E4.48
CS6.2

IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2009

MSc and EEE PART IV: MEng and ACGI

POWER SYSTEM CONTROL, MEASUREMENT AND PROTECTION

Friday, 22 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) Answer the following:

i) Why does the synchronous generator operate at synchronous speed?

[2]

ii) Which of the voltage and frequency control can be influenced by the network?

[1]

iii) How does one characterise the lightning strike in the transmission line?

[2]

iv) What is of prime importance in small signal stability study?

[1]

v) What types of power plant exhibit mechanical resonance in the sub-synchronous frequency range?

[1]

vi) Why does a large synchronous machine typically have a high gain and fast acting excitation system?

[1]

b) A 3-phase, star connected, 23.5 kV (V_t) (line-line), 600 MVA alternator is connected to the grid operating at 50 Hz. The resistance is negligible and the synchronous reactance (X_s) is 2.5 Ohm. Derive the power angle relationship as a function of terminal voltage (V_t), excitation voltage (E_{fd}), reactance (X_s) and power angle (δ) and subsequently solve the following:

[5]

i) Find the excitation voltage (line-line) and the power angle when the generator is delivering a full load at 0.85 power factor lagging.

[4]

ii) Keeping the prime mover power at the value obtained in (i), if the excitation is gradually increased by 10% the generator will continue to deliver the same MW but at a different power angle. Find the new power angle and comment on the impact of the increased excitation voltage on the machine stability.

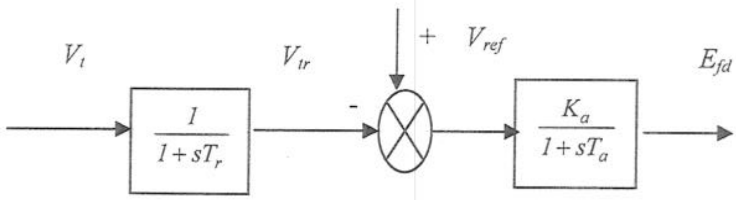
[3]

2.

a) List and briefly describe the major components in an excitation system.

[10]

b) A simplified model of a fast excitation system is shown in Figure 2.1. 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 0.03 s. Compute the reference voltage V_{ref} that needs to be set in order to maintain a terminal voltage of 1.05 p.u.



2.1 Block Diagram of a Fast Excitation System

[5]

c) Briefly describe how the high voltage lines and cables contribute to the improved voltage profile of the system.

[5]

3.

a) Answer the following

i) Why is the direct axis synchronous reactance of the synchronous machine designed to be so high (1.5 to 2.0 p.u.)?

[3]

ii) How does a salient pole synchronous generator produce MW even after loosing excitation?

[3]

b) Starting from the inertia constant J (Kg-m^2), rated VA as VAbase, basic torque and angle equations in a rotational system, derive the following swing equations of a synchronous generator connected to the grid:

$$\frac{d\delta}{dt} = \omega_r - \omega_s$$

$$\frac{2H}{\omega_s}\frac{d\omega_r}{dt} = P_{mech} - P_{elec} - D(\omega_r - \omega_s)$$

δ is the angle of the rotor with respect to a synchronously rotating reference frame;

ω_r, ω_s: speed of the rotor and synchronous reference frame respectively in rad/sec.

P_{mech}, P_{elec} : mechanical power input and electrical power output in p.u. respectively

$H =$ H-constant in seconds

D : mechanical damping co-efficient in p.u.-sec/rad

[7]

c) The moment of inertia of a generator-turbine mass is 40,000 Kg-m^2. The generator has a rating of 600 MVA and operates at 3600 RPM. Find the

i) stored kinetic energy

[3]

ii) H-constant (H)

[2]

iii) mechanical starting time (T_M)

[2]

4.

a) Describe how primary frequency control is implemented in a system with many generators.

[8]

b) An interconnected power system has two commercial areas. The composite droop and load frequency sensitivity of Area 1 are R_1 and D_1 respectively and the same for Area 2 are R_2 and D_2. For a change in Area 1 load by ΔP_{L1} the change in the generation in Area 1 and 2 are ΔP_{m1} , ΔP_{m2} respectively. The associated change in the tie line flow is ΔP_{12} . Derive that the associated frequency deviation Δf is related as:

$$\Delta f = -\frac{\Delta P_{L1}}{D_1 + \frac{1}{R_1} + D_2 + \frac{1}{R_2}}$$

[7]

c) Area 1 has Gen 19,000 MW, Load 20,000 MW; Area 2 has Gen 41,000 MW and Load 40,000 MW. The load in each area varies 1% with 1% change in the frequency. The composite droop is 5% for both areas. Area 1 is importing 1000 MW from Area 2. For the loss of 1000 MW load in Area 1, find the change in the system frequency when there is no tie-line supplementary control. Assume the nominal system frequency to be 50 Hz.

[5]

5.

a) Describe the operating principle of electromechanical relays. Why do they require a larger burden compared to other types?

[7]

b) Distinguish between the dependability and security of a relay.

[5]

c) The performance of an over current relay was monitored for a period of three years. It was found that the relay operated 38 times, out of which 34 were correct trips. If the relay failed to issue trip decisions on 5 occasions, compute dependability, security and reliability of the relay as percentages.

[6]

d) What desirable attributes are guaranteed in transformer differential protection?

[2]

6

a) A 1000/5 C400 current transformer (CT) is connected to a relay with a burden of 1.0 Ω. The secondary resistance of the CT is 0.51 Ω. The total lead (connecting the CT to the relay room) resistance is 1.0 Ω. For a secondary current of 110 A flowing through the relay coil;

i) Is the CT still expected to behave in a linear manner? Justify your answer.

[5]

ii) The magnetising impedance (as referred to the secondary of the CT) is 3 kΩ. Calculate the % ratio error.

[3]

b) In what way does a high phase angle error affect the quality of CT's measurement?

[2]

c) By mistake someone has interchanged the terminals of measurement CT and protection CT. Both CTs are at the same place and having the same current ratings. What will happen in normal and abnormal condition?

[3]

d) Draw the equivalent circuit for a capacitive coupled voltage transformer (CCVT). What is the purpose of and the required expression for the *tuning inductor* in this circuit?

