UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 7 Examination in Engineering: August 2018

Module Number: EE7203 **Module Name: Power System Analysis**

[Three Hours]

[Answer **all questions**, each question carries **10 marks**]

Q1. a) Starting from the first principles, develop the sequence network diagrams for a Line to line (L-L) fault.

[3 Marks]

b) A single-line diagram of a power system is shown in Figure Q1, where positive, negative and zero-sequence reactances are given. The neutrals of the generator and Δ-Y transformers are solidly grounded. The motor neutral is grounded through a reactance X_n=0.05 per-unit on the motor base. Assume the zero sequence reactance of the Y-Δ transformers is the same as leakage reactance. Ignore the pre-fault load current and Δ-Y transformer phase shift.

i) Draw the per-unit zero, positive and negative sequence networks on a 100 MVA, 13.8 kV base in the zone of the generator.

ii) If the pre fault voltages of the generator and motor are 1.05 per-unit, calculate the sub transient fault current in per-unit and in kA for a bolted **line-to-line fault** from phase **b** to **c** at bus 2.

[7 Marks]

Q2. a) Explain the variation of symmetrical short circuit current in a synchronous machine indicating the sub transient, transient and steady state regions in a graph of a short circuit current.

[2 Marks]

b) A power plant arrangement with outgoing feeder is described in Figure Q2. This power plant has two generating units rated at 3500 kVA, 3.3 kV and 5000 kVA, 3.3 kV with reactances of 8% per-unit and 9% per-unit respectively connected to the busbar A. It is planned to extend the system by connecting it into another busbar (busbar B) having another generator rated at 7500 kVA, 3.3 kV, 7% per-unit reactance through a reactor as indicated in Figure Q2. The busbar voltages are 3.3 kV. A circuit breaker has been installed at the outgoing feeder of busbar A for the three phase short circuit protection of the feeder. The maximum circuit breaker capacity is 175 MVA.

i) Considering 7500 kVA as the base kVA, calculate the generator and transformer per unit reactances for the common base.

ii) Assume generator voltages remain at 1.0 per-unit. Draw the per-unit reactance diagram for this arrangement including the unknown reactance of the reactor (denoted as X_R %).

iii) Using the knowledge of symmetrical short circuit current calculations, calculate the reactance of the unknown reactor (X_R %).

[8 Marks]

Q3. a) Starting from the swing equation, show that

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

where, M =Moment of inertia in MJ-s/elect rad

P_m =Mechanical power input in MW

P_e = Electrical power output in MW (neglecting stator copper loss)

[2 Marks]

b) A 50 Hz, 4 pole generator rated at 100 MVA, 11 kV has an inertia constant of 8 MJ/MVA.

i) Calculate the stored energy in the rotor at synchronous speed.

ii) If the Mechanical input is suddenly increased to 80 MW for an electrical load of 50 MW, find the rotor acceleration. (Neglect electrical and mechanical losses).

[3 Marks]

c) Figure Q3 shows a single line diagram of a three phase 60 Hz synchronous generator, connected through parallel transmission lines to an infinite bus. All reactances are given in per-unit on a common system base. The infinite bus receives 1.0 per unit real power at 0.95 p.f. lagging. A temporary three-phase to-ground bolted short circuit occurs on line 1-3 at bus 1, shown as point F and the fault is extinguished at the critical clearing angle (consider there is no power transfer during the fault). Due to a relay misoperation, all circuit breakers remain closed. The inertia constant of the generator is 3.0 per-unit-seconds on the system base. Assume mechanical power input P_m remains constant throughout the disturbance. Also assume ω_{syn}=1 per unit in the swing equation.

i) Calculate the internal voltage of the generator.

ii) Find the equation for the power delivered by the generator versus its power angle δ.

iii) Calculate the critical clearing angle.

iv) If the fault is cleared after 15 seconds, state whether the stability could be maintained or not using calculations.

[5 Marks]

Q4. a) i) Explain the function of Automatic Generation Control (AGC) and its main control loops using diagrams.

ii) Explain the operation of a speed governing system.

