1. Explain the tie-line bias control of two area load frequency control, with the help of block diagram and necessary equations.

TIE-LINE BIAS CONTROL FOR TWO-AREA SYSTEM:—

* Since the steady state change in frequency $\Delta f_{ss} \neq 0$, for two-area system, the control adopted should be modified.
* The modified control is called as TIE-LINE BIAS CONTROL.
* The required change in generation (called ACE) represents the shift in area's generation required to restore frequency and net tie-line power. i.e. Δf_{ss} and ΔP_{12ss} must be zero.

Δf	ΔP_{12}	LOAD CHANGE	REQUIRED CONTROL ACTION
↓	↓	$\Delta P_{D_1} = \uparrow$ $\Delta P_{D_2} = 0$	Increase Generation in AREA-1
↓	↑	$\Delta P_{D_1} = 0$ $\Delta P_{D_2} = \uparrow$	Increase Generation in AREA-2
↑	↓	$\Delta P_{D_1} = 0$ $\Delta P_{D_2} = \downarrow$	Decrease Generation in AREA-2
↑	↑	$\Delta P_{D_1} = \downarrow$ $\Delta P_{D_2} = 0$	Decrease Generation in AREA-1

↑ — INCREASE ‖ ↓ — DECREASE

Define Area Control Error of AREA1;

$$ACE_1 = \Delta P_{12} + B_1 \Delta f_1$$

Area Control Error of AREA2;

$$ACE_2 = \Delta P_{21} + B_2 \Delta f_2 \quad [\because \Delta P_{21} = a_{12} \Delta P_{12}]$$

$$ACE_2 = a_{12} \Delta P_{12} + B_2 \Delta f_2$$

For steady state change in frequency and steady state change in tie-line power to be zero

i.e. $\Delta f_{ss} = 0$ and $\Delta P_{12ss} = 0$

The speed changer setting of two areas should be:

$$\Delta P_{C_1} = -K_{i_1} \int ACE_1 \cdot dt$$

$$= -K_{i_1} \int (\Delta P_{12} + B_1 \Delta f_1) \cdot dt$$

Taking Laplace Transform;

$$\Delta P_{C_1}(s) = -\frac{K_{i_1}}{s} \left[\Delta P_{12}(s) + B_1 \Delta F_1(s) \right] \quad \text{— (7)}$$

similarly $\Delta P_{C_2}(s) = -K_{i_2} \int ACE_2 \cdot dt$

$$= -K_{i_2} \int (a_{12} \Delta P_{12} + B_2 \Delta f_2) \cdot dt$$

Taking Laplace Transform;

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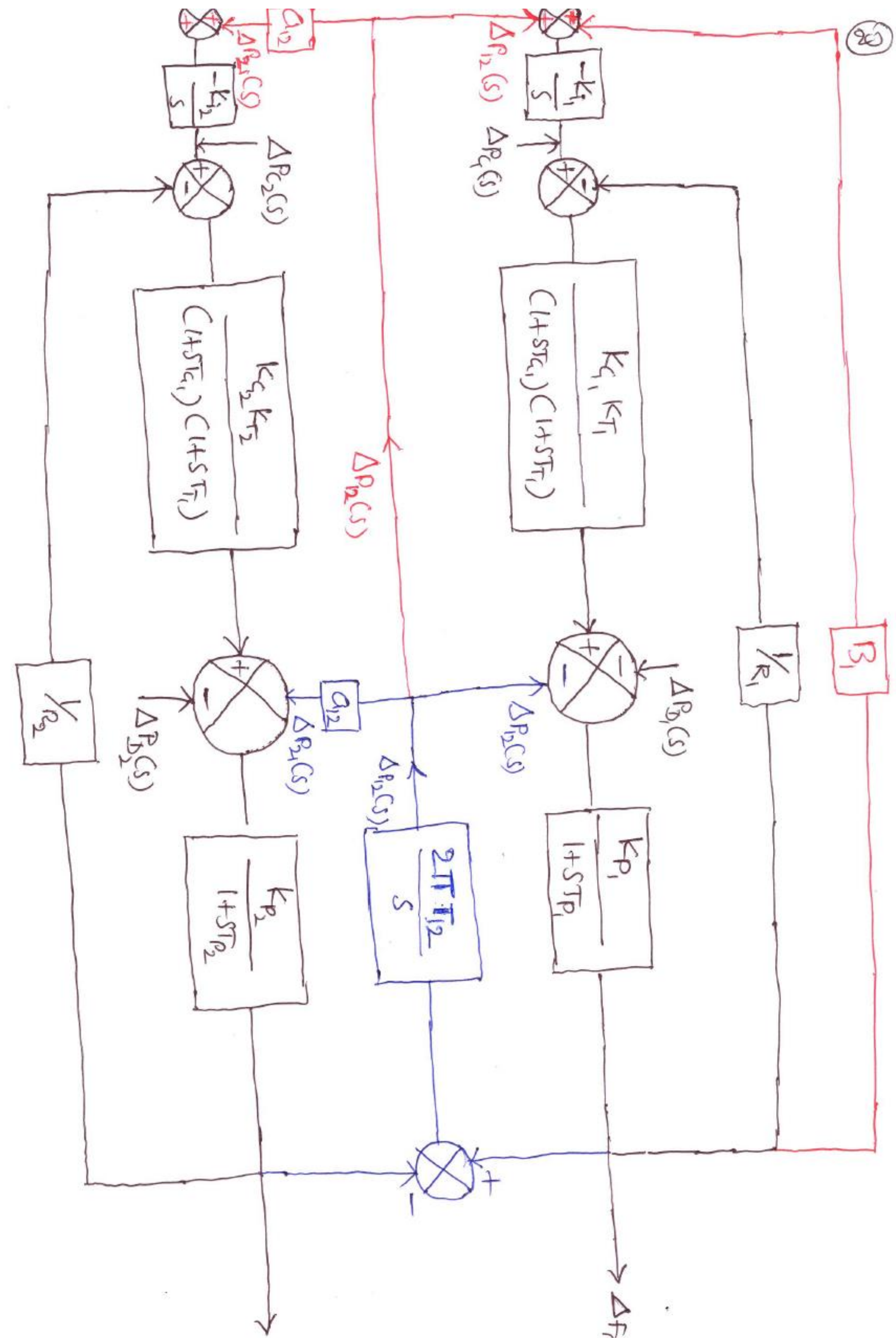
$$\Delta P_{C_2}(s) = -\frac{K_{i_2}}{s} \left[a_{12} \Delta P_{12}(s) + B_2 \Delta F_2(s) \right] \quad \text{— (8)}$$



