CBCS SCHEME

USN

18EE81

Eighth Semester B.E. Degree Examination, June/July 2023
Power System Operation & Control

Time: 3 hrs. Max. Marks: 100

Note: Answer any FIVE full questions, choosing ONE full question from each module.

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

Module-1

1 a. List out the operating states of a power system and explain them with a neat block diagram. (08 Marks)

b. Define preventive and emergency controls used in power system operation and list out them in detail. (08 Marks)

c. Define Energy Management centre and list out its functions. (04 Marks)

OR

2 a. List out the major components of SCADA and explain them in detail. (08 Marks)

b. Define an IED as per the industry standard. Explain the fundamental blocks of an IED in detail using the structural block diagram. (08 Marks)

c. Explain the following categories of SCADA systems with their configuration:
   (i) Single master-single remote SCADA systems.
   (ii) Single master-multiple RTU SCADA systems. (04 Marks)

Module-2

3 Derive the complete mathematical model of load frequency control of an isolated power system with the help of modeling the following components of it.
   (i) Model of speed governing system.
   (ii) Turbine model.
   (iii) Generator-load model. (20 Marks)

OR

4 a. Explain the operation of load frequency and excitation voltage regulators equipped in turbo-generators with a neat schematic diagram. (08 Marks)

b. State the need for proportional plus integral control in an isolated power system and derive the transfer function of it with PI controller through the block diagram of it. (12 Marks)

Module-3

5 Derive the state variable model of LFC of a two area power system in terms of state variables, control variables and disturbance variables by properly defining them. (20 Marks)

OR

6 a. Explain the operation of AVR equipped in a turbo-alternator with a neat schematic diagram and also derive its transfer function model with usual notations. (10 Marks)

b. Explain the need for Generation Rate Constraints (GRCs) in LFC and various ways of incorporating them in the mathematical model of LFC. (05 Marks)

c. Define speed governor dead-band and explain in detail about its effects on AGC with neat control block diagram. (05 Marks)

Module-4

7 a. Explain in detail about the generation and absorption of reactive power by various power system components. (08 Marks)

b. Consider a transmission system shown in Fig. Q7 (b) below. The pu reactance values are referred to the respective voltage bases and 100 MVA base. Determine the power supplied by the generator and its power factor.

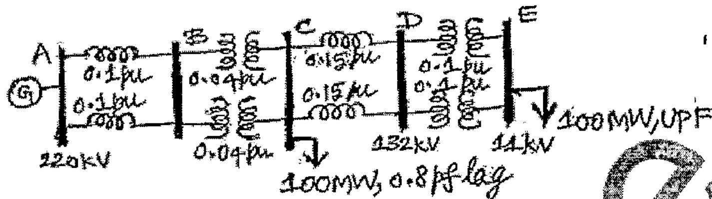

Fig. Q7 (b) (12 Marks)

OR

8 a. Explain various methods of voltage control by injection of reactive power at a node in a power system. (12 Marks)

b. Explain the following methods of voltage control at a node in a power system :
 (i) Using booster transformers.
 (ii) Using phase-shift transformers. (08 Marks)

Module-5

9 a. Define power system security and explain in detail about its three major functions that are carried out in an operation control center. (10 Marks)

b. Explain the simplest form of contingency analysis technique with the help of a neat flow chart. (06 Marks)

c. List out the factors affecting the power system security and explain them briefly. (04 Marks)

OR

10 a. List out and explain the linear sensitivity factors. Explain the contingency analysis procedure using sensitivity factors with a neat flow chart. (12 Marks)

b. Explain 1P1Q method for contingency selection procedure with a neat flow chart. (08 Marks)

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Department of Electrical & Electronics Engineering

Solution of VTU Question Paper June-July 2023

Subject: Power System Operation & Control.

Code: 18EE81.

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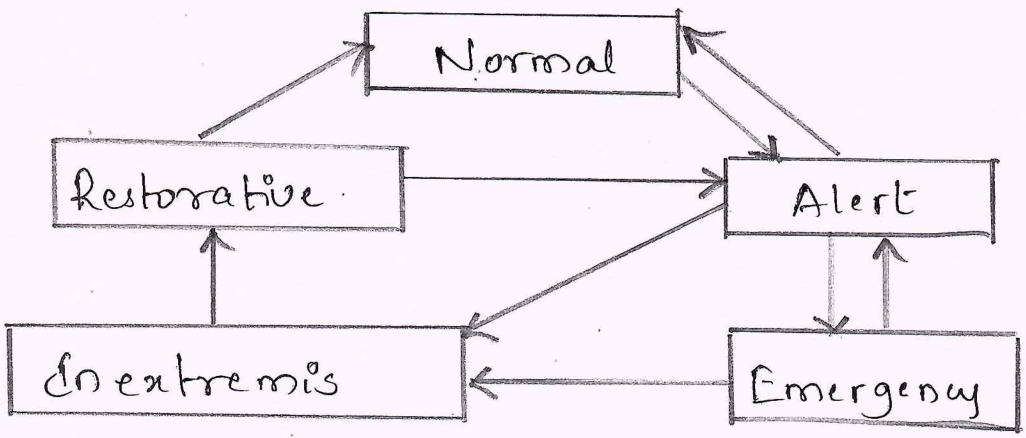
Module - 01

1 a) List out the operating states of power system & explain them with a neat block diagram [08]



1) Normal state: In this state generation is adequate to meet the demand without any equipment being overloaded & reserve margins are sufficient to provide security for normal stresses.

2) Alert state: There is possibility that some inequality constraints may be violated in the event of disturbances. Preventive control will lead the system from alert state to normal state.

3) Emergency state: Due to severe disturbances the system may enter an emergency state because of imbalance

between generation & load. Control measures such as direct or indirect load shedding, generation shedding, network splitting are taken.

4) Inextremis state: In this state, the generation & load demand do not match. This means that, some part of the system load is lost. Emergency measures must be taken to prevent a total grid collapse.

5) Restorative state: This is a transitional state where the inequality constraints are satisfied by the emergency control actions taken, but system has still not come to normal state interms of equality constraints.

1 b) Define preventive & emergency controls used in power system operation & list out them in detail. [08]

Preventive control is meant to keep the system in normal state or bring it back to the normal state from the alert state. Automatic controls are provided for frequency & voltage control.

Preventive control measures used are,

1) Rescheduling of active power generated by various units to match the changing load.

2) Start-up of generation units & providing adequate spinning reserve.

3) Change in the voltage reference points of generators & voltage control devices.

4) Change of substation configurations like bus-bar splitting etc.,

Emergency control measures are taken to stop worsening of the situation, prevent degradation of system & cascading failure effects & bring back the system to alert state.

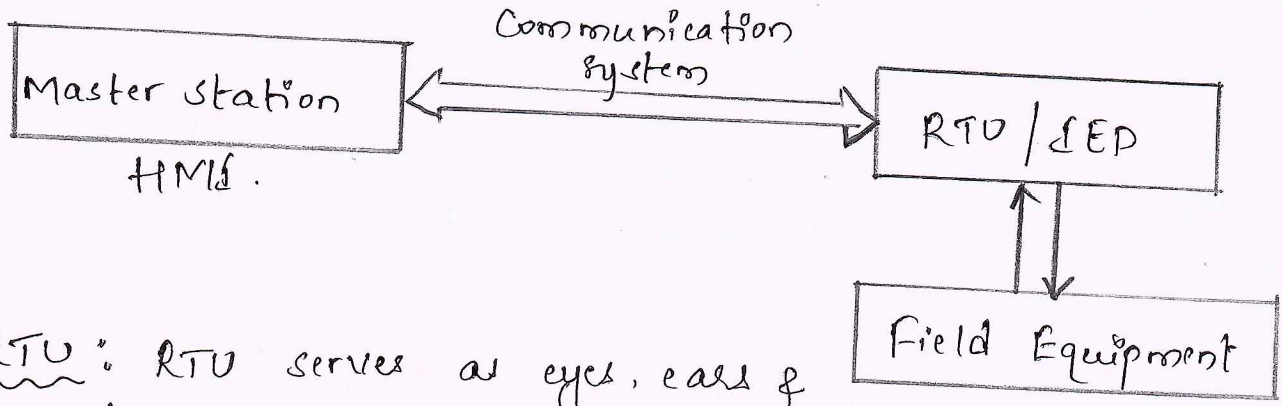
Emergency control measures are,
1) Tripping of generators
2) Load shedding
3) Blocking of tap changers of transformers.
4) Fast HVDC power transfer control.

1 c) Define Energy Management System/center & list out its functions. [04]

The EMC comprises both hardware & software to monitor & control the system operation. In modern power system monitoring is fully automated & Controlling is combination of automated & manual.
The functions of EMC are,
1) The dispatch subsystem: It involves functions of unit commitment, economic dispatch, AGC & demand forecasting.
2) Data subsystem: This is for data aquisition & processing which contains units of SCADA, state estimation & all the associated alarms & displays.
3) Security subsystem: This is basically to oversee the secure operation of power system. The functions includes are security monitoring, contingency analysis, decisions on control actions based on state of the system.

2 a) List out major components of SCADA & explain them in detail. [08]

SCADA is an integrated technology composed of 4 major components.
1) RTU
2) Communication system.
3) Master station
4) Human Machine Interface [HMI]



1) RTU: RTU serves as eyes, ears & hands of SCADA. RTU aquires all the field data from different field devices, process the data & transmit the relevant data to the master station. At the same time, it distributes the control signals received from master station to the field devices.

2) Communication system: This refers to communication channel employed between field equipment & master station.

3) Master Station: This is a collection of computers, peripherals & appropriate I/O systems that enable the operators to monitor the state of power system & control it.