[4 Marks]

b) A single area consists of two generating units with the characteristics given in Table Q4. The units are operating in parallel sharing 900 MW at the nominal frequency. Unit 1 supplies 500 MW and Unit 2 supplies 400 MW at 60 Hz. The load is suddenly increased by 90 MW. Consider the base as 1000 MW.

i) Calculate the new system frequency (Assume there is no frequency dependent load).

ii) Calculate the change in the generation for each unit.

iii) If the load varies 1.5% for every 1% change in the frequency, calculate the steady state frequency deviation and the change in generation.

[6 Marks]

Q5. a) i) Explain the main requirements of a basic protection system.

ii) Explain the Primary and Backup protection using diagrams.

iii) An IDMT over-current relay has a current setting of 150% and time multiplier setting (TMS) of 0.6. The primary of the relay is connected to a secondary of a CT having a CT ratio of 400/5. If the circuit carries a fault current of 5000A, considering the characteristics of an IDMT over-current relay calculate the operating time of the relay.

[3 Marks]

b) A three-phase 500 kVA, 11 kV/400 V, delta to star transformer has a differential protection scheme with the CTs illustrated in Figure Q5(a). For the proper operation of **differential protection**, secondary winding of CTs installed at the delta side(HV side) of the transformer are star connected and secondary winding of the CTs installed at the star side(LV side) of the transformer are delta connected as shown in Figure Q5(b). CTs installed at LV side of the transformer have a ratio of 500/5.

i) If the line current in the LV winding of the transformer is 500A, calculate the current through each secondary of delta connected CTs in LV side of transformer. *(Hint: primary of the delta connected CTs will carry the same current in the LV winding of the transformer).*

ii) Accordingly, calculate the line current in the pilot wires of the protection scheme.

iii) Equating the apparent power of both sides of 11 kV/400 V transformer, calculate the line current through HV winding of the transformer when the line current in the LV winding is 500 A.

iv) Accordingly determine a suitable ratio for the CTs installed at the HV side of the transformer.

[7 Marks]

