DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

(ACADEMIC YEAR: 2023-2024)

EE3602 –POWER SYSTEM OPERATION AND CONTROL

(Regulation 2021)

III YEAR

Semester-VI

FIVE UNITS MATERIAL

Prepared by

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ODD SEMESTER 2023-2024

EE3602 –POWER SYSTEM OPERATION AND CONTROL

IV YEAR / VII SEMESTER 2021 REGULATION

SYLLABUS

OBJECTIVES:

To impart knowledge on the following topics

- Significance of power system operation and control.
- Real power-frequency interaction and design of power-frequency controller.
- Reactive power-voltage interaction and the control actions to be implemented for
- maintaining the voltage profile against varying system load.
- Economic operation of power system.
- SCADA and its application for real time operation and control of power systems

UNIT I PRELIMINARIES ON POWER SYSTEM OPERATION AND CONTROL

Power scenario in Indian grid – National and Regional load dispatching centers –requirements of good power system - necessity of voltage and frequency regulation – real power vs frequency and reactive power vs voltage control loops - system load variation, load curves and basic concepts of load dispatching - load forecasting - Basics of speed governing mechanisms and modeling - speed load characteristics - regulation of two generators in parallel.

UNIT II REAL POWER - FREQUENCY CONTROL 9

Load Frequency Control (LFC) of single area system-static and dynamic analysis of uncontrolled and controlled cases - LFC of two area system - tie line modeling – block diagram representation of two area system - static and dynamic analysis - tie line with frequency bias control – state variability model - integration of economic dispatch control with LFC.

UNIT III REACTIVE POWER – VOLTAGE CONTROL 9

Generation and absorption of reactive power - basics of reactive power control – Automatic Voltage Regulator (AVR) – brushless AC excitation system – block diagram representation of AVR loop - static and dynamic analysis – stability compensation – voltage drop in transmission line - methods of reactive power injection - tap changing transformer, SVC (TCR + TSC) and STATCOM for voltage control.

UNIT IV ECONOMIC OPERATION OF POWER SYSTEM 9

Statement of economic dispatch problem - input and output characteristics of thermal plant - incremental cost curve - optimal operation of thermal units without and with transmission losses (no derivation of transmission loss coefficients) - base point and participation factors method - statement of unit commitment (UC) problem - constraints on UC problem – solution of UC problem using priority list – special aspects of short term and long term hydrothermal problems.

UNIT V COMPUTER CONTROL OF POWER SYSTEMS 9

Need of computer control of power systems-concept of energy control centers and functions – PMU - system monitoring, data acquisition and controls - System hardware configurations - SCADA and EMS functions - state estimation problem – measurements and errors - weighted least square estimation - various operating states - state transition diagram.

TOTAL : 45 PERIODS

OUTCOMES:

- Ability to understand the day-to-day operation of electric power system.
- Ability to analyze the control actions to be implemented on the system to meet the
- minute-to-minute variation of system demand.
- Ability to understand the significance of power system operation and control.
- Ability to acquire knowledge on real power-frequency interaction.
- Ability to understand the reactive power-voltage interaction.
- Ability to design SCADA and its application for real time operation.

TEXT BOOKS:

1. Olle.I.Elgerd, 'Electric Energy Systems theory - An introduction', McGraw Hill Education Pvt. Ltd., New Delhi, 34th reprint, 2010.

1. Allen. J. Wood and Bruce F. Wollen berg, 'Power Generation, Operation and Control', John Wiley & Sons, Inc., 2016.
2. Abhijit Chakrabarti and Sunita Halder, 'Power System Analysis Operation and Control', PHI learning Pvt. Ltd., New Delhi, Third Edition, 2010.

REFERENCES

1. Kothari D.P. and Nagrath I.J., 'Power System Engineering', Tata McGraw-Hill Education, Second Edition, 2008.

1. Hadi Saadat, 'Power System Analysis', McGraw Hill Education Pvt. Ltd., New Delhi, 21st reprint, 2010.
2. Kundur P., 'Power System Stability and Control, McGraw Hill Education Pvt. Ltd., New Delhi, 10th reprint, 2010.

UNIT I – PRELIMINARIES ON POWER SYSTEM OPERATION AND CONTROL

INTRODUCTION

Freq regulation:-

1. Normal operation of Syn. unit in P.S.
2. 80% of the IM is used to get the constant speed
3. $\eta \downarrow$, life time of equipment $\downarrow$
4. Electrical clocks - Syn. motor
5. 50Hz, ±2% tollerence

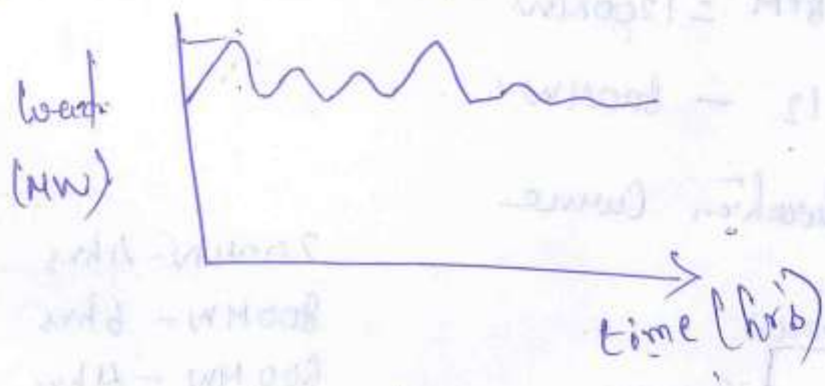
Voltage regulation

1. Lighting loads - very sensitive to voltage fluctuation
2. $\eta \downarrow$, life $\downarrow$
3. 50% IM $\downarrow$ $T \propto V^2 \downarrow$ Power loads to transfer
4. Power over transmission lines - voltage constant

System - load variation:-

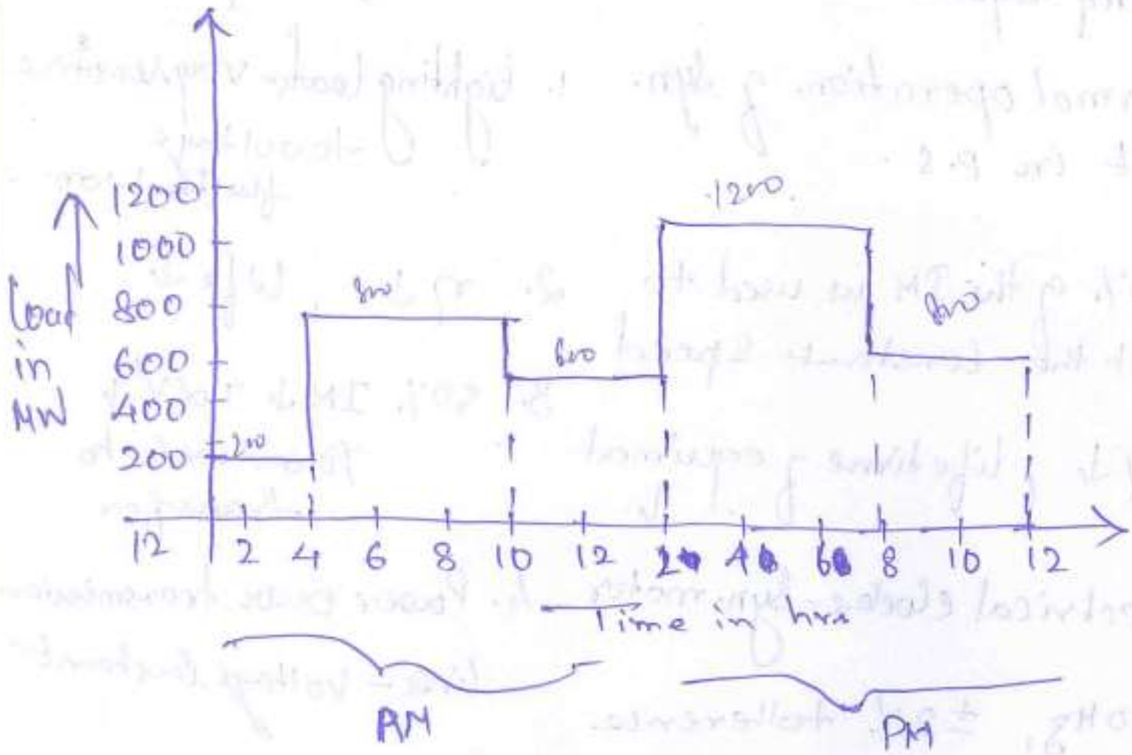
Load curve:-

The curve drawn b/w load and time.



i) Maximum demand
ii) Average demand
iii) variation of load wrt time
iv) unit gen / day, MWhr
v) rating of gen & turn ON

Load Curve:-



12-4AM - 200MW

4AM-10AM - 800MW

10AM-2PM - 600MW

2PM-8PM = 1200MW

8PM-12 - 800MW.

Load duration Curve

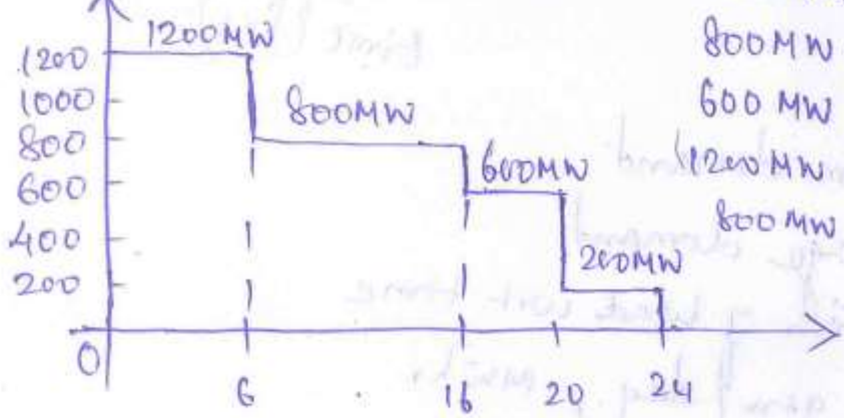
200MW - 4hrs

800MW - 6hrs

600 MW - 4hrs

1200 MW - 6hrs

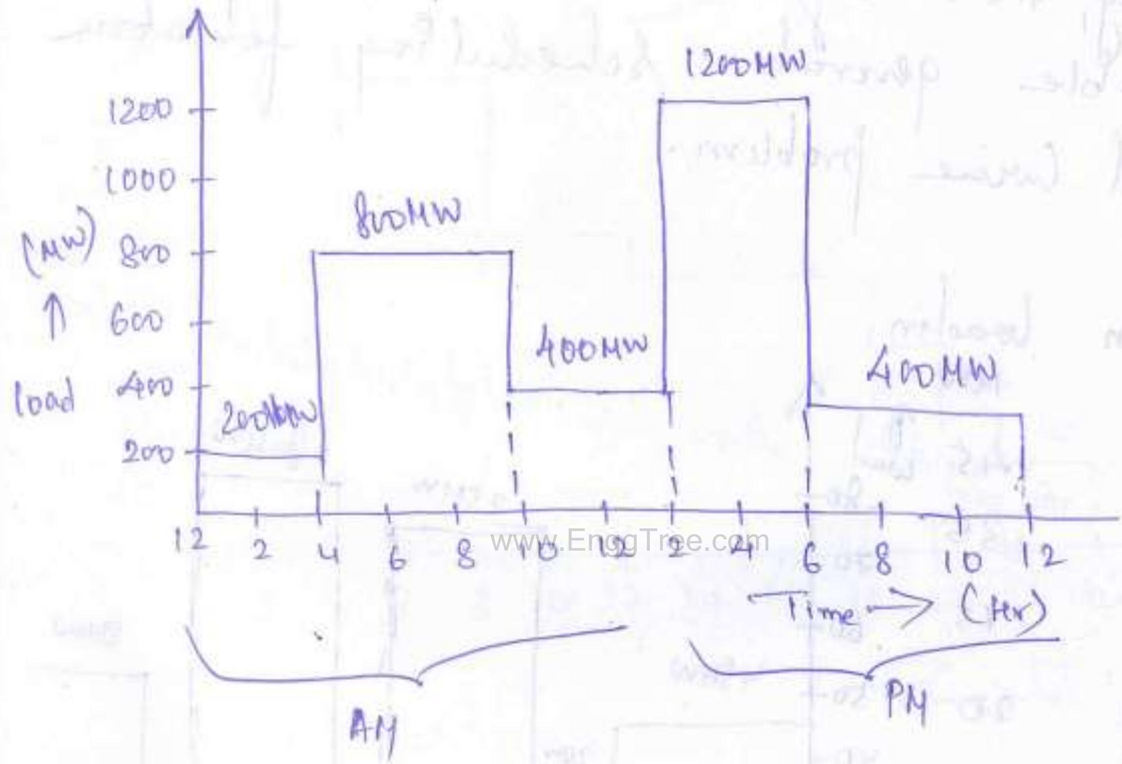
800 MW - 4hrs



1) Max demand = 1200MW

2) $A.D = \frac{\text{Area}}{\text{time}} = \frac{\text{No. g unit gen/day}}{\text{time}}$