4) HMI: HMI refers to the interface required for the interaction between the master station & operators or users of SCADA system.

2 b) Define an IED as per industry standard. Explain fundamental blocks of an IED in detail using structural block diagram. [08]

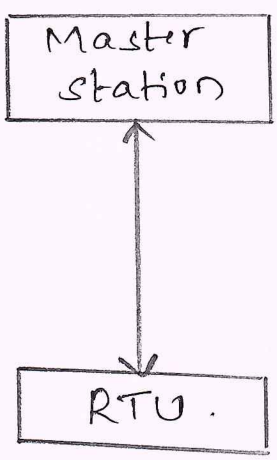
The industry standard definition of an IED is "Any device incorporating one or more processors with the capability to receive or send data/control from or to an external source."

IED functional block diagram.

External Communication	Data Processing	Input/Output Measurement
Selectable protocol	Protection	Discrete Inputs
Selectable protocol	Metering	Analog inputs
Rapid response	Event recording	Discrete outputs
Real-time data	Fault recording	Analog outputs
Multiple ports	Application Logic	Selectable Ratings.

2c) Explain the following categories of SCADA systems with their configurations.
i) Single master - Single remote
ii) Single master - multiple RTU. [04]

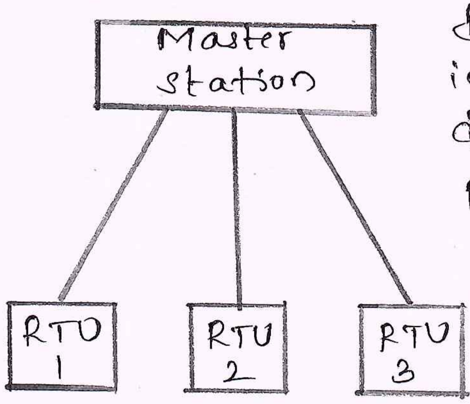
1) Single - master - Single remote.



It is utilized for simple systems where small no. of points are involved, since it requires one master station & one Communication channel per RTU.

This one-on-one configuration has one indicator or display at the master station for each remote data point.

2) Sing master - multiple RTU:



In this master station communicates inturn to each RTU using serial digital data messages.

Example is power distribution system with one master station controlling no. of substations with RTUs.

3) Derive the complete mathematical model of load-frequency control of an isolated power system with the help of modeling the following components of it.
i) Model of speed governing system.
ii) Turbine model
iii) Generator - load model. [20]

1) Modeling of speed - governor system.

Let point A on linkage mechanism be moved downwards by small amount ΔY_A. It is a command which causes the turbine power output to change & can be written as,

$$\Delta Y_A = K_c \cdot \Delta P_c \qquad \text{—— (1)}$$

Two factors contribute to the movement of C.
1) ΔY_A contributes $-K_1 \Delta Y_A$ (ie upwards) of $-K_1 K_c \Delta P_c$
2) Increase in frequency Δf causes the flyballs to move outwards so that B moves downwards by a proportional amount $K_2' \Delta f$.

The net movement of C is therefore,

$$\Delta Y_C = -K_1 K_c \Delta P_c + K_2 \cdot \Delta f \qquad \text{—— (2)}$$

The movement of D, ΔY_D is the amount by which the pilot value opens. It is contributed by ΔY_C & ΔY_E.

$$\therefore \Delta Y_D = K_3 \Delta Y_C + K_4 \Delta Y_E \qquad \text{—— (3)}$$

The volume of oil admitted to the cylinder is thus proportional to the time integral of ΔY_D. The movement ΔY_E is obtained by dividing oil volume by area of the cross - section of the piston. Thus,

$$\Delta Y_E = K_5 \int_0^t (-\Delta Y_D)\, dt \qquad \text{—— (4)}$$

Taking Laplace Transform of eqns. (2), (3) & (4)

$$\Delta Y_C(s) = -K_1 K_c \Delta P_c(s) + K_2 \Delta F(s) \qquad \text{—— (5)}$$

$$\Delta Y_D(s) = K_3 \Delta Y_C(s) + K_4 \Delta Y_E(s) \qquad \text{—— (6)}$$

$$\Delta Y_E(s) = -K_5 \cdot \frac{1}{s} \Delta Y_D(s) \qquad \text{—— (7)}$$

Eliminating $\Delta Y_C(s)$ & $\Delta Y_D(s)$ we get,

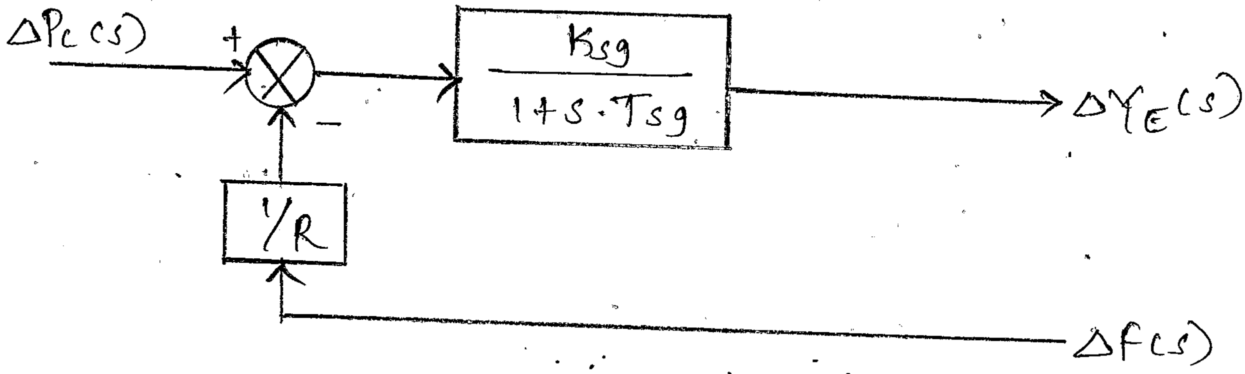
$$\Delta Y_E(s) = \frac{K_1 K_3 K_C \Delta P_C(s) - K_2 K_3 \Delta f(s)}{K_4 + \frac{s}{K_5}}$$

$$\Delta Y_E(s) = \left[\Delta P_C(s) - \frac{1}{R}\Delta f(s)\right] \times \left[\frac{K_{sg}}{1+s \cdot T_{sg}}\right]$$

where, $R = \frac{K_1 K_C}{K_2}$ = speed regulation of governor.

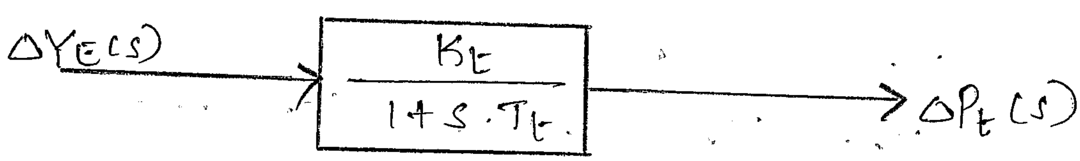
$K_{sg} = \frac{K_1 K_3 K_C}{K_4}$ = gain of speed governor.

$T_{sg} = \frac{1}{K_4 K_5}$ = time constant of speed governor.



2) Turbine model.

Considering dynamic response of a steam turbine in terms of changes in power output to changes in steam value opening ΔY_E.



3) Generator - Load model.

The increment in power input to the generator-load system is, $\Delta P_G - \Delta P_D$

This increment in power input to the system is accounted for in two ways:

1) The kinetic energy being proportional to square of speed (freq), the KE at a freq. of $(f^0 + \Delta f)$ is,

$$W_{ke} = H P_r \left[1 + \frac{2\Delta f}{f^0}\right]$$

Rate of change of KE is therefore,

$$\frac{d}{dt}(W_{KE}) = \frac{2HP_r}{f^0}\frac{d}{dt}(\Delta f)$$

2) As the frequency changes, the motor load changes being sensitive to speed, the rate of change of load wrt. frequency ie $\partial P_D/\partial f$ can be regarded as nearly constant for small changes in frequency Δf & can be expressed as,

$$(\partial P_D/\partial f)\cdot\Delta f = B\cdot\Delta f$$

Writing power balance eqn.

$$\Delta P_G - \Delta P_D = \frac{2HP_r}{f^0}\frac{d}{dt}(\Delta f) + B\cdot\Delta f$$

Dividing throughout by P_r & rearranging, we get

$$\Delta P_G(pu) - \Delta P_D(pu) = \frac{2H}{f^0}\frac{d}{dt}(\Delta f) + B(pu)\cdot\Delta f$$