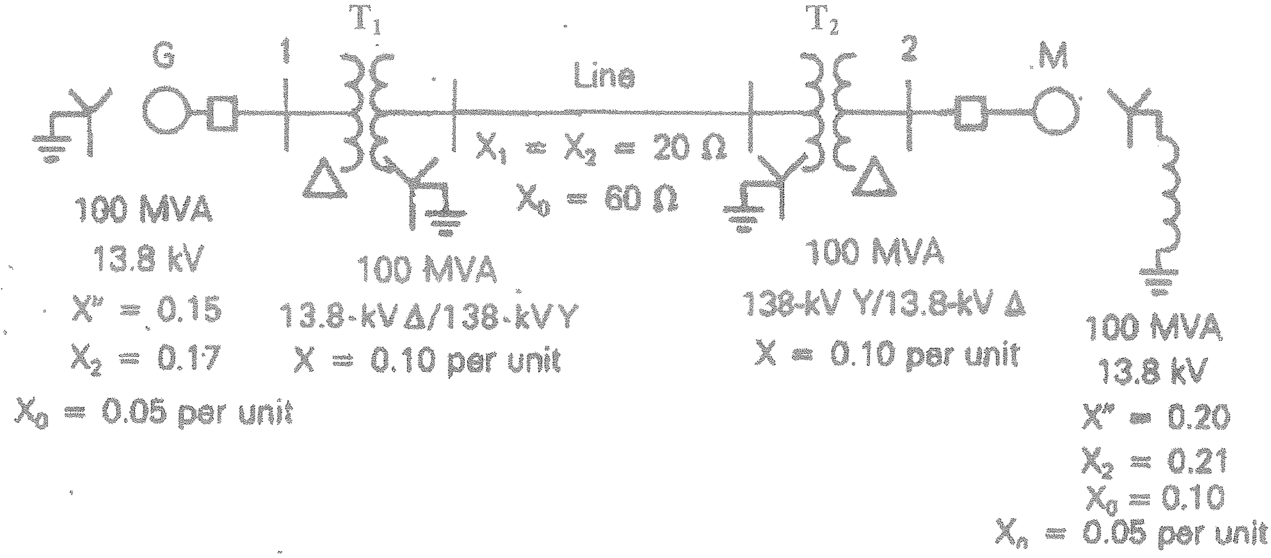

Figure Q1

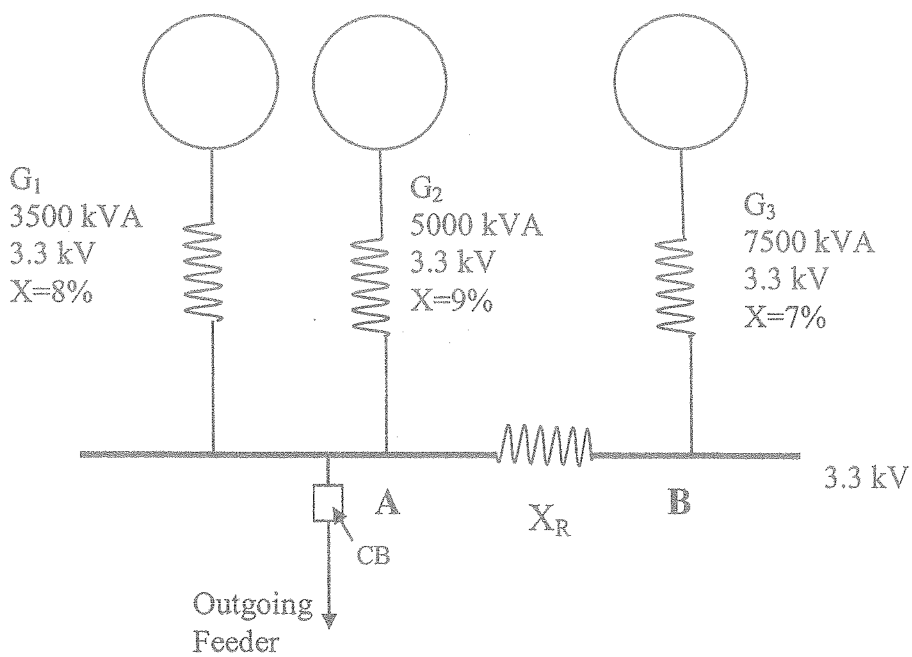

Figure Q2

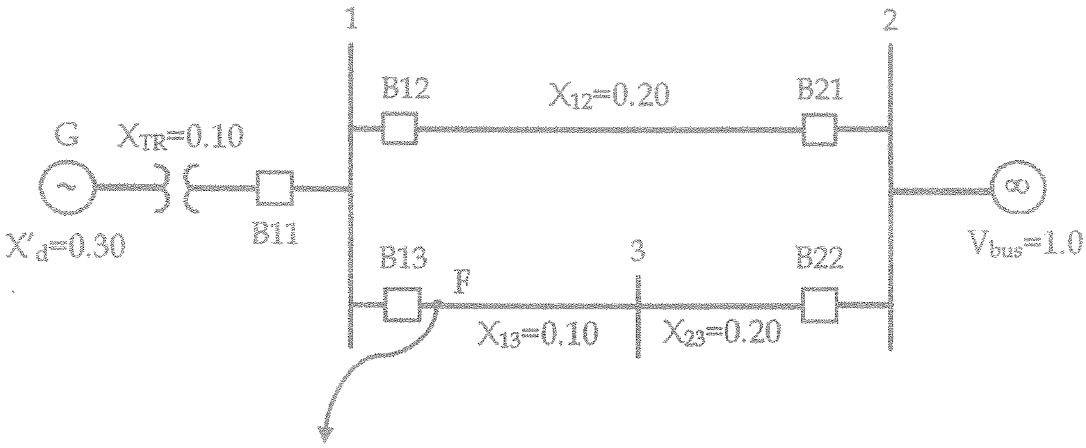

Figure Q3

