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Engineering Tripos Part IB | SECOND YEAR

Part IB Paper 5: Electrical Engineering
ELECTRICAL POWER

Examples Paper 4 : Synchronous Machines and Per-Unit Calculations

Straightforward questions are marked †
*Tripos standard questions are marked **

Synchronous Machines

† 1. A 500 MVA, 60 kV star-connected synchronous machine is connected to a 3 phase 60 kV infinite bus. If the synchronous reactance is 4.8 ohms per phase and the stator resistance is negligible, draw the phasor diagram for the machine generating rated MVA at a leading power factor of 0.6. Hence determine the generated emf, E, and the rotor load angle, δ.

2. A star-connected synchronous generator has a synchronous reactance of 1.2 Ω per phase and negligible stator resistance. It delivers 250 MW at unity power factor to a 22 kV three-phase infinite bus. The excitation is increased by 15%. Calculate the stator current, power factor, and load angle at this new level of excitation.

3. The excitation of the generator in question 2 is held at its increased value, and the turbine power (i.e. mechanical power in) is increased until the machine delivers 300 MW. Calculate the new value of current, power factor, and load angle.

* *Questions 2 & 3 together constitute a question of Tripos standard.*

* 4. A 500 MVA, 33 kV alternator is star-connected and has a synchronous reactance of 2.5 ohms, and negligible stator resistance. It is driven by a steam turbine which has a rated output power of 400 MW. The maximum excitation produces a generated emf of 67.5 kV line. Draw an operating chart for the alternator, marking on the various operating limits. Determine the range of power factors at which rated MVA can be delivered.

Per-unit Calculations

† 5. For VA_b = 100 MVA, and V_b = 132 kV, express the following in per-unit.

(i)	125 MVA	(ii)	107 kV
(iii)	35 Ω	(iv)	950 A

The following per-unit quantities are expressed to the above bases. Convert them to bases of VA_b = 75 MVA, V_b = 100 kV.

(v)	V = 1.2 pu	(vi)	Z = 0.35 pu
(vii)	I = 0.9 pu	(viii)	MVA = 1.6 pu

* 6. A 100 MVA, 22 kV generator with a reactance of 60 % is connected to a 100 MVA 22/132 kV step-up transformer with a reactance of 15 %. The high voltage side of the transformer feeds a 100 mile transmission line, with a reactance of 0.2 ohms per mile and negligible resistance. At the end of the transmission line there is a second transformer, rated at 125 MVA, 132/11 kV, with a reactance of 18 %. The low voltage side of this step-down transformer is connected to a distribution bus, which supplies 80 MW at 0.9 pf lag to an industrial estate. The voltage at the distribution bus is 10.5 kV.

Calculate the generator excitation (line).

† 7.

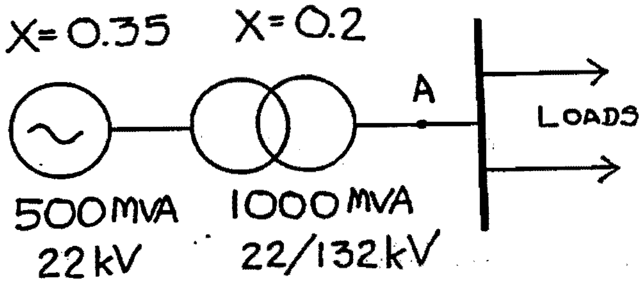

Fig. 1.

Fig. 1 shows the line diagram for a 500 MVA generator of reactance 35 % connected to a load bus via a 1000 MVA transformer of reactance 20 %. No other generators feed power to the load bus. Determine the appropriate MVA rating for a circuit breaker to be located between the transformer and the load bus (i.e. at A). Calculate also the short-circuit line current on the high-voltage side of the transformer.

* 8.

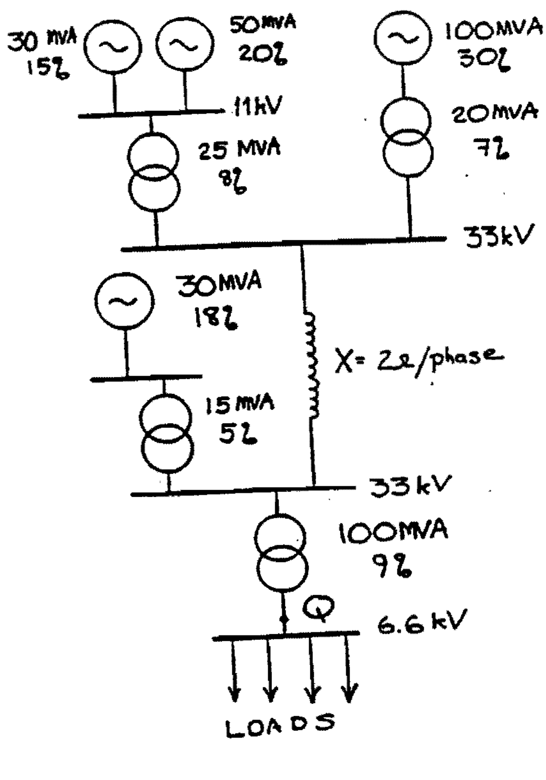

Fig. 2.

Fig. 2 shows part of a power system, which is feeding a 6.6 kV industrial load. A symmetrical three-phase short circuit to ground occurs at the 6.6 kV bus-bars.

Determine: (i) the fault current;
(ii) the reactance that must be added at Q to limit the fault to 100 MVA.

Answers

1. 36.9 kV (line), 40.6°
2. 6902 A, 0.95 (lag), 27.3°
3. 7993 A, 0.985 (lag), 33.4°
4. 0.582 to 0.800 (lag)
5. (i) 1.25 pu (ii) 0.81 pu (iii) 0.20 pu (iv) 2.17 pu
   (v) 1.58 pu (vi) 0.46 pu (vii) 0.91 pu (viii) 2.13 pu
6. 35.3 kV
7. 1110 MVA, 4860 A
8. 21.5 kA, 0.26 ohm/phase

Tripos Questions (Paper 5)

Year	**Paper 5/3**	**Paper 5/4**	**Paper 5/5**
2002	3	4	
2003	3	4 (pu)	5
2004	3	4	5
2005	5	3	4
2006	3	4	5
2007	3,4		5
2008	4	3	5
2009	3	4	5

T A Coombs
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