$$\frac{800 + 4800 + 7200 + 3200 + 2400}{24} = \frac{18400}{24} = 766.6\,MW$$



No. g gen /

Load duration curve :-

80 MW - 4hrs

75 MW - 4hrs

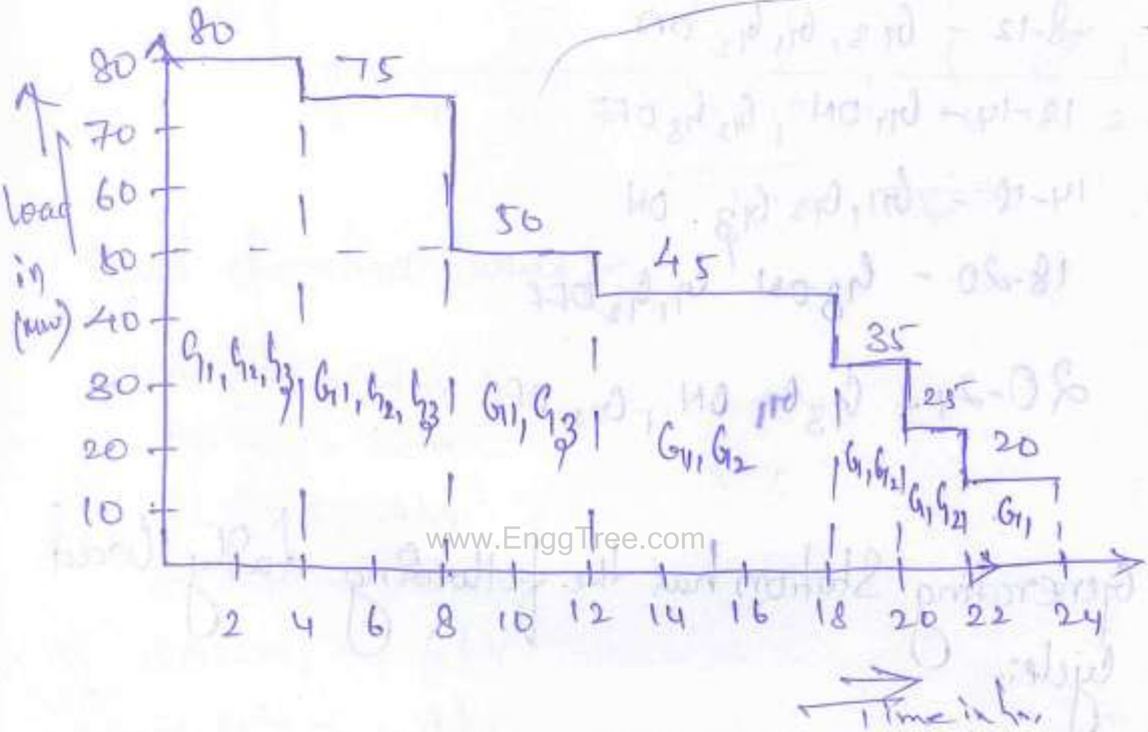
50 MW - 4hrs

45 MW - 6hrs

35 MW - 2hrs

25 MW - 2hrs

20 MW - 2hrs



Maximum demand:

$MD = 80 MW$

Average demand:-

$$AD = \frac{\text{No. of units gen/day}}{\text{Time}}$$

No. of units gen/day $= (80\times4)+(75\times4)+(50\times4)+(45\times6)$
$+ (35\times2)+(25\times2)+(20\times2)$

$= 320+300+200+270+70+50+40$

$= 1250$

Average demand $= \frac{1250}{24} = 52.09 MW$

No. of generator :-

25 MW - 2 G_1, G_2
50 MW - 1 G_3

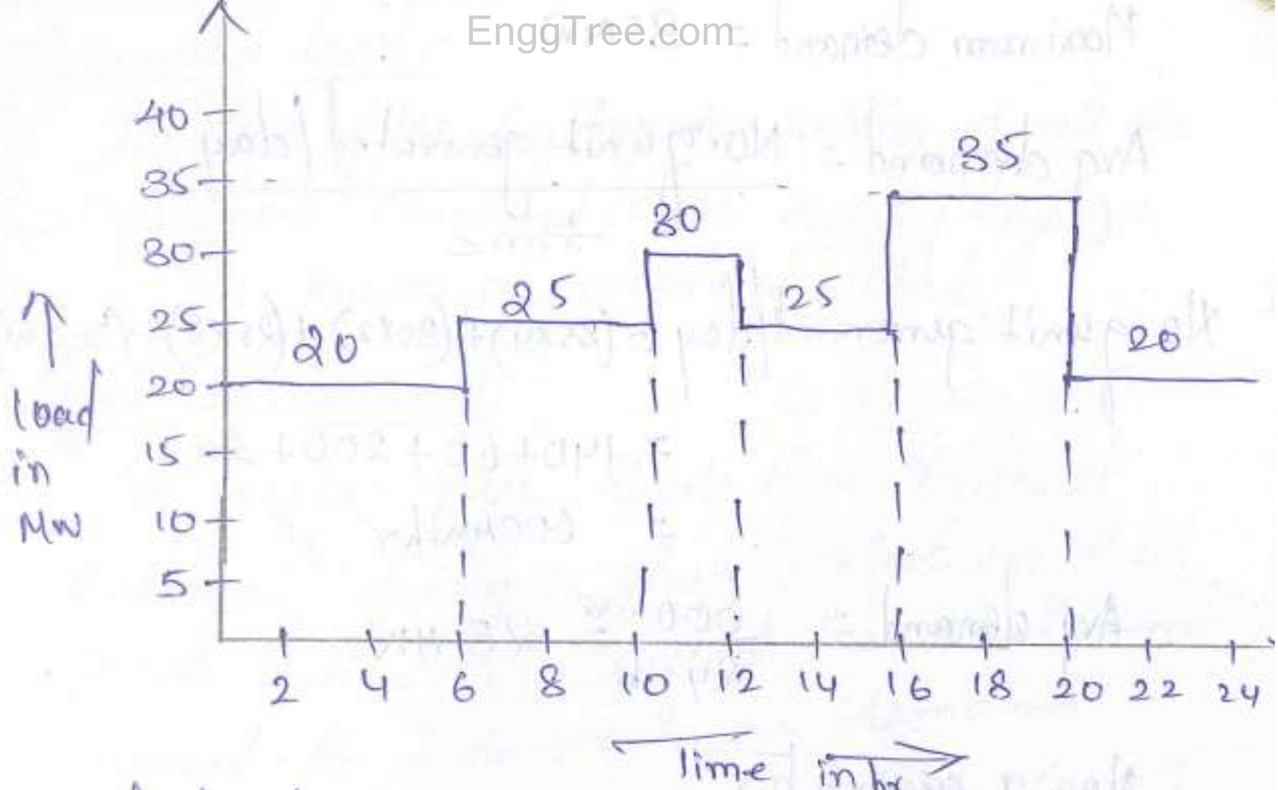
Soln

0-6 - G_3 ON
6-8 - G_3 ON
8-12 - G_3, G_1, G_2 ON
12-14 - G_1 ON, G_2 G_3 OFF
14-18 - G_1, G_2 G_3 ON
18-20 - G_3 ON, G_1, G_2 OFF
20-24 - G_3 G_1 ON, G_2 OFF

(8) A Generating Station has the following daily cycle:-

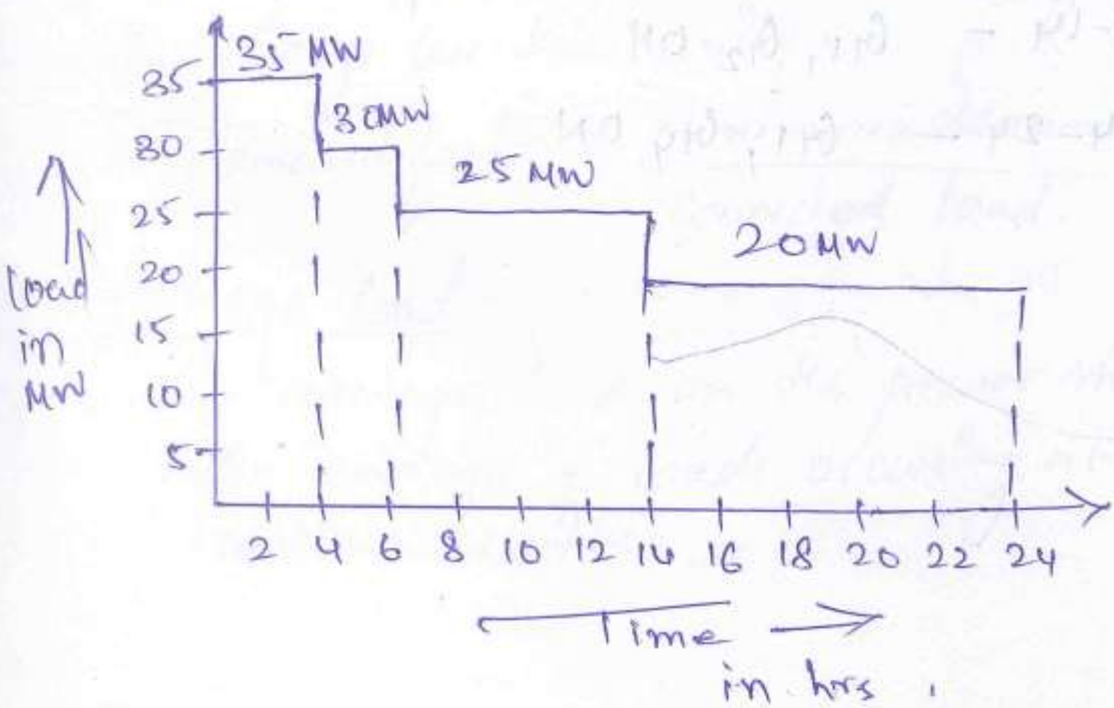
Time (Hours)	0-6	6-10	10-12	12-16	16-20	20-2
Load (MW)	20	25	30	25	35	20

Draw the load curve & Calculate
1) Max demand
2) units generated per day



load duration Curve:-

35 MW – 4hr
30 MW – 2hr
25 MW = 4hr
25 MW – 4hr
20 MW – 6hr
20 MW – 4hr



Maximum demand = 85MW

Avg demand = $\frac{\text{No. of unit generated/day}}{\text{time}}$

No. of unit generated/day = (85x4) + (30x2) + (25x8) + (20x

= 140+60+200+200

= 600MWhr

Avg demand = $\frac{600 \text{ MWhr}}{24 \text{ hr}}$ = 25 MW

No. of generator

20MW - 1 G1

10MW - 2 G2, G3

5MW - 1 G4

0-4 - G1, G2, G3 ON

4-6 - G1, G2, G4 ON

6-14 - G1, G2 ON

14-24 - G1, G4 ON

Connected load:-

The Sum of the Continuous rating of all the equipment connected to the Supply system is known as connected load.

Maximum demand:-

The greatest of all short time interval averaged, during a given period on the power station is called the maximum demand. It is the maximum demand which determines the size and the cost of the installation.

Demand factor :-

The ratio of actual max demand on the System to the total rated load connected to the System is called the demand factor. It is always less than unity.

$$\text{demand factor} = \frac{\text{Maximum demand}}{\text{Connected load}}$$

Average load:-

The average load on the power station is the average of loads occuring at various events.