Unit	Rating (MW)	Speed Regulation (per unit on unit MW base)
1	600	6%
2	500	4%

Table Q4

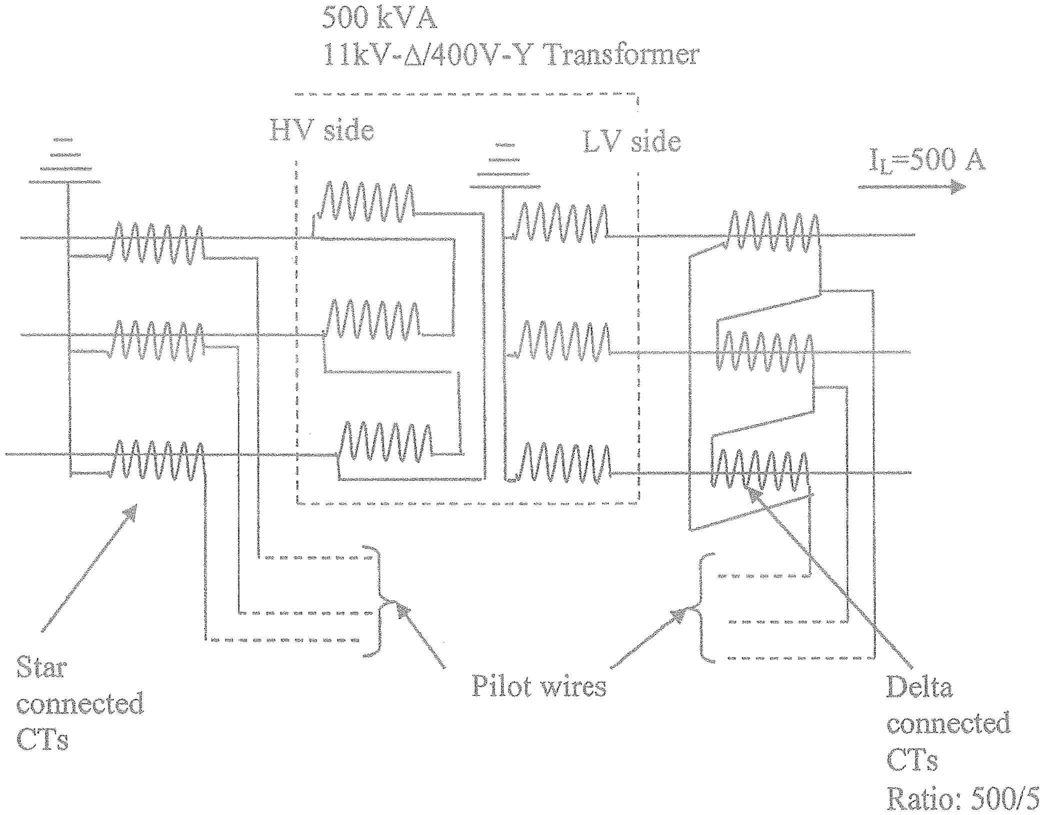

Figure Q5 (a)

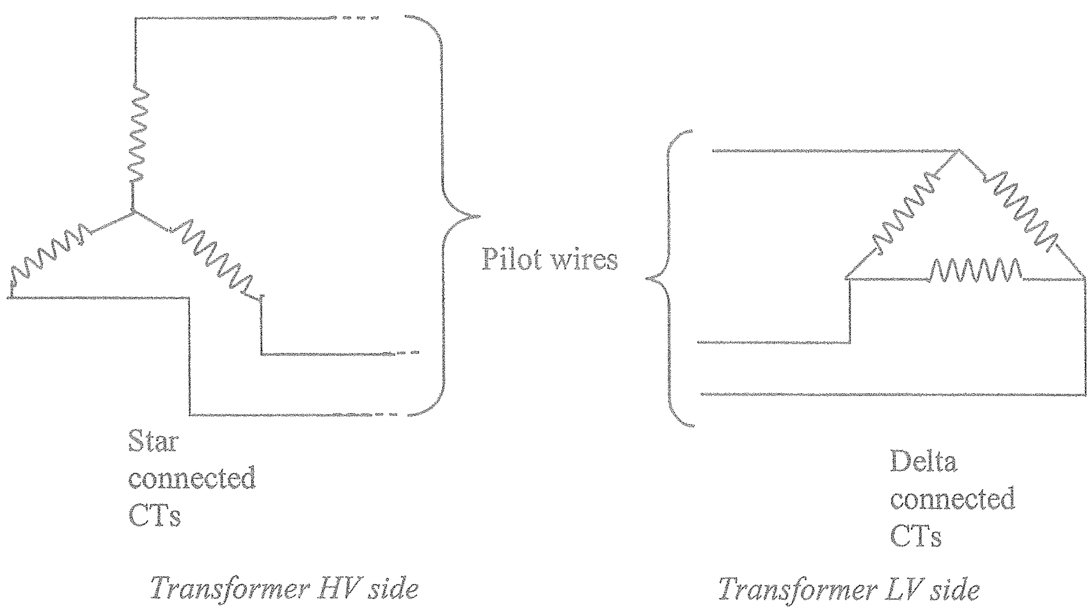

Figure Q5 (b)