[7]

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Answers

1.

a)

i) The electromechanical torque and power conversion only takes place at synchronous speed when the magnetic fields of the rotor and that of the stator are locked.

[2]

ii) Voltage controlled can be influenced by the network as it generates/absorbs reactive power.

[1]

iii) The lightning is a natural phenomenon; hits the line and propagates along; usually currents in the range of tens of kA for few micro seconds: A typical one is 10 kA, 1.2 micro second front and 50 micro-seconds tail. This is useful for designing lightning conductor and tower footing resistance.

[2]

iv) Oscillatory stability of the system is main focus of small signal stability, the quantity of interest is damping of the electromechanical oscillations.

[1]

v) Multistage steam turbine coupled to generator exhibits resonance in the sub-synchronous frequency range.

[1]

vi) The transient stability or maintaining synchronism during large close in fault is very necessary. High gain and fast acting excitation system precisely does that by boosting developed voltage.

[1]

b) A synchronous machine is normally connected to a fixed voltage bus and operates at constant speed. There is a limit on the power that can be delivered by the machine to the system or the torque that can be applied to it when working as a motor. Analytical expressions for the steady state power transfer between the machine and the infinite bus or the torque developed by the machine are derived in terms of bus voltage, machine voltage and machine parameters on per phase basis. The per phase voltage, current and reactance are shown in the equivalent circuit: Induced voltage $\overline{E} = E\angle\delta$, Terminal voltage or infinite bus voltage: $\overline{V_t} = V_t\angle 0$

Stator impedance: $\overline{Z}_s = R_s + jX_s = Z_s\angle\theta_s$

The complex power delivered to infinite bus:

$$S = V_t I_s^{\ *};$$

$$I_s^{\ *} = \left|\frac{E - V_t}{Z_s}\right|^* = \frac{E}{Z_s}\angle\theta_s - \delta - \frac{V_t}{Z_s}\angle\theta_s$$

$$S = \frac{EV_t}{Z_s}\angle\theta_s - \delta - \frac{V_t^2}{Z_s}\cos\angle\theta_s$$

$$S = P + jQ;$$

$$P = \frac{EV_t}{Z_s}\cos(\theta_s - \delta) - \frac{V_t^2}{Z_s}\cos\theta_s \quad \text{watt/phase}$$

$$Q = \frac{EV_t}{Z_s}\sin(\theta_s - \delta) - \frac{V_t^2}{Z_s}\sin\theta_s \quad \text{VAR/phase}$$

When the stator resistance is negligible, $\theta_s = 90\ degree$; $Z_s \cong X_s$ for three phases:

$$P_{3\phi} = 3\frac{EV_t}{X_s}\sin\delta = P_{\max}\sin\delta$$

$$Q_{3\phi} = 3\frac{EV_t}{X_s}\cos\delta - 3\frac{V_t^2}{X_s}$$

[5]

i) Rated current I = $\frac{600}{\sqrt{3}*23.5} = 14.741\ KA, X_s = j2.5\ ohm$

$E_{fd} = V_t + \sqrt{3} * I < -cos^{-1}0.85 * j2.5 = 78.78kV < 43.52\ degree$ line to line

[4]

ii) The rated power is 600*0.85 = 510 MW. $P_{max} = \frac{E_{fd}V_t}{X}$ = 740.56 MW. With 10% increase in excitation voltage, the new angle will be $Sin^{-1}(\frac{510}{1.2*P_{max}}) = 35\ degree$

Since power angle is reduced, the stability margin is improved.

[3]

2

a) Excitation system has broadly following major components

Exciter

This block provides DC power to the synchronous machine field winding, constituting the power stage of the excitation system.

Regulator

It processes and amplifies input control signals to a level and form appropriate for control of the exciter. This includes regulating and excitation system stabilising function (rate feedback and lead-lag compensation).

Voltage and current sensor

Senses generator terminal voltage and currents and feed to the regulator block for voltage regulation and load current compensation.

Power system stabilizer

This block provides an additional input signal to the regulator to damp power system oscillations. Some commonly used input signals are rotor speed deviation, accelerating power and frequency deviation.

Limiter and protective circuits

These include a wide array of control and protective functions that ensure that the capability limits of the exciter and synchronous generator are not exceeded. Some of the commonly used functions are the field current limiter, maximum excitation limiter, terminal voltage limiter, volt/Hz regulator and protection and under excitation limiter. These are normally distinct circuits and their output signals may be applied to the excitation system at various locations as a summing input or a gated input.

[10]

b) The differential equations describing the excitation system dynamics are:

$$T_r \frac{dV_{tr}}{dt} = -V_{tr} + V_t$$

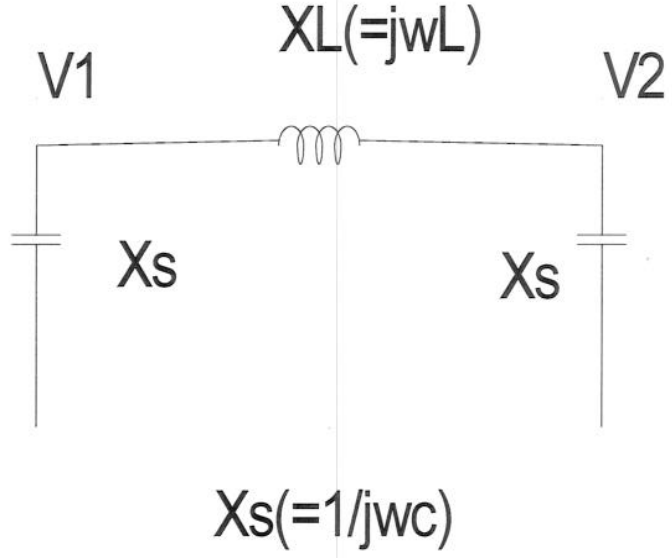
$$T_a \frac{dE_{fd}}{dt} = -E_{fd} + K_a\left(V_{ref} - V_{tr}\right)$$

At steady state the time derivative term will be zero. So $V_{tr} = V_t$; so $V_{ref} = \frac{E_{fd}}{K_a} + V_t$

For $E_{fd} = 4.0, K_a = 400, V_t = 1.05; V_{ref} = 1.06$

[5]

c) Typically a 400-KV single circuit line produces capacitive <u>60-70 MVAR per 100 km</u>
400-KV cable produces <u>20 MVAR per km</u> at 1.0 p.u voltage



At light load (during night) generation is more than the absorption: hence the system voltage is higher than nominal.