Load factor:-

Load factor is defined as the ratio of average load to the max. demand during a certain period of time such as day or month or year is called a load factor

$$\text{Load factor} = \frac{\text{Average demand}}{\text{Max. demand}}$$

Diversity factor:-

The ratio of sum of the individuals maximum demands of the consumers supplied by it to the maximum demand of the power station is called the diversity factor

$$\text{Diversity factor} = \frac{\text{Sum of the individual max. demand}}{\text{Max demand of power st.}}$$

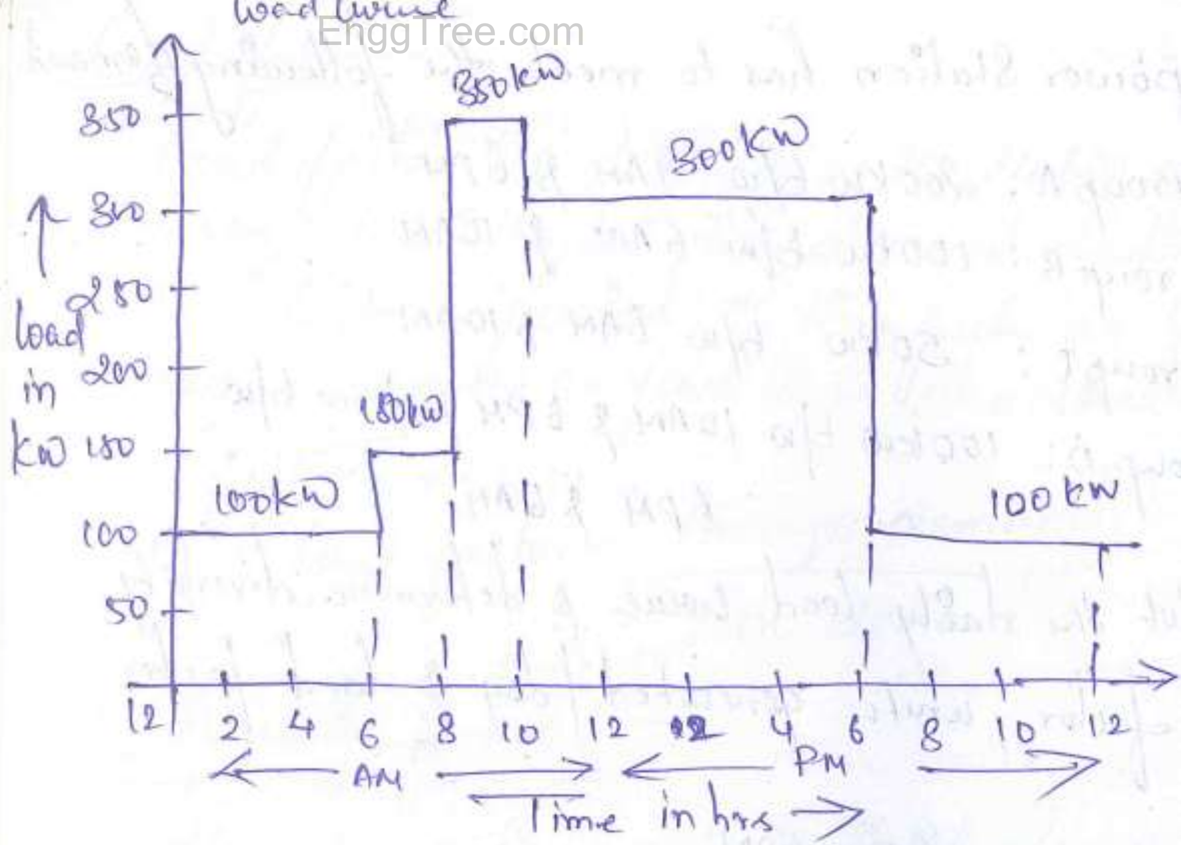
A power Station has to meet the following demand

Group A : 200kw b/w 8AM & 6PM
Group B : 100kw b/w 6AM & 10AM
Group C : 50kw b/w 6AM & 10AM
Group D : 100kw b/w 10AM & 6PM & then b/w 6PM & 6AM

Plot the daily load curve & determine diversity factor, units generated / day & load factor.

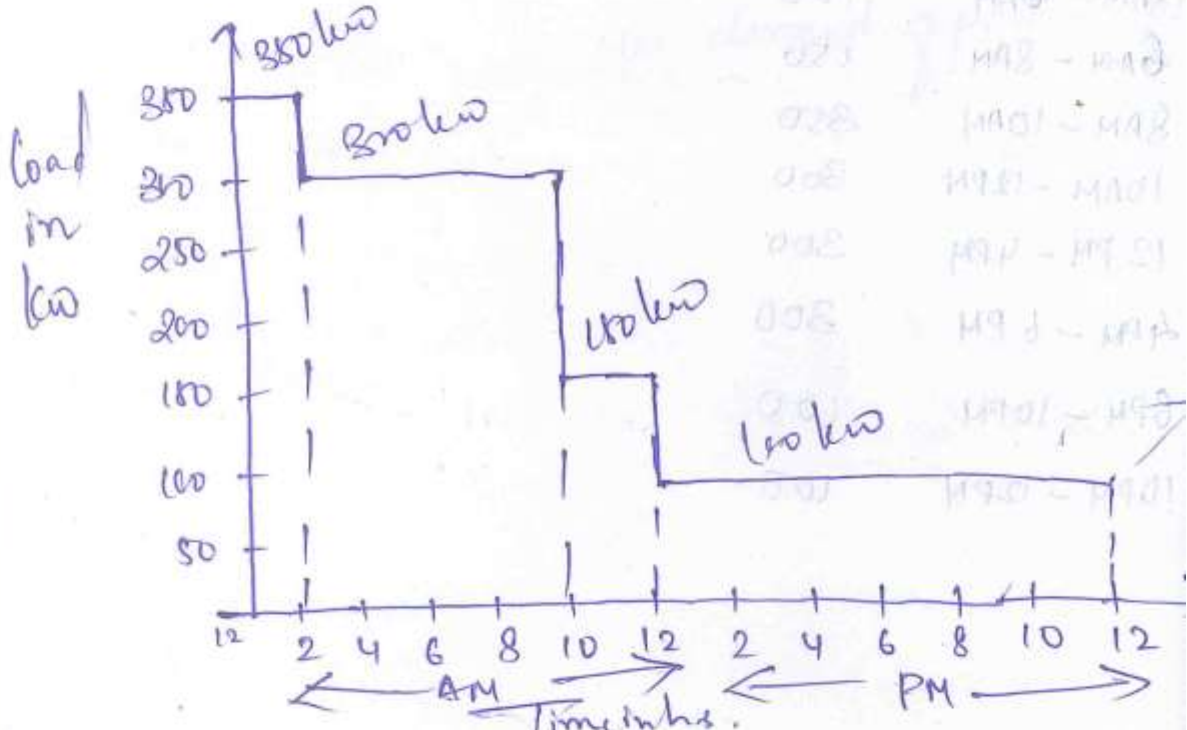
200kw - 8AM - 6PM
100kw - 6AM - 10AM
50kw - 6AM - 10AM
100kw - 10AM - 6PM
6PM - 6AM

Time in hrs	Load in kw
12AM - 2AM	100
2AM - 6AM	100
6AM - 8AM	150
8AM - 10AM	350
10AM - 12PM	300
12 PM - 4PM	300
4PM - 6 PM	300
6PM - 10PM	100
10PM - 12PM	100



Load duration curve:-

Load in kw	Time in hrs
350kw	2 hrs
300 kw	8 hrs.
150 kw	2 hrs
100 kw	12 hrs.



Max demand = 350 kW

$$\boxed{\text{load factor} = \frac{\text{Average demand}}{\text{Max demand}}}$$

$$\text{Average demand} = \frac{\text{No. of unit generator/day}}{\text{time}}$$

No of unit generator/day = $(350 \times 2) + (300 \times 8) + (150 \times 2) + (100 \times 12)$

$= 700 + 2400 + 300 + 1200$

$$\boxed{\text{No. of unit generator per day} = 4600\ \text{Kw/hr}}$$

$$\text{Average demand} = \frac{4600}{24}$$

$= 191.66\ \text{Kw}$

$$\boxed{A.D = 191.6\ \text{kw}}$$

$$\text{load factor} = \frac{191.6}{350}$$

$$\boxed{\text{load factor} = 0.54}$$

$$\text{Diversity factor} = \frac{\text{Sum of individual max - demand}}{\text{Max demand of power Station}}$$

$= \frac{450}{350}$

$$\boxed{\text{Divercity factor} = 1.28}$$

Q) A diesel Station supplies the following loads
various consumers:

Industrial consumer = 1500 kW
Commercial establishment = 750 kW
Domestic power = 100 kW
Domestic light = 450 kW

If the max demand on the Station is 250
and the number of kWh generated per
is 45×10^6, determine
1) diversity factors
2) Annual load factors.

Sol

1) $\boxed{\text{Diversity factor} = \frac{\text{Sum of the individual max-dem}}{\text{Max demand of Po Stat}}}$

$$\text{Diversity factor} = \frac{1500+750+100+450}{2500}$$

$\boxed{\text{Diversity factor} = 1.12}$

2) $\boxed{\text{Annual load factor} = \frac{\text{No of unit generat}}{\text{M.D} \times \text{tim}}}$

12-2 unit gen/year = $\frac{0.4 \times 100 \times 24 \times 365}{\cancel{2500} \times 5}$

$= 3.504 \times 10$

$= \frac{45 \times 10^6}{2500 \times 24 \times 365}$

$\boxed{\text{Annual load factor} = 2.05}$

Q The Max demand on a power station is 100 MW. If the annual load factor is 40%. Calculate the total energy generated in a year.

Max demand = 100 MW

Annual load factor = 40%

= 0.4

Annual load factor = $\frac{\text{unit gen/year}}{M.D \times 24 \times 365}$

unit gen/year = $0.4 \times 100 \times 8760$

$\boxed{\text{no. of unit gen/year} = 3.504 \times 10^5 \text{ MWhr}}$

Q) A Generating Station Supplies the following loads.

15000 kw, 12000 kw, 8500 kw, 6000 kw &

650 kw

The Station has a max demand of 220

The annual load factor of the Station

is 48%. Calculate

i) the no. of units supplied

ii) the diversity factor

iii) the demand factor

Sol

Max demand = 22000 kw

Annual load factor = 48%

$$0.48 = \frac{A.D}{M.D}$$

$$0.48 = \frac{\text{unit gen/year}}{M.D \times 24 \times 365}$$

i) unit gen/year = $0.48 \times 22000 \times 24 \times 365$

$$\boxed{\text{unit gen/year} = 9.25 \times 10^7 \text{ kwhr}}$$

ii) Diversity factor = $\frac{\text{Sum of the individual max de}}{\text{Max demand of power Sta}}$