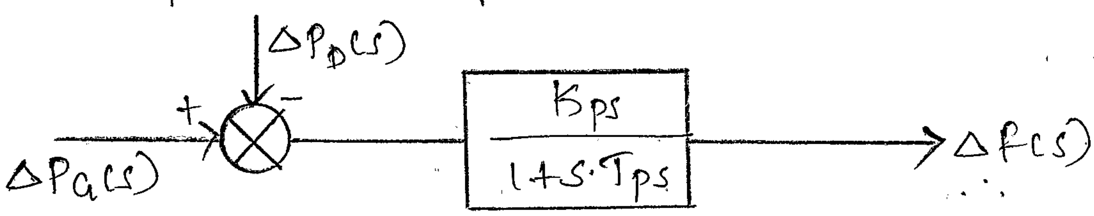
Taking the Laplace transform, we can write $\Delta f(s)$

$$\Delta F(s) = \frac{\Delta P_G(s) - \Delta P_D(s)}{B + \frac{2H}{f^0}(s)}$$

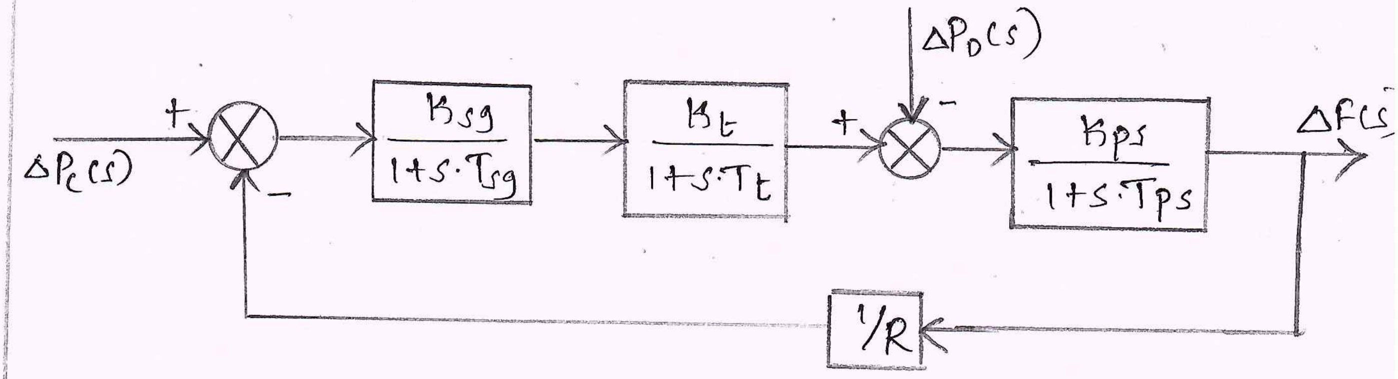
$$\Delta F(s) = [\Delta P_G(s) - \Delta P_D(s)] \times \left[\frac{K_{ps}}{1+s\cdot T_{ps}}\right]$$

where, $T_{ps} = 2H/Bf^0$ = power system time constant

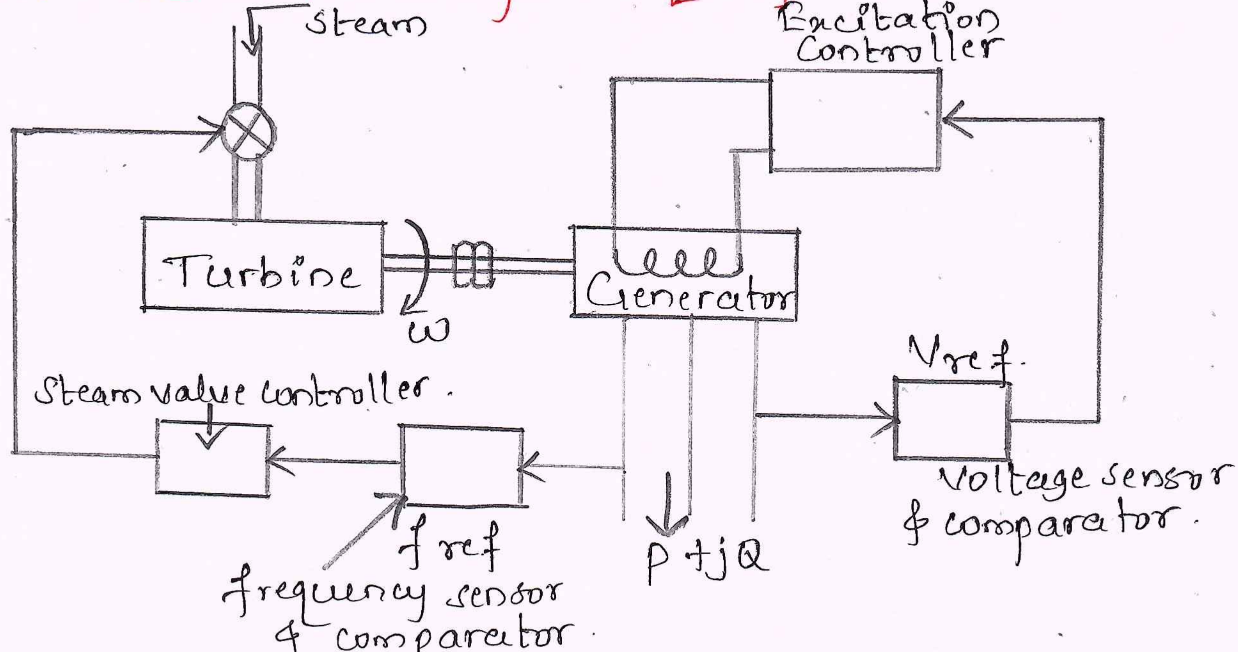
$K_{ps} = 1/B$ = power system gain.



The complete block diagram of isolated power system is shown.



4 a) Explain the operation of load-frequency & excitation voltage regulators equipped in turbo generators with a neat schematic diagram [08]



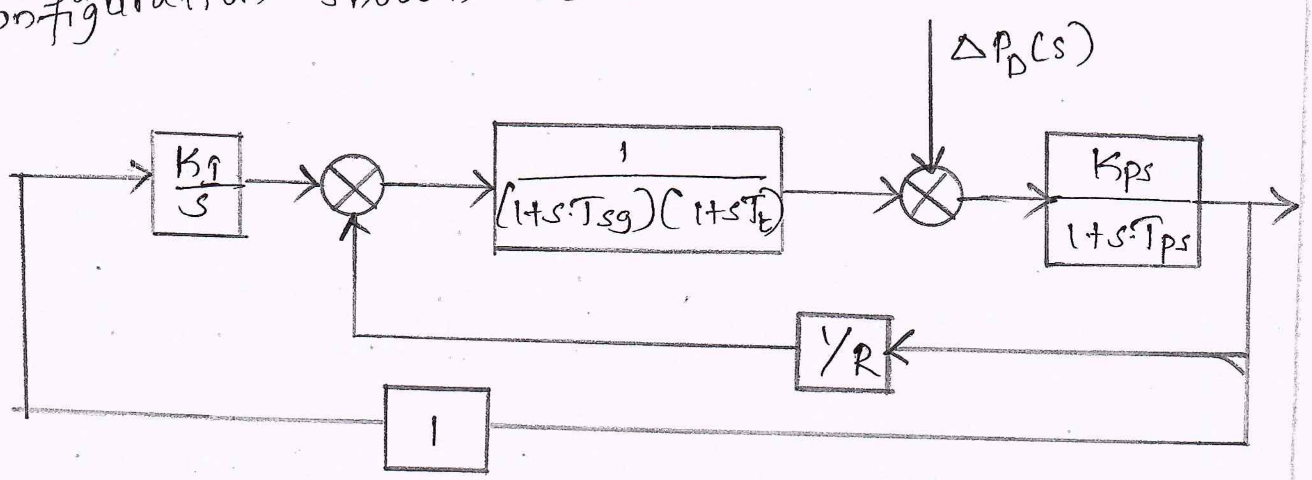
In power system both active & reactive power demands are never steady & they continually change with rising or falling trend. Steam input to turbo-generators be continuously regulated to match active power demand, failing which the machine speed will vary with consequent change in frequency which is highly undesirable.

Also, the excitation of generators must be continuously regulated to match the reactive power demand with reactive generation, otherwise the voltage at various system buses may go beyond the prescribed limit.

figure gives schematic diagram of load frequency & excitation voltage regulators of turbo generator. The controllers are set for perticular operating condition & they take care of small changes in load demand without frequency & voltage exceeding the prescribed limits.

4b) State the need for proportional plus integral control in an isolated power system & derive the transfer function of it with PI controller through the block diagram of it. [12]

System frequency specifications are rather stringent & therefore, so much change in frequency cannot be tolerated. It is expected that steady change in frequency will be zero. While steady state frequency can be brought back to scheduled value by adjusting speed changer setting, the system could undergo intolerable dynamic frequency changes, with changes in load. For this purpose, a signal from Δf is fed back through an integrator to the speed changer resulting in the block diagram configuration shown below.



The system now modifies to a proportional plus integral controller, which gives zero steady state error. ie $\Delta f|_{steady\ state} = 0$.

$$\Delta F(s) = -\frac{K_{ps}}{(1+sT_{ps}) + \left[\frac{1}{R} + \frac{K_i}{s}\right] \times \frac{K_{ps}}{(1+sT_{sg})(1+sT_t)}} \times \frac{\Delta P_D}{s}$$

$$= \frac{R K_{ps} s\,(1+sT_{sg})(1+sT_t)}{s(1+sT_{sg})(1+sT_t)(1+sT_{ps})R + K_{ps}(K_i R + s)} \times \frac{\Delta P_D}{s}$$