At higher load (during peak hours) absorption in the series branch is considerably higher than the generation in the shunt branch: the net effect brings the system voltage lesser than normal.

During light load, mechanically switched reactor are connected in shunt to maintain the voltage by absorbing the excess var generated by the line capacitance.

[5]

3.

a)

i) Low air gap machines are preferred because of over all reduced cost. The low air gap machine results in higher magnetic circuit inductance. This has effect on poor voltage regulation. However, automatic voltage regulator (AVR) regulates the voltage so higher reactance is not a problem. The only concern is the machine, rotor and stator copper losses are generally more.

[3]

ii) Because of the difference in direct and quadrature axis reactance, the reluctance torque is developed. This is purely because of the air gap geometry and is not dependent on excitation. About 10 to 15 % of total power is produced by the machine because of the reluctance. This can be easily seen in the power angle equation of salient pole machine.

$$P = V_d I_d + V_q I_q = \frac{E_{fd} V_t}{X_d} \sin\delta + \frac{V_t^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta$$

The second term in the RHS of the above equation is independent of excitation voltage E_{fd}

[3]

b)

Our general notion is that the generator shaft accelerates or decelerates during disturbance. Let ask ourselves with a question what governs this process.
Balance of torque (mechanical input (Tmech) – electrical output (Telec)). Let's assume that the combined inertia of the generator and prime mover is J (Kg-m2). If the rotational speed is ω_m (rad/sec); the following equation of motion can be written

$$J\frac{d\omega_m}{dt} = T_a = T_{mech} - T_{elec}$$

Generator manufacturers provide machine inertia constant as H.

Where, $H = \frac{1}{2}\frac{J\omega_{0m}^2}{VA_{base}}$ (Stored energy per rated VA at rated speed)

The substitution of this into above will yield following set of equations

$$\frac{2H}{\omega_{0m}^{\;2}} VA_{base} \frac{d\omega_m}{dt} = T_{mech} - T_{elec}$$

$$\frac{2H}{\omega_{0m}} VA_{base} \frac{d\omega_m}{dt} = P_{mech0} - P_{elec0}$$

Multiplying ω_m by number of pole pairs will result electrical speed ω_r ; ω_{0m} accordingly will correspond to synchronous speed ω_s

The final equation will appear as:

$$\frac{2H}{\omega_s}\frac{d\omega_r}{dt} = P_{mech} - P_{elec}$$

The mechanical damping effect is to retard the acceleration; This can be included as a term proportional to speed deviation on the right side of the above equation

The resulting equation can be written as:

$$\frac{2H}{\omega_s}\frac{d\omega_r}{dt} = P_{mech} - P_{elec} + D(\omega_r - \omega_s)$$

The angle equation: The rotor rotates at speed ω_r ; The angle (δ) of the rotor at any point of time *t* with respect to a synchronously rotating reference speed ω_s is

$$\delta(t) = (\omega_r - \omega_s)t + \delta_0$$

The initial rotor position at time t = 0 is δ_0

The rate of change of angle is therefore

$$\frac{d\delta}{dt} = \omega_r - \omega_s$$

These two differential equations are known as swing equations

$$\frac{d\delta}{dt} = \omega_r - \omega_s$$

$$\frac{2H}{\omega_s}\frac{d\omega_r}{dt} = P_{mech} - P_{elec} + D(\omega_r - \omega_s)$$

[7]

c)

i) Stored energy = $\frac{1}{2}J\omega_m{}^2 = 0.5 * 40{,}000 * (120\pi)^2$ = 2842.4 *MJoules*

[3]

ii) H constant: 2842.4/600 = 4.73 seconds

[2]

iii) Mechanical time constant = 2H = 9.46 seconds

[2]

4

a) During operation due to finite balance between the generation and demand the system frequency moves away from nominal value (normally 50 Hz in the UK). This deviation needs to be corrected through control of either generation or load to bring the frequency back to normal. Generators are easier to control than demands and so speed regulating mechanism is needed. Governor offers precisely this option. The system frequency is sensed and compared with desired value. The error is integrated over time and amplified to produce desired valve and gate opening and closing option. Since frequency is common through out the system, all connected generators will see the change in frequency and associated governor control with all of them will act. In case of drop in frequency governor control send signal to increase valve opening to inlet more steam and increase gate opening for admitting more water. The action will be reverse when frequency increases (due to load rejection etc.)

Let's take a look at the governor control block diagram. Let's skip the lower part (R and load reference portion for the time being. Usually with simple gain and integrator they fight to take share of the whole change in demand/generation unless the setting is exactly identical. Identical speed and power reference setting are impossible to achieve (no matter how high the setting resolutions are). This will lead to hunting and unless there is only one governor in the system the control scheme will not work. How does more than one governor work then? Through droop control setting. Now look at the lower feedback path involving R. This is managed by including a droop in the feedback path. The droop can be set at different values for different generators in order to define their relative shares on the total change in demand. This will also allow insertion of new input load reference point.