$$= \frac{15000 + 12000 + 8500 + 6000 +}{22000}$$

$$= \frac{41950}{22000}$$

$$\boxed{\text{Diversity factor} = 1.90}$$

iii) Demand factor $= \frac{\text{Max demand}}{\text{Connected load}}$

$$= \frac{22000}{41950}$$

$$\boxed{\text{Demand factor} = 0.52}$$

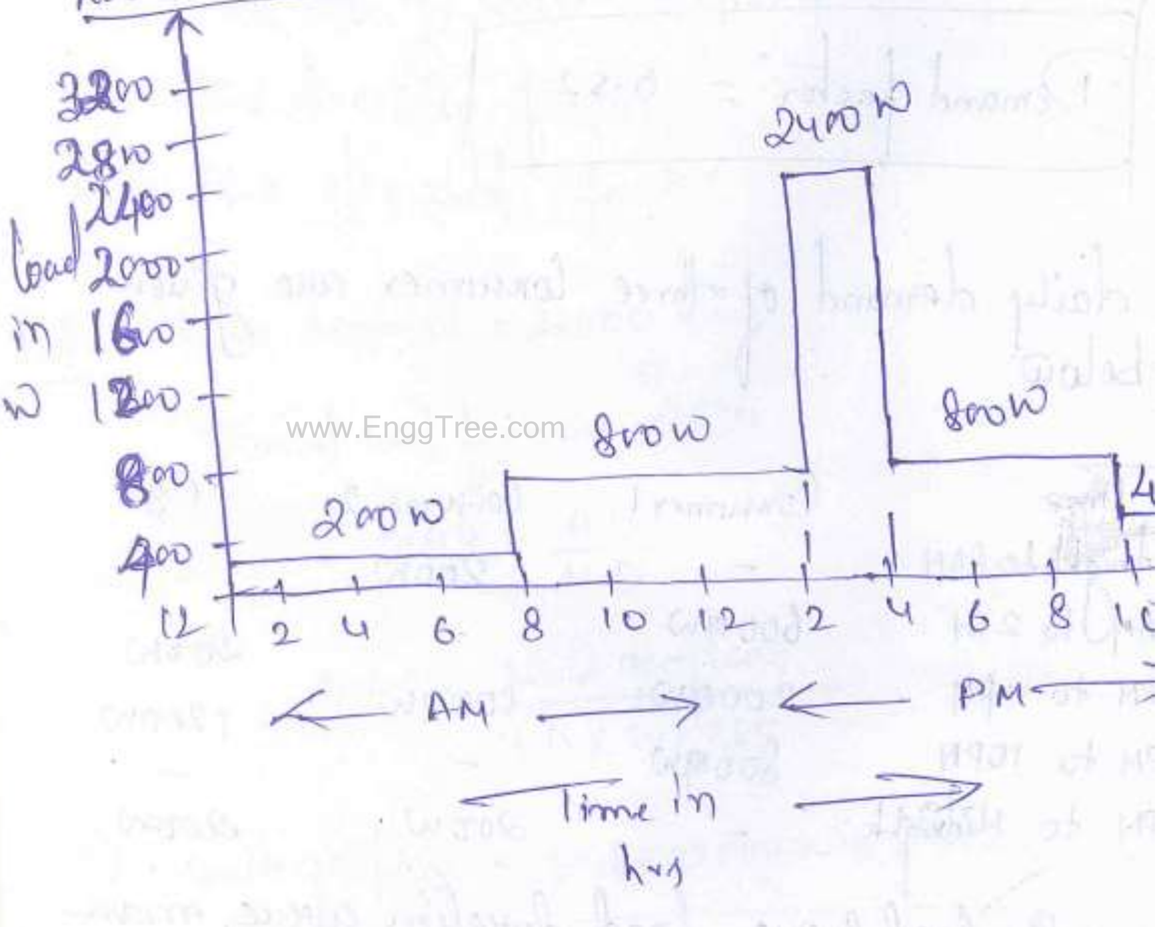
Q A daily demand of three consumer are given below

Time	Consumer 1	Consumer 2	C3
12 midnight to 8AM	–	200W	–
8AM to 2PM	600W	–	200W
2PM to 4PM	200W	1000W	1200W
4PM to 10PM	800W	–	–
10PM to Midnight	–	200W	200W

Draw the load curve, load duration curve, max demand of an individual consumer, load factor of individual consumer & diversity factor.

Time in hrs.	load in W
12MN to 8AM	200W
8AM to 2PM	800W
2PM to 4PM	~~2~~400 W
4PM to 10PM	800 W
10PM to ~~M~~ 12Midnight	400W

Load curve:



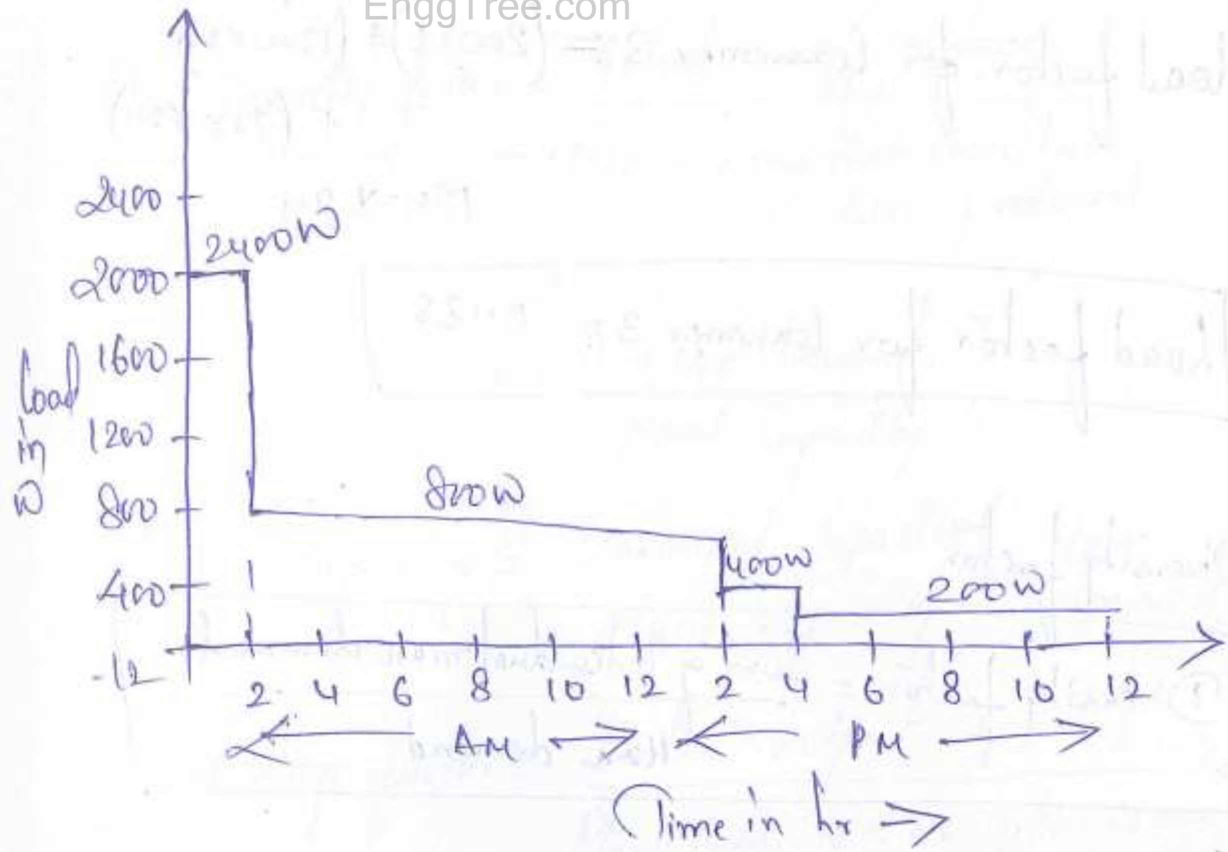
Load duration curve.

2400W – 2hrs

800W – 12hrs

400W – 2hrs

200W – 8hrs



Max demand of Consumer 1 = 800W

Max demand of Consumer 2 = 1000W

Max demand of Consumer 3 = 1200W

$$\boxed{\text{Load factor} = \frac{\text{Average demand}}{\text{M.D}}}$$

$$A.D = \frac{\text{No. of unit of generator per day}}{\text{MD} \times 24}$$

=

$$\text{Load factor for Consumer 1} = \frac{(600\times6)+(200\times2)+(800\times 6 \ldots}{800 \times 24}$$

$$\boxed{\text{Load factor for Consumer 1} = 0.45}$$

$$\text{Load factor for Consumer 2} = \frac{(200\times8)+(1000\times2)+(200\times 2 \ldots}{1000\times24}$$

$$\boxed{\text{Load factor for Consumer 2} = 0.166}$$

$$\text{Plant Capacity factor} = \frac{\text{Actual energy produced}}{\text{Max energy that could have been produced}}$$

(or)

$$= \frac{\text{Average demand}}{\text{plant Capacity}}$$

$$\text{Reserve Capacity} = \left.\begin{matrix}\text{Installed Capacity} \\ \text{or} \\ \text{plant capacity}\end{matrix}\right\} - \text{Max demand}$$

$$\text{Plant usage factor} = \frac{\text{Station output}}{\text{Plant Capacity} \times \text{No. of hrs is use}}$$

Q A Generating Station max demand of 25MW, a load factor of 60%, a plant capacity factor of 50% & plant use factor of 72%. Find the reserved capacity of plant, the daily energy use, the max energy that could be prouduced that plant were fully loaded.

Sol

Reserve capacity = plant Capacity - Max demand

= plant cap - 25MW → (1)

$$\text{Plant Capacity factor} = \frac{\text{Average demand}}{\text{Plant capacity}}$$

$$\text{Load factor} = \frac{\text{Average demand}}{\text{M.D}}$$

Average demand = Load factor × M.D

$= 0.6 \times 25 = 15\,MW$

$\boxed{\text{Load factor} = 15\,MW}$

Annual dem

Plant capacity = $\frac{\text{Average demand}}{\text{Plant capacity factor}}$

$= \frac{15}{0.5}$

$\boxed{\text{Plant Capacity} = 30\,MW}$

Reserve Capacity $= 30 - 25$

$\boxed{\text{Reserve Capacity} = 5\,MW}$

Daily energy produced :-

Daily energy produced = No. of units gen/day

Average demand = $\frac{\text{No. of units gen/day}}{24}$

15×24 = No. of units gen/day

360 MWhr = No. of units gen/day

Plant Capacity factor = $\frac{\text{Actual energy produced}}{\text{Max. Energy that could have Produced}}$

Max. Energy that Could have been produced = $\frac{\text{Actual energy prod}}{\text{Plant Capacity fa}}$

Reserves:-

1. Firm power → emergency
2. Dump power
3. Spill power

hydro electric plants → flood

4. Spinning Reserve → $T_h - T_0 - T_L$.
5. Installed capacity
6. Cold Reserve → not in operation but available
7. Hot reserve → in operation not available for service

Load forecasting:-

→ Predict

- Predicting the future demand generation
- generation
- for proper financing
- T &D.

Very S.T	few sec to 30 min	real time control
S.T	half hr to few hr	allocate for SR.
MT	few day to few week	to meet unexpected load
LT	few month to few year	for future expansion

Reserves:-

1. Spinning Reserve:-
Spinning reserve is that generating capacity which is connected to the bus and is ready to take load.

2. Installed capacity:-
Installed reserve is that generating capacity which is the power intended to be always available. Installed reserve can be kept low by the achievement of good diversity factor

~~2 Spinning reserves:-~~
~~Spinning reserve is the generating capacity~~
~~toi~~

3. Cold reserve:-
Cold reserve is that reserve generating capacity which is available for service but is not in operation.

4. Hot reserves:-
Hot reserve is that reserve generating capacity which is in operation but is not in service

5. Firm power:- It is the power intended to be always available (even under emergency condi

6. Dump power:-

7. Spill power:-

Load forecasting :-

The load on their Systems should be estimated in advance. This estimation in advance is known as load forecasting.

Classification of load forecasting :-

Forecast	Lead Time	Application
Very Short time	few min to half an ~~half~~ hours	Real time contro Real time secur Evaluation
Short term	Half an hour to a few hours	Allocation of spi reserve, unit commitment, mai -ance Scheduling
Medium term	few day to a few weeks	Planning or season peak winter, summ
Long term	few months to a few years	To plan the growth the generation capa

Need for load forecasting :-

* To meet out the future demand
* long-term forecasting is required for prepar maintenance schedule of the generating un planning future expansion of the System.
* For day-to-day operation, short term lo forecasting is needed in order to commit enough generating capacity for the fore

Overview of Control of Power System:-

Power Quality

Constancy of freq

Constancy of voltage.

level of reliability.