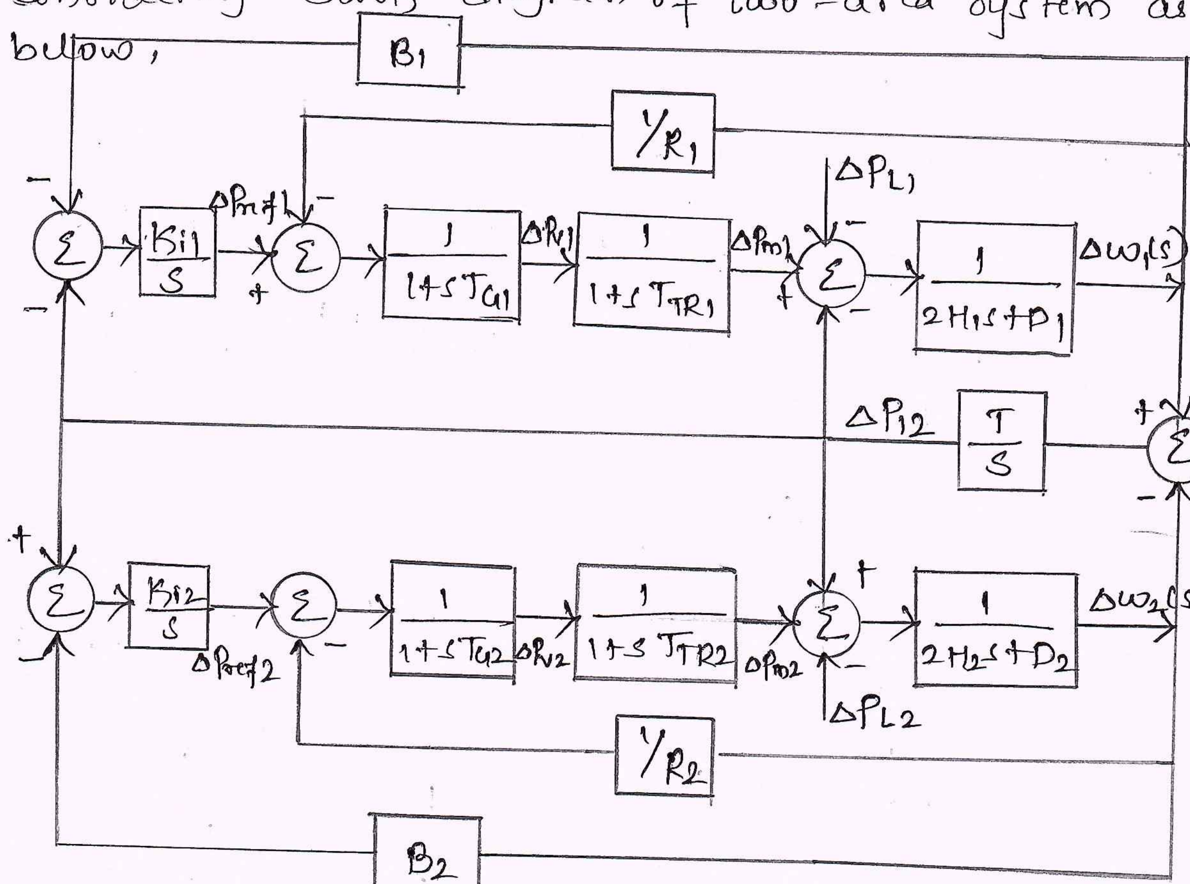
$\therefore \Delta f|_{steady\ state} = s \cdot \Delta F(s) = 0$.

Thus we found that, the steady state change in frequency has been reduced to zero by the addition of integral controller.

Module - 03

5) Derive the state variable model of LFC of two-area power system interms of state variables, control variable & disturbance variables by properly defining them. [20]

Considering block diagram of two-area system as shown bellow,



Let us consider the state vector,

$$x = [\Delta\omega_1 \; \Delta P_{m1} \; \Delta P_{V1} \; \Delta P_{ref1} \; \Delta P_{tie} \; \Delta\omega_2 \; \Delta P_{m2} \; \Delta P_{V2} \; \Delta P_{ref2}]$$

$$\Delta\omega_1(s) = \frac{1}{2H_1 s + D_1}\left[\Delta P_{m1}(s) - \Delta P_{L1}(s) - \Delta P_{tie}(s)\right]$$

$$s\,\Delta\omega_1(s) = -\frac{D_1}{2H_1}\Delta\omega_1(s) + \frac{1}{2H_1}\Delta P_{m1}(s) - \frac{1}{2H_1}\Delta P_{L1}(s) - \frac{1}{2H_1}\Delta P_{tie}(s) \quad \text{--- (1)}$$

$$\Delta P_{m1}(s) = \frac{1}{1+sT_{TR1}}\left[\Delta P_{V1}(s)\right]$$

$$s\,\Delta P_{m1}(s) = -\frac{1}{T_{TR1}}\Delta P_{m1}(s) + \frac{1}{T_{TR1}}\Delta P_{V1}(s) \quad \text{--- (2)}$$

$$\Delta P_{V1}(s) = \frac{1}{1+sT_{G1}}\left[\Delta P_{ref}(s) - \frac{1}{R_1}\Delta\omega_1(s)\right]$$

$$s\cdot\Delta P_{V1}(s) = -\frac{1}{T_{G1}}\Delta P_{V1}(s) + \frac{1}{T_{G1}}\Delta P_{ref}(s) - \frac{1}{R_1 T_{G1}}\Delta\omega_1(s) \quad \text{--- (3)}$$

$$\Delta P_{ref1}(s) = -\frac{K_{i1}}{s}\left[B_1\Delta\omega_1(s) + \Delta P_{tie}(s)\right]$$

$$s\cdot\Delta P_{ref1}(s) = -K_{i1}B_1\Delta\omega_1(s) - K_{i1}\Delta P_{tie}(s) \quad \text{--- (4)}$$

$$\Delta P_{tie}(s) = \frac{T_{12}}{s}\left[\Delta\omega_1(s) - \Delta\omega_2(s)\right]$$

$$s\cdot\Delta P_{tie}(s) = T_{12}\Delta\omega_1(s) - T_{12}\Delta\omega_2(s) \quad \text{--- (5)}$$

$$\Delta\omega_2(s) = \frac{1}{2H_2 s + D_2}\left[\Delta P_{m2}(s) - \Delta P_{L2}(s) + \Delta P_{tie}(s)\right]$$

$$s\cdot\Delta\omega_2(s) = -\frac{D_2}{2H_2}\Delta\omega_2(s) - \frac{1}{2H_2}\Delta P_{L2}(s) + \frac{1}{2H_2}\Delta P_{tie}(s) \quad \text{--- (6)}$$

$$\Delta P_{m2}(s) = \frac{1}{1+sT_{TR2}}\left[\Delta P_{V2}(s)\right]$$

$$s\cdot\Delta P_{m2}(s) = -\frac{1}{T_{TR2}}\Delta P_{m2}(s) + \frac{1}{T_{TR2}}\Delta P_{V2}(s) \quad \text{--- (7)}$$

$$\Delta P_{V2}(s) = \frac{1}{1+sT_{G2}}\left[\Delta P_{ref2}(s) - \frac{1}{R_2}\Delta\omega_2(s)\right]$$

$$s\cdot\Delta P_{V2}(s) = -\frac{1}{T_{G2}}\Delta P_{V2}(s) + \frac{1}{T_{G2}}\Delta P_{ref2}(s) - \frac{1}{R_2 T_{G2}}\Delta\omega_2(s) \quad \text{--- (8)}$$

$$\Delta P_{ref2}(s) = \frac{-K_{i2}}{s}\left[B_2 \Delta\omega_2(s) - \Delta P_{tie}(s)\right]$$

$$s\,\Delta P_{ref2}(s) = -K_{i2} B_2 \Delta\omega_2(s) + K_{i2}\,\Delta P_{tie}(s) \quad \text{——— (9)}$$

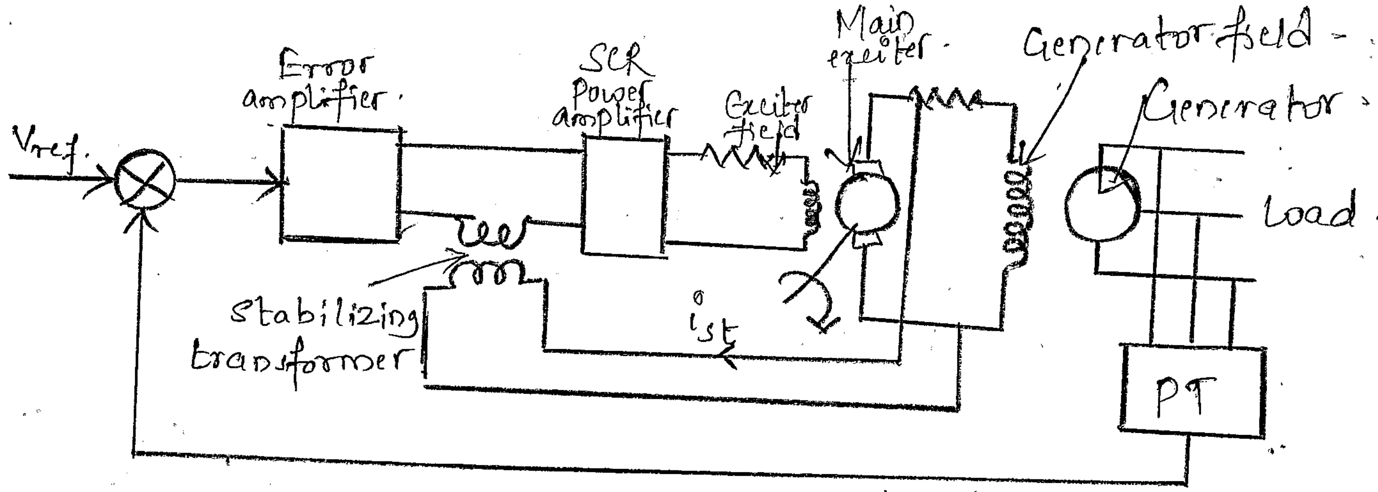
The eqns. (1) to (9) are state equations. We can express them in time domain in standard form,

$$\dot{x}(t) = A\,x(t) + B\cdot u(t)$$

$$\begin{bmatrix} \Delta\dot{\omega}_1 \\ \Delta\dot{P}_{m1} \\ \Delta\dot{P}_{v1} \\ \Delta\dot{P}_{ref1} \\ \Delta\dot{P}_{tie} \\ \Delta\dot{\omega}_2 \\ \Delta\dot{P}_{m2} \\ \Delta\dot{P}_{v2} \\ \Delta\dot{P}_{ref2} \end{bmatrix} = \begin{bmatrix} \frac{-D_1}{2H_1} & \frac{1}{2H_1} & 0 & 0 & \frac{-1}{2H_1} & 0 & 0 & 0 & 0 \\ 0 & \frac{-1}{T_{TR1}} & \frac{1}{T_{R1}} & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{-1}{R_1 T_{G1}} & 0 & \frac{-1}{T_{G1}} & \frac{1}{T_{G1}} & 0 & 0 & 0 & 0 & 0 \\ -K_{i1}B_1 & 0 & 0 & 0 & -K_{i1} & 0 & 0 & 0 & 0 \\ T_{12} & 0 & 0 & 0 & 0 & -T_{12} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{-1}{2H_2} & \frac{-D_2}{2H_2} & \frac{1}{2H_2} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{TR2}} & \frac{1}{T_{TR2}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{-1}{R_2 T_{G2}} & 0 & \frac{-1}{T_{G2}} & \frac{1}{T_{G2}} \\ 0 & 0 & 0 & 0 & K_{i2} & -K_{i2}B_2 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta\omega_1 \\ \Delta P_{m1} \\ \Delta P_{v1} \\ \Delta P_{ref1} \\ \Delta P_{tie} \\ \Delta\omega_2 \\ \Delta P_{m2} \\ \Delta P_{v2} \\ \Delta P_{ref2} \end{bmatrix} + \begin{bmatrix} \frac{-1}{2H_1} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & \frac{-1}{2H_2} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta P_{L1} \\ \Delta P_{L2} \end{bmatrix}$$