TIE-LINE BIAS CONTROL FOR TWO-AREA SYSTEM

STEADY STATE ANALYSIS (STATIC PERFORMANCE) OF TIE-LINE BIAS CONTROL FOR TWO-AREA SYSTEM:—

If $B_1 = D_1 + \frac{1}{R_1}$ and $B_2 = D_2 + \frac{1}{R_2}$, from the steady state analysis of two-area system, we know that;

$$\Delta f_{ss} = \frac{X_2 - a_{12}X_1}{a_{12}B_1 - B_2} \text{ and } \Delta P_{12ss} = \frac{B_1 X_2 - B_2 X_1}{B_2 - a_{12}B_1}$$

Then Area Control Error of AREA1 @ steady state:

$$ACE_{1ss} = \Delta P_{12ss} + B_1 \Delta f_{ss}$$

$$= \left[\frac{B_1 X_2 - B_2 X_1}{B_2 - a_{12}B_1}\right] + B_1\left[\frac{X_2 - a_{12}X_1}{a_{12}B_1 - B_2}\right]$$

$$= -X_1$$

Since $\Delta P_{D_1} = X_1$, $ACE_{1ss} = -X_1$

Similarly $ACE_{2ss} = a_{12}\Delta P_{12ss} + B_2 \Delta f_{ss}$

$$= a_{12}\left[\frac{B_1 X_2 - B_2 X_1}{B_2 - a_{12}B_1}\right] + B_2\left[\frac{X_2 - a_{12}X_1}{a_{12}B_1 - B_2}\right]$$

$$= -X_2$$

Since $\Delta P_{D_2} = X_2$, $ACE_{2ss} = -X_2$

$\therefore$ Bias factors are adjusted such that change in load of a particular area should be met by its area.

To produce $\Delta f_{ss} = 0$ and $\Delta P_{12ss} = 0$.

2. Explain with suitable block diagram, the mathematical modeling of AVR.

OBJECTIVES:—

* To maintain the static accuracy of the terminal voltage.
* For better transient response.

AMPLIFIER MODEL:—

Let the transfer function of Amplifier;

$$G_A(s) = \frac{K_A}{1+sT_A} = \frac{\Delta V_R(s)}{\Delta e(s)}$$

K_A = Gain of Amplifier

T_A = Time constant of Amplifier.

$$\therefore \Delta V_R(s) = G_A(s) \cdot \Delta e(s)$$

EXCITER MODELING:—

Define R_e = Exciter Field Resistance (Ω)

L_e = Exciter Field Inductance (H)

$$\therefore \Delta V_R = R_e \cdot \Delta i_e + L_e \frac{d}{dt}(\Delta i_e)$$

Taking Laplace Transform; $\Delta V_R(s) = R_e \cdot \Delta I_e(s) + s L_e \Delta I_e(s)$

$$\Delta I_e(s) = \Delta V_R(s) / [R_e + sL_e]$$

From above AVR loop it is clear that;

$$\Delta V_f \propto \Delta i_e$$

$$\therefore \ \Delta V_f(s) = K_1 \Delta I_e(s)$$

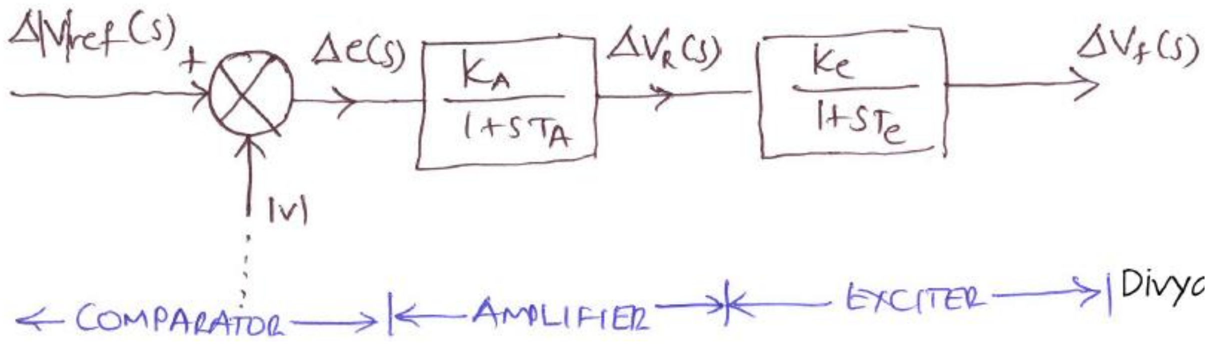
$$\Delta V_f(s) = K_1 \cdot \left[\frac{\Delta V_R(s)}{R_e + sL_e}\right]$$

$$\boxed{\frac{\Delta V_f(s)}{\Delta V_R(s)} = \frac{K_1/R_e}{1+s\left(\frac{L_e}{R_e}\right)} = \frac{K_e}{1+sT_e} = G_e(s)}$$

→ Transfer Function of Exciter

Where; K_e = Gain constant of Exciter

T_e = Time constant of Exciter.

