CBCS SCHEME

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18EE81

**Eighth Semester B.E. Degree Examination, June/July 2024**
# Power System Operation and Control

Time: 3 hrs. Max. Marks: 100

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



## Module-1

1 a. Discuss the various operating states of power system with neat block diagram. (06 Marks)
b. What is energy control center? Explain the functions of energy control center. (07 Marks)
c. List out the objectives of power system control. Explain the various controls involved. (07 Marks)

OR

2 a. With a neat diagram, explain the components of RTU (Remote Terminal Unit). (08 Marks)
b. What are Intelligent Electronic Devices [IED's]? Explain its functional block diagram. (07 Marks)
c. Discuss the classification of SCADA system with neat sketches wherever necessary. (05 Marks)

## Module-2

3 a. Explain the AVR and ALFC control loops with schematic block diagram. (07 Marks)
b. Explain the different modes of Governer operation. (05 Marks)
c. Draw the schematic diagram of a steam turbine governing system and explain the functions of various components. (08 Marks)

OR

4 a. Obtain the transfer function for the complete ALFC system. (10 Marks)
b. Obtain the overall expression of an AGC with PI controller from its relevant block diagram representation of ALFC. (10 Marks)

## Module-3

5 a. Obtain the state space model of an isolated system with necessary equations. (10 Marks)
b. Explain the two area load frequency control with neat block diagram and necessary equations. (10 Marks)

OR

6 a. With a schematic block diagram, explain Automatic Voltage Control (AVR). With necessary equations and mathematical models. (10 Marks)
b. Explain the decentralized control of AGC. (04 Marks)
c. Two generators rated 200 MW and 400 MW are operating in parallel. Their droop characteristics are 4% and 5% respectively from no load to full load. The speed changers are so set that the generators operate at 50 Hz sharing a full load of 600 MW in the ratio of their ratings. If the load reduces to 400 MW, how will it be shared among the generators and what will be the system frequency? (06 Marks)

## Module-4

7 a. Explain briefly the various elements of power system that can generate or absorb reactive epower. (10 Marks)
b. Show that the real power flow between two nodes is determined by the transmission angle, and the reactive power flow is determined by the scalar voltage difference between the nodes. (10 Marks)

**OR**

8 a. Explain the different methods of voltage control by reactive power injection. (10 Marks)
b. With neat diagram, explain Booster transformers and phase shift transformers used for voltage control. (06 Marks)
c. Discuss the process of voltage collapse with a neat sketch. (04 Marks)

## Module-5

9 a. Explain the security constrained optimal power flow with the help of an example showing various states involved. (07 Marks)
b. List out the factors affecting the Power System Security. (05 Marks)
c. With a neat flow chart, discuss the process involved in AC power flow security analysis with contingency case selection. (08 Marks)

**OR**

10 a. With neat diagrams and necessary equations, explain:
(i) Generation shift factors
(ii) Line outage distribution factors (10 Marks)
b. Explain the linear least square estimation technique used for state estimation in power system with flow chart. (10 Marks)

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# KLS VDIT Haliyal.

## Department of Electrical & Electronics Engineering

VTU Question paper Solution June/July - 2024

Sub: Power System Operation & Control.

Code: 18EE81

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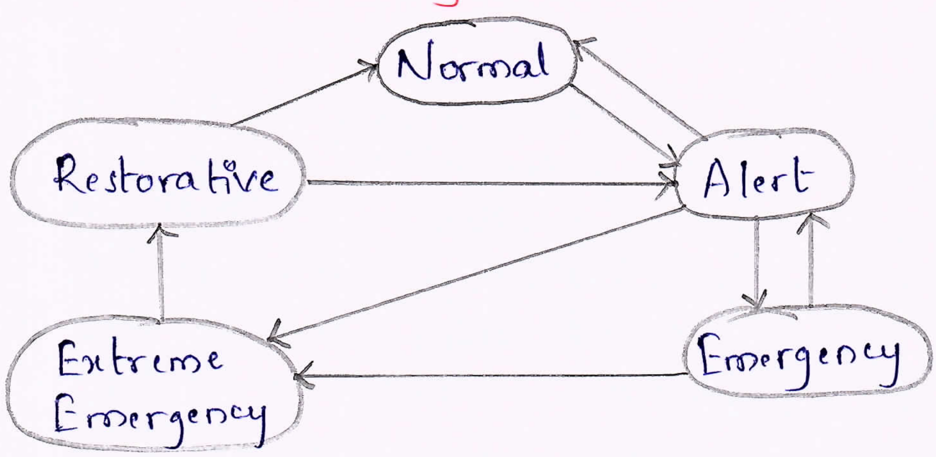
## Module - 01

1 a) Discuss the various operating states of power system with neat block diagram. [06 Marks]




1) Normal state: In this case 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 a possibility that, some inequality constraints (limit on equipment) 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. If these measures are not taken on time, system breakdown & go to inextremis state.

4) Extreme emergency / 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. System can have a transition either to alert state or to the normal state.

1b) What is energy control center? Explain the functions of energy control center. [07 Marks]

The energy control center comprises both hardware & software to monitor & control the system.
In modern power system monitoring is fully automated & controlling is a combination of automated & manual operations. The functions of energy centers can be divided into 3 sub systems blocks as follows.

1) The dispatch subsystem : This system involves the function of unit committment, economic dispatch, AGC & demand forecasting.

2) Data subsystem : This subsystem 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 the power system. The functions included are security monitoring, contingency analysis, decisions on control actions based on state of the system such as preventive control / emergency control / restorative control etc.;

1 c) List out the objectives of power system control. Explain the various controls involved. [07 Marks]

* Objectives of power system control.

1) The system must be able to meet the changing demand in active & reactive power. The spinning reserve maintained should be sufficient to take call of sudden variations in the demand.

2) The power quality should meet certain standards with regard to frequency, amplitude & wave shape.

3) The energy should be supplied at a minimum cost.

* Controls involved.

1) Generators are provided essentially with excitation control, to keep the voltage at the desired level & with prime mover Control to maintain the frequency at desired level.

2) The prime mover control is concerned with regulation of Speed & the Controls are for the associated parameters such as water discharge quantity, boiler pressure, flows etc.,

3) System generation control maintains the required active power balance in the system. The AGC is responsible for maintaining this balance.

4) The transmission control includes power & voltage control devices which helps in maintaining the voltage levels within the limits, maintaining system stability, protect the system & results in reliable operation of the system

5) Distribution level controls such as capacitors, wave shaping circuits etc., are used to provide quality power to the consumers. These devices maintain the system voltage at the correct frequency & amplitude & helps in removing harmonics injected into the load or the system.

Various controls of power system are shown in fig. 2

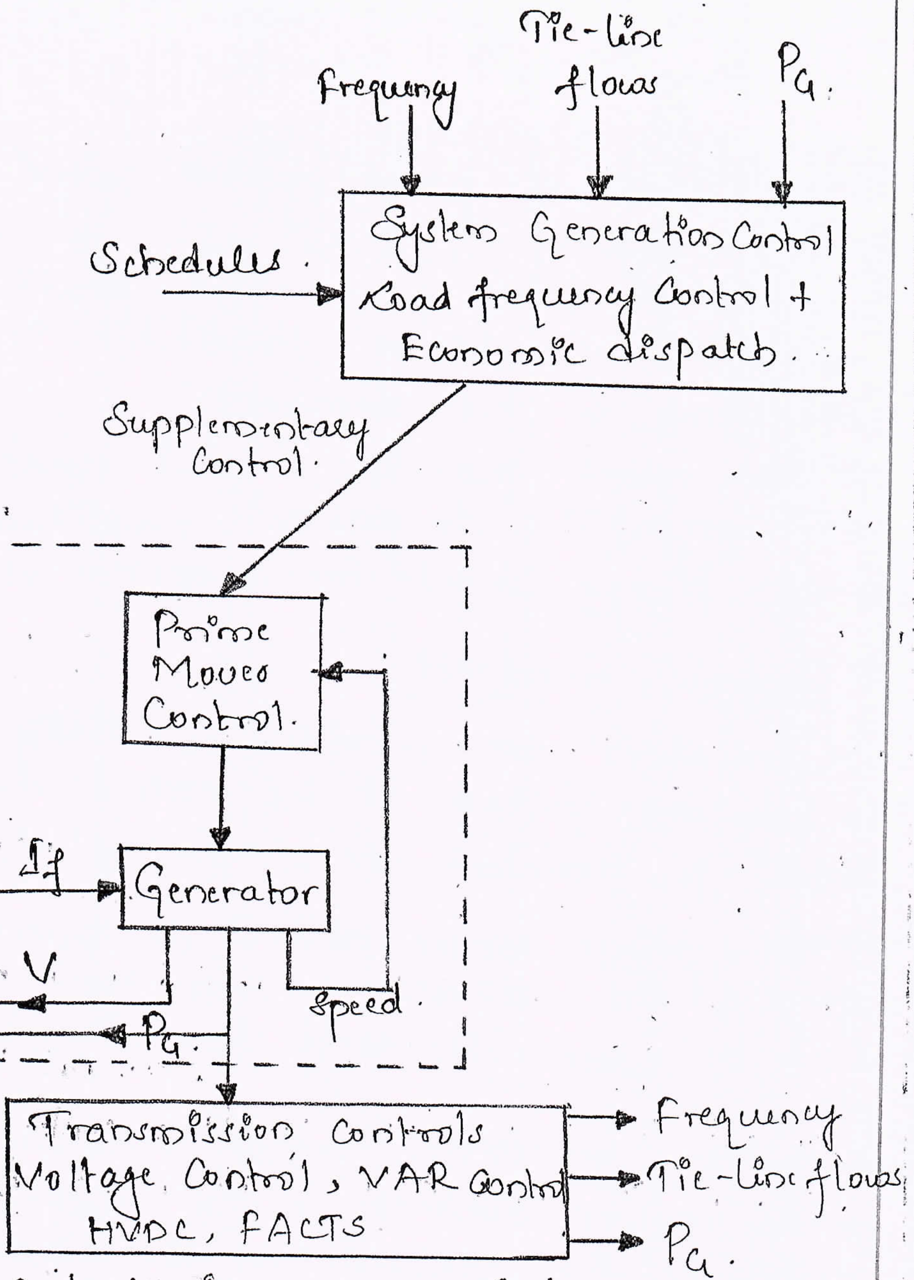
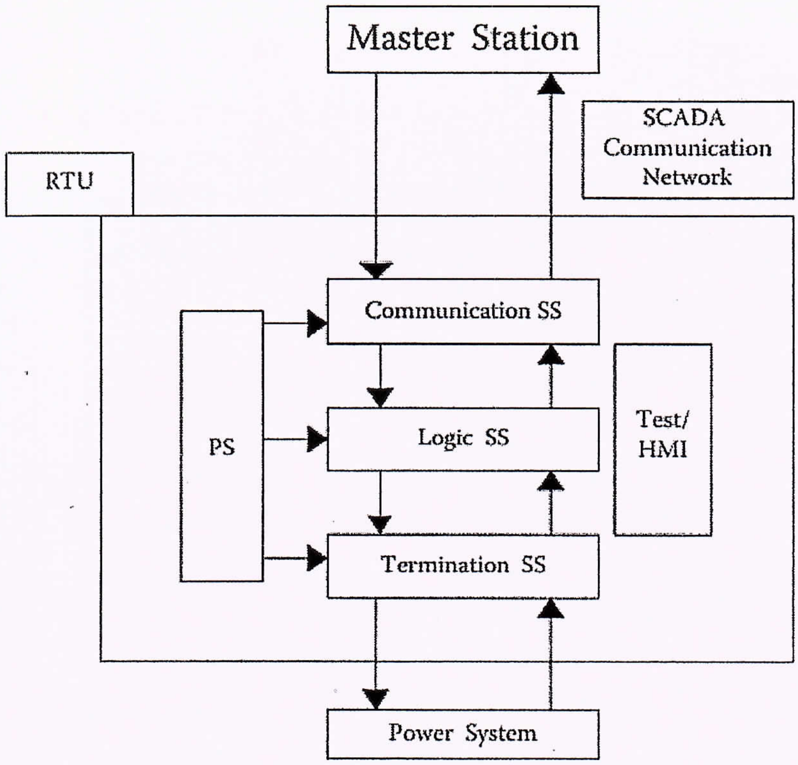