6 a) Explain the operation of AVR equipped in a turbo-alternator with a neat schematic diagram & also derive its transfer function model with usual notations [10]

AVR consist of main exciter which excites the alternator field to control the output voltage. The exciter field is automatically controlled through error $e = V_{ref} - V_T$, suitably amplified through voltage & power amplifiers.



1. Potential transformer :
It gives sample of terminal voltage V_T.

2. Differencing device : It gives the actuating error
$$e = V_{ref} - V_T$$

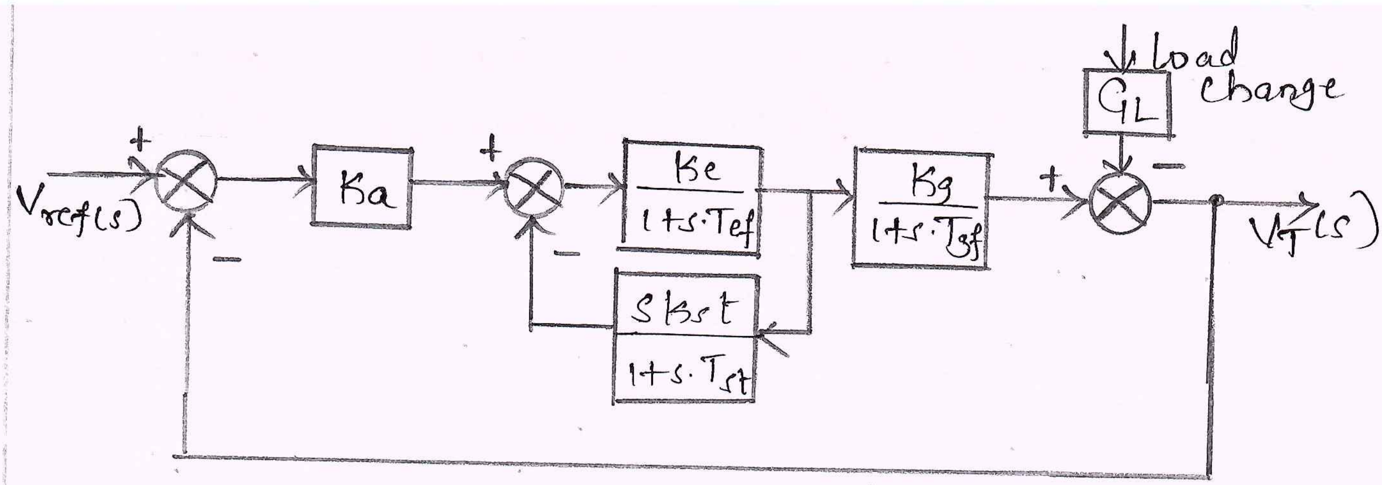
3. Error amplifier : It demodulates & amplifies the error signal. Its gain is K_a.

4. SCR power amplifier & exciter field :
It provides the necessary power amplification to the signal for controlling exciter field.
Overall transfer function $= \dfrac{K_e}{1+s \cdot T_{ef}}$

5. Alternator : Its field is excited by main exciter voltage V_E. The no-load transfer function is,
$$\frac{K_g}{1+s \cdot T_{gf}}$$

6. Stabilizing transformer :
$$= \frac{s \cdot K_{st}}{1+s \cdot T_{st}}$$

The overall block diagram of AVR is,

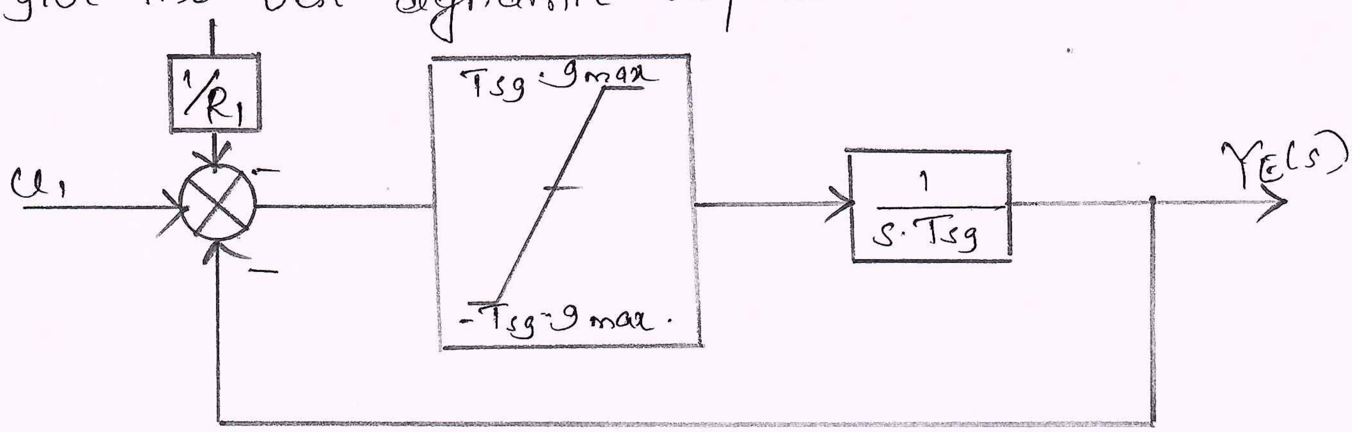


6 b) Explain the need for Generation Rate Constraints (GRC) in LFC & various ways of incorporating them in the mathematical model of LFC. [05]

If the generation rates denoted by P_{Gi} are included in the state vector, the system order will be altered. Another way of considering GRC's for both areas is to add limiters to the governors as shown in fig. ie the maximum rate of value opening or closing speed is restricted by the limiters. Here $T_{sg}\, g_{max}$ is the power rate limit imposed by value or gate control. In this model,

$$|\Delta Y_E| < g_{max}.$$

With GRC's, R should be selected with care so as to give the best dynamic response.



6 c) Define speed-governor dead band & explain in detail about its effects on AGC with neat control block diagram. [05]

The effect of the speed governor dead band is that for a given position of the governor or control values, an increase/decrease in speed can occur before the position of the value changes. The effect of the dead-band may be included in the speed governor control loop block diagram as shown.

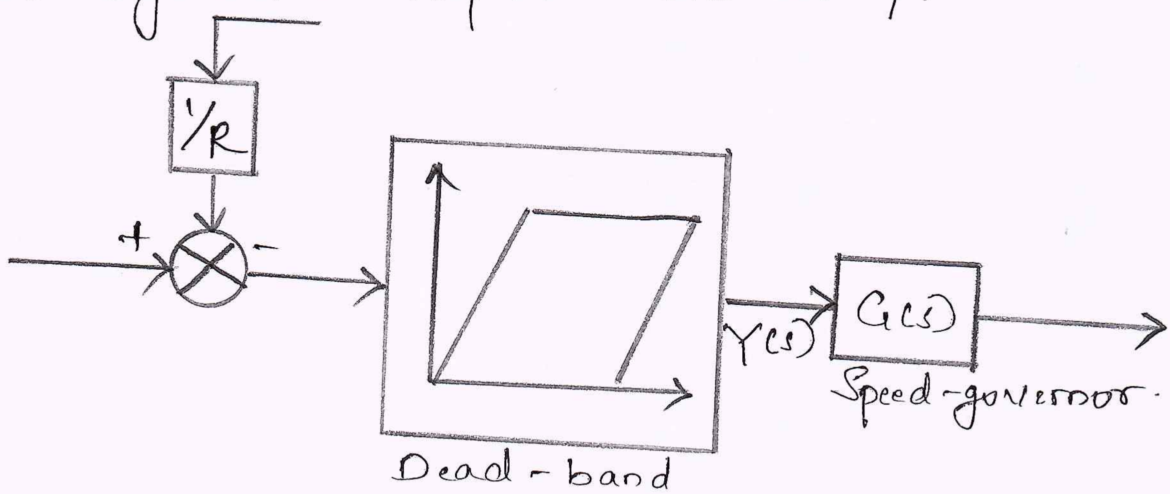
Considering the worst case for the dead band & examining the dead band block in fig., the following set of equations completely define the behaviour of the dead-band.

$$y^{(r+1)} = x^{(r)} \quad \text{if} \quad x^{(r+1)} - x^{(r)} \leq \text{dead-band}$$

$$= x^{(r+1)} - \text{dead band} \quad \text{if} \quad x^{(r+1)} - x^{(r)} > 0.$$

$$= x^{(r+1)}; \quad \text{if} \quad x^{r+1} - x^{r} < 0.$$

The presence of governor dead-band make the dynamic response oscillatory.