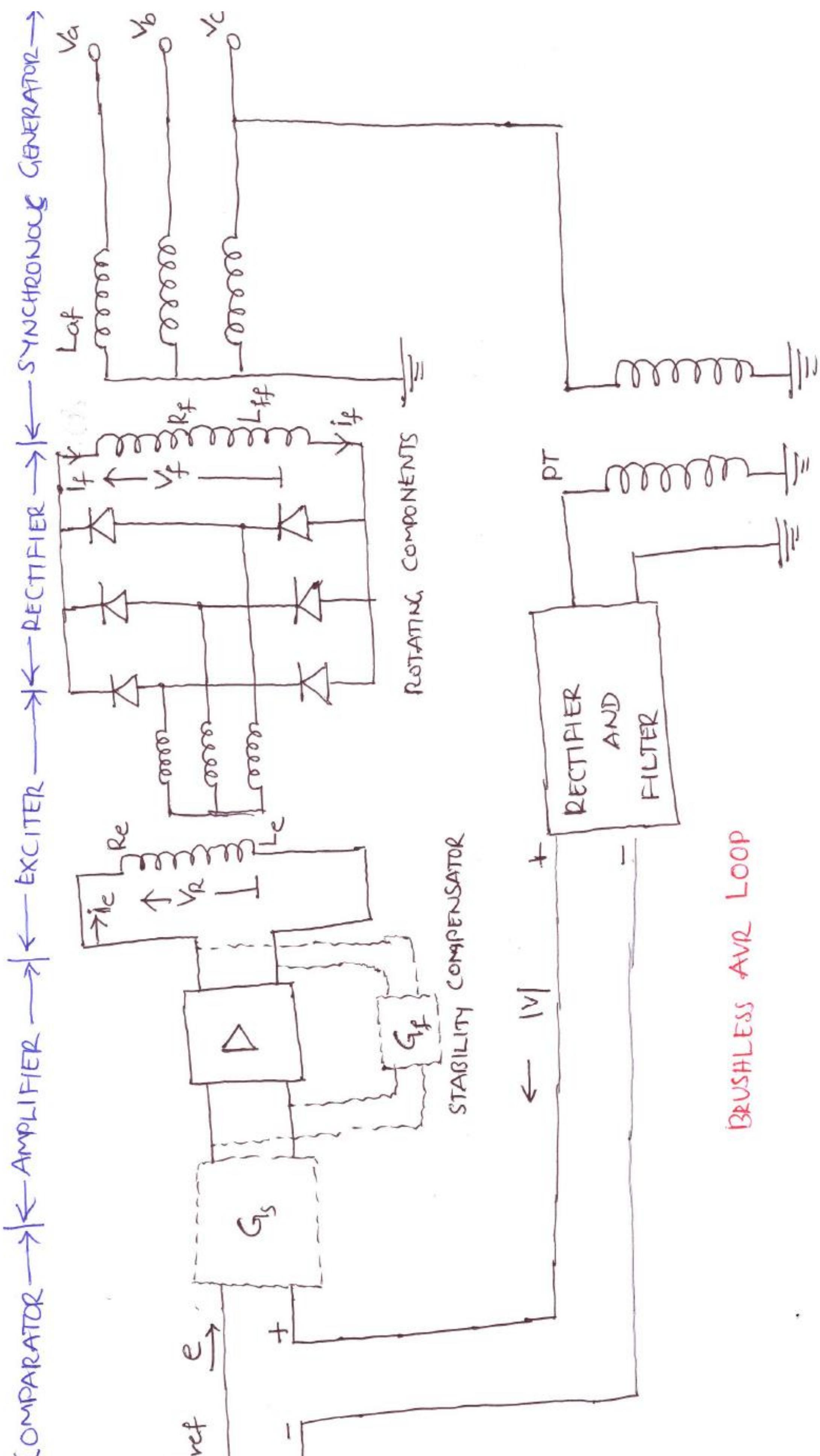


We need to close the above loop, if the voltage drop across armature winding is neglected we can write;

$|E| \simeq |V|$

→ Terminal voltage/ph

→ Induced EMF/ph in armature


COMPARATOR
AMPLIFIER
EXCITER
RECTIFIER
SYNCHRONOUS GENERATOR
Va
Vb
Vc
Laf
Rf
Lff
if
Vf
Re
Le
ie
VR
ROTATING COMPONENTS
STABILITY COMPENSATOR
Gf
Gs
e
|V|
PT
RECTIFIER AND FILTER
BRUSHLESS AVR LOOP

GENERATOR FIELD MODELING:—

Define R_f = Generator field resistance (Ω)

L_{ff} = Generator field inductance (H)

L_{af} = Mutual inductance between rotor and stator fields.

$$\therefore \Delta V_f = R_f \Delta i_f + L_{ff} \frac{d}{dt}(\Delta i_f)$$

Taking Laplace Transform; $\Delta V_f(s) = (R_f + sL_{ff})\Delta I_f(s)$

$$\Delta I_f(s) = \frac{\Delta V_f(s)}{(R_f + sL_{ff})}$$

$$\Delta|E|(s) = \Delta|V|(s) = \frac{\omega L_{af}}{\sqrt{2}} \Delta I_f(s)$$

$$\Delta|V|(s) = \frac{\omega L_{af}}{\sqrt{2}} \cdot \frac{\Delta V_f(s)}{(R_f + sL_{ff})}$$

$$\Delta|V|(s)/\Delta V_f(s) = \frac{[\omega L_{af}/\sqrt{2}R_f]}{[1 + s[L_{ff}/R_f]]}$$

$$\boxed{\frac{\Delta|V|(s)}{\Delta V_f(s)} = \frac{K_f}{1+sT'_{do}} = G_f(s)}$$ → TF of Generator field.