Fig 2 : Various Controls in a power System.

2 a) With a neat diagram explain components of RTU. [08 Marks]

RTU has the following major components to accomplish the tasks of monitoring & controlling the field devices.

1) Communication subsystem: It is the interface between SCADA Communication network & RTU internal logic. It receives messages from the master, interprets, initiates actions within RTU which inturn initiate some actions in the field. It collects data from the field & process & conveys relevant data to the master station.




2) Logic Subsystem: It consist of main processor & database & handles all major processing - time keeping & control sensing. It also handles the Analog to digital conversions & Computational optimization.

3) Termination Subsystem: It provides the interface between RTU & external equipment such as communication lines, primary source & substation devices. RTU logic need to be protected from harsh environment of the substation.

4) Power supply Subsystem: It converts primary power usually from substation battery to the supply requirements of the other RTU subsystems.

5) Test/HMI Subsystem: It covers a variety of component built in hardware/firmware tests & visual indicators, within the RTU & built in or portable test/ maintenance panels or displays.

2b) What are Intelligent Electronic Devices (IED's)? Explain its functional block diagram. [07 Marks]

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 |

1) The IED is multipurpose, modular in nature, flexible & adaptable & has robust communication capabilities.

2) Communication capabilities include multiple selectable protocols, multi-drop facilities with multiple ports & rapid response for real-time data.

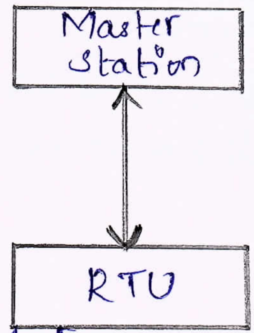
3) IED's have data processing capability for a variety of functions, for various applications like protection & metering.

4) IED's have event recording capability that can be very useful for post-event analysis, for fault waveform recording & for power quality measurements. This eliminates additional digital fault recorders & power quality monitors.

5) IED's can also accept or send out analog & digital signals with selectable ratings, thus making IED's versatile.

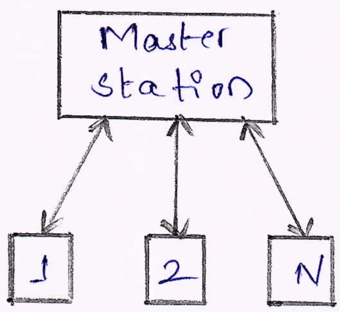
2 c) Discuss the classification of SCADA system with neat sketches wherever necessary. [05 Marks]

1) Single master - single remote:




It is utilized for simple systems where small numbers of points are involved, since it requires one master station & one communication channel per RTU. An example is control center of a generating station with one RTU to collect data.

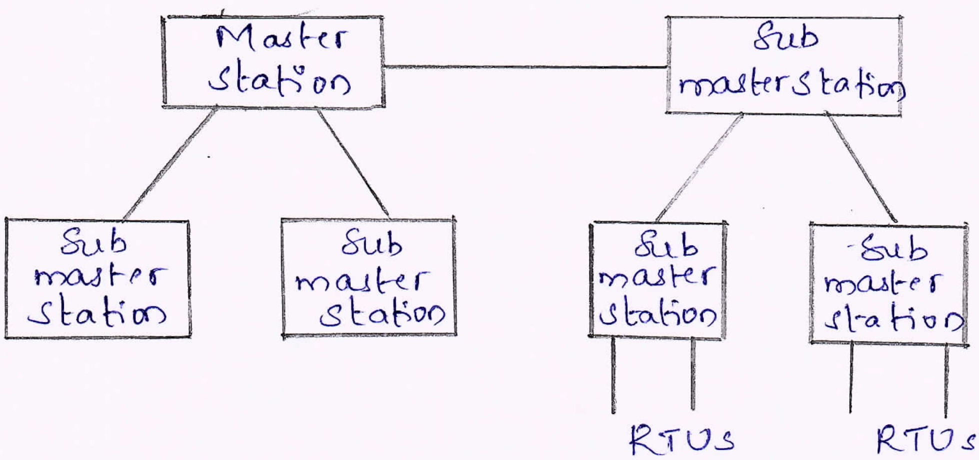
2) Single master - multiple RTU:




In this one master station is shared by several RTUs. The master station communicates inturn to each RTU using serial digital data messages.

An example is power distribution system with one master station controlling a number of substations with RTUs.

3) Multiple master - multiple RTUs:




In this, there will be submasters available with multiple RTUs reporting to each master. These systems have a large number of RTUs connected to it & extensive engineering & customization are required for commissioning of the system. These system take longer time to execute & implement. An example is a generation & transmission utility with multiple distribution members, where each member has its own SCADA system.

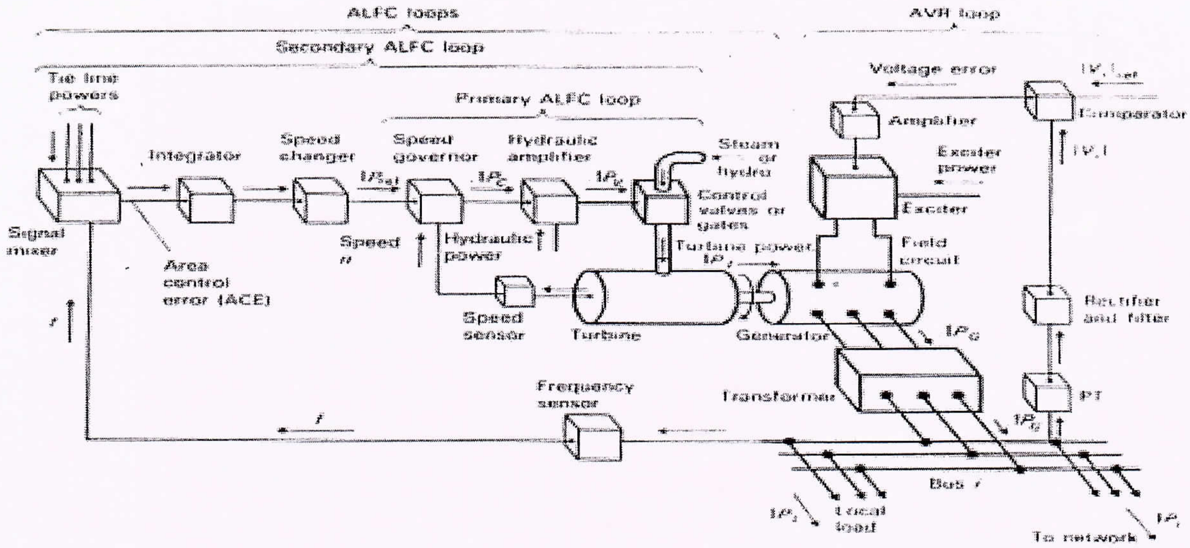
4) Single master, multiple submaster, multiple remote:
In this system there is a single master, with additional submasters, with each submaster reporting to the master station. The remote RTUs / IEDs will typically be connected to the submasters.

## Module - 02

3a) Explain the AVR and ALFC control loops with schematic block diagram. [07 Marks]

The AVR is used to control the terminal voltage of the generator which is controlled by the field current supplied by the exciter. To implement AVR, the terminal voltage is continuously sensed, rectified & smoothened. This DC signal is then compared with a reference dc to produce the error voltage which is amplified & is used as input to the exciter to adjust the field current in such a way that the terminal voltage reaches the reference value.