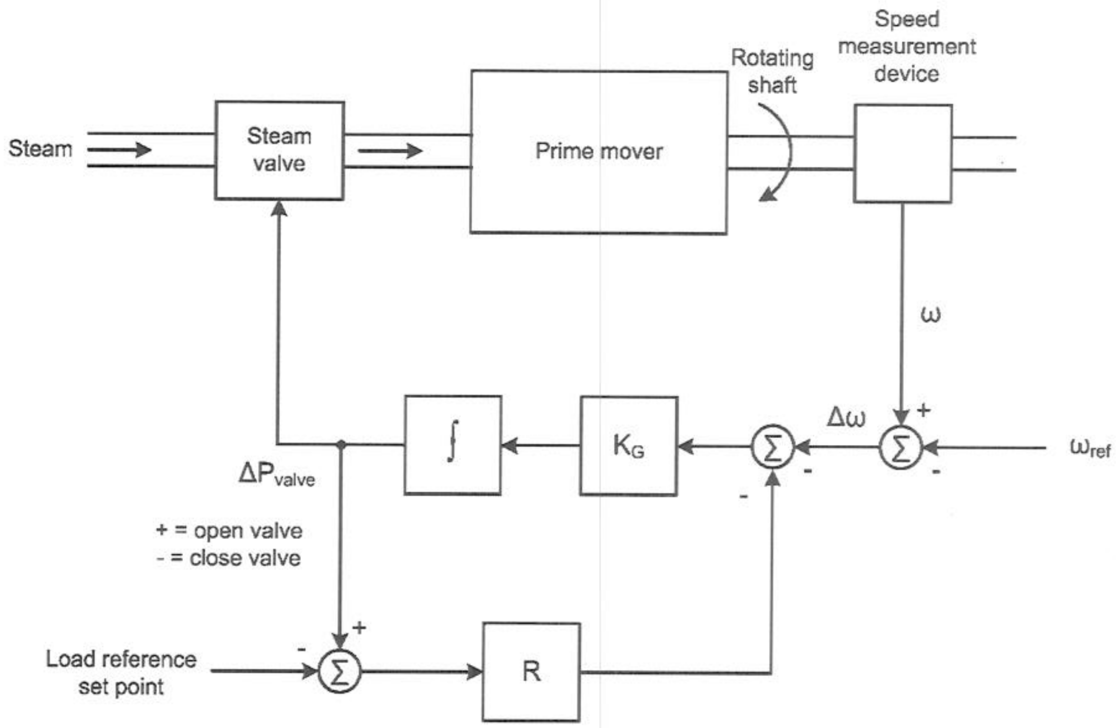
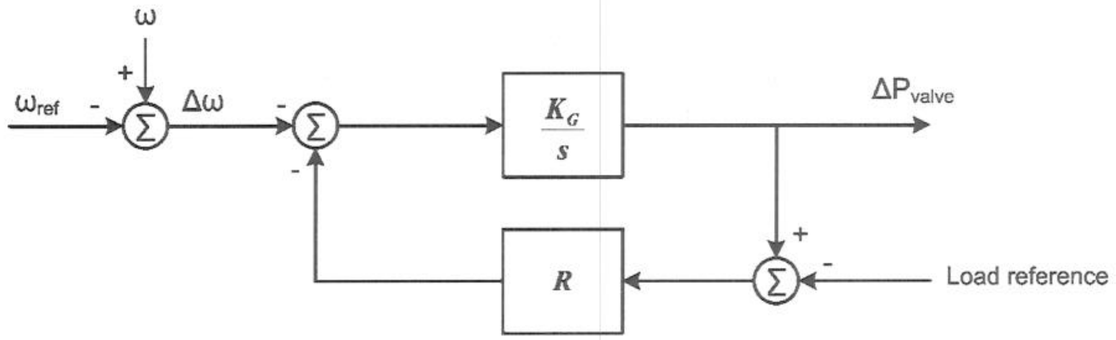
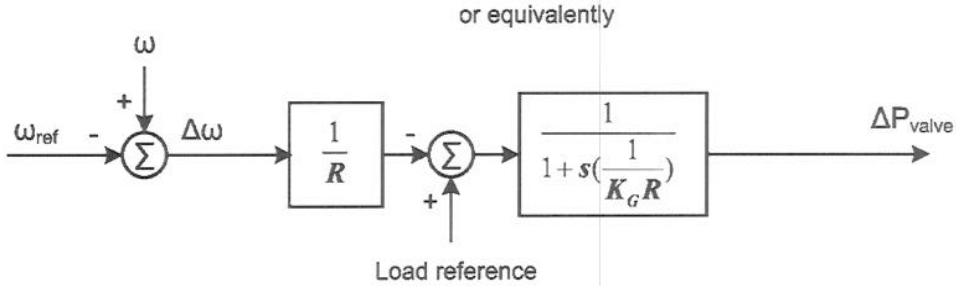


Figure: Governor control block diagram



or equivalently



Let $\dfrac{1}{K_G R} = T_G$ (Governor time constant)

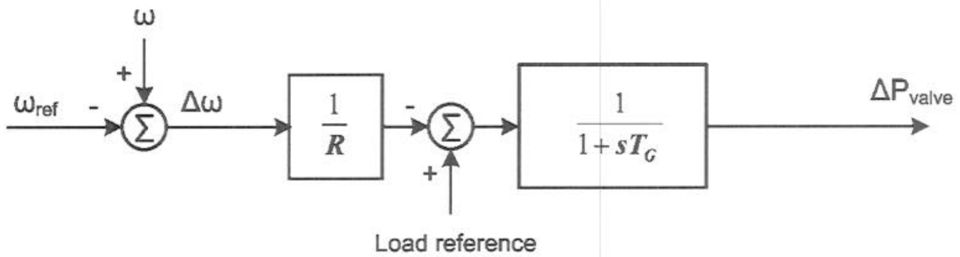
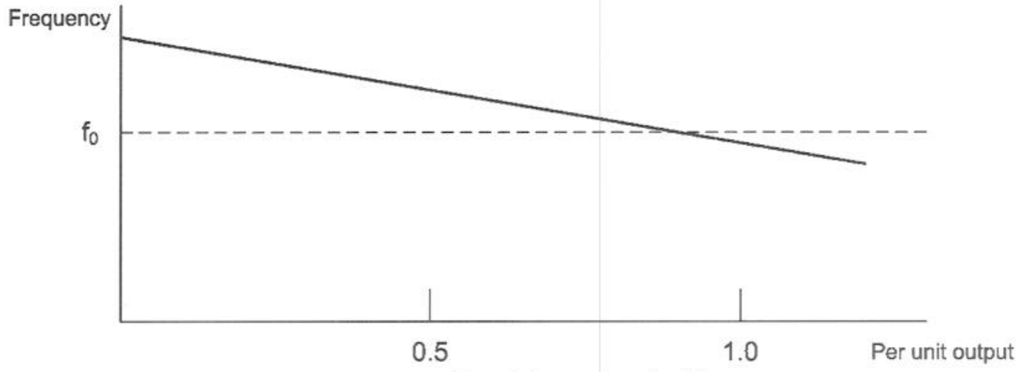


Fig: Simplified block diagram of governor control

In steady state the unit output in response to system frequency deviation will have droop (negative slope) as shown in the following figure.