$\phi_{fa} = \phi_m \sin\omega t$

$e(t) = \frac{d\phi_{fa}}{dt}$

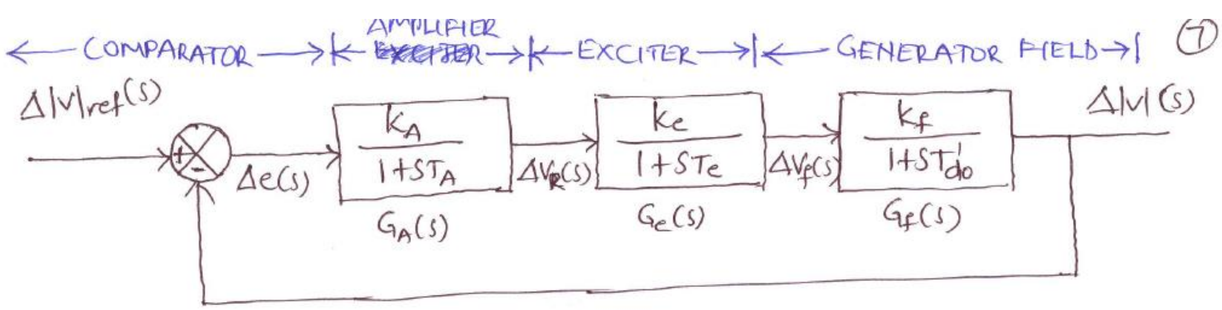
$= \omega\phi_{fa}\cos\omega t$

$E_m \doteq \omega\phi_{fa}$

$E_{rms} = |E| = \frac{E_m}{\sqrt{2}} = \frac{\omega\phi_{fa}}{\sqrt{2}}$

$\phi_{af} = L_{af} \cdot i_f$

$|E| = \frac{\omega L_{af}}{\sqrt{2}} \cdot i_f$

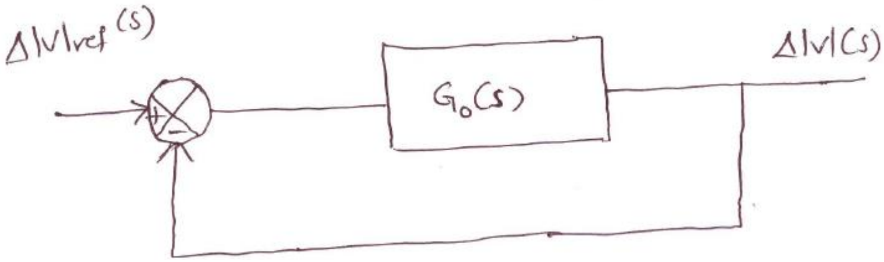


Open loop transfer function:

$$G_o(s) = G_A(s) \cdot G_e(s) \cdot G_f(s) = \frac{K_A \cdot K_e \cdot K_f}{(1+sT_A)(1+sT_e)(1+sT'_{do})}$$

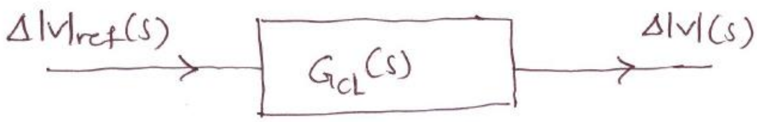
Let $K = K_A \cdot K_e \cdot K_f$

$$G_o(s) = \frac{K}{(1+sT_A)(1+sT_e)(1+sT'_{do})}$$



Closed loop transfer function:

$$G_{CL}(s) = \frac{G_o(s)}{1+G_o(s)} = \frac{K}{K + (1+sT_A)(1+sT_e)(1+sT'_{do})}$$

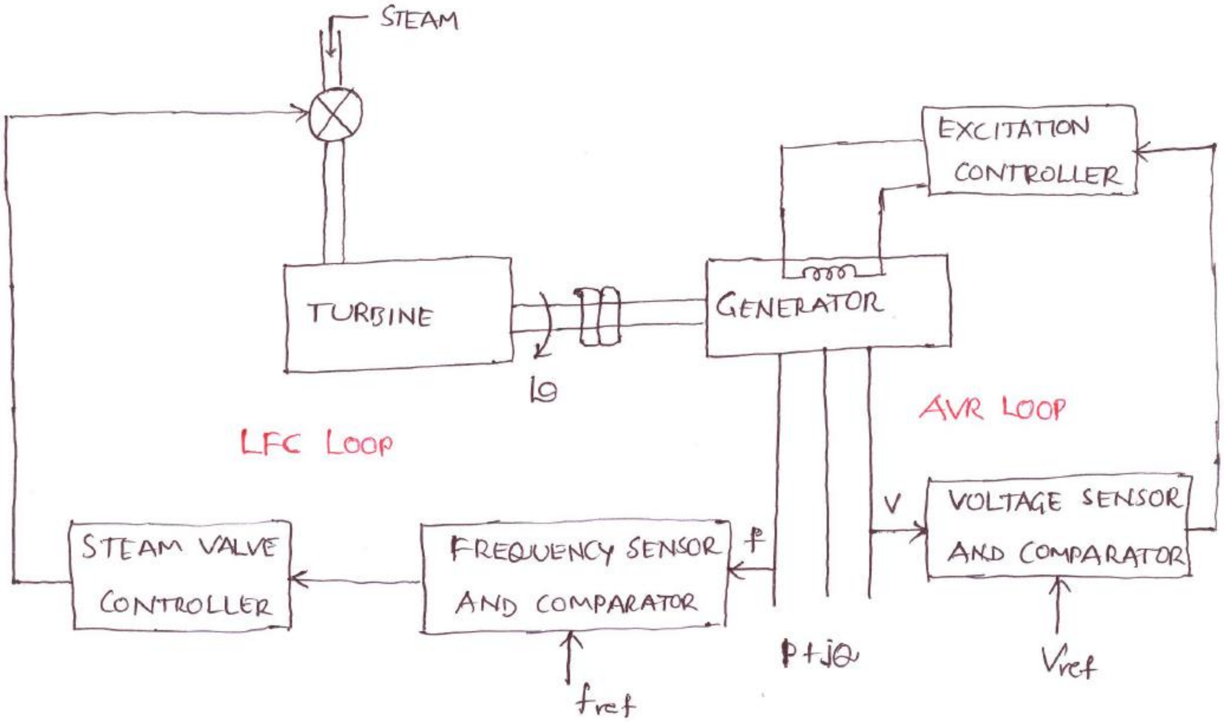


3A. Write notes on basic generator control loops, and cross coupling between loops.

The two control loops are:

- Control of turbine input also called as:
  - → Load Frequency Control (LFC)
  - → Automatic Generation Control (AGC)
  - → Automatic Load Frequency Control (ALFC)
  - → MW−f control loop
  - → Power − frequency control loop

BASIC GENERATOR CONTROL LOOPS:



— Excitation control (or) MVAR-Voltage (Q-V) Control

CROSS-COUPLING BETWEEN CONTROL LOOPS:

* Active power change is dependent on internal machine angle 'δ' and is independent of bus voltage. Change in angle 'δ' is caused by momentary change in generator speed.

