EE4-48
EE9-CS6-2

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2015

MSc and EEE PART IV: MEng and ACGI

POWER SYSTEM CONTROL, MEASUREMENT AND PROTECTION

Friday, 8 May 10:00 am

Time allowed: 3:00 hours

Corrected Copy

There are SIX questions on this paper.

Answer FOUR questions.

All questions carry equal marks.

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : B.C. Pal
Second Marker(s) : B. Chaudhuri

The Questions

1.

a)

i) How is the switching surge in a power network characterised? [2]

ii) Why is the consideration of switching surge so important in power system design and operation? [2]

iii) Why is sub synchronous resonance (SSR) a major problem in steam driven power plants? [2]

iv) Why is high gain fast acting excitation system is good for transient stability but not so for oscillatory or small signal stability? [4]

v) Why is the rotor of a synchronous generator of solid construction while the stator made up of laminated steel? [4]

vi) Why is it easier to control a steam turbine than a hydro turbine? [3]

vii) Modern synchronous generators are designed to have large steady state synchronous reactance (between 1.0 to 2.0 pu). Whenever a direct terminal short circuit occurs initial currents are several times the load current. Why is it so? [3]

2.

a)

i) Why does one neglect the stator and network circuit transients in assessing transient stability of a synchronous generator? [2]

ii) Why is individual machine d-q to network transformation necessary in multi-machine power system stability computation and analysis? [1]

iii) Derive the relationship between the quantities in two reference frame when the angle difference between the two reference frames is δ-θ. [4]

iv) A synchronous generator supports a terminal voltage of 23.5 kV line to line at the generator terminal bus. This bus is part of a large network which has a reference bus at another location. The power flow solution produces an angle (θ) of 10 degree for this bus voltage. The generator load angle (δ) is 30 degree. Compute the direct and quadrature axis components of this terminal voltage. [3]

b) In a salient pole synchronous generator, the voltage-current relationship along the generator d and q axis are as follows:

$E_{fd} - V_q + I_d X_d = 0$

$V_d + I_q X_q = 0$

where the symbols carry their usual meanings.

Taking the terminal voltage $\bar{V}_t$ as the reference vector, the q-axis is defined to lead $\bar{V}_t$ by an angle δ.

The terminal voltage and current vector of the generator are related by:

$$\bar{V}_q + j\bar{V}_d = \bar{V}_t e^{-j\delta}; \ \bar{I}_q + j\bar{I}_d = \bar{I}_t e^{-j\delta}$$

i) Making use of the above information, derive the power angle expression of the generator. [5]

ii) For the following values of the variables in per unit, obtain the per unit real power output of the generator.

$X_d = 2.3$, $X_q = 1.6$, $V_t = 1.05$, $E_{fd} = 3.8$ and $\delta = 25$ degrees [2]

iii) Suddenly the generator loses excitation. What percentage of power obtained in (ii) can still be produced with the loss of excitation? [3]

3

a)

i) How much excitation power is approximately required to operate a 300 MW synchronous machine? [2]

ii) What is the purpose of field forcing in excitation system control? [3]

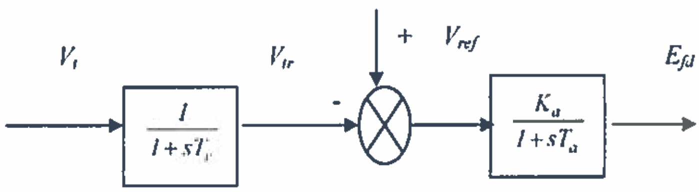
iii) What is the purpose of a power system stabilizer (PSS) in a large synchronous generator with fast acting voltage control? [2]

iv) How does transformer with taps control the network voltage control? [2]

v) Why is the voltage rise problem in a 400 kV cable network more severe than that of an overhead line of similar rating? [2]

vi) Why are the fixed shunt capacitors not as effective as the automatic voltage control in synchronous generators? [3]

b) A simplified model of a fast excitation system is shown in Figure 3.1. It is required to produce a 4.0 p.u. of E_{fd} in the steady state. The voltage regulator has a gain of 400 and time constant of 0.02 s. Compute the reference voltage V_{ref} that needs to be set in order to maintain a terminal voltage of 1.07 p.u.



3.1 Block Diagram of a Fast Excitation System [6]

4.

a) Briefly discuss the nature, importance and model of the primary frequency control in power systems. [5]

b) Including the effect of the governor droop characteristic, develop the following load frequency control characteristic:

$$\Delta\omega_{ss} = -\frac{\Delta P_L}{D+\frac{1}{R}}$$

where, D is the load damping co-efficient, ΔP_L is change in demand, R is the droop and $\Delta\omega_{ss}$ is the steady state angular frequency deviation in p.u. [7]

c) A 60 Hz power system consists of 5 identical 700 MVA , 600MW, units feeding a total load of 2500 MW. The H constant of each unit is 6.0 sec on their own base MVA. Each unit has 5% governor droop mechanism fitted. The demand varies by 2% for 1% change in frequency. For a sudden increase of 100 MW of load find the steady state frequency deviation in Hz:

i) without droop [3]

ii) with droop [3]

iii) justify the effectiveness of droop control in steady state frequency deviation in view of the results obtained above. [2]

5.

a) What are the fundamental differences between apparatus protection and system protection? [3]

b) Discuss various advantages of solid state relays. [5]

c) Distinguish between the dependability and security of a relay. [4]

d) The performance of an over current relay was monitored for a period of one year. It was found that the relay operated 15 times, out of which 13 were correct trips. If the relay failed to issue trip decisions on 3 occasions, compute the dependability, security and reliability of the relay as a percentage of its ideal performance. [6]

e) Power transformer usually draws huge amount of inrush current during starting. What type of protection can you suggest to distinguish between the normal starting and closing on fault? [2]

6

a) A 1000/5 C400 current transformer (CT) is connected to a relay with a burden of 2.50 Ω. The secondary resistance of the CT is 0.5 Ω. A secondary current of 120 A flows through the relay coil.

   i) For this secondary current, is the CT still expected to behave in a linear manner? Justify your answer. [3]

   ii) With added generation the fault level of the substation where the CT remains connected is increased. It was decided not to replace the CT rather upgrade some of the relays with lower burden so that when primary fault current is 30 kA, the CT could faithfully reflect the primary current to the relay input terminal. Find the upper limit of the relay burden to realise this. [3]

b) How is % ratio error in CTs defined? [3]

c) What will be the approximate ratio error (%) if a 500:5 class C CT is connected to a secondary burden of 2.5 Ω when carrying 70 A in the secondary and 5 A exciting current? [3]

d) This question relates to capacitive coupled voltage transformer(CCVT)

   i) Why is capacitive coupled voltage transformer (CCVT) preferred over normal electromagnetic voltage transformer (VT)? [2]

   ii) Draw the equivalent circuit of a capacitive coupled voltage transformer (CCVT). [3]

   iii) Briefly describe the purpose of the tuning inductor in a CCVT [3]