Speed-droop characteristic

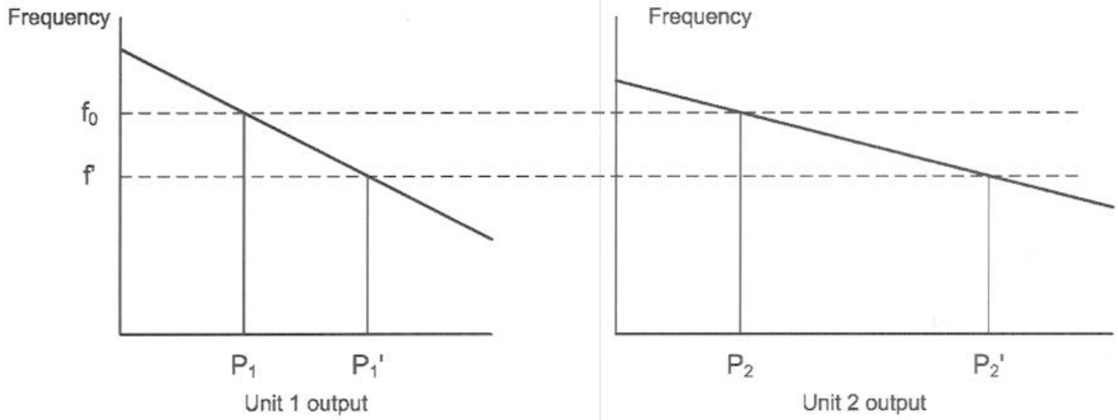


Fig: load sharing through proper droop arrangement

Let's now turn our attention to the influence of speed governing control on the frequency deviation due to change in load. We assume a generic turbine model $G_t(s)$.

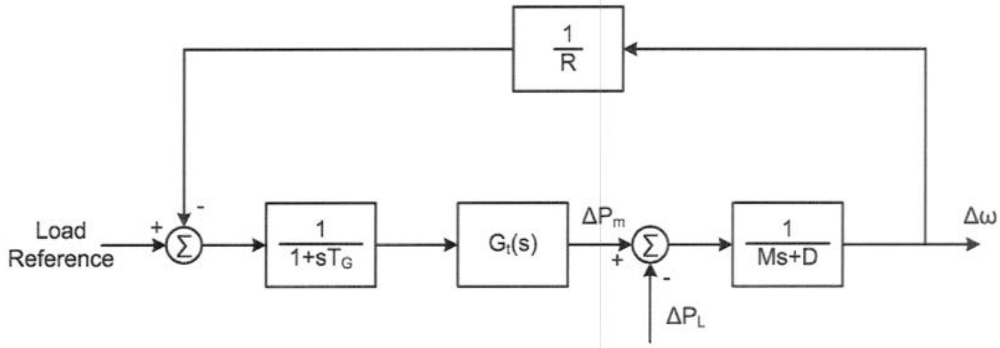


Fig: Block diagram of governor with droop for generator speed control

Let us assume that generic transfer function of turbine (steam as well as hydro) is expressed as $G_t(s)$. Assuming 100% efficiency the gain between the power input to the turbine to the power output will be unity. The transfer characteristic between ΔP_L and $\Delta\omega$ can be expressed as

$$\frac{\Delta\omega}{\Delta P_L} = -\frac{R(1+sT_G)}{G_t(s)+(Ms+D)R(1+sT_G)}$$

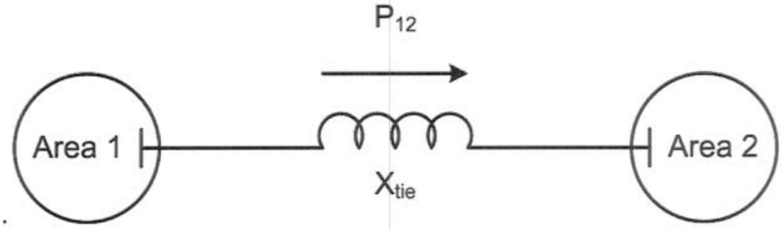
The steady state frequency deviation

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

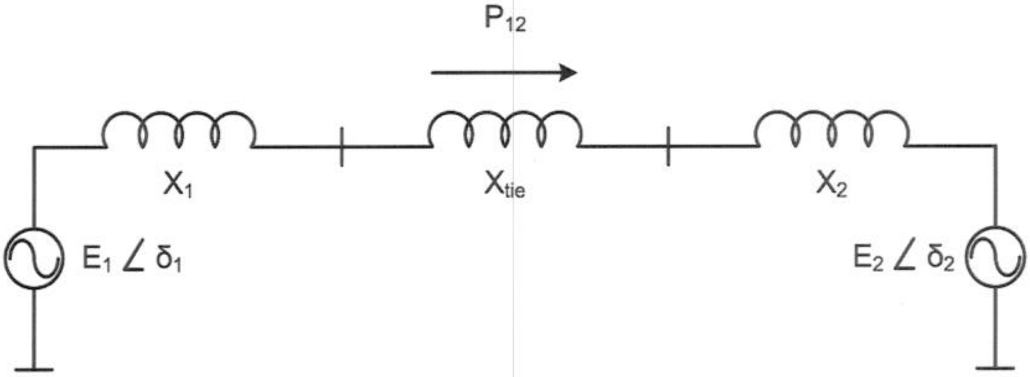
It is interesting to note that the denominator is now dominated by the reciprocal of the droop (R). This will reduce the steady state speed deviation because of change in demand.

[8]

b) For interconnected system schedule tie line power is an additional variable.