* While ~~bo~~ bus voltage is dependent on machine excitation and therefore on reactive power generation 'Q' and is independent of machine angle 'δ'.

* Therefore, load frequency and excitation voltage controls are non-interactive and can be modelled, analysed independently.

* Excitation voltage control is fast acting in which the major time constant is that of generator field.
* Power-frequency control is slow acting with major time constant contributed by the turbine and generator moment of inertia. This time constant is much larger than that of the generator field.

* Thus the transients in excitation voltage control vanish much faster and do not affect the dynamics of power frequency control.

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3B. Determine the primary ALFC loop parameters for control area having the following data.

Total rated area capacity Pr = 2000 MW

Inertia Constant H = 5.0 s

Frequency f_0 = 60Hz

Normal opearating load = 1000 MW

→ Assume that the load frequency dependency is linear, meaning that the load would increase 1% for 1% frequency change.

$$\partial P_D = 1\% \text{ of } 1000 = 10 \text{ MW}$$

$$\partial f = 1\% \text{ of } 50 = 0.5 \text{ Hz}.$$

$$D = \frac{\partial P_D}{\partial f} = \frac{10}{0.5} = 20 \text{ MW/Hz} = \frac{20}{2000} = 0.01 \text{ pu MW/Hz}.$$

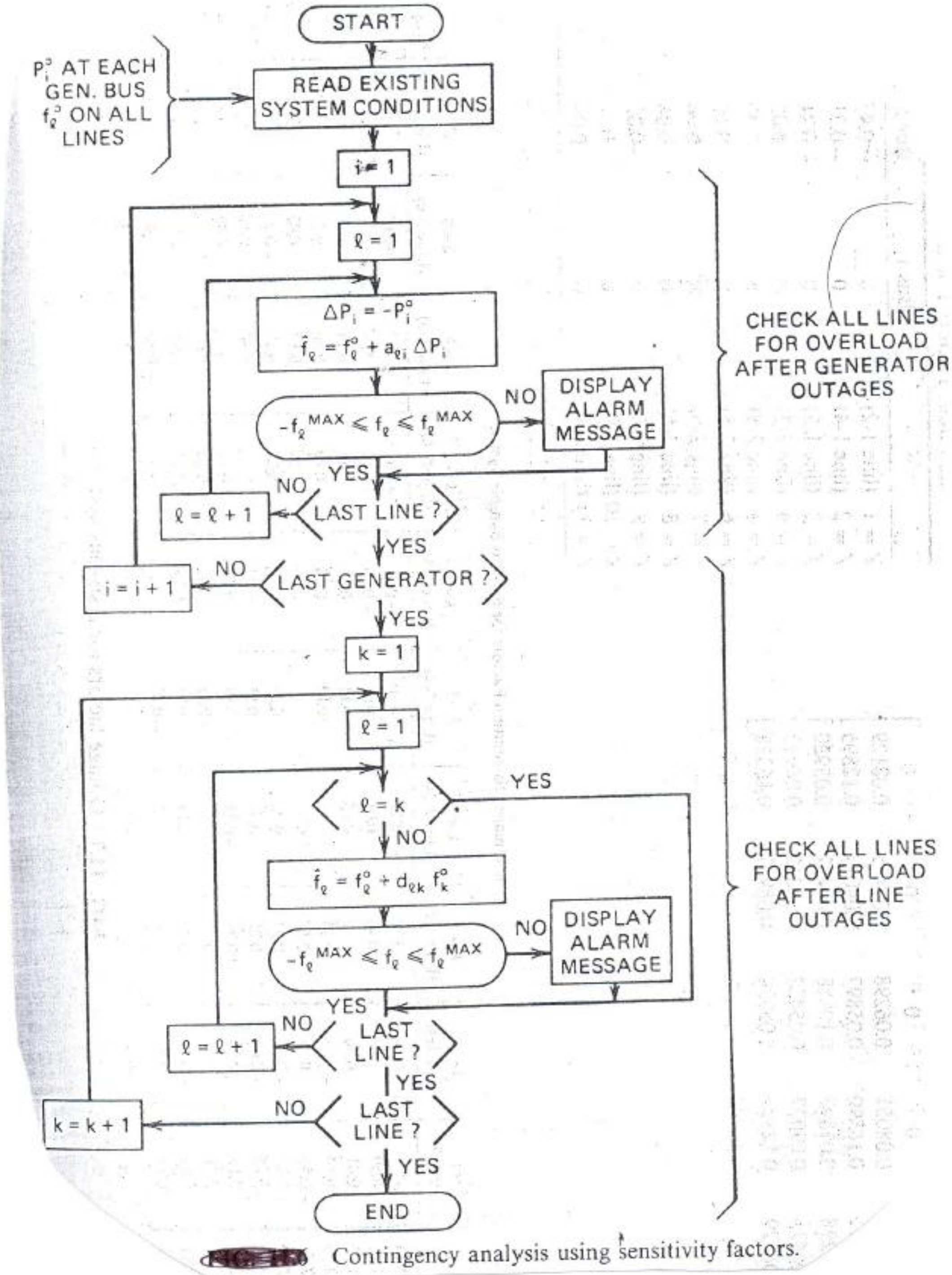
$K_p = 1/D = 100$ Hz/pu MW — Power system gain

$T_p = \frac{2H}{f^0 D} = 20$ Sec. — power system time constant

$$G_p(s) = \boxed{\frac{K_p}{1+sT_p} = \frac{100}{1+20s}}$$

→ Power System Transfer Function

4A. Draw the flow chart of contingency analysis using sensitivity factors.



[redacted] Contingency analysis using sensitivity factors.

4b. A 100MVA alternator operating on rated load,upf, at a frequency of 50Hz.The load is suddenly reduced to 50MW. Due to time lag in the governor system, the steam valve begins to close after 0.4 sec. Determine the change in frequency that occurs in this time. Take H = 5 kW-sec/kVA of generator capacity.

