuit breakers.
(d) Increasing the turbine valve opening

12. During a disturbance on a synchronous machine, the rotor swings from A to B before finally settling down to a steady state at point C on the power angle curve. The speed of the machine during oscillation is synchronous at point(s)

(a) A and B (b) A and C
(c) B and C (d) only at C

13. A 100 MVA, 11 kV, 3-phase, 50 Hz, 8-pole synchronous generator has an inertia constant H equal to 4 MJ/MVA. The stored energy in the rotor of the generator at synchronous speed will be $H = \frac{E}{G}$

(a) 100 MJ (b) 400 MJ
(c) 800 MJ (d) 12.5 MJ

14. Steady state stability of a power system is the ability of the power system to

(a) Maintain voltage at the rated voltage level.
(b) Maintain frequency exactly at 50 Hz.
(c) Maintain a spinning reserve margin at all times.
(d) Maintain synchronism between machines and on external tie lines.

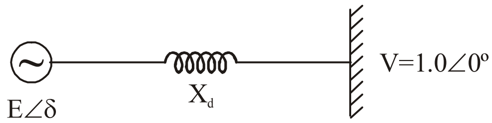
15. A power station consists of two synchronous generators A & B of ratings 250 MVA and 500MVA with inertia 1.6 p.u. and 1.0 p.u., respectively on their own base MVA ratings. The equivalent p.u. inertia constant for the system on 100MVA common base is

(a) 2.6 (b) 0.615
(c) 1.625 (d) 9.0

16. In a system, there are two generators operating in parallel. One generator, of rating 250 MVA, has an inertia-constant of 6 MJ/MVA while the other generator of 150 MVA has an inertia-constant of 4 MJ/MVA. The inertia-constant for the combined system on 100 MVA common base is ______ MJ/MVA.

17. A synchronous motor is receiving 50% of the power, from an infinite bus. If the load on the motor is suddenly reduced to 80% of the previous value, swing of the motor around its new equilibrium position.

18. An alternator is connected to an infinite bus as shown in figure. It delivers 1.0 p.u. current at 0.8 p.f lagging at V = 1.0 p.u.. The reactance X_d of the alternator is 1.2 p.u. Determine the active power output and the steady state power limit. Keeping the active power fixed, if the excitation is reduced, find the critical excitation corresponding to operation at stability limit.



19. A synchronous generator, having a reactance of 0.15 p.u., is connected to an infinite bus through two identical parallel transmission lines having reactance of 0.3 p.u. each. In steady state, the generator is delivering 1 p.u. power to the infinite bus. For a three phase fault at the receiving end of one line, calculate the rotor angle at the end of first time step of 0.05 seconds. Assume the voltage behind transient reactance for the generator as 1.1 p.u. and infinite bus voltage as 1.0 p.u. Also indicate how the accelerating powers will be evaluated for the next time step if the breaker clears the fault, (i) at the end of an interval (ii) at the middle of an interval.

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ANSWERS AND EXPLANATIONS

1. ***Ans.*** **(d)**
2. ***Ans.*** **(b)**
3. ***Ans.*** **(c)**
4. ***Ans.*** **(c)**
5. ***Ans.*** **(b)**
6. ***Ans.*** **(d)**
7. ***Ans.*** **(c)**
8. ***Ans.*** **(a)**
9. ***Ans.*** **(b)**
10. ***Ans.*** **(a)** $P_{G1} = 140.9$ MW, $P_{G2} = 159.1$ MW
    (b) Net saving = Rs 218.16/day
11. ***Ans.*** **(c)**

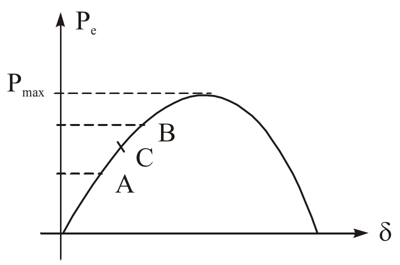
The transient stability of a power system can be improved by fast excitation system, use of high speed circuit breakers, use of high speed governers, single pole circuit breakers, and by dynamic resistance switching.