The ALFC or AGC controls the real power so as to maintain the system frequency constant. The ALFC comprises two loops. The fast primary loop which responds to frequency changes & regulate the steam or water flow via speed governor & control valves to match the real power output with that of load.
The slower secondary loop maintains fine frequency adjustments to maintain proper active power interchange with other interconnected networks via tie-lines. This loop is insensitive to fast load & frequency changes & acts on deviations which takes place over several minutes.



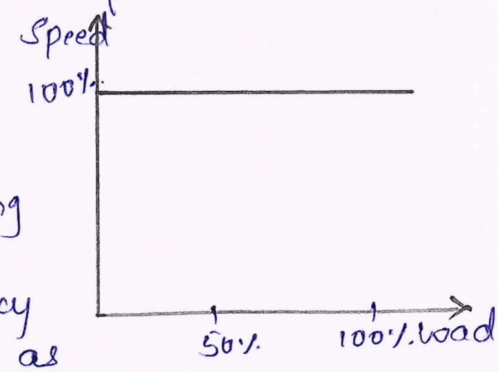

3b) Explain the different modes of governor operation. [05 marks]

In defining the modes of governor operation, the normal speed is considered as 100% & full load as 100% load. There are two modes of operation.

1) Isochronous Operation.

The governor maintains constant speed from no-load to full-load.

The prime mover & generator operating in the isochronous mode can maintain the desired output frequency regardless of load changes as long as prime mover capacity is not exceeded.

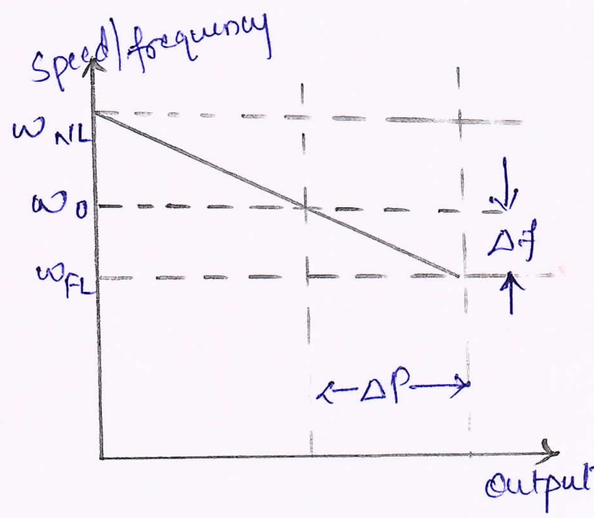



2) Droop mode Operation.

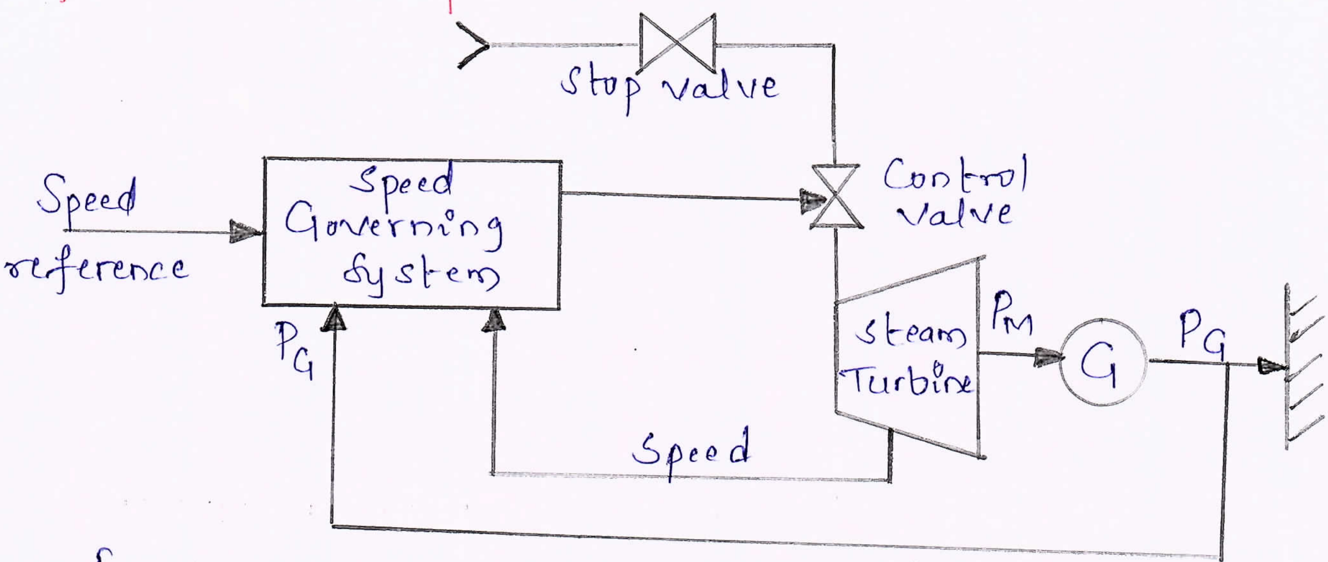
Speed droop is a decrease in speed or frequency proportional to the load as shown.

The steady state speed - Regulation (R) is given by,

$$R = \frac{\Delta \omega}{\Delta P}$$



3c) Draw the schematic diagram of a steam-turbine governing system & explain the functions of various components. [08 Marks]




In the operating range, the steam flow through control valve is proportional to the valve opening. When valve opening changes, the steam flow to the turbine changes, changing the mechanical output power of the turbine & hence electrical power of generator. The rate of change of speed depends upon the inertia of entire rotor system. When turbine-generator unit is being started, the governing system controls the speed by regulating steam flow. After the unit has been synchronised to grid, the governor increases the output to load the unit. From above fig. we can see that the valve output can be changed by changing the reference input or by change in speed with the reference speed remaining the same.

4a) Obtain the transfer function for the complete ALFC system. [10 Marks]

1) Speed-governor system model.

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

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

The net movement of C is,

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

The movement of D, $\Delta Y_D$ is,

$$\Delta Y_D = \left[\frac{l_4}{l_3 + l_4}\right] \Delta Y_C + \left[\frac{l_3}{l_3 + l_4}\right] \Delta Y_E$$

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

The movement $\Delta Y_E$ is obtained by dividing the oil volume by area of cross section of piston.

Thus,

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

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

$$\Delta Y_C(s) = -K_1 K_c \Delta P_c(s) + K_2 \cdot \Delta F(s)$$

$$\Delta Y_D(s) = K_3 \Delta Y_C(s) + K_4 \Delta Y_E(s)$$

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

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

$$\Delta Y_E(s) = \frac{K_1 K_3 K_c \, \Delta P_c(s) - K_2 K_3 \Delta F(s)}{K_4 + s/K_5}$$

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

2> Turbine model:

$$\Delta P_t(s) = \left[\frac{K_t}{1 + s \cdot T_t}\right] \Delta Y_E(s)$$

3> Generator - Load model:

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

The increment in power input to the system is accounted for in two ways.

1> Rate of increase of stored K.E. in the generator rotor. At scheduled frequency ($f^\circ$), the stored energy is,

$$W_{ke}^{\circ} = H \times P_r \quad \text{kWs}$$

The K.E. being proportional to square of speed, the K.E. at a frequency of $(f^0 + \Delta f)$ is given by,

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

$$= HP_r \left[ 1 + \frac{2\Delta f}{f^0} \right]$$

Rate of change of K.E. is therefore,

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

2) As the frequency changes, the motor load changes being sensitive to speed, the rate of change of load w.r.t. frequency ie $\partial P_D / \partial f$ can be regarded as nearly constant for small changes in frequency $\Delta f$ & can be expressed as. $(\partial P_D / \partial f) \cdot \Delta f = B \cdot \Delta f$

Writing the power balance eqn.,

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

Dividing throughout by $P_r$ & rearranging,

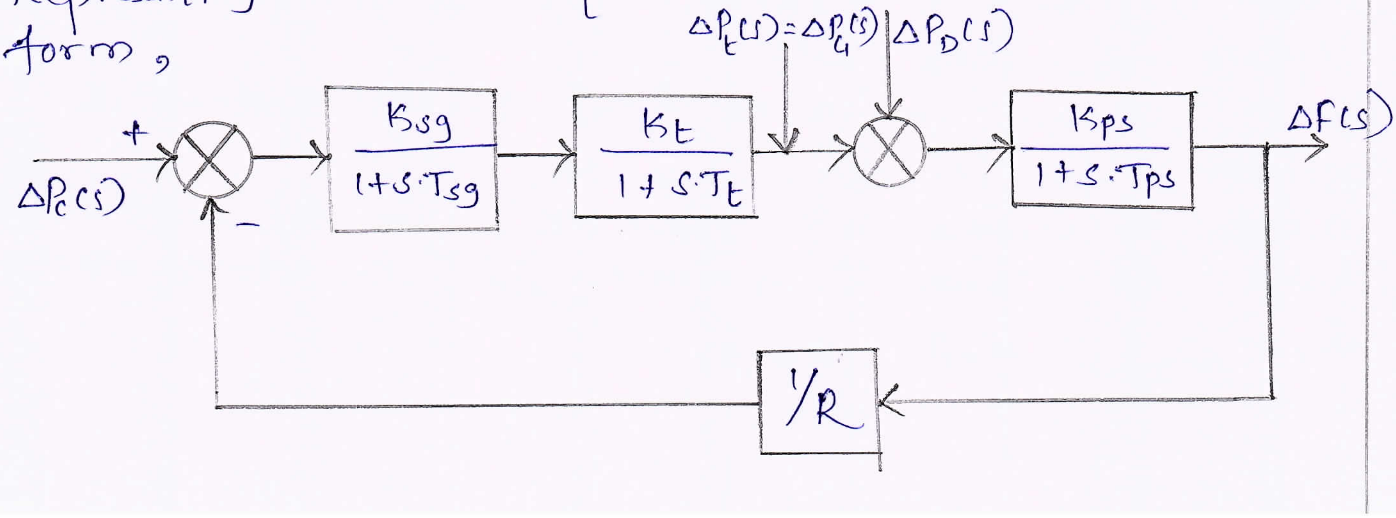
$$\Delta P_G\,(pu) - \Delta P_D\,(pu) = \frac{2H}{f^0} \cdot \frac{d}{dt}(\Delta f) + B \cdot \Delta f$$