$P_r = 100\,MVA$ | $f_0 = 50Hz$ | $t = 0.4\,s$ | $P_D = 50MW$

$= 100 * 10^3\,MVA$

K.E stored in rotating parts of generator and turbine;

$$W^0 = HP_r = 50 * 10^4\ kW\text{-}Sec.$$

Excess power input to generator before the steam valve begins to close; $P_D = 50MW$

Excess energy input to rotating parts in 0.4 sec;

$$\Delta W = P_D * t = 20{,}000\ kW\text{-}Sec.$$

From $W_0 \propto f_0^2$ — (1)

$$(W_0 + \Delta W) \propto (f_0 + \Delta f)^2 \quad \text{— (2)}$$

$$\frac{(2)}{(1)} \rightarrow (f_0 + \Delta f) = \left(\frac{W_0 + \Delta W}{W_0}\right)^{1/2} \cdot f_0 = 51\,Hz.$$

$\therefore$ Change in frequency; $\boxed{\Delta f = 1\ Hz}$

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5.Explain how mathematical model of speed governor system is developed for Automatic Generation Control (Automatic Load Frequency Control).

SPEED GOVERNING SYSTEM:

Figure shows the schematic diagram of a speed governing system which controls the real power flow in the power system. The speed governing system consists of the following parts:

1. Speed Governor:

This is a fly-ball type of speed governor and constitutes the heart of the system as it senses the change in speed or frequency. With increase in speed the fly-balls move outwards and the point B on linkage mechanism moves downwards and vice-versa

2. Linkage Mechanism:

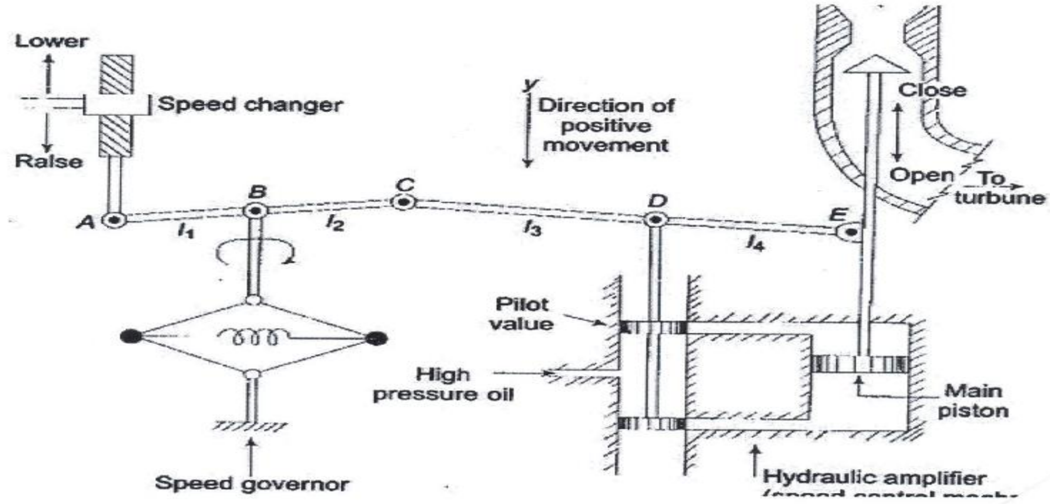
ABC and CDE are the rigid links pivoted at B and D respectively. The mechanism provides a movement to the control value in the proportion to change in speed. Link 4 (l_4) provides a feedback from the steam valve movement.

3. Hydraulic Amplifier:

This consists of the main piston and pilot valve. Low power level pilot valve movement is converted into high power level piston valve movement which is necessary to open or close the steam value against high pressure steam.

4. Speed Changer:

The speed changer provides a steady state power output setting for the turbine. The downward movement of the speed changer opens for the upper pilot value so that more steam is admitted to the turbine under steady condition. The reverse happens when speed changer moves upward.



·MODEL OF SPEED GOVERNING SYSTEM:

We consider the steady state condition by assuming that the linkage mechanism is stationary, pilot valve closed, steam valve opened by a definite magnitude, the turbine output balances the generator output and the turbine or generator is running at a particular speed

Two factors contribute to the movement of C

a) Increase in frequency causes B to move by Δx_B, downward

b) The lowering of speed changer by an amount Δx_A lifts the point C upwards

$$\therefore \text{Movement or change at } C,\ \Delta x_C = K_1 \Delta f - K_2 \Delta P_C \quad \text{—(1)}$$

SPEED CHANGER 'RAISE' CASE

A	↓	Δx_A	+ve
B	—	Δx_B	0
C	↑	Δx_C	−ve
D	↑	Δx_D	−ve
E	↓	Δx_E	+ve

SPEED CHANGER 'LOWER' CASE. (3)

A	↑	Δx_A	−ve
B	—	Δx_B	0
C	↓	Δx_C	+ve
D	↓	Δx_D	+ve
E	↑	Δx_E	−ve.

TURBINE @ HIGHER SPEED($\omega\uparrow$)

A	—	Δx_A	0
B	↓	Δx_B	+ve
C	↓	Δx_C	+ve
D	↓	Δx_D	+ve
E	↑	Δx_E	−ve

TURBINE @ LOWER SPEED($\omega\downarrow$)

A	—	Δx_A	0
B	↑	Δx_B	−ve
C	↑	Δx_C	−ve
D	↑	Δx_D	−ve
E	↓	Δx_E	+ve.

The movement of D is contributed by the movement of C and E

Therefore, $\therefore \Delta X_D = K_3 \Delta X_C + K_4 \Delta X_E$ —— (2).

Assuming that oil flow into hydraulic cylinder is proportional to position ΔX_D of the pilot value, then

$$\Delta X_E = K_5 \int_0^t \Delta X_D \cdot dt \quad \text{—— (3)}$$

where K_1, K_2, K_3, K_4 depend upon the length of linkage arms and K_5 depends upon the fluid pressure and the geometry of the culinder.