In case of alternator terminal, the line to ground fault is more severe. In order to maintain transient stability employ single pole breaker operation. In case of a transmission line the frequently occurring fault is line to ground fault. In this case instead of opening all the 3 lines if we open one line on which fault is occurred then the net electrical power transferred during fault will not be zero. Hence accelerating power is reduced and hence the transient stability is improved,

$$\left[\because P_{acc} = P_{mechanical} - P_{electrical}\right]$$

12. ***Ans.*** **(a)**

When the synchronous machine swings from A to B due to disturbance and settles at a point 'C', then during this process, rotor angle 'δ' increases until synchronous speed is achieved and the mechanical input and electrical output are balanced. The rotor will be having synchronous speed at point 'A' and also at point 'B' before it finally settles.



13. ***Ans.*** **(b)**

Inertia constant (H) =

$$\frac{\text{kinetic energy stored in rotor in MJ}}{\text{Machine rating in MVA(S)}}$$

Kinetic energy stored in rotor

$$H \times S = 4 \times 100 = 400 \text{ MJ}$$

14. ***Ans.*** **(b)**

Reactive power compensation is required at the converter stations. The inter connection of two systems is alone by using isolation transformers so that the fault on one side will not be reflected on to other side. By using dc transmission corona can be reduced but not completely avoided.

15. ***Ans.*** **(d)**

Inertia constant,

$$H \propto \frac{1}{\text{MVA rating}(S)}$$

$$H_{A\ new} = H_{A\ old} \times \frac{S_{old}}{S_{new}}$$

$$= 1.6 \times \frac{250}{100} = 4.0 \text{ p.u.}$$

$$H_{B\ new} = H_{B\ old} \times \frac{S_{old}}{S_{new}}$$

$$= 1.0 \times \frac{500}{100} = 5.0 \text{ p.u.}$$

$$\therefore \quad H_{eq} = H_{A\ new} + H_{B\,new}$$

$$= 4.0 + 5.0 = 9.0 \text{ p.u.}$$

16.

Moment of inertia

$$M = \frac{SH}{\pi f} \text{ MJ – sec / (elect-rad)}$$

H = Inertia constant of rotor

S = MVA rating of alternator

For a given frequency

f = constant

$$\therefore \quad S \propto \frac{1}{H}$$

$$\Rightarrow \quad \frac{S_2}{S_1} = \frac{H_1}{H_2}$$

Case(i): for 250MVA generator

$S_1 = 250MVA,$

$H_1 = 6$ MJ/MVA

$S = S_{base} = 100MVA$

$$\therefore \quad \frac{100}{250} = \frac{6}{H_{21}}$$

$H_{21} = 15$

Case(ii): for 150MVA generator

$S_1 = 150MVA,$

$H_1 = 4$ MJ/MVA

$S = S_{base} = 100MVA$

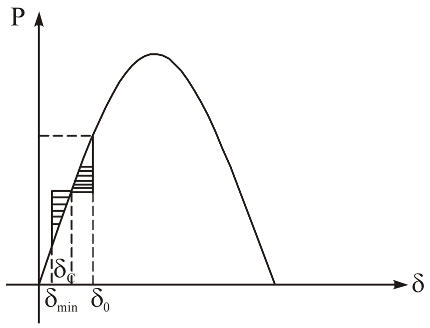
$H_{22} = 6$

$\therefore$ for whole system the total moment of inertia

$H_{eq} = H_{21} + H_{22}$

$H_{eq} = 15 + 6 = 21$

17.