Taking Laplace Transform, we can write $\Delta F(s)$ as,

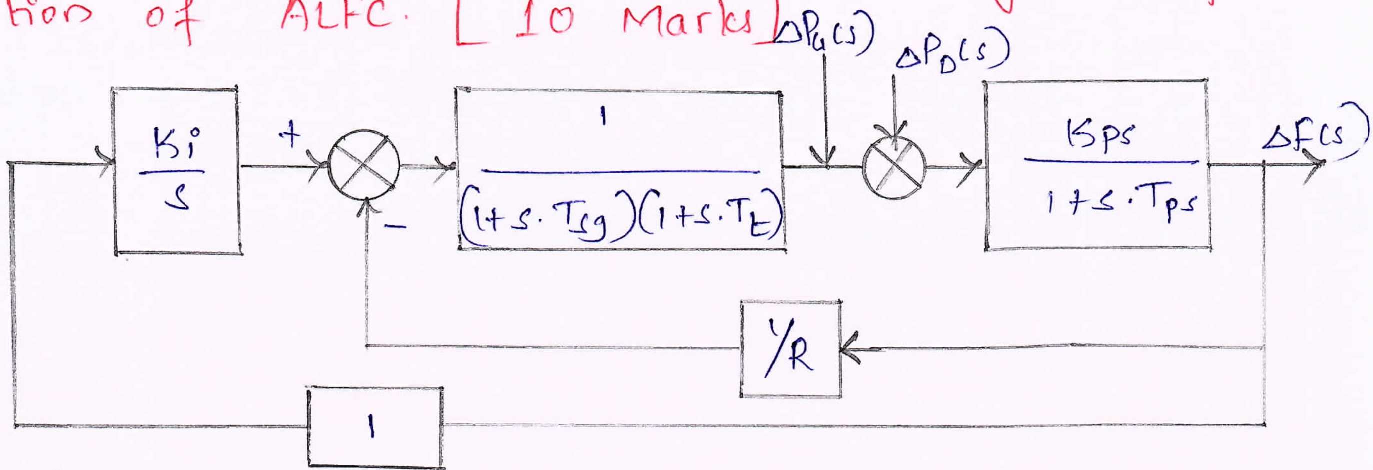
$$\Delta F(s) = \frac{\Delta P_G(s) - \Delta P_D(s)}{B + \frac{2H}{f^0}(s)}$$

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

Representing all the equations in the block diagram form,



4 b) Obtain the overall expression of an AGC with PI controller from its relevant block diagram representation of ALFC. [10 Marks]




It is expected that the steady change in frequency will be zero. While steady state frequency can be brought back to the 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 $\Delta f$ is fed through an integrator to the speed changer resulting in the block diagram configuration as shown above. The system now modifies to a proportional plus integral controller gives zero steady state error. ie $\Delta f|_{\text{steady state}} = 0$.

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

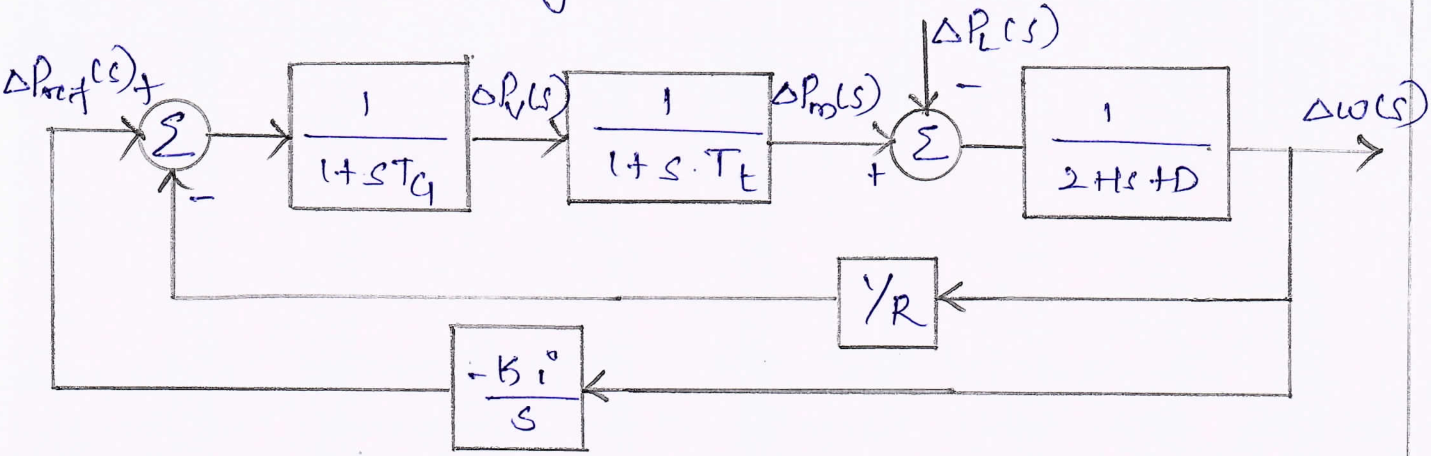
$$= \frac{R K_{ps}\, s\,(1+sT_{sg})(1+sT_t)}{s(1+s\cdot T_{sg})(1+sT_t)(1+sT_{ps})R + K_{ps}(s+K_iR)} \times \frac{\Delta P_D}{s}$$

$$\Delta f\Big|_{\text{steady state}} = \lim_{s\to 0} s\cdot\Delta f(s) = 0.$$

# Module-03

5a) Obtain the state space model of an isolated system with necessary equations. [10 Marks]

The isolated system with AGC is shown below.




The s-domain equations are as follows.

$$\left[\frac{1}{2Hs+D}\right]\left(\Delta P_m(s) - \Delta P_L(s)\right) = \Delta \omega(s)$$

$$s \cdot \Delta \omega(s) = \frac{-D}{2H}\Delta \omega(s) + \frac{1}{2H}\Delta P_m(s) - \frac{1}{2H}\Delta P_L(s) \quad \text{—— (1)}$$

For the turbine we have,

$$\Delta P_V(s)\left[\frac{1}{1+s \cdot T_t}\right] = \Delta P_m(s)$$

$$s \cdot \Delta P_m(s) = -\frac{1}{T_t}\Delta P_m(s) + \frac{1}{T_t}\Delta P_V(s) \quad \text{—— (2)}$$

For the governor,

$$\left[\Delta P_{ref}(s) - \frac{1}{R}\Delta \omega(s)\right]\left[\frac{1}{1+sT_G}\right] = \Delta P_V(s)$$

$$s\,\Delta P_V(s) = -\frac{1}{T_G}\Delta P_V(s) + \frac{1}{T_G}\Delta P_{ref}(s) - \frac{1}{RT_G}\Delta \omega(s) \quad \text{—— (3)}$$

For the integrator we have,

$$\Delta P_{ref}(s) = \frac{-K_i}{s}\Delta \omega(s)$$

$$s \cdot \Delta P_{ref}(s) = -K_i\,\Delta \omega(s) \quad \text{—— (4)}$$

Equations (1) to (4) are the required state equations. We can define state vector in time domain as,

$$x = \left[\Delta \omega \quad \Delta P_m \quad \Delta P_V \quad \Delta P_{ref}\right]^T \quad \text{—— (5)}$$

The external input is $\Delta P_L$. Now the state equations can be transformed into time domain & written in a matrix form as below.

$$\begin{bmatrix} \Delta \dot{\omega} \\ \Delta \dot{P}_m \\ \Delta \dot{P}_v \\ \Delta \dot{P}_{ref} \end{bmatrix} = \begin{bmatrix} -D/2H & 1/2H & 0 & 0 \\ 0 & -1/T_t & 1/T_t & 0 \\ -1/RT_G & 0 & -1/T_G & 1/T_G \\ -K_i & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta \omega \\ \Delta P_m \\ \Delta P_v \\ \Delta P_{ref} \end{bmatrix} + \begin{bmatrix} -1/2H \\ 0 \\ 0 \\ 0 \end{bmatrix} \Delta P_L$$

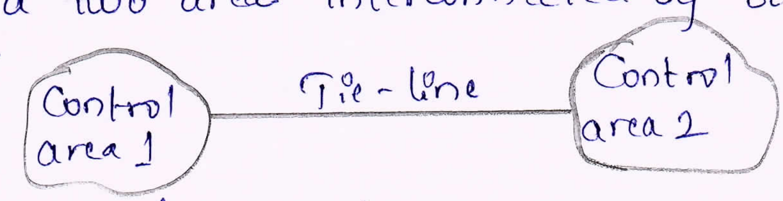
This is in the standard form of state space model,

$$\dot{x}(t) = A \cdot x(t) + B \cdot u(t)$$
$$y(t) = C \cdot x(t) + D \cdot u(t)$$

where, $x(t)$ = state vector.
$u(t)$ = input vector.
$y(t)$ = output vector.

5b) Explain the two area load frequency control with neat block diagram & necessary equations. [10 Marks]

Consider a two areas interconnected by single tie-line as shown.




Power transported out of area 1 is given by,

$$P_{tie,1} = \frac{|V_1||V_2|}{X_{12}} \sin(\delta_1^\circ - \delta_2^\circ) \quad \text{—— (1)}$$

where, $\delta_1^\circ, \delta_2^\circ$ = power angles of equivalent machines of two areas.