Laplace transform of eq(1), eq(2), eq(3) →

$$\Delta X_C(S) = K_1 \Delta F(S) - K_2 \Delta P_C(S) \quad \text{—— (4)}.$$

$$\Delta X_D(S) = K_3 \Delta X_C(S) + K_4 \Delta X_E(S) \quad \text{—— (5)}$$

$$\Delta X_E(S) = -\frac{K_5}{S} \cdot \Delta X_D(S)$$

$$S \cdot \Delta X_E(S) = -K_5 \cdot \Delta X_D(S) \quad \text{—— (6)}.$$

(4) in (5) →

$$\Delta X_D(S) = K_3 K_1 \Delta F(S) - K_3 K_2 \Delta P_C(S) + K_4 \Delta X_E(S) \quad \text{—— (7)}$$

(7) in (6) →

$$S \cdot \Delta X_E(S) = -K_3 K_1 K_5 \Delta F(S) + K_3 K_2 K_5 \Delta P_C(S) - K_4 K_5 \Delta X_E(S) \left[\div K_4 K_5 \right]$$

$$\frac{S \cdot \Delta X_E(S)}{K_4 \cdot K_5} = \frac{-K_3 K_1 \cancel{K_5}}{K_4 \cdot \cancel{K_5}} \cdot \frac{K_2}{K_2} \Delta F(S) + \frac{K_3 K_2 \cancel{K_5}}{K_4 \cdot \cancel{K_5}} \Delta P_C(S) - \Delta X_E(S)$$

$$\Delta X_E(s)\left[1+s\cdot\frac{1}{K_4\cdot K_5}\right] = -\left(\frac{K_2K_3}{K_4}\right)\left(\frac{K_1}{K_2}\right)\Delta F(s) + \left(\frac{K_2K_3}{K_4}\right)\Delta P_c(s)$$

Define; K_G = Governor gain constant $= \frac{K_2K_3}{K_4}$

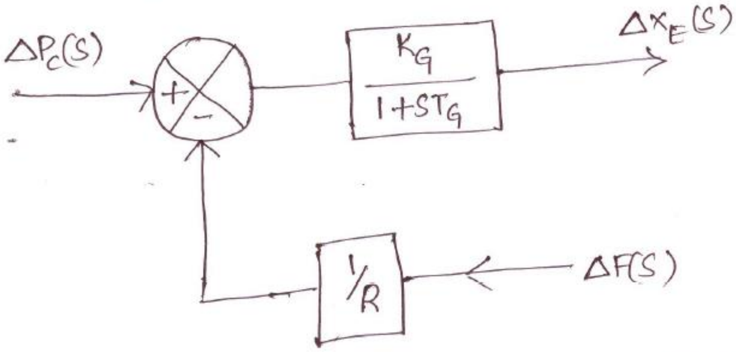
T_G = Governor time constant $= \frac{1}{K_4K_5}$

$R = K_2/K_1$ = Regulation of governor.

Then

$$\Delta X_E(s)\left[1+sT_G\right] = -K_G\cdot\left(\frac{1}{R}\right)\Delta F(s) + K_G\,\Delta P_c(s)$$

$$\boxed{\Delta X_E(s) = \left[\frac{K_G}{1+sT_G}\right]\left[\Delta P_c(s) - \frac{1}{R}\cdot\Delta F(s)\right]}$$



$\Delta P_c(s)$ = change in speed changer setting.

$\Delta X_E(s)$ = change in valve movement

$\Delta F(s)$ = change in system frequency.

BLOCK DIAGRAM OF SPEED GOVERNOR MODEL.

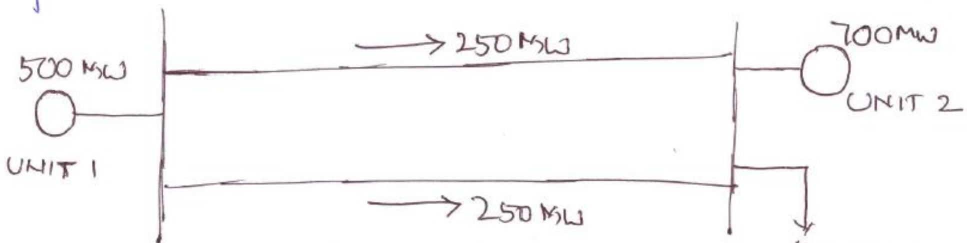
6. Explain the Security-Constrained Optimal Power Flow (SCOPF) function of power system security with an example.

In this function, a contingency analysis is combined with an optimal power flow. To show how this can be done, let us consider the following example, considering the power system into four operating states.

A power system consisting of two generators, a load and a double circuit line, with both the generators supplying the load.

OPTIMAL DISPATCH:

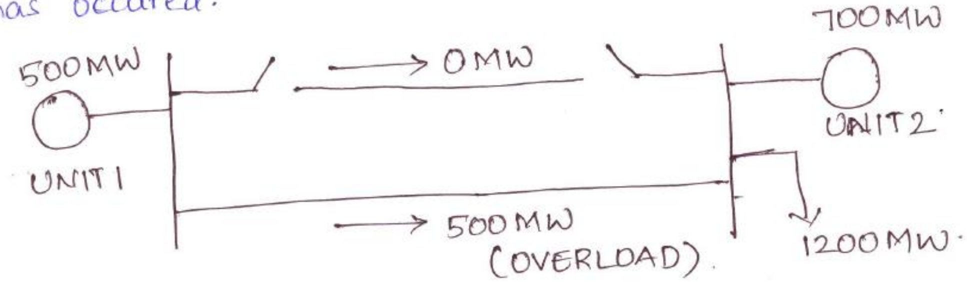
This is the state prior to any contingency. It is optimal with respect to economic operation, but it may not be secure.



We assume that the system shown above is in economic dispatch. We also consider that each circuit of the double circuit line can carry a maximum of 400MW.

POST CONTINGENCY:

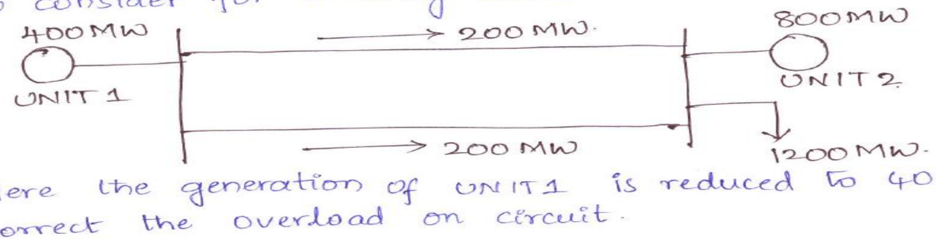
This is the state of the power system after a contingency has occured.