Initially

Mechanical Input (P_{S1}) = Electrical output

$(P_{el}) = 0.5\ P_{max}$

But $\quad P_{e_1} = P_{max}\sin\delta_0$

$$0.5P_{max} = P_{max}\sin\delta_0$$

$$\delta_0 = \sin^{-1}0.5 = 30^o$$

$$P_{e_2} = P_{s_2} = (0.8)\times 0.5P_{max}$$

But $\quad P_{e_2} = P_{max}\sin\delta_c$

$$0.4P_{max} = P_{max}\sin\delta_c$$

$$\delta_c = 23.578^o$$

$$(\delta_0 - \delta_{min})0.4 = \int_{\delta_{min}}^{\delta_0}\sin\delta\, d\delta$$

$$0.4\delta_0 - 0.4\delta_{min} = \cos\delta_{min} - \cos\delta_0$$

$$0.4\delta_0 + \cos\delta_0 = 0.4\delta_{min} + \cos\delta_{min}$$

$$0.4\times\frac{30\times\pi}{180} + \cos 30 = 0.4\delta_{min} + \cos\delta_{min}$$

$$1.07546 = 0.4\delta_{min} + \cos\delta_{min}$$

By trial & error method

$$\delta_{min} = 17^o$$

18.

$$E\angle\delta = V\angle 0^o + jI_aX_d$$

$$E\angle\delta = 1.0\angle 0^o + j(1\angle -36.86)(1.2)$$

$$E\angle\delta = 1.9696\angle 29.17^o$$

$\therefore \quad \delta = 29.17^o$

Active power output

$(P_e) = VI\cos\theta$

$= 0.8$ P.u.

Steady state power limit

$$= \frac{EV}{X_d}$$

$$\frac{1.9696\times 1.0}{1.2} = 1.64 \text{ P.u.}$$

By keeping active power fixed if the excitation is reduced, then the critical excitation corresponding to operation at stability limit be E^1

$$\therefore \quad 0.8 = \frac{E^1V}{X_d}\sin 90$$

($\because$ $\delta = 90^o$ at stability limit)

$$E^1 = \frac{0.8\times 1.2}{1.0} = 0.96 \text{ p.u.}$$

19.

To find the rotor angle at the end of first time step:

Before fault

$$P_{m_1} = \frac{EV}{X_{1eq}}$$

$$= \frac{1.1\times 1.0}{0.15 + (0.3\,\|\,0.3)} = 3.67 \text{ p.u.}$$

$$\delta_0 = \sin^{-1}\left(\frac{P_s}{P_{m_1}}\right)$$

$$\delta_0 = \sin^{-1}\left(\frac{1.0}{3.67}\right) = 15.826^o$$

$$\Delta\delta_n = \Delta\delta_{n-1} + \alpha(\Delta t)^2$$

where, $\alpha = \dfrac{P_a}{M}$

$$\therefore\ \Delta\delta_1 + \frac{P_a}{M}(\Delta t)^2$$

$$= \Delta\delta_0 + \frac{P_a}{M}(\Delta t)^2$$

Let us consider the inertia constant of generator as H = 1.0 P.u.

$$\therefore\quad M = \frac{SH}{180f}$$

$$= \frac{1.0\times1.0}{180\times50} = 1.11\times10^{-4}\text{ P.u.}$$

We have to calculate the accelerating power as the average of accelerating power before and after fault.

Hence $P_a = P_{a\,avg} = \dfrac{P_{a1} + P_{a_2}}{2} = 0 + P$

$$= \frac{0 + P_s - P_{e_2}}{2} = \frac{1.0 - P_{m2}\sin\delta_0}{2}$$

During fault

$$P_{m_2} = 0$$

$$\Rightarrow\quad P_{e_2} = 0$$

$$\therefore\quad P_a = \frac{1.0}{2} = 0.5\text{ P.u.}$$

$$\therefore\quad \Delta\delta_1 = 0 + \frac{0.5}{1.11\times10^{-4}}(0.05)^2$$

$$\Delta\delta_1 = 11.26^o$$

Rotor angle

$$\delta_1 = \delta_0 + \Delta\delta_1$$
$$= 15.826 + 11.26^o$$
$$= 27.087^o$$

(i) If the breaker clears fault at the end of 2nd step (or) interval then the accelerating power will be considered as the average of before and after faults,

(ii) If the breaker clears the fault at the middle of 2nd interval then we have to consider the accelerating power same as that of beginning of that interval, i.e. $P_a = P_s - P_m \sin\delta_0$.

Where

P_s = mechanical input (or) shaft power.

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