For incremental changes in $\delta_1$ & $\delta_2$, the incremental tie-line power can be expressed as,

$$\Delta P_{tie} = T_{12}(\Delta\delta_1 - \Delta\delta_2) \quad \text{—— (2)}$$

where,

$$T_{12} = \frac{|V_1||V_2|}{X_{12}} \cos(\delta_1^0 - \delta_2^0) = \text{synchronizing coefficient.}$$

Since incremental power angles are integrals of incremental frequencies, we can write eqn.(2) as,

$$\Delta P_{tie,1} = 2\pi T_{12} \left[ \int \Delta f_1 \cdot dt - \int \Delta f_2 \cdot dt \right]$$

IIIly,

$$\Delta P_{tie,2} = 2\pi T_{21} \left[ \int \Delta f_2 \, dt - \int \Delta f_1 \cdot dt \right]$$

where, $T_{21} = a_{12} \cdot T_{12}$

The incremental power balance equation for area 1 can be written as,

$$\Delta P_{G1} - \Delta P_{D1} = \frac{2H_1}{f_1^0} \frac{d}{dt}(\Delta f_1) + B_1 \Delta f_1 + \Delta P_{tie,1} \quad \text{--- (3)}$$

Taking Laplace Transform of eqn-(3),

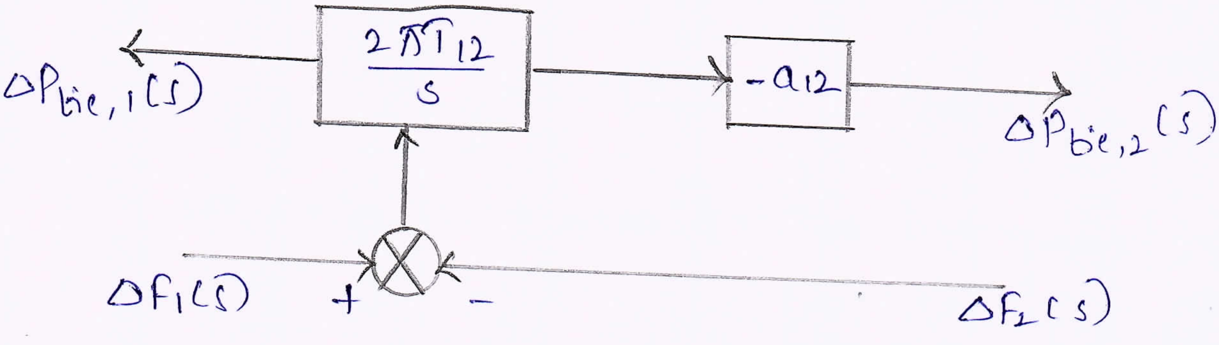
$$\Delta F_1(s) = \left[ \Delta P_{G1}(s) - \Delta P_{D1}(s) - \Delta P_{tie,1}(s) \right] \times \frac{K_{ps1}}{1 + s \cdot T_{ps1}}$$

Taking Laplace Transform of $\Delta P_{tie,1}$ and $\Delta P_{tie,2}$

$$\Delta P_{tie,1}(s) = \frac{2\pi T_{12}}{s} \left[ \Delta F_1(s) - \Delta F_2(s) \right]$$

$$\Delta P_{tie,2}(s) = -\frac{2\pi a_{12} T_{12}}{s} \left[ \Delta F_1(s) - \Delta F_2(s) \right]$$

The corresponding block diagram is shown below.



6 a) With schematic block diagram explain Automatic Voltage control with necessary equations & mathematical models. [ 10 Marks ]

1) Potential transformer : It gives sample of terminal Voltage $V_T$.

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

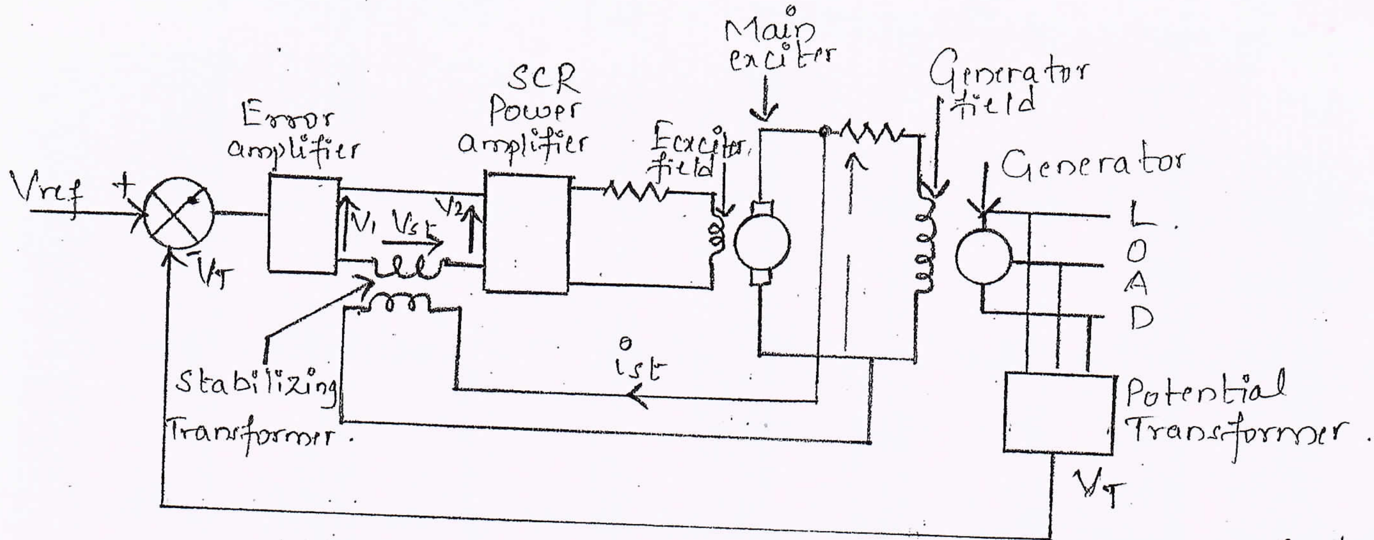
3) Error amplifiers : It demodulates & amplifies the error signal. Its gain is $K_a$.

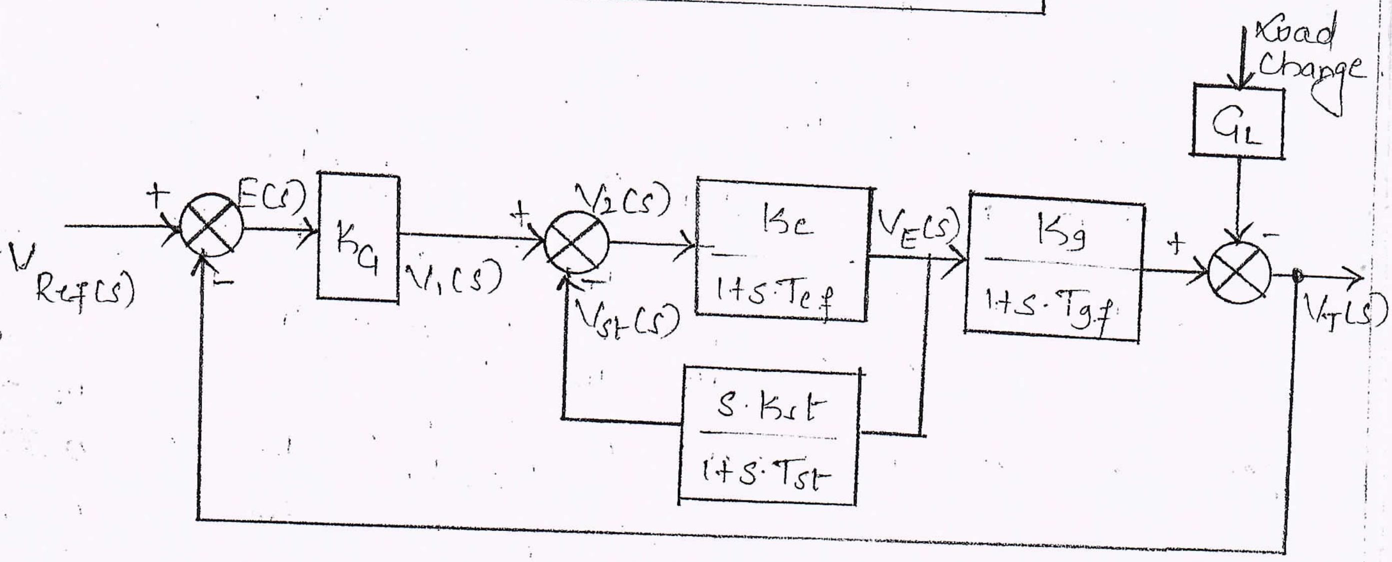
4) SCR power amplifier & exciter field : It provides the necessary power amplification to the signal for controlling the exciter field. The transfer function is,
$$\frac{K_e}{1 + s \cdot T_{ef}}$$

5) Alternator : Its field is excited by the main exciter voltage $V_E$. Under no-load it produces a voltage proportional to field current. The no-load transfer function is,
$$\frac{K_g}{1 + s \cdot T_{gf}}$$

6) Stabilizing transformer :
The derivative feedback is provided by means of a stabilizing transformer excited by the exciter output voltage $V_E$. The transfer function is,
$$\frac{V_{st}(s)}{V_E(s)} = \frac{s \cdot K_{st}}{1 + s \cdot T_{st}}$$

The ~~bloc~~ schematic & block diagrams are shown.