Let us consider one of the two circuits making up the transmission line has been opened because of a failure. This results in an overload on the remaining circuit. We do not want this condition to arise and should be corrected.

SECURE DISPATCH:

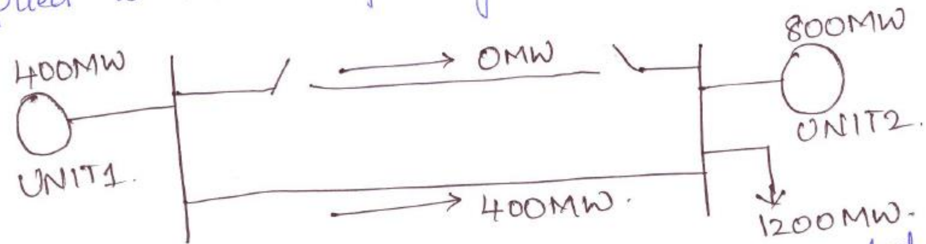
This is the state of the system with no contingency outages, but with corrections to the operating parameters to consider for security violations.



Here the generation of UNIT 1 is reduced to 400MW to correct the overload on circuit.

SECURE POST-CONTINGENCY:

This is the state of the system when the contingency is applied to the base-operating condition - with corrections.



Post-contingency operating state has been prevented from overload by adjusting generation on unit1 and unit2.

1. These are called 'SECURITY CORRECTIONS.
2. Programs which can make control adjustments to the base or pre-contingency operation to prevent violations in post-contingency conditions are called 'SECURITY-CONSTRAINED OPTIMAL POWER FLOW (SCOPF).
3. These programs can take account of many contingencies and calculate adjustments to generator MW, generator voltages, transformer taps, interchange etc.

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7. With the help of flow chart ,explain the contingency selection procedure.

1. We should have a mechanism to prepare a short list of outages from list of all possible outages.
2. We should have some measure as to how much a particular outage must affect the power system. An index called 'Performance Index' can make us measure the effect of an outage on the power system.

Performance Index, $$\boxed{PI = \sum_{\text{all branches } l} \left(\frac{P_{flow,l}}{P_l^{max}}\right)^{2n}} \qquad (1).$$

where $P_{flow,l}$ = flow through line l, post outage (MW)

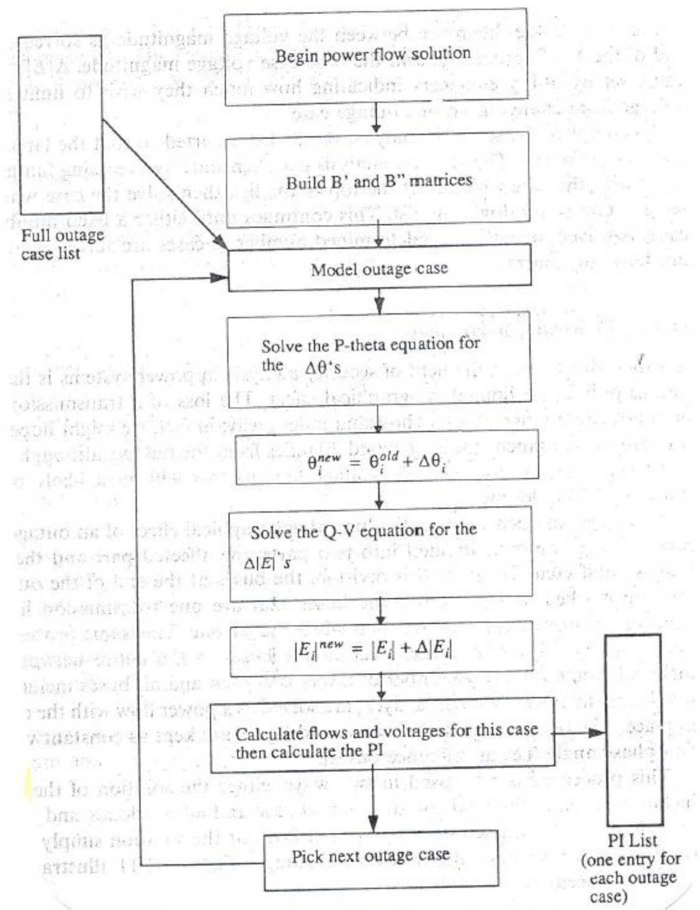
P_l^{max} = the maximum allowed limit for power flow through line 'l'. (MW)

3. The PI will be a small number if all flows are within the limit, and it will be large if one or more lines are overloaded.
4. The PI's ability to distinguish the bad cases of outages is limited when $n=1$. Hence $n=2$ is an ideal value, $n>2$ the problem solution is difficult.
5. The selection of bad outages from a list of possible outages is a procedure that involves ordering the PI table from largest value to the least.
6. The lines corresponding to the top of the list are then the candidates for the short list.
7. The contingency selection procedure is explained in the flow chart below which is called as 'The 1P1Q contingency selection procedure' why because the selection procedure is interrupted after one iteration. (One P-θ calculation and one Q-V calculation)
8. The another advantange of this procedure is the voltages can also be included in the PI.

$$\boxed{PI = \sum_{\substack{\text{all branches} \\ l}} \left(\frac{P_{flow,l}}{P_l^{max}}\right)^{2n} + \sum_{\substack{\text{all buses} \\ i}} \left(\frac{\Delta|E_i|}{\Delta|E|^{max}}\right)^{2m}} \quad \text{——— (2).}$$

where $\Delta|E_i|$ = Difference between the voltage magnitude at the (13) end of 1P1Q procedure and the base case voltage magnitude, @ bus 'i'.

$\Delta|E_i|^{max}$ = The maximum allowed change in voltage for one outage case, @ bus 'i'.



The 1P1Q contingency selection procedure.