Factor affecting power quality

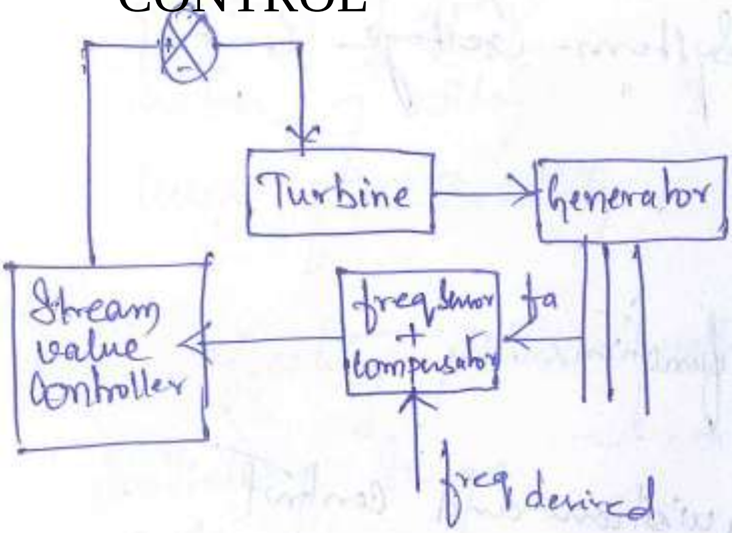
- Switching surge.
- lightning.
- flickering of voltage
- load capacitance
- Electronic interference.
- welding machine

3 main Control

- Plant-level Control
- System generation Control
- Transmission Control

- Plant-level Control
  1) Prime mover Control
  2) Automatic voltage Control (AVR)

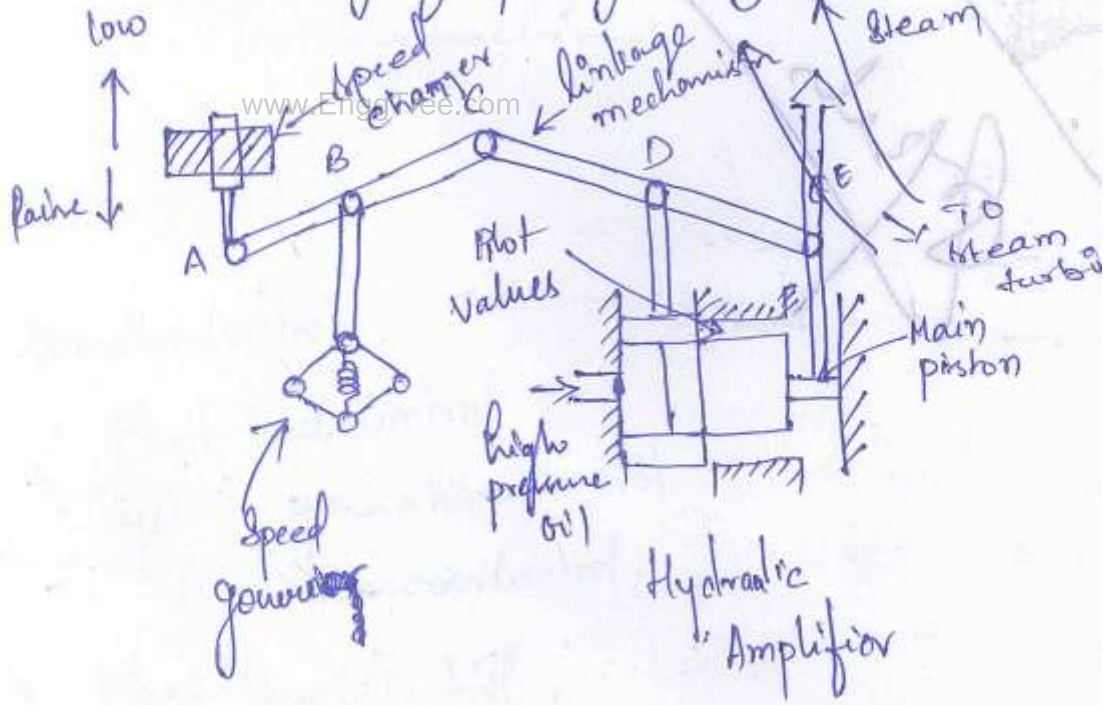
UNIT – II REAL POWER – FREQUENCY CONTROL



~~Modelling of Speed governing m~~

Load frequency Control (LFC) of single Area System - uncontrolled

Modelling of Speed governing mechanism



* When the freq decreases, raise command is given to the speed changer (downward movement)

* As the speed changer moves ↓ A move ↓, B↓ & C↑

* when B↓, fly ball speed governer expands.

* As C↑, D↑ & E↓
  when D↑, the pilot or piston value moves up as a result, the high pressure oil flows to the pilot value opening & pushes the main piston

* As a result E↓ & hence more amount of stream is injected into the turbine

* The vice-verse operation happen when frequency increase

Construction

1. Speed changer
2. flyball speed governor
3. ~~Hydraulic~~ Hydraulic Amplifier
4. linkage mechanism

1. Speed changer :- It is used to change the speed as high or low which is depends on the frequency.

2. Flyball speed governer :-

Taking Laplace transform of (1), (2), (3) & (4)

$$\Delta x_A(s) = k_c \, \Delta P_c(s) \rightarrow (5)$$

$$\Delta x_C(s) = k_1 \, \Delta F(s) - k_2 \, \Delta P_c(s) \rightarrow (6)$$

$$\Delta x_D(s) = k_3 \, \Delta x_C(s) + k_4 \, \Delta x_E(s) \rightarrow (7)$$

$$\Delta x_E(s) = k_5 \left(- \frac{\Delta x_D(s)}{s} \right) \rightarrow (8)$$

Sub (7) in (8)

$$\Delta x_E(s) = \frac{-k_5}{s} \left\{ k_3 \Delta x_C(s) + k_4 \Delta x_E(s) \right\}$$

$$\Delta x_E(s) + \frac{k_4 k_5}{s} \Delta x_E(s) = \frac{-k_3 k_5}{s} \Delta x_C(s)$$

$$\Delta x_E(s) \left\{ 1 + \frac{k_4 k_5}{s} \right\} = \frac{-k_3 k_5}{s} \Delta x_C(s) \rightarrow (9)$$

Sub (6) in (9)

$$\Delta x_E(s) \left\{ 1 + \frac{k_4 k_5}{s} \right\} = \frac{-k_3 k_5}{s} \left\{ k_1 \Delta F(s) - k_2 \Delta P_c(s) \right\}$$

$$\Delta x_E(s) \left\{ 1 + \frac{k_4 k_5}{s} \right\} = \frac{k_2 k_3 k_5}{s} \Delta P_c(s) - \frac{k_1 k_3 k_5}{s} \Delta F(s)$$

$$= \frac{k_3 k_5}{s} \left\{ k_2 \Delta P_c(s) - k_1 \Delta F(s) \right\}$$

$$\Delta x_E(s) = \frac{\dfrac{k_3 k_5}{s} \left\{ k_2 \Delta P_c(s) - k_1 \Delta F(s) \right\}}{\dfrac{s + k_4 k_5}{s}}$$

$\div$ by k_5 $$\Delta X_E(s) = \frac{k_3\{k_2 \Delta P_C(s) - k_1 \Delta F(s)\}}{k_4 + s/k_5}$$

$\div$ by k_4.

$$\Delta X_E(s) = \frac{\frac{k_2 k_3}{k_4}\Delta P_c(s) - \frac{k_1 k_3}{k_4}\Delta F(s))}{1 + s/k_4 k_5}$$

$\times$ $\div$ k_2

$$\Delta X_E(s) = \frac{\frac{k_2 k_3}{k_4}\Delta P_c(s) - \frac{k_1 k_2 k_3}{k_4 k_2}\Delta F(s))}{1 + s/k_4 k_5}$$

$$= \frac{\frac{k_2 k_3}{k_4}\left\{\Delta P_C(s) - \frac{k_1}{k_2}\Delta F(s)\right\}}{1 + s/k_4 k_5}$$

Let:-

$\frac{k_2 k_3}{k_4} = k_g \rightarrow$ Gain of speed governor

$k_2/k_1 = R$ - speed regulation.

$1/k_4 k_5 - T_g$ - Time constant

$$\boxed{\Delta X_E(s) = \frac{k_g\{P_c(s) - 1/R\,\Delta F(s)\}}{(1 + sT_g)}}$$

$\Delta X_{E}(s) \Rightarrow$ Steam valve setting

$\Delta P_T(s) \rightarrow$ Turbine power o/p

$\Delta P_G(s)$ - Generator power o/p

k_T - Turbine Gain Constant.

T_T -- Time Constant of turbine

Modelling of Generator / Power System / Load

A change in increament in power $\Delta P_G - \Delta P_D$, depends on 2 factor

i) rate of change of KE $\left(\frac{d}{dt}(W_{KE})\right)$

ii) change of demand wrt frequency $\left(\frac{\partial P_D}{\partial f}\right)$

we know that KE is directly proportional to rotor power

$$W_{KE} \propto P_r$$

$$\boxed{W_{KE} = H.P_r} \rightarrow (1)$$

Also

$$W^0_{KE} \propto (f^0)^2$$

$$W_{KE} \propto (f^0 + \Delta f)^2$$

$$\frac{W_{KE}}{W^0_{KE}} \propto \left(\frac{f^0 + \Delta f}{f^0}\right)^2$$

$$\omega_{KE} \propto \omega_{KE}^{0}\left(1+\frac{\Delta f}{f^{0}}\right)^{2}$$

$$\omega_{KE} \propto \omega_{KE}^{0}\left(1+\left(\frac{\Delta f}{f^{0}}\right)^{2}+\frac{2\Delta f}{f^{0}}\right)$$

$$= \omega_{KE}^{0}\left(1+2\frac{\Delta f}{f^{0}}\right)$$

$$\frac{d\omega_{KE}}{dt} = \omega_{KE}^{0}\left(0+\frac{2}{f^{0}}\cdot\frac{d\Delta f}{dt}\right)$$

$$= \frac{2\omega_{KE}^{0}}{f^{0}}\cdot\frac{d}{dt}\Delta f$$

$$\boxed{\frac{d\omega_{KE}}{dt} = \frac{2HP_r}{f^{0}}\frac{d}{dt}\Delta f}$$

$$\boxed{\frac{\partial P_D}{\Delta f} = B\,\Delta f}$$

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

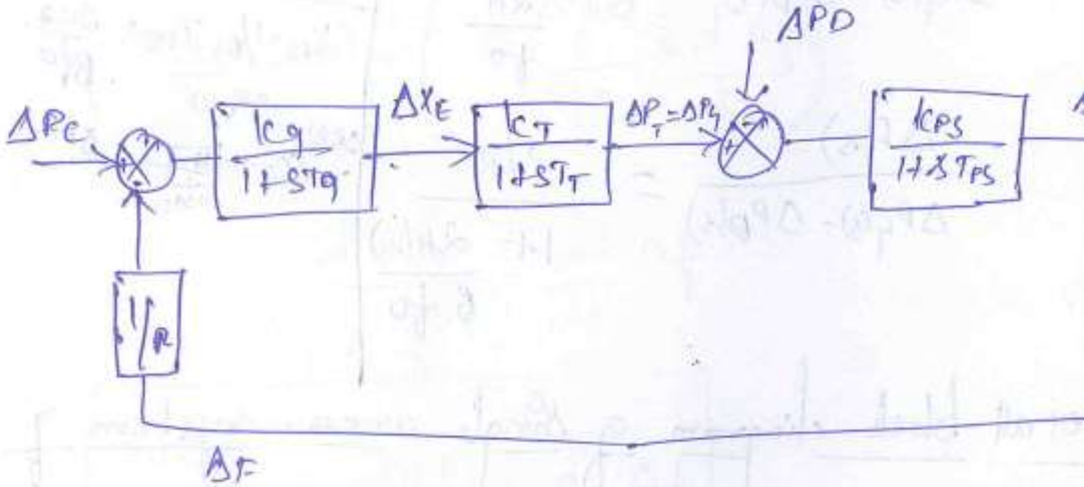
$\div$ by P_r (pu values)

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

- Static Analysis
- Dynamic Analysis

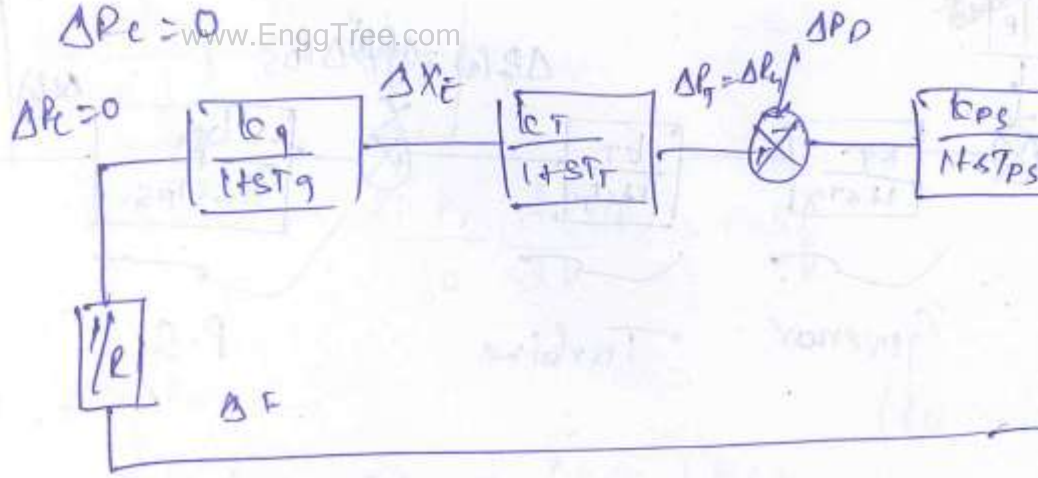
i) Controlled Case
ii) uncontrolled c

i) Static Analysis of Single area System (uncontrolled Ca



Since it is a static analysis

$\Delta P_c = 0$



$$\frac{\Delta F(s)}{-\Delta P_D(s)} = \frac{G(s)}{1+G(s)H(s)}$$

$$= \frac{\frac{K_{PS}}{1+ST_{PS}}}{1+\left(\frac{K_{PS}}{1+ST_{PS}}\right)\left(\frac{K_g}{1+ST_g}\right)\left(\frac{K_T}{1+ST_T}\right)\left(1/\right.}$$

$$\frac{\Delta F(s)}{-\Delta P_D(s)} = \frac{\dfrac{K_{ps}}{1+sT_{ps}}}{\dfrac{(1+sT_{ps})(1+sT_g)(1+sT_T)(R)+(K_{ps})(K_g)(K_T)}{(1+sT_{ps})(1+sT_g)(1+sT_T)R}}$$