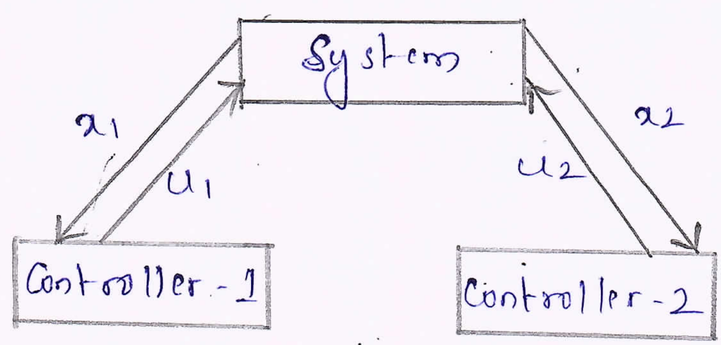

5b) Explain the decentralized control of AGC. [04 Marks]

In large size modern power system, it is vertially impossible to implement either the classical or modern LFC algorithm in a centralized manner. A decentralized control scheme is shown below. $x_1$ is used to findout the vector $u_1$ while $x_2$ alone is employed to findout $u_2$. Thus

$$x = (x_1 \, x_2)^T$$

$$u_1 = -K_1 \cdot x_1$$

$$u_2 = -K_2 \cdot x_2$$



6 c) Two generators rated 200 MW & 400 MW are operating in parallel. Their droop characteristics are 4% & 5% respectively from no load to full load. The speed changers are so set that the generators operate at 50 Hz sharing full load of 600 MW in the ratio of their ratings. If the load reduces to 400 MW, how will it be shared among the generators & what will be the system frequency? [06 Marks]

Let load on generator 1 (200 MW) = $x$ MW.

& load on generator 2 (400 MW) = $(600 - x)$ MW

Reduction in frequency = $\Delta f$

Now,

$$\frac{\Delta f}{x} = \frac{0.04 \times 50}{200} \quad \text{—— (1)}$$

$$\frac{\Delta f}{600 - x} = \frac{0.05 \times 50}{400} \quad \text{—— (2)}$$

Equating $\Delta f$ in (1) & (2) we get,

$x = 231$ MW (Generator 1)

$600 - x = 369$ MW ( " 2)

System frequency $= 50 - \frac{0.04 \times 50}{200} \times 231$

$= 47.69$ Hz.

## Module - 04

7 a) Explain briefly the various elements of power system that can generate or absorb reactive power. [10 Marks]

1) Synchronous generators:

They can absorb or generate reactive power depending on the excitation. When the generator is over excited, its generated emf is greater than terminal voltage hence generates reactive power. An under excited generator absorb reactive power.

2) Overhead lines:

The surge impedance load is given by,

$$SIL = \frac{V_0^2}{Z_C} \text{ W}$$

At load below SIL, transmission line generate reactive power & at loads above SIL, over head lines absorb reactive power.

3) Underground cables :

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

4) Transformers : They always absorb reactive power, irrespective of their load.

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.

7b) Show that real power flow between two nodes is determined by transmission angle, & reactive power flow is determined by scalar voltage difference between the nodes. [ 10 Marks ]

We know that voltage at a node is function of P & Q. ie $V = f(P, Q)$

$$dV = \frac{\partial V}{\partial P} \cdot dP + \frac{\partial V}{\partial Q} \cdot dQ$$

W.K.T. $\frac{\partial P}{\partial V} \cdot \frac{\partial V}{\partial P} = 1$ & $\frac{\partial Q}{\partial V} \cdot \frac{\partial V}{\partial Q} = 1$

$$\therefore dV = \frac{dP}{\partial P/\partial V} + \frac{dQ}{\partial Q/\partial V}$$

and, $\Delta V = E - V$,

$$(E - V)V - RP - XQ = 0.$$

Here E is the sending end voltage & V is the receiving end voltage. From above eqns.

$$\frac{\partial P}{\partial V} = \frac{E - 2V}{R}$$

$$\frac{\partial Q}{\partial V} = \frac{E - 2V}{X}$$

$$dV = \frac{dP}{\frac{E-2V}{R}} + \frac{dQ}{\frac{E-2V}{X}}$$

$$dV = \frac{dP \cdot R + dQ \cdot X}{E-2V}$$

8a) Explain the different methods of voltage control by reactive power injection. [10 Marks]

1) Shunt reactors:

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

i) 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.

ii) Shunt capacitors: These supply reactive power at a bus & are used with lagging loads. They boost local voltages & are used extensively throughout the system in wide range of ratings & sizes.

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 a line of reactance $X_{12}$ is given by,

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

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 condensor: It is a synchronous machine running without a prime mover or mechanical load. When connected at a bus, it can control 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.

8b) With neat diagram explain Booster transformers & phase shift transformers used for voltage control. [06 Marks]

It may be necessary or desirable to increase or decrease the voltages 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. These transformers offer an economical solution to the adjustment of line voltages that are slightly above or below the nominal value & also used in distribution feeders.

2) Phase shifting transformer:

These are used when there is a need to control the active power flow in a line. If we try to control the active power flow by control of voltage, the reactive power also changes significantly. These phase shifting transformers alter the active power flow by changing the electrical angle $\delta$.

A voltage is injected in series with line voltage as shown. Similarly injections are made in the other two phases as well. Taps can be provided to obtain varying phase shifts.

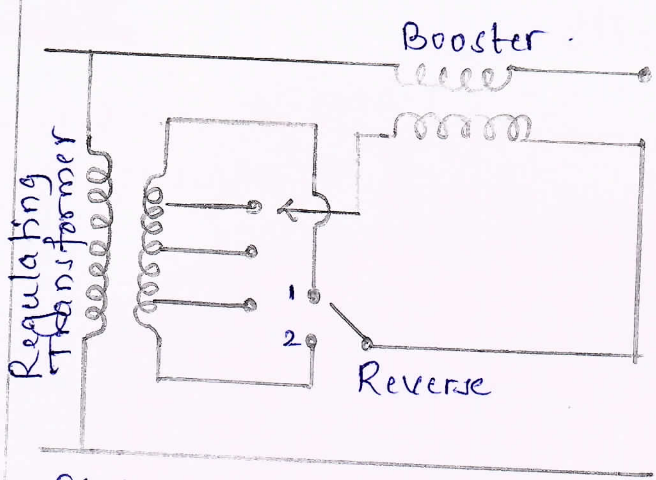



Fig: Booster transformer.

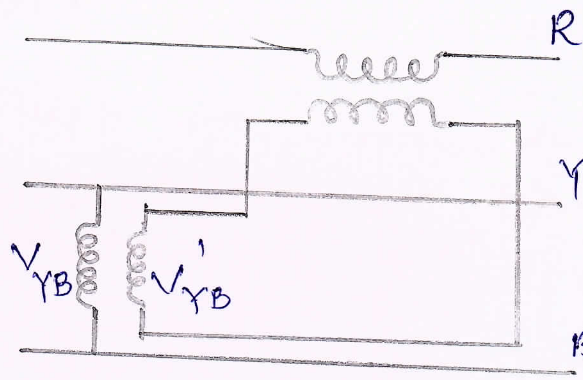
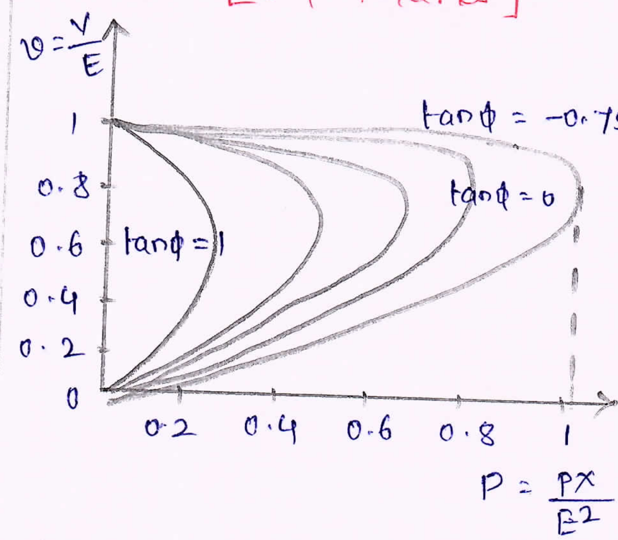



Fig: Phase shifting transformer.

8 c) Discuss the process of voltage collapse with neat sketch. [04 Marks]




At the lower voltage, a very high current is drawn to meet the required real power. As the real power load demand is increased the voltage falls, until it reaches the knee point. If now the load is further increased, the voltage falls drastically.

The possibility of voltage collapse depends on the nature of the load. Constant power loads such as induction motors, aggravate the collapse. Loads such as heating, where the real power falls off as a square of the voltage, mitigate voltage collapse.

# Module - 05

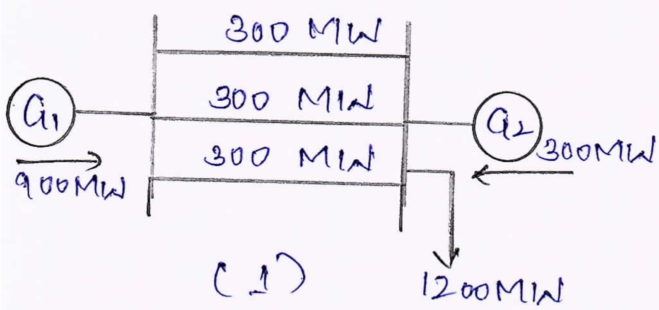
9a) Explain the security constrained optimal power flow with the help of an example showing various states involved. [07 Marks]

1) Optimal dispatch: This state may not be secure, but is economically optimal, prior to any contingency.

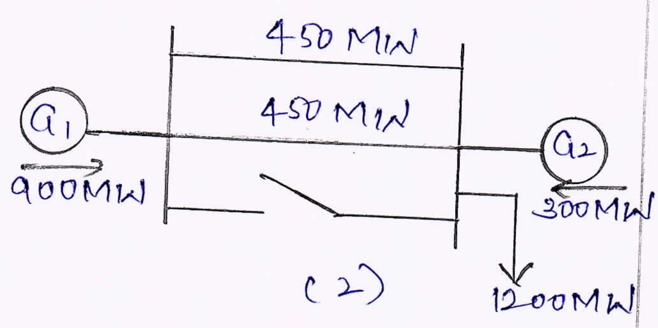
2) Post Contingency: This state is state after a contingency. This may lead to non-secure state where there is a violation in line power flows, voltages etc.,

3) Secure dispatch: This is the state where there are no contingencies, but operating parameters are corrected to account for security violations.