Module - 04

7 a) Explain in detail about the generation & absorption of reactive power by various power system components [08]

1) Synchronous generators.

They can generate or absorb reactive power depending on the excitation. An over excited generator generates reactive power & an under excited generator absorbs reactive power.

2) Overhead lines.

The natural load or surge impedance load is given by, $SIL = \frac{V_0^2}{Z_c}$ W. (V_0 - rated voltage of line)

At loads below SIL transmission line generate reactive power & at loads above SIL, overhead lines absorbs reactive power.

3) Underground cables.

They have high capacitance, owing to which they have high SIL. Hence they are always used below their SIL & generates reactive power.

4) Transformers.

They always absorb reactive power irrespective of their loads.

5) Loads.

They normally absorb reactive power.

6) Compensating devices.

These are added to either generate or absorb reactive power. They are controlled to balance the reactive power as desired.

7 b) Consider a transmission system shown in Fig 7(b). The pu reactance values are reffered to the respective voltage bases & 100 MVA base. Determine the power supplied by the generator & its power factor [12]

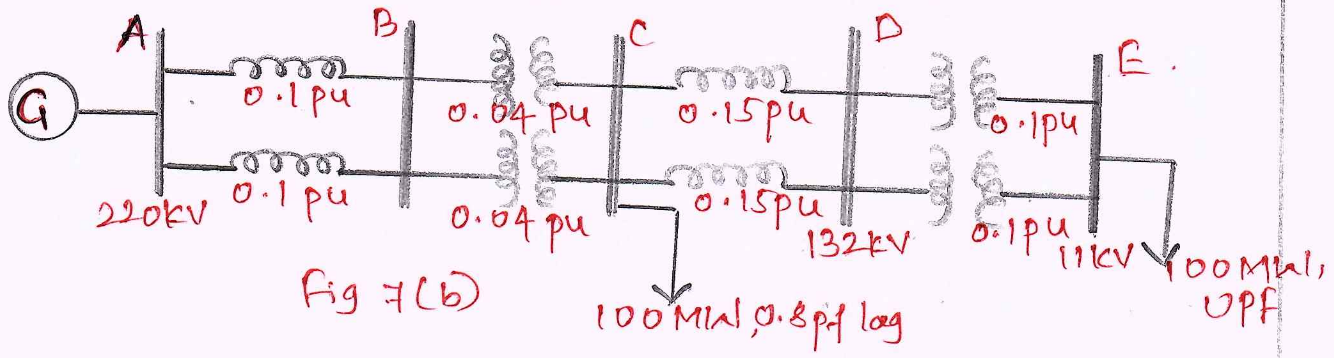


Fig 7(b)

The reactance from C-E = $\frac{0.15+0.1}{2} = 0.125$ pu.

The reactance from A-C = $\frac{0.1+0.04}{2} = 0.07$ pu

At the receiving end, Bus E

$P = 100\text{ MW} = 1\text{pu}, \quad Q = 0 \text{ (upf)}$

$$I^2 = \frac{P^2+Q^2}{V^2} = \frac{1^2+0}{1^2} = 1\text{ pu}$$

The reactive power loss from C-E is I^2X

$= 1 \times 0.125 = 0.125$ pu.

At bus C we add load powers & loss in line C-E. Since R=0, there is no real power loss. The load at C = 1 + j0.75 pu. Therefore at C,

$P = 1+1 = 2$ pu

$Q = 0.75 + 0.125 = 0.875$ pu.

Loss in line A-C is, $= \frac{2^2 + 0.875^2}{1^2} \times 0.07 = 0.333$ pu.

Q at A $= 0.875 + 0.333 = 1.208$ pu.

∴ The generator must supply $P = 2$ pu, $Q = 1.208$ pu.

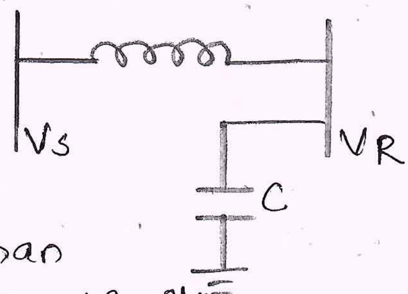
The generator power factor $= 0.856$

8 a) Explain various methods of voltage control by injection of reactive power at a node in a power system [12]

Methods of voltage control by injection of reactive power.

1) Shunt reactors | capacitors.
2) Series capacitors.
3) Synchronous condensors.

* Shunt reactors: These are used to compensate the effect of line capacitance especially to limit voltage rise on light loads.



1) A shunt reactor of sufficient size must be permanently connected to limit fundamental frequency, temporary overvoltages to about 1.5pu for less than 1 sec. These reactors are also useful in limiting overvoltages due to switching transients.

2) Series Capacitors: These are connected in series with line conductors to compensate the inductive reactance of the line. The power transfer from a bus of voltage V_1 to another bus of voltage V_2 connected through line of reactance X_{12} is, $P_{12} = \dfrac{V_1 V_2 \sin(\delta_1 - \delta_2)}{X_{12}}$

A series capacitor would partially compensate for X_{12} & thus increase maximum power that can be transmitted reducing the effective reactive power loss

3) Synchronous Condensors: It is a synchronous machine running without a prime mover or a mechanical load. When connected at a bus, it can control the bus voltage by absorbing or generating reactive power.

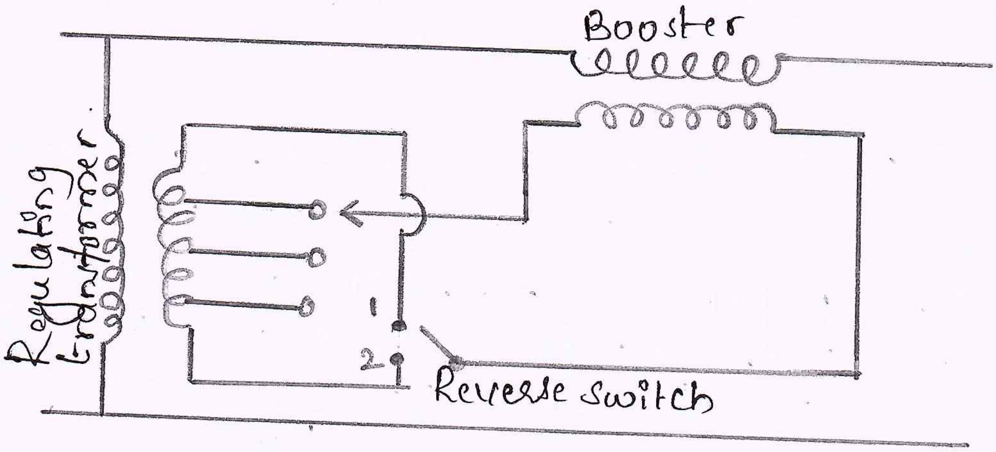
If a load is connected at the bus & draws lagging current, the synchronous condensor can be made to compensate the lagging current by drawing a leading current, thus improving the power factor.

8 b) Explain the following methods of voltage control at a node in a power system.
i) Using Booster transformers.
ii) Using phase - shift transformers. [08]

Using Booster transformers:

It may be necessary or desirable to increase or decrease the voltage at an intermediate point in a line rather than at the ends. In such cases, a separate transformer is used to boost or buck the voltage of the main transformer. This is done by injecting a voltage in series with the line through a transformer.

Fig. shows the booster primary is fed from a regulating transformer. The reverse switch reverses the polarity of the injected voltage & hence boost is converted into a buck.



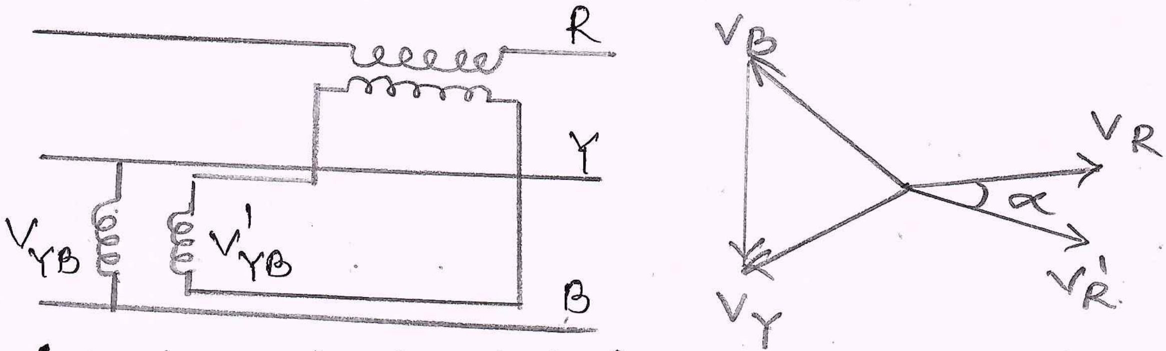
2) Phase shifting transformer:

These are used when there is need to control the active power flow in a line. We know that active & reactive power flow over a line connected between buses with voltage V_1 & V_2 are given by:

$$P_{12} = \frac{V_1 V_2}{X_{12}} \cdot \sin(\delta_1 - \delta_2)$$

$$Q_{12} = \frac{V_1 V_2}{X_{12}} \left[\cos(\delta_1 - \delta_2) - \frac{V_2}{V_1}\right]$$

If we try to control the active power flow by control of voltage, the reactive power also changes.
Phase shifting transformers alter the active power flow by changing the electrical angle δ as shown below



A voltage is injected in series with line voltage. Taps can be provided to obtain varying phase shifts.