Let $K_g = K_T = 1$

$$\frac{\Delta F(s)}{-\Delta P_D(s)} = \frac{K_{ps}}{\dfrac{(1+sT_{ps})(1+sT_T)(1+sT_g)R + K_{ps}}{(1+sT_g)(1+sT_T)R}}$$

$$\Delta F(s) = \frac{K_{ps}}{\dfrac{(1+sT_{ps})(1+sT_T)(1+sT_g)R + K_{ps}}{(1+sT_g)(1+sT_T)R}} \times (-\Delta P_D(s))$$

For step i/p, $\Delta P_D(s) = \Delta P_D / s$

$$\Delta F(s) = \frac{K_{ps}}{\dfrac{(1+sT_{ps})(1+sT_T)(1+sT_g)R + K_{ps}}{(1+sT_g)(1+sT_T)R}} \times \frac{(-\Delta P_D)}{s}$$

$$\Delta f_{static} = \underset{s\to 0}{Lt}\ sF(s)$$

$$= \underset{s\to 0}{Lt}\ \cancel{s} \times \frac{K_{ps}}{\dfrac{(1+sT_g)(1+sT_T)(1+sT_{ps})R + K_{ps}}{(1+sT_T)(1+sT_p)R}} \times \frac{-\Delta P}{\cancel{s}}$$

$$\boxed{\Delta F_{static} = \frac{-K_{ps}\,\Delta P_D}{\dfrac{R+K_{ps}}{R}}}$$

$$\boxed{\Delta f_{static} = \frac{-1/B \cdot \Delta P_D}{1+1/BR}}$$

Multiplied by B

$$= -\frac{1}{B+1/R}\,\Delta P_D$$

$(B+1/R) \to$ AFRC

Area freq response co-eff

$B <<< 1/R$

$B+1/R \simeq 1/R$

$$\Delta F_{static} = -R\,\Delta P_D$$

$$= \lim_{s \to 0} s \times \frac{K_{ps}}{\dfrac{(1+sT_g)(1+sT_T)(1+sT_{ps})R + K_{ps}}{R}} \times \frac{\Delta P_c}{s}$$

$$= \frac{K_{ps} \cdot \Delta P_c}{\dfrac{R + K_{ps}}{R}} = \frac{K_{ps} \cdot \Delta P_s}{1 + \dfrac{K_{ps}}{R}}$$

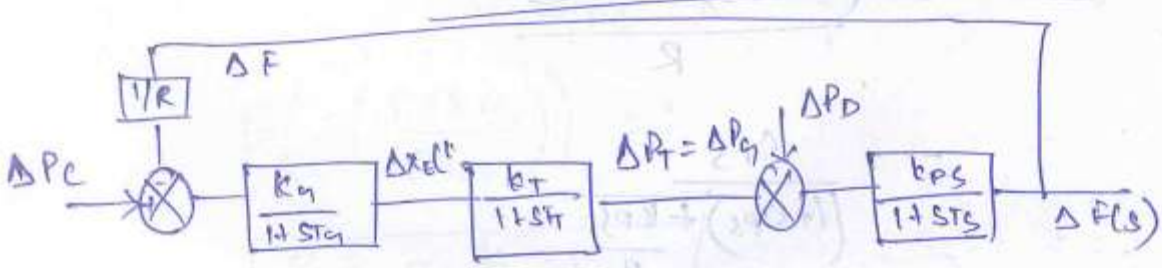
$$\Delta F_{static} = \frac{\frac{1}{B}\,\Delta P_c}{1 + \frac{1}{BR}}$$

$$= \frac{\Delta P_c}{B + 1/R}$$

$$B << 1/R$$

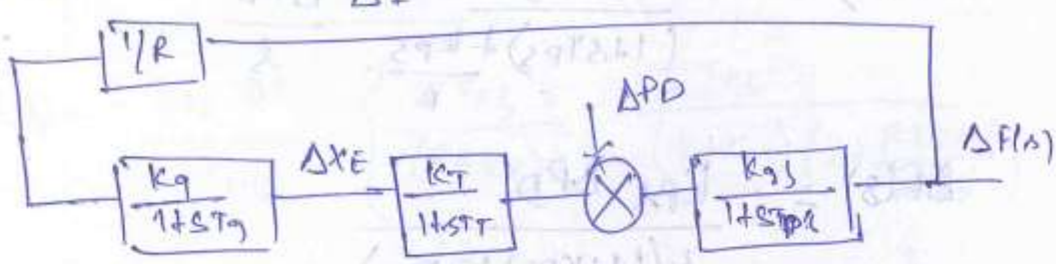
$$\Delta F_{static} = R \cdot \Delta P_c$$

Dynamic Analysis of Single area System for uncontrolled case

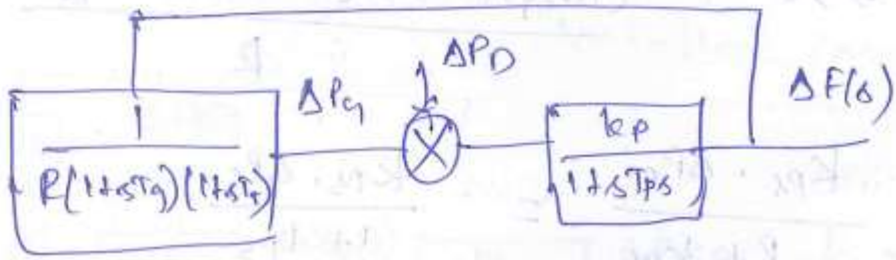


$\Delta P_c = 0$

ΔI



$K_g = K_T = 1$



$T_g = T_T = 0$

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

$$-\frac{\Delta F(s)}{\Delta P_D(s)} = \frac{K_{ps}}{\frac{(1+sT_{ps})R+K_{ps}}{R}} \qquad \frac{\Delta P_D}{s}$$

$$= \frac{K_{ps}}{(1+sT_{ps})+\frac{K_{ps}}{R}}$$

$$\Delta F(s) = -\frac{K_{ps}}{(1+sT_{ps})+\frac{K_{ps}}{R}} \cdot \frac{\Delta P_D}{s}$$

$$\Delta F(s) = -\frac{K_{ps}\,\Delta P_D}{s\left(\left(1+\frac{K_{ps}}{R}\right)+sT_{ps}\right)}$$

$$= -\frac{K_{ps}\cdot \Delta P_D/T_{ps}}{s\left(\frac{1+\frac{K_{ps}}{R}}{T_{ps}}+s\right)}$$

$$\Delta F(s) = \frac{-K_{ps}\cdot \Delta P_D / T_{ps}}{s\left(s + \frac{R+K_{ps}}{RT_{ps}}\right)}$$

$$\Delta F(s) = \left(-\frac{K_{ps}\cdot \Delta P_D}{T_{ps}}\right)\cdot \frac{1}{s\left(s+\frac{R+K_{ps}}{RT_{ps}}\right)}$$

$$= \left(-\frac{K_{ps}\,\Delta P_D}{T_{ps}}\right)\cdot \frac{A}{s} + \frac{B}{s+\frac{R+K_{ps}}{RT_{ps}}} \rightarrow (1)$$

$$\frac{A}{s} + \frac{B}{s+\frac{R+K_{ps}}{RT_{ps}}} \Rightarrow A\left(s+\frac{R+K_{ps}}{RT_{ps}}\right) + Bs = 1$$

Put $s = 0$, $A\left(\frac{R+K_{ps}}{RT_{ps}}\right) = 1$

$$A = \frac{RT_{ps}}{R+K_{ps}}$$

Put $s = -\left(\frac{R+K_{ps}}{RT_{ps}}\right)$

$$B\left(-\left(\frac{R+K_{ps}}{RT_{ps}}\right)\right) = 1$$

$$\boxed{B = -\frac{RT_{ps}}{R+K_{ps}}}$$

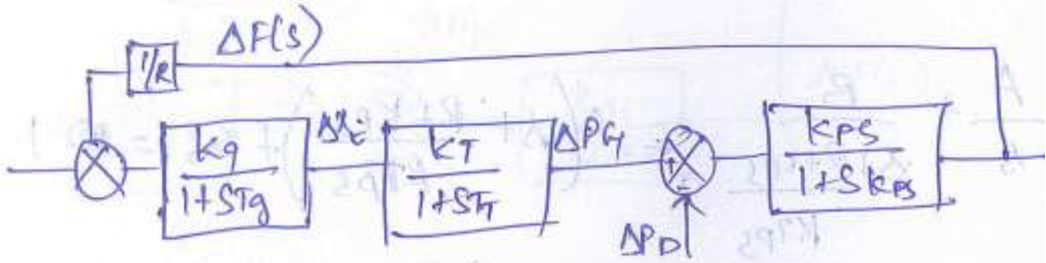
$$\Delta F(s) = -\frac{K_{ps}\,\Delta P_D}{T_{ps}}\left\{\frac{RT_{ps}}{(R+K_{ps})s} - \frac{RT_{ps}}{(R+K_{ps})\left(s+\frac{R+K_{ps}}{RT_{ps}}\right)}\right\}$$

$$\Delta F(s) = -\frac{K_{ps}\,\Delta P_D R}{(R+K_{ps})}\left\{\frac{1}{s} - \frac{1}{s+\left(\frac{R+K_{ps}}{RT_{ps}}\right)}\right\}$$

ILT :-

$$\Delta f = -\frac{K_{PS} R \, \Delta P_D}{(R + K_{PS})} \left\{ 1 - e^{-\left(\frac{R + K_{PS}}{R T_{PS}}\right)t} \right\}$$

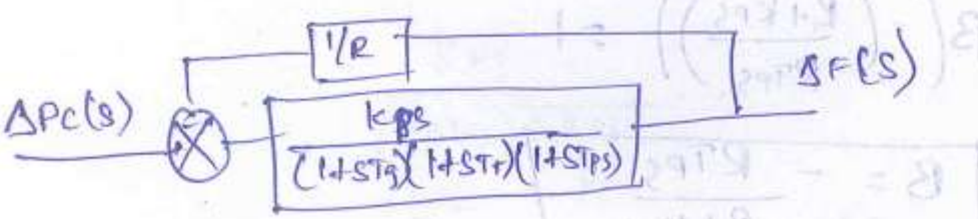
Dynamic analysis of SAS for controlled case



$\Delta P_D = 0$

$k_g = k_T = 1$

$T_g = T_T = 0$



$$\frac{\Delta F(s)}{\Delta P_C(s)} = \frac{K_{PS} / (1 + S T_{PS})}{1 + \frac{K_{PS}}{1 + S T_{PS}} \times 1/R}$$

$$= \frac{K_{ps}/(1+sT_{ps})}{\frac{(1+sT_{ps})R + K_{ps}}{(1+sT_{ps})}}$$

$$= \frac{K_{ps}}{(1+sT_{ps})R + K_{ps}}$$

$$\Delta F(s) = \frac{K_{ps}}{\frac{(1+sT_{ps})R + K_{ps}}{R}} \Delta P_c(s)$$

$$= \frac{K_{ps}}{\left(1+\frac{K_{ps}}{R}\right) + sT_{ps}} \Delta P_c(s)$$

$$\Delta F(s) = \frac{K_{ps}}{\left(1+\frac{K_{ps}}{R}\right) + sT_{ps}} \cdot \frac{\Delta P_c}{s}$$

$$= \frac{K_{ps}\,\Delta P_c / T_{ps}}{s\left(\frac{1+\frac{K_{ps}}{R}}{T_{ps}} + s\right)}$$

$$= \frac{K_{pc}\,\Delta P_c / T_{ps}}{s\left(\frac{R+K_{ps}}{RT_{ps}} + s\right)}$$