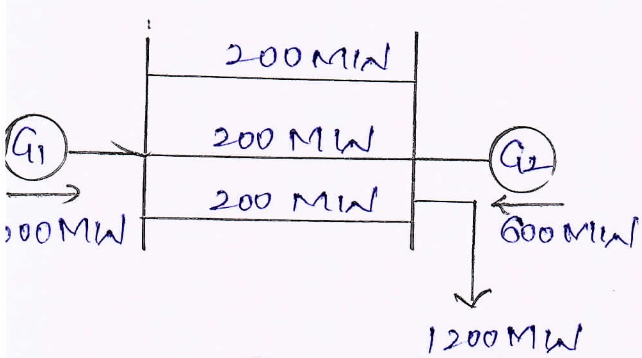
4) Secure post contingency: The state where the system is secure after a contingency occurs. ~~Hence there~~ Security corrections are applied.



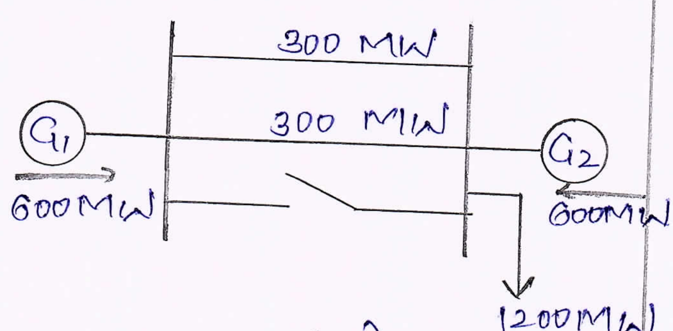
(1)



(2)



(3)



(4)

9 b) List out the factors affecting the power system Security. [05 Marks]

There are two major objectives to be met.

1) Operate the system reliably

2) Within the security constraints operate the system economically.

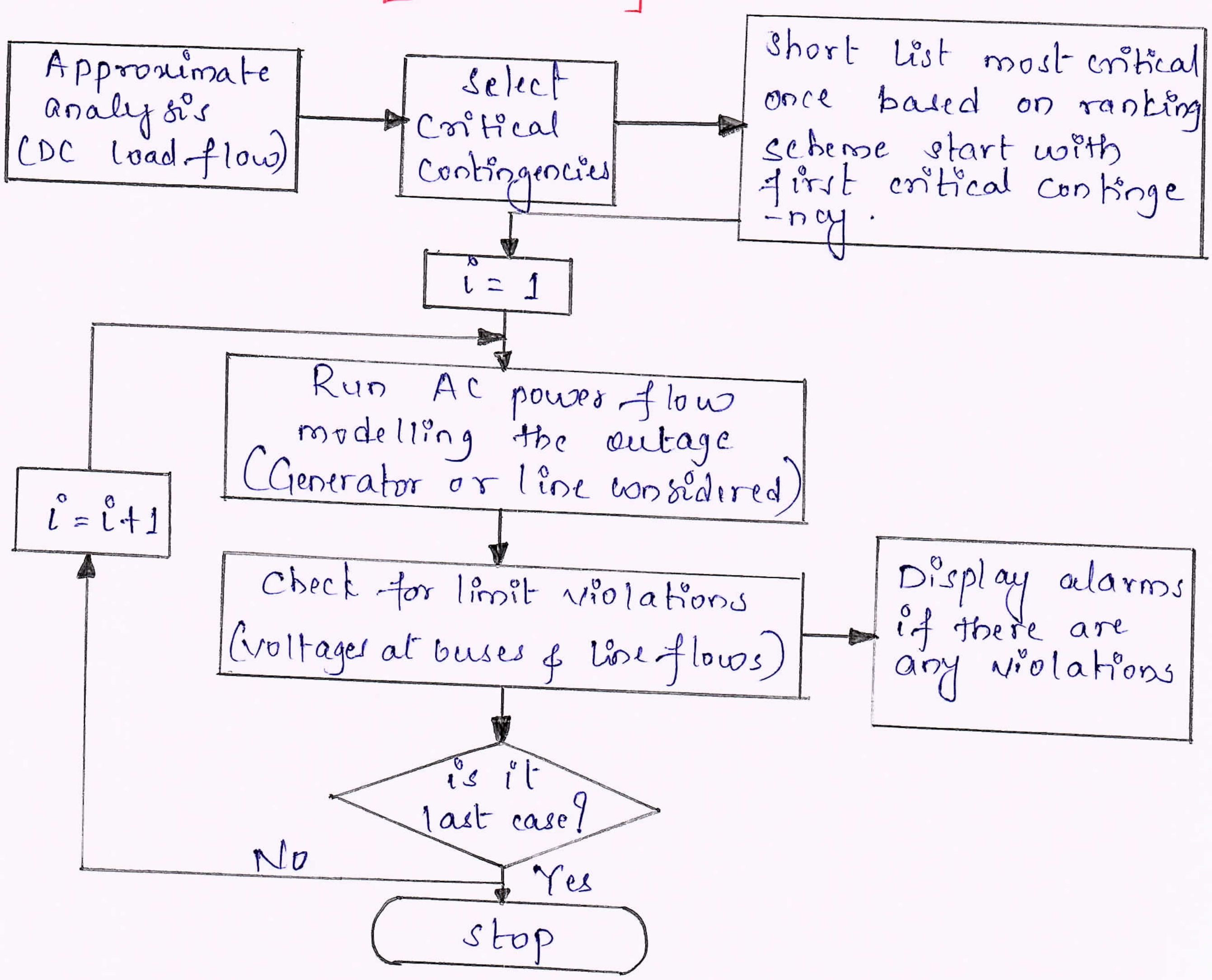
Two major factors affecting power system reliabity/ Security are,

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.

9 c) With a neat flow chart, discuss process involved in AC power flow security analysis with contingency case selection. [08 Marks]



In many systems, voltage magnitudes are a critical factor in assessing the system reliability & also voltage magnitudes are necessary to plan the reactive power support required. In such cases we need to perform AC power flow for contingency analysis.

10 a) With neat diagram & necessary equations explain (i) Generation shift factors.
(ii) Line outage distribution factors. [10 Marks]

1) Generation shift factor:

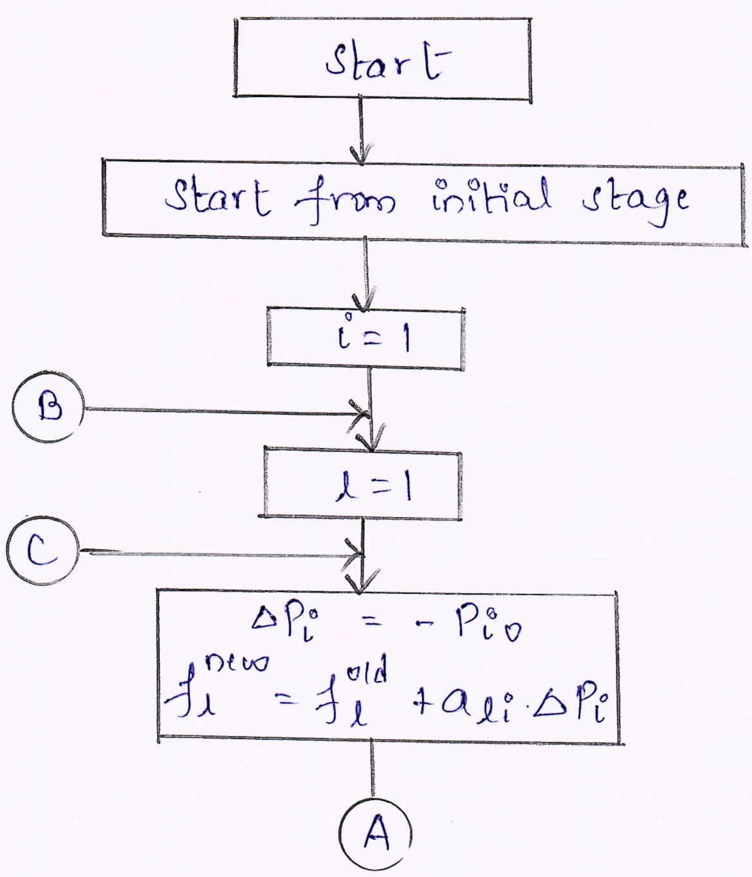
$$a_{li} = \frac{\Delta f_l}{\Delta P_i}$$