The electrical equivalent is as follows:

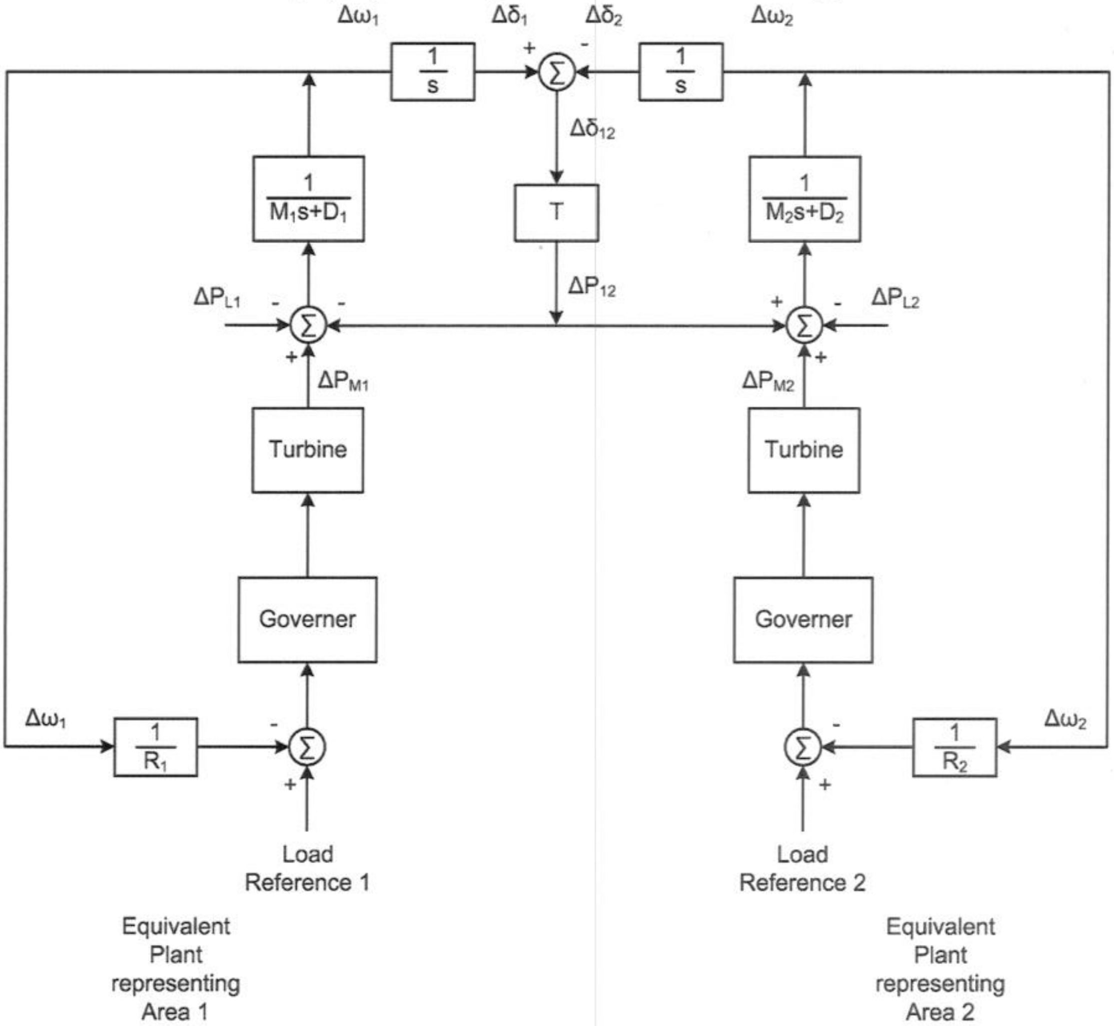


In an interconnected system operation as shown in the figure, it is important to consider the scheduled interchange power. These two areas can be modelled as two equivalent voltage sources behind source reactance and tie line reactance.

$$P_{12} = \frac{E_1 E_2}{X_T} sin(\delta_1 - \delta_2)$$

The linearized form of the above equation is:

$\Delta P_{12} = T(\Delta\delta_1 - \Delta\delta_2)$ where $T = \frac{E_1 E_2}{X_T} cos(\delta_{10} - \delta_{20})$ is the synchronising power co-efficient. The block diagram below shows this. Note each area is represented by its composite load damping and frequency characteristic. The frequency deviation $\Delta\omega_1 = \Delta\omega_2 = \Delta\omega = \Delta f$ is common in both area connected by tie. The tie power deviation ΔP_{12} will be seen as load in area 1 and generation in area 2 (import) and its sign will be assumed accordingly.



This two area system with primary governor control can easily be characterised by the following equation or relation:

$$\Delta f = -\frac{\Delta P_L}{D_1 + D_2 + \frac{1}{R_1} + \frac{1}{R_2}}$$

Let us assume that there is a change in area 1 load. It will be natural to see the implication of this change on system frequency, area loads and interchange.

In the steady state following hold

Area1: $\Delta P_{m1} - \Delta P_{L1} - \Delta P_{12} = D_1 \Delta f$

Area 2: $\Delta P_{m2} + \Delta P_{12} = D_2 \Delta f$

From droop characteristics: $\Delta P_{m1} = -\frac{\Delta f}{R_1}; \Delta P_{m2} = -\frac{\Delta f}{R_2}$

On substitution $\Delta P_{m1}, \Delta P_{m2}$ into the first two equations and solving for Δf

$$\Delta f = -\frac{\Delta P_{L1}}{D_1 + D_2 + \frac{1}{R_1} + \frac{1}{R_2}}$$

[7]

b) Assume that all the generating units in both areas respond to the loss of load.

$$\frac{1}{R_1} = \frac{19000}{0.05 * 50} = 7600\ MW/Hz$$

$$\frac{1}{R_2} = \frac{41000}{0.05 * 50} = 16400\ MW/Hz$$

Load damping (D_1) in the remaining load in Area 1: $\frac{19000}{100}\frac{100}{50} = 380\ MW/Hz$