Module - 05

9 a) Define power system security & explain in detail about its three major functions that are carried out in an operation control center. [10]

Power system security → It involves practices suitably designed to keep the system operating when components fail. Most power systems are operated in such a way that any single contingency will not leave other components heavily overloaded, so that cascading failures are avoided.

Three major functions

1) System Monitoring:

It supplies power system operators or dispatchers with pertinent up-to-date information on the conditions of power system on real time basis as load & generation change. Digital computers in control center then process the telemetered data & place them in a data base form & inform the operators in case of an overload or out of limit voltage. Important data displayed on large screen. Alarms or warnings may be given if required.

2) Contingency analysis:

Modern operation computers have contingency analysis programs stored in them. These forces possible system troubles before they occur. They study outage events & alert the operators to any potential overloads or serious voltage violations.

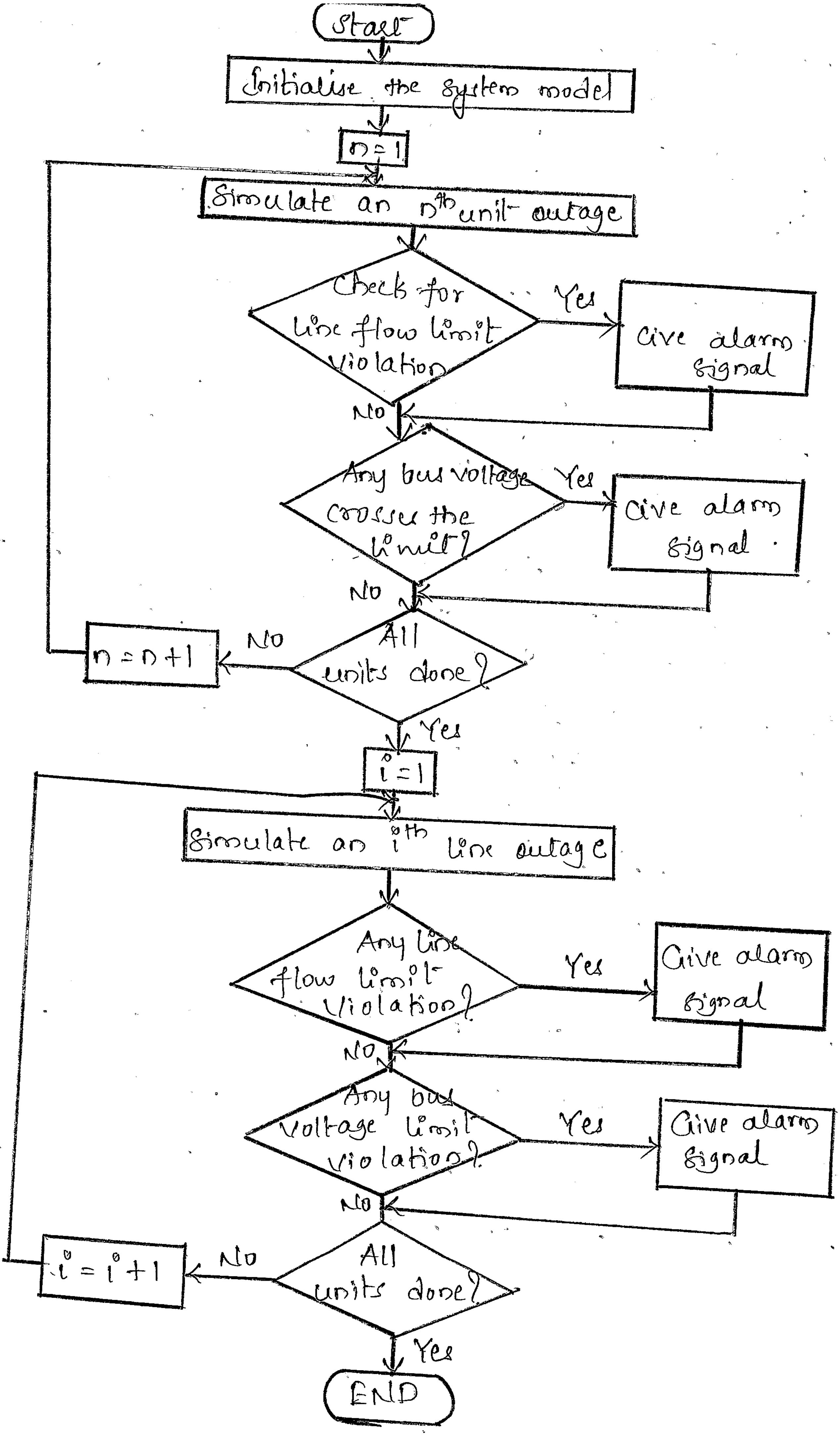
3) Corrective action analysis:

It permits operator to change the operation of power system if a contingency analysis program predicts a serious problem in the event of the occurance of certain outage. Thus this provides preventive & post contingency control.

9 b) Explain the simplest form of contingency analysis technique with the help of neat flow chart. [06]

It is important for the operator to know which contingency (generator or transmission line) will cause line-flow or voltage violations. Contingency analysis procedures model all events one after the other until all possible & probable outages have been covered. For each outages, all voltages & line flows are tested for limit violations.

Contingency flow chart.



Start
Initialise the system model
n = 1
Simulate an nth unit outage
Check for line flow limit violation
Yes
Give alarm signal
No
Any bus voltage crosses the limit?
Yes
Give alarm signal
No
All units done?
No
n = n+1
Yes
i = 1
Simulate an ith line outage
Any line flow limit violation?
Yes
Give alarm signal
No
Any bus voltage limit violation?
Yes
Give alarm signal
No
All units done?
No
i = i+1
Yes
END

9 c) List out the factors affecting the power system security & explain them briefly. [04]

There are two major objectives to be met.

1) Operate the system reliably.

2) Within security constraints operate system economically.

Two major factors affecting power system security are,

1) Generator outages.

2) Transmission line outages.

Transmission equipment failure leads to voltage & line flow changes, generator loss in addition involves changes in system frequency.

10 a) List out & explain the linear sensitivity factors. Explain the contingency analysis procedure using sensitivity factors with flow chart. [12]

Linear sensitivity factors are,

1) Generation shift factor.

2) Line outage distribution factor.

Generation shift factor:

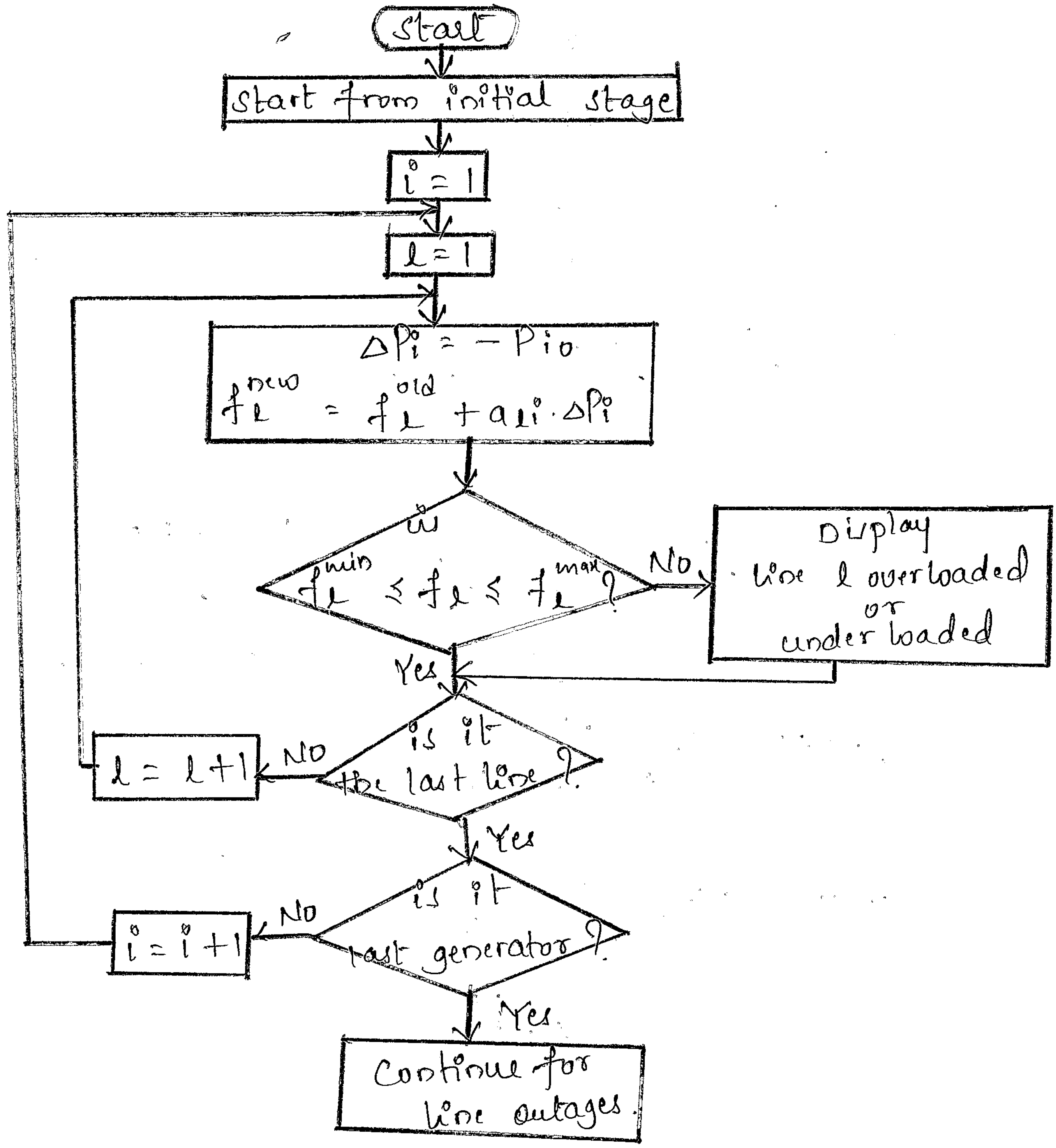
$$a_{li} = \frac{\Delta f_l}{\Delta P_i}$$

The new power flow on each line in the network can be calculated using precalculated set of 'a' factors as,

$$\hat{f}_l = f_l^0 + a_{li} \cdot \Delta P_i \quad \text{for } l = 1 \ldots . L$$

$\hat{f}_l$ = flow on line l after the generator on bus i fails.

f_l^0 = flow before the failure.