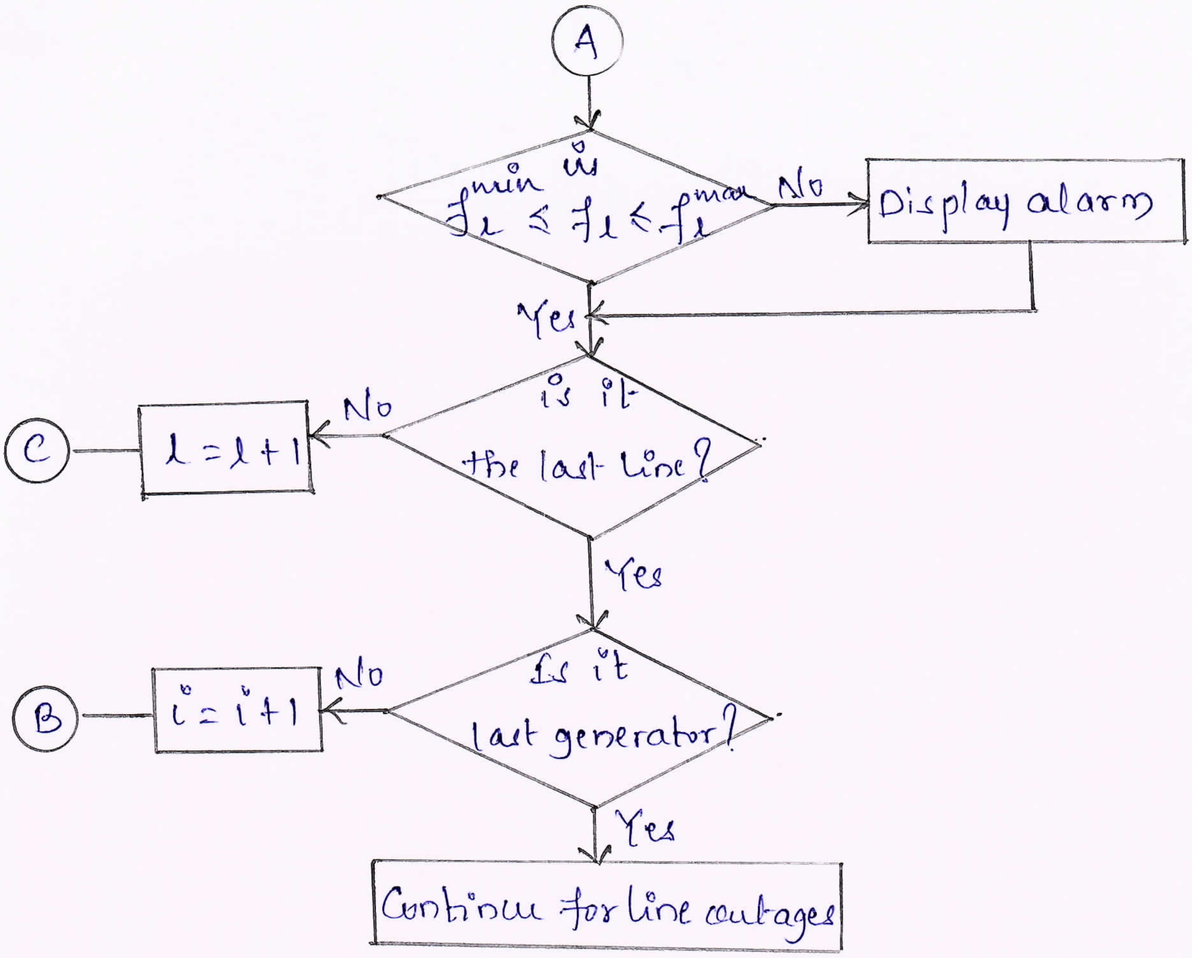
The new power flow on each line in the network can be calculated using precalculated set of "a" factors as,

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

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

$f_l^0$ = flow before the failure.






2) Line outage distribution factor.

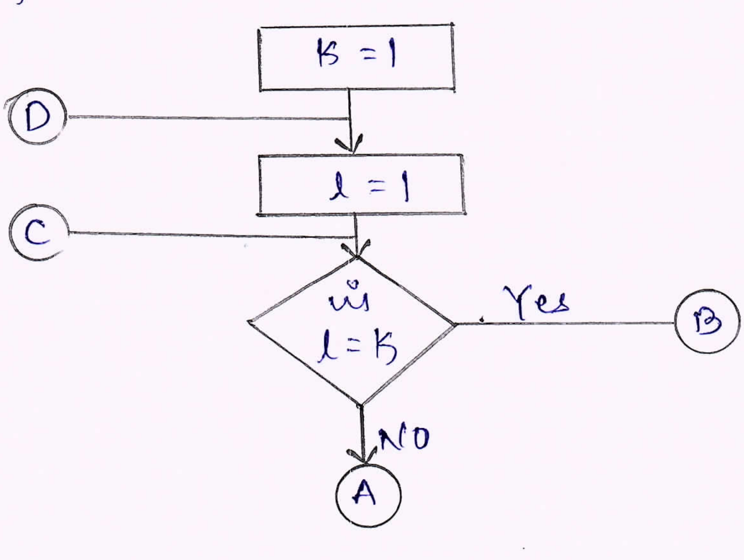
$$d_{lK} = \frac{\Delta f_l}{f_K^0}$$

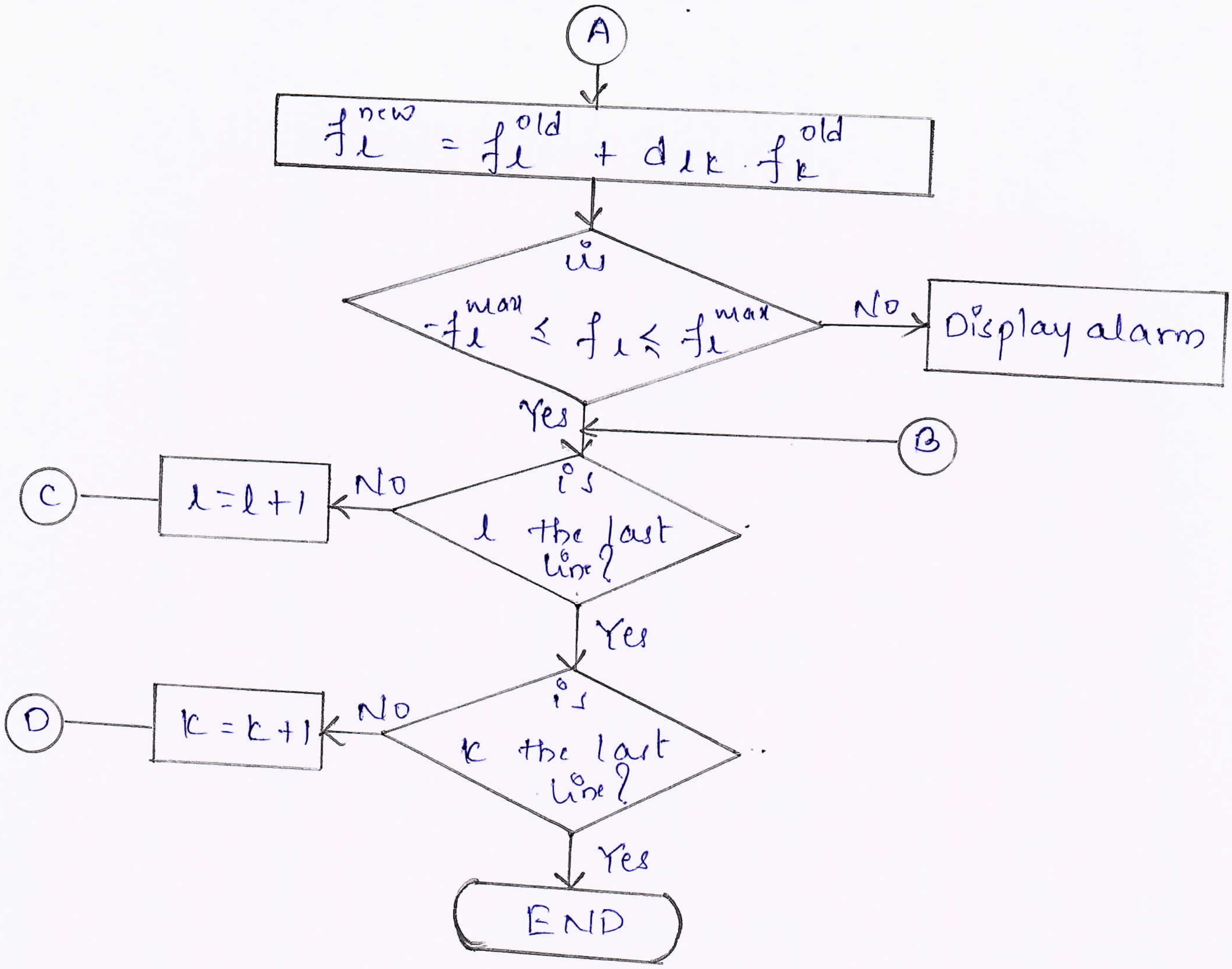
If one knows power on line l & line K, the flow on line l with line K out can be determined using "d" factors.

$$\hat{f}_l = f_l^0 + d_{lK} f_K^0$$

$f_l^0, f_K^0$ = pre outage flows on line l & K

$\hat{f}_l$ = flow on line l with line K out.






10 b) Explain the linear least square estimation technique used for state estimation in power system with flow chart. [10 Marks]

Least square solution is used for estimating over-determined systems of linear equations. The eqn. is given by,

$$Ax = b \quad \text{—— (1)}$$

where $x$ is a vector of size 'n' & $b$ is a vector of size 'm'. In an over-determined state $n < m$.

* Formulation :

The least square problem is to solve the n-vector $x$ for which the index $J(x)$ defined by,

$$J(x) = \frac{1}{2}(b - Ax)^T \cdot (b - Ax) \quad \text{—— (2)}$$

is minimized. The residual vector is defined by,

$$r = b - Ax \quad \text{—— (3)}$$

The least square solution $\hat{x}$ is such that,

$$J(\hat{x}) = \min r^T . r \quad \text{---} (4)$$

*** Determination of state estimate:**

The performance index $J(\hat{x})$ is differentiated to get the optimal condition.

$$\left.\frac{\partial J(x)}{\partial x}\right|_{x=\hat{x}} = A^T A \hat{x} - A^T b = 0 \quad \text{---} (5)$$

we get, $A^T A \hat{x} = A^T b$

Solving for $\hat{x}$, $\hat{x} = (A^T A)^{-1} A^T b$ — (6)

where $\hat{x}$ is the state estimate. The gain matrix $G$ is defined by. $G = A^T A$ — (7)

and pseudo-inverse of A is defined as,

$$A' = (A^T A)^{-1} A^T$$

So that, $\hat{x} = A' b$

If $m = n = \text{rank}(A)$, then $A' = A^{-1}$.

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