For Area 2 load damping (D_2)= $\frac{40000}{100}\frac{100}{50} = 800\ MW/Hz$

Frequency deviation due to loss of 1000 MW load is

$$\Delta f = -\frac{-1000}{D_1 + D_2 + \frac{1}{R_1} + \frac{1}{R_2}} = 0.04\ Hz$$

[5]

5

a)

The relay technology evolved over 80 years and it is never ending process like other technologies. Broadly this can be classified into three generations:

Electromechanical relays;

Solid state relays and

Numerical relays

Electromechanical relays

When the principle of electromechanical energy conversion is used for decision making, the relay is referred as an electromechanical relay. These relays represent the first generation of relays. Let us consider a simple example of an over current relay, which issues a trip signal if current in the apparatus is above a reference value. By proper geometrical placement of current carrying conductor in the magnetic field, Lorentz force $F = Bil \sin\theta$ is produced in the coil (Fig 9.3)

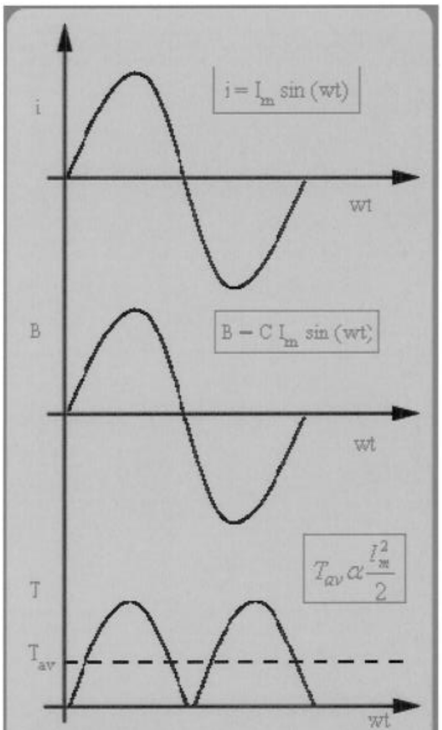


Fig. 9.3 Torque and Current Relationship in Attracted Armature Relay

This force is used to create the operating torque. If constant 'B' is used (for example by a permanent magnet), then the instantaneous torque produced is proportional to instantaneous value of the current. Since the instantaneous current is sinusoidal, the instantaneous torque is also sinusoidal which has a zero average value. Thus, no net deflection of operating coil is perceived.

On the other hand, if the B is also made proportional to the instantaneous value of the current, then the instantaneous torque will be proportional to square of the instantaneous current (non-negative quantity). The average torque will be proportional to square of the rms current. Movement of the relay contact caused by the operating torque may be restrained by a spring in the over current relay. If the spring has a spring constant 'k', then the deflection is proportional to the operating torque (in this case proportional to I_{rms}^2). When the deflection exceeds a preset value, the relay contacts closes and a trip decision is issued. Electromechanical relays are known for their ruggedness and immunity to Electromagnetic Interference (EMI).

The power required to operate the magnetic coils and move contactors are higher when compared to its solid state or digital counterpart. This reflects into higher volt-ampere rating (burden)

[7]

b)

A relay is said to be dependable if it trips only when it is expected to trip. This happens either when the fault is in its primary jurisdiction or when it is called upon to provide the back-up protection. However, false tripping of relays or tripping for faults that is either not within its jurisdiction, or within its purview, compromises system operation. Power system may get unnecessarily stressed or else there can be loss of service. **Dependability** is the degree of certainty that the relay will operate correctly. Dependability can be improved by increasing the sensitivity of the relaying system.

On the other hand, **security** is a property used to characterize false tripping of the relays. A relay is said to be secure if it does not trip when it is not expected to trip. It is the degree of certainty that the relay will not operate incorrectly: False trips do not just create nuisance. They can even affect system security. For example, tripping of a tie-line in a two area system can result in load-generation imbalance in each area which can be dangerous. Even when multiple paths for power flow are available, under peak load conditions, overloads or congestion in the system may result. Dependability and security are contrasting requirements. Typically, a relay engineer biases his setting towards dependability. This may cause some nuisance tripping, which can in the worst case, trigger partial or complete blackout! Security of the relaying system can be improved by improving selectivity of the relaying system

[5]

c) Number of correct trips = 34; Number of desired trips = 34 + 5 = 39

$$\%\ Dependability = \frac{Number\ of\ correct\ trips}{Number\ of\ desired\ trips} \times 100$$

—

$$\%\ Security = \frac{Number\ of\ correct\ trips}{Total\ number\ of\ trips} \times 100$$

—

$$\%\ Reliability = \frac{Number\ of\ correct\ trips}{Number\ of\ desired\ trips + Number\ of\ incorrect\ trips} \times 100$$

———

[6]

d) Sensitivity and selectivity are achieved. The differential protection with second harmonic restraints can offer discrimination between fault in the transformer and starting inrush current which have predominantly noticeably high second harmonic components. The differential current flowing through differential elements discriminates whether the fault is within the zone of CT or outside it.

[2]

6)

a)

i) Total resistance in the secondary circuit is = 1.0+1.0+0.51 = 2.51 Ω. When 110 A flows through the secondary, the excitation voltage developed is = 110*2.51 = 276.1 V. This is way below knee-point saturation voltage (400 Volt as designated as C400). The CT will be operating very much in linear region.

[5]

ii) the magnetising current is 276.1/3000 = 0.092 A, the % ratio error is 0.092/110*100 = 0.083%. [Note: the students are expected to know or remember the ratio error].

[3]

b) The phase angle error influences the performance of directional distance protection scheme. The phase angle error influences measure power also. When they are used for metering for billing purpose in to large customers (inter regional or industrial consumers), it is very important to have a CT with minimum phase angle error.

[2]

c) The relay will receive the current from the measurement CT. Under normal condition it will produce faithful reproduction primary current with very high accuracy in magnitude and phase angle error. Under abnormal condition, particularly for high fault current, the core will saturate and the relay will be fed with incorrect reflection of primary current. The dependability, security and sensitivity of the relay will be affected. The meter will receive current from the secondary of protection CT. The ratio and phase angle error will be small as such but if the meters poses high burden they may saturate even at normal condition. The accuracy of the metered output may be affected in case they have high burden otherwise not. During abnormal condition the protection CT will produce faith representation of primary current, but the metering is not any useful here as the system goes through abnormal operating conditions.