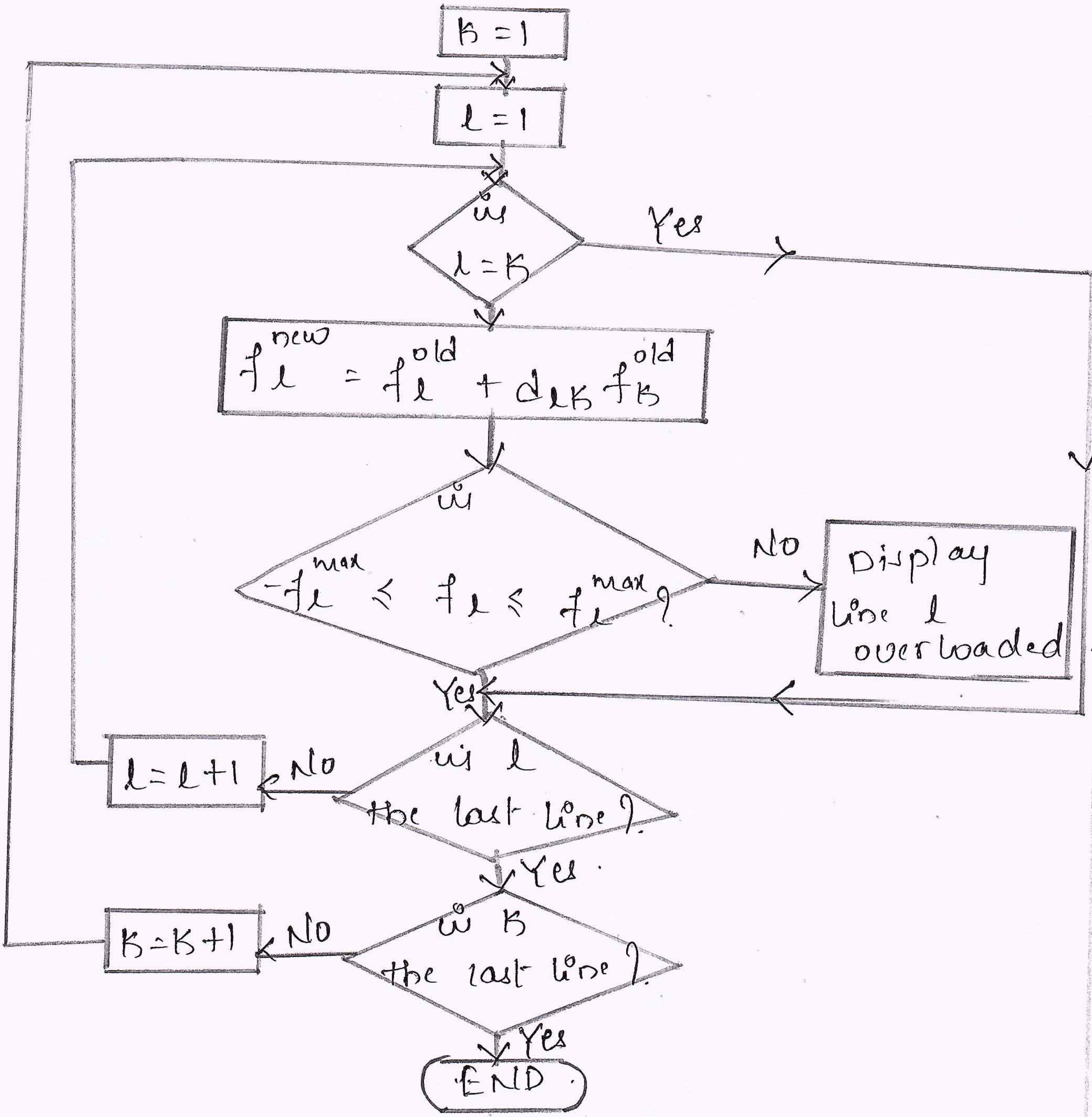


2) Line outage distribution factor

$$d_{lk} = \frac{\Delta f_l}{f_k^0}$$

If one knows the power on line l & line k, the flow on line l with line k outage can be determined using 'd' factors.

$$\hat{f}_l = f_l^0 + d_{lk} \cdot f_k^0$$



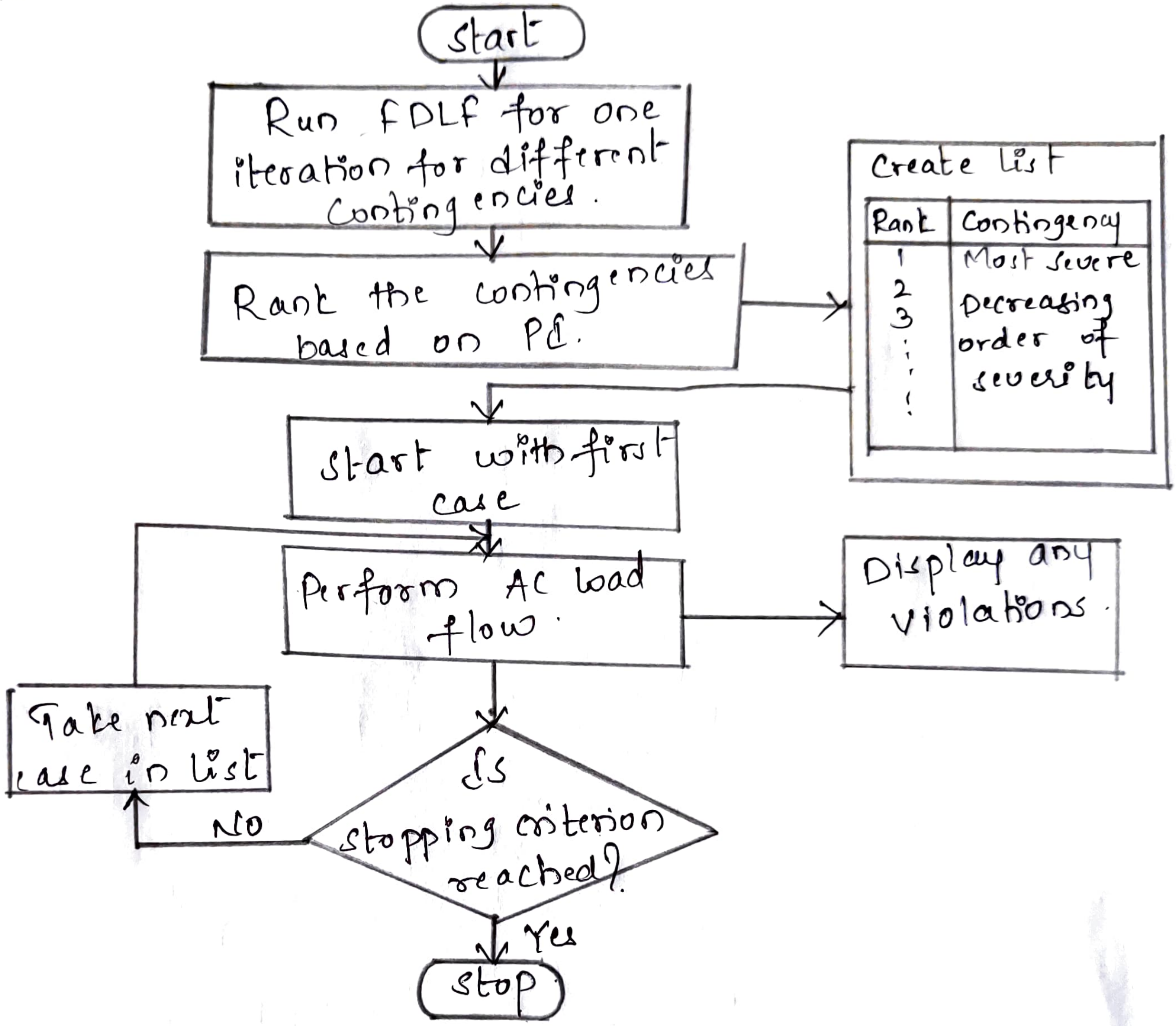
10 b) Explain 1P1Q method for contingency selection procedure with neat flow chart. [08]

One iteration of Fast Decoupled Load flow is sufficient to give a good PI, which indicate the severity of the contingency. A PI which indicates both line flow deviation & voltage magnitude deviation is defined as,

$$PI = \sum_{i=1}^{l} \left[\frac{P_l}{P_l^{max}} \right]^{2n} + \sum_{i=1}^{N} \left[\frac{\Delta|V_i|}{\Delta|V_i|^{max}} \right]^{2m}$$

ΔV_i is the difference between the voltage magnitude obtained at the end of 1^{st} iteration & the base case voltage magnitude. Hence method is called 1P1Q.

We then perform the AC power flow analysis starting from the most severe contingency (Rank 1). AC power flow analysis can then be done starting from first & continued till some level or stopped when we have the first case without violations. The flow chart is shown below.



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