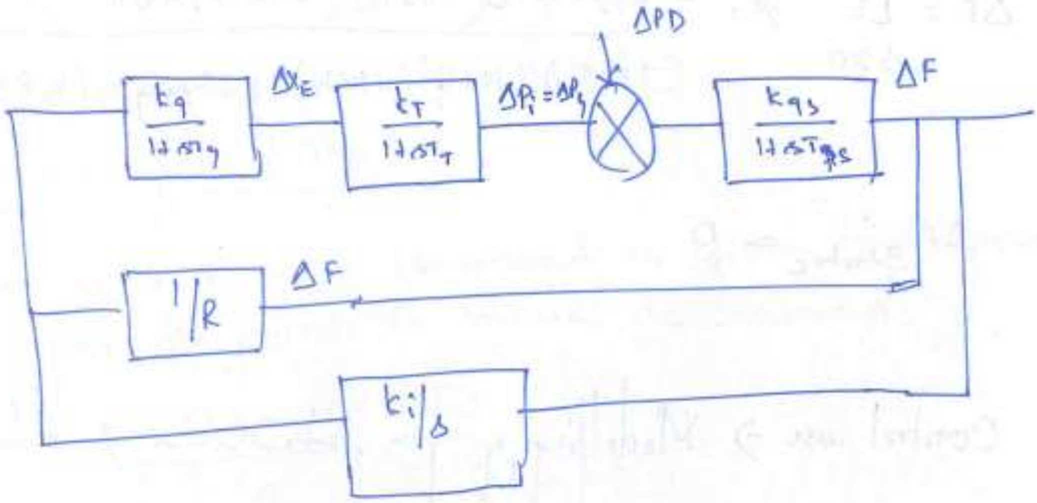
$$= \frac{K_{ps}\,\Delta P_c}{T_{ps}} \left(\frac{A}{s} + \frac{B}{s + \frac{RT_{ps}+K_{ps}}{RT_{ps}}} \right)$$

$$\frac{A}{s} + \frac{B}{s+\frac{RT_{ps}+K_{ps}}{RT_{ps}}} = A\left(s + \frac{RT_{ps}+K_{ps}}{RT_{ps}}\right) + B(s) = 1$$

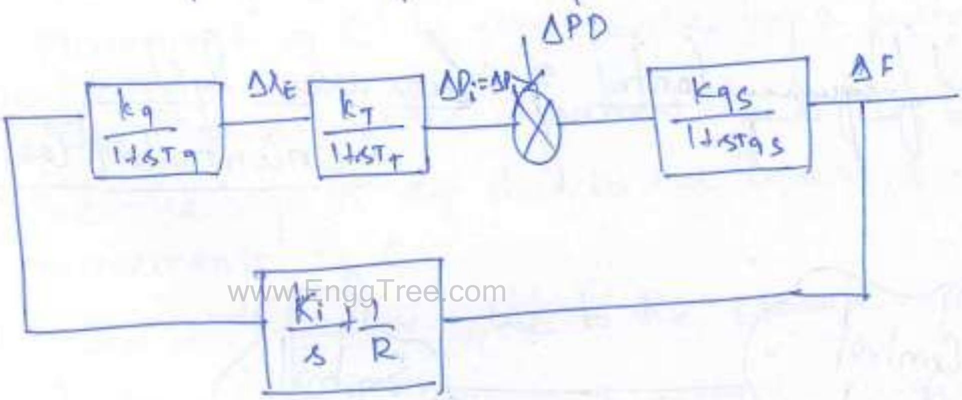
put $s = 0$

$$A\left(\frac{R+K_{ps}}{RT_{ps}}\right) = 1 \quad , \quad A = \frac{RT_{ps}}{R+K_{ps}}$$

34) Integral Controller added to Load frequency Control of SAS (Controlled Case)



Since two paths are parallel



$$\frac{\Delta F(s)}{-\Delta P_D} = \frac{G(s)}{1+H(s)G(s)}$$

$$= \frac{\dfrac{K_{ps}}{1+sT_{ps}}}{1 + \dfrac{K_p}{1+sT_{ps}} \cdot \dfrac{K_g K_T}{(1+sT_g)(1+sT_T)} \cdot \left(\dfrac{K_i}{s} + \dfrac{1}{R}\right)}$$

$$F = - \frac{\dfrac{K_{ps}}{1+sT_{ps}}}{\dfrac{(1+sT_{ps})(1+sT_g)(1+sT_T)(sR) + K_{ps} K_g K_T \left(\dfrac{K_i R + s}{sR}\right)}{(1+sT_{ps})(1+sT_g)(1+sT_T)}} \times \frac{\Delta P_D}{s}$$

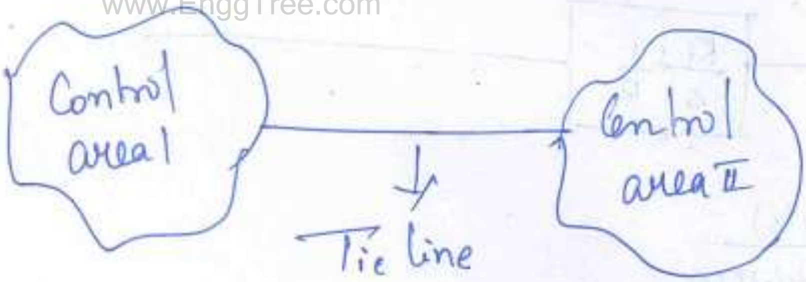
$$\Delta F = \underset{s \to 0}{Lt} \; s\,\Delta F(s)$$

$$\Delta F = \underset{s \to 0}{Lt} \; \cancel{s} \cdot \frac{-K_{ps} \cdot \Delta P_D (1+sT_1)(1+sT_P) \times sR}{(1+sT_{ps})(1+sT_g)(1+sT_T) sR + K_{ps}K_g K_T (Ki}$$

$$\Delta F_{static} = 0$$

Control Case → Modelling of gen, turbine & in

Load frequency Control of two area System (Uncontrolled Ca



I- Modelling of the governor:-

* Assume the System work under Steady Condition
* under Steady State Condition
  1) Linkage mechanism
  2) Generator O/P P_G is constant
  3) Turbine speed is constant
  4) Steam value is opened for a defin magnitude

* under Steady State condition, let

$f^0 \rightarrow$ be Steady State frequency

$P_G^0 \rightarrow$ Steady State generator power o/p.

$x_E^0 \rightarrow$ Steam wall setting

Movement of A (Δx_A)

When a small raise command is given to a speed changer, the point B move downward

$$\Delta x_A \propto \Delta P_C$$

$$\boxed{\Delta x_A = k_C \Delta P_C} \rightarrow (1)$$

Movement of C:

Movement of C is contributes by 2 factors

(1) The 1st factor is the movement of A $(\Delta x_A \propto \Delta P_C)$ the -ve sign in eq due to the upward movement of C

(2) The 2nd factor due to the ~~operati~~ expansion of speed ball governing which is given

(3) The net movement

$$\boxed{\Delta x_C = k_C \Delta f - k_2 \Delta P_C} \rightarrow (2)$$

(4) Movement of D

Movement of D is contributed by both the movement C (Δx_C) & movement of $(\Delta x$

Hence, $\Delta x_D = k_3 \Delta x_C + k_4 \Delta x_E \rightarrow (3)$

(5) Movement of E:-

The movement of E is contribut by the amount of high pressure oil flows ~~through~~ the main piston

Here

$$\Delta x_E = k_5 \int_0^K - \Delta x_D \rightarrow (4)$$

Taking laplace transform of (1),(2),(3)

$$\Delta x_A(s) = K_C \, \Delta P_C(s) \rightarrow (5)$$

$$\Delta x_C(s) = K_1 \, \Delta F(s) - K_2 \Delta P_C(s) \rightarrow (6)$$

$$\Delta x_D(s) = K_3 \, \Delta x_C(s) + K_4 \Delta x_E(s) \rightarrow (7)$$

$$\Delta x_E(s) = K_5 - \frac{\Delta x_D(s)}{s} \rightarrow (8)$$

Sub (7) in (8)

$$\Delta x_E(s) = -\frac{K_5}{s} \left\{ K_3 \Delta x_C(s) + K_4 \Delta x_E(s) \right\}$$

$$\Delta x_E(s) + \frac{K_4 K_5}{s} \Delta x_E(s) = -\frac{K_3 K_5}{s} \Delta x_C(s)$$

$$\Delta x_E(s) \left\{ 1 + \frac{K_4 K_5}{s} \right\} = -\frac{K_3 K_5}{s} \Delta x_C(s)$$

Sub (6) in (7)

$$\Delta x_E(s) \left\{ 1 + \frac{K_4 K_5}{s} \right\} = -\frac{K_3 K_5}{s} \left\{ K_1 \Delta F(s) - K_2 \right.$$

$$\Delta x_E(s) \left\{ 1 + \frac{K_4 K_5}{s} \right\} = \frac{K_2 K_3 K_5}{s} \Delta P_C(s) -$$

$$= \frac{K_3 K_5}{s} \left\{ K_2 \Delta P_C(s) - K_1 \Delta \right.$$

$$\Delta x_E(s) = \frac{K_3 K_5}{s} \left\{ \frac{K_2 \Delta P_C(s) - K_1 \Delta}{\frac{s + K_4 K_5}{s}} \right.$$

$\div$ by k_5, $\Delta X_E(s) = \dfrac{k_3\{k_2 \Delta P_c(s) - k_1 \Delta F(s)\}}{k_4 + s/k_5}$

$\div$ by k_4

$$\Delta X_E(s) = \frac{\frac{k_2 k_3}{k_4} \Delta P_c(s) - \frac{k_1 k_3}{k_4} \Delta F(s)}{1 + s/k_4 k_5}$$

Mult & divid. by k_2

$$\Delta X_E(s) = \frac{\frac{k_2 k_3}{k_4} \Delta P_c(s) - \frac{k_1 k_2 k_3}{k_4 k_2} \Delta F(s)}{1 + s/k_4 k_5}$$

$$= \frac{\frac{k_3 k_2}{k_4}\left\{\Delta P_c(s) - \frac{k_1}{k_2} \Delta F(s)\right\}}{1 + s/k_4 k_5}$$

Let

$\frac{k_2 k_3}{k_4} = k_g \rightarrow$ Gain of speed governer

$k_1/k_1 = R \rightarrow$ speed regulation

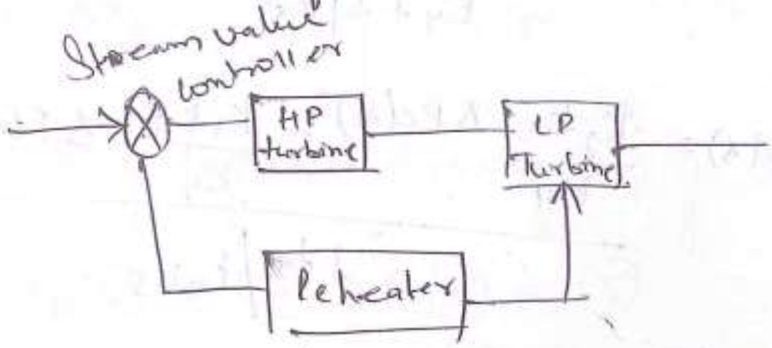
$1/k_4 k_5 - T_g$ - Time constant

$$\boxed{\Delta X_{E_1}(s) = \frac{k_{g_1}\left(P_{c_1}(s) - 1/R_1 \Delta F_1(s)\right)}{(1 + sT_{g_1})}}$$

IIIly for control area II

$$\boxed{\Delta X_{E_2}(s) = \frac{k_{g_2}\left(P_{c_2}(s) - 1/R_2 \Delta F_2(s)\right)}{(1 + sT_{g_2})}}$$

Modelling of turbine



The dynamic response of the turbine ... upon two factor

i) Amount of steam present b/w steam v... controller & HP turbine

ii) amount of steam is send to reheat...