[3]

d) Typically, the secondary voltage of the VT is standardized to 110 V (ac). Hence, as the primary voltage increases, the turns ratio N_1:N_2 increases and transformer becomes bulky. A capacitance potential divider is used (Fig 10.8) to cut down the cost. Thus, a reduced voltage is fed to primary of the transformer. This reduces the size of VT. This leads to development of coupling capacitor voltage transformers (CCVT) or simply as capacitive voltage transformer (CVT).

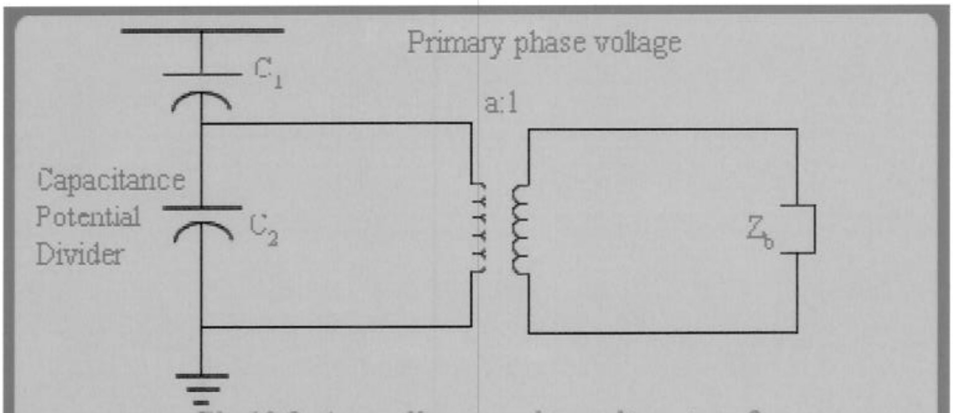


Fig 10.8: A coupling capacitor voltage transformer

Role of Tuning Reactor L: Assuming, the transformer to be ideal, and source with negligible reactance, the Thevenin's equivalent circuit of CCVT is shown in Fig 10.9.

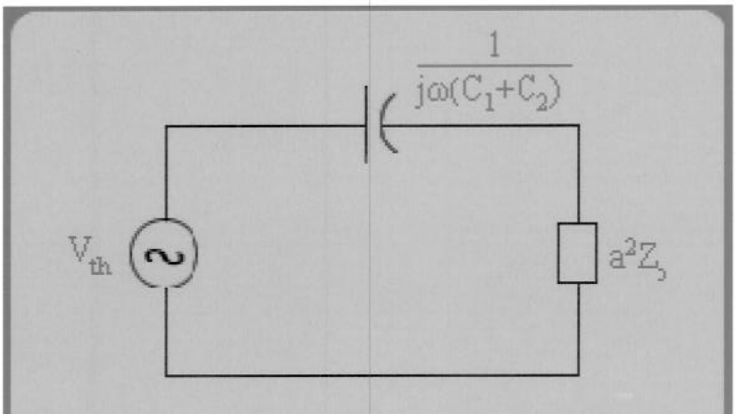


Fig 10.9: CCVT as seen from primary of VT

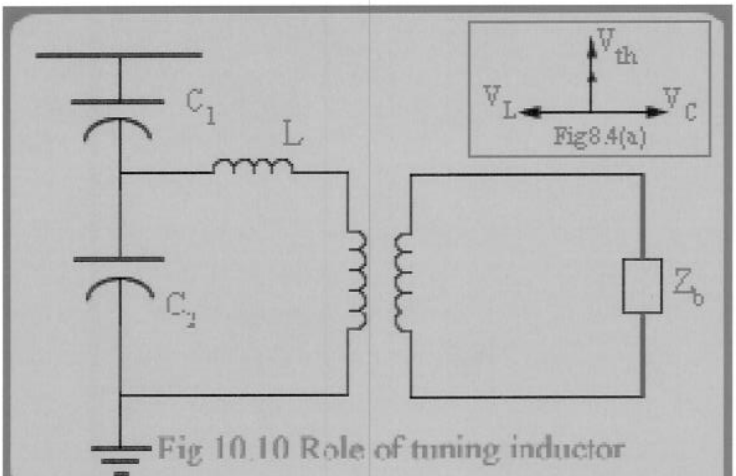


Fig 10.10 Role of tuning inductor

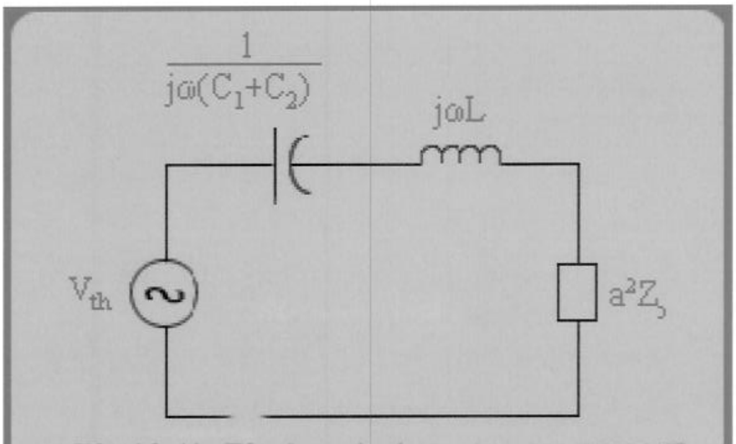


Fig 10.11: Final equivalent circuit of CCVT

It is now obvious that Z_{th} due to the capacitance divider affects the voltage received by the relay. To achieve high level of accuracy, it is therefore necessary to compensate for this voltage drop by connecting a tuning inductor. The tuning inductor's value is so chosen that it compensates for the 'net C' at power frequency (50/60Hz). $\omega L = \frac{1}{\omega(C_1 + C_2)}$ The phasor diagram across resistive load, is as shown in Fig 10.10.

From the corresponding equivalent circuit, it is apparent that, if, then voltage drop across C is neutralized and the relay sees the actual voltage to be measured.

[7]