$$\Delta X_E(s) \longrightarrow \boxed{\frac{K_T}{1+sT_T}} \longrightarrow \Delta P_T(s) = \Delta P_G$$

$$\boxed{\Delta P_{T_1}(s) = \left(\frac{K_{T_1}}{1+sT_1}\right) \Delta X_{E_1}(s)}$$

$\Delta X_E(s)$ - Steam value Setting

$\Delta P_T(s)$ - Turbine power O/P

$\Delta P_G(s)$ - Generator power O/P

K_T - Turbine gain constant

T_T - Time constant of turbine

IIIly for controller 2

$$\boxed{\Delta P_{T_2}(s) = \left(\frac{K_{T_2}}{(1+sT_2)} \Delta X_{E_2}(s)\right)}$$

Modelling of Generator | Power System load

A change in increment in power $\Delta P_G - \Delta P_D$, depends on 2 factor

i) rate of change of $k_E \left(\frac{d}{dt} (\omega_{kE}) \right)$

ii) Change of demand wrt frequency $\left(\frac{\partial P_D}{\partial f} \right)$

we know that k_E is directly proportional to rotor power

$$\omega_{kE} \propto P_r$$

$$\boxed{\omega_{kE} = H \cdot P_r} \rightarrow (1)$$

Also, $\omega^0_{kE} \propto (f^0)^2$

$$\omega_{kE} \propto (f^0 + \Delta f)^2$$

$$\frac{\omega_{kE}}{\omega^0_{kE}} \propto \left(\frac{f^0 + \Delta f}{f^0} \right)^2$$

$$\omega_{kE} \propto \omega^0_{kE} \left(1 + \frac{\Delta f}{f^0} \right)^2$$

$$\omega_{kE} \propto \omega^0_{kE} \left(1 + \left(\frac{\Delta f}{f^0} \right)^2 + \frac{2 \Delta f}{f^0} \right)$$

$$= \omega^0_{kE} \left(1 + \frac{2 \Delta f}{f^0} \right)$$

$$\frac{d\omega_{kE}}{dt} = \omega^0_{kE} \left(0 + \frac{2}{f^0} \cdot \frac{d \Delta f}{dt} \right)$$

$$= \frac{2 \omega^0_{kE}}{f^0} \cdot \frac{d}{dt} \Delta f$$

$$\boxed{\frac{d\omega_{kE}}{\partial t} = \frac{2 H P_r}{f^0} \frac{d}{dt} \Delta f}$$

$$\frac{\partial P_D}{\Delta f} = B\Delta f$$

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

$\div$ by P_r

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

Taking LT

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

$$= F(s)\left\{B + \frac{s2H}{f^0}\right\}$$

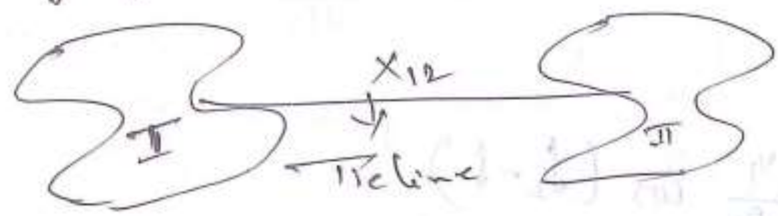
$$\frac{\Delta F(s)}{\Delta P_g(s) - \Delta P_D(s)} = \frac{1}{B + \frac{s2H}{f^0}}$$

$$\boxed{\frac{\Delta F(s)}{\Delta P_g(s) - \Delta P_D(s)} = \frac{1/B}{\frac{2H(s)}{f^0}}}$$

III^{ly} for Controller (2)

$$\boxed{\frac{\Delta F_2(s)}{\Delta P_{g_1}(s) - \Delta P_{D_1}(s)} = \frac{1/B_1}{\frac{2H_1(s)}{f_1^0}}}$$

Modelling of Tie-line:-



Consider a 2 control area Connected by Tie line as Shown.

- The amount of electrical power that get transmit from one area to another area using power angle equation

$$\boxed{P_{tie1} = \frac{V_1 V_2}{X_{12}} \sin(\delta_1 - \delta_2)}$$

$$\frac{\delta P}{\delta \delta} = \frac{V_1 V_2}{X_{12}} \cos(\delta_1 - \delta_2)(\Delta\delta_1 - \Delta\delta_2)$$

$\div$ by P_r $\quad \Delta P_{tie(pu)} = \frac{V_1 V_1}{X_{12} P_{r1}} \cos(\delta_1 - \delta_2)(\Delta\delta_1 - \Delta\delta_2)$

$$\boxed{\Delta P_{\cancel{elect}\ tie\ 1,2} = T_{12}(\Delta\delta_1 - \Delta\delta_2)} \rightarrow (2)$$

Synchronizing Torque Coeff

$$\boxed{T_{12} = \frac{V_1 V_2}{X_{12} P_{r1}} \cos(\delta_1 - \delta_2)}$$

IIIly for Area 2

$$\boxed{\Delta P_{\cancel{elect}\ tie\ 2,1} = T_{21}(\Delta\delta_2 - \Delta\delta_1)} \rightarrow (3)$$

where $\boxed{T_{21} = \frac{V_2 V_1}{X_{21} P_{r2}} \cos(\delta_2 - \delta_1)}$

$$\frac{\cancel{T_{21}}}{\cancel{T_{12}}} = \frac{\cancel{P_{r1}}}{\cancel{P_{r2}}}.$$

$$\frac{T_{21}}{T_{12}} = \frac{\frac{V_2 V_1}{X_{21} P_{r2}} \cos(\delta_2 - \delta_1)}{\frac{V_1 V_2}{X_{12} P_{r1}} \cdot \cos(\delta_1 - \delta_2)}$$

$$= \frac{P_{r1}}{P_{r2}}$$

$$\frac{T_{21}}{T_{12}} = a_{12}$$

$$\boxed{T_{21} = a_{12} T_{12}} \rightarrow (4)$$

$$\Delta P_{G_1} - \Delta P_{D1} = \frac{2H_1}{f_0} \frac{d\Delta f_1}{dt} + B\Delta f_1 + \Delta P_{re12}$$

$$\Delta P_{G_1}(s) - \Delta P_{D_1}(s) = \frac{2H_1}{f_0} s\, \Delta f(s) + B\Delta F_1(s) + \Delta P_{re1,2}(s)$$

$$\Delta P_{G_1}(s) - \Delta P_{D_1}(s) - \Delta P_{re1,2}(s) = \Delta f_1(s) \left\{ \frac{2H_1 s}{f_0} + B_1 \right\}$$

III^{ly} Area-II

$$\Delta P_{G_2}(s) - \Delta P_{D_2}(s) - \Delta P_{re2,1}(s) = \Delta F_2(s) \left\{ \frac{2H_2 s}{f_0} + B_2 \right\}$$

$\omega = 2\pi f$

$\omega = \frac{d\delta}{dt}$

$\frac{d\delta}{dt} = 2\pi f$

$d\delta = 2\pi f \, dt$

$$\left.\begin{aligned} \Delta\delta_1 &= 2\pi \int \Delta f_1 \, dt \\ \text{III}^{ly} \quad \Delta\delta_2 &= 2\pi \int \Delta f_2 \, dt \end{aligned}\right\} \rightarrow 6$$

from eq 1

$\Delta P_{tie\,12} = T_{12} (\Delta\delta_1 - \Delta\delta_2)$

$\Delta P_{tie\,1,2}(s) = T_{12} (\Delta\delta_1(s) - \Delta\delta_2(s))$

$= T_{12} \left(\frac{2\pi \Delta F_1(s)}{s} - 2\pi \frac{\Delta F_2(s)}{s} \right)$

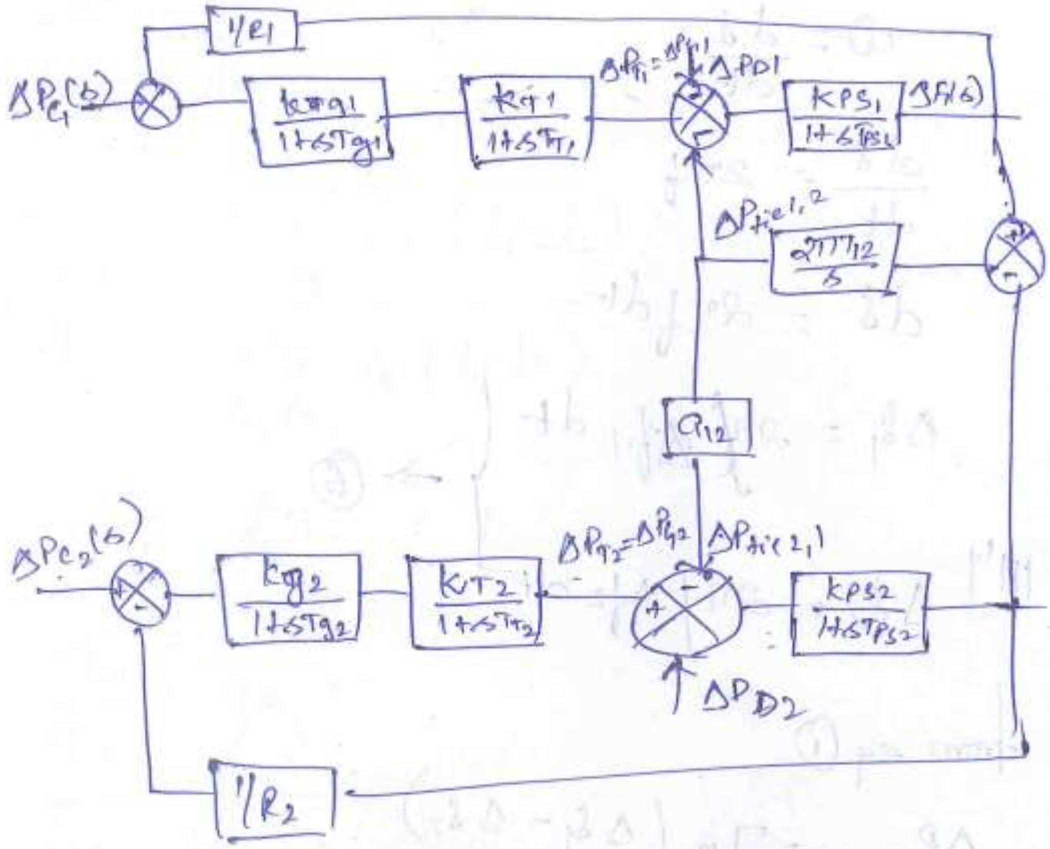
$$\boxed{\Delta P_{tie\,12}(s) = \frac{2\pi T_{12}}{s} (\Delta F_1(s) - \Delta F_2(s))} \rightarrow 7$$

III^{ly} for Area - II

$\Delta P_{tie\,2,1}(s) = \frac{2\pi T_{21}}{s} (\Delta F_2(s) - \Delta F_1(s)) \rightarrow 8$

$= -\frac{2\pi T_{21}}{s} (\Delta F_1(s) - \Delta F_2(s))$

$P_{tie\,2,1}(s) = -\frac{2\pi a_{12} T_{12}}{s} (\Delta F_1(s) - \Delta F_2(s)) \rightarrow 9$



from eq (4)

$$\Delta P_{G_1}(s) - \Delta P_{D_1}(s) - \Delta P_{tie1,2}(s) = \Delta F_1(s)\left\{\frac{2H_1 s}{f_0} + B_1\right.$$

$$= \Delta F_1(s)\, B\left\{1 + \frac{2H_1 s}{f_0 B}\right.$$

$$\Delta F_1(s) = \frac{\Delta P_{G_1}(s) - \Delta P_{D_1}(s) - \Delta P_{tie1,2}(s)}{B\left\{1 + \frac{2H_1 s}{f_0 B_1}\right\}}$$

$$\boxed{\Delta F_1(s) = \left(\Delta P_{G_1}(s) - \Delta P_{D_1}(s) - \Delta P_{tie1,2}(s)\right)}$$

IIIly for Area II

$$\boxed{\Delta F_2(s) = \left(\Delta P_{G_2}(s) - \Delta P_{D_2}(s) - \Delta P_{tie2,1}(s)\right)}$$

Q. Two Synchronous generator, operate in parallel with Capacities 300 & 400 MW. The ~~group~~ drop characteristics of 4% & 5% from No load to full load, how would a load of 600 MW be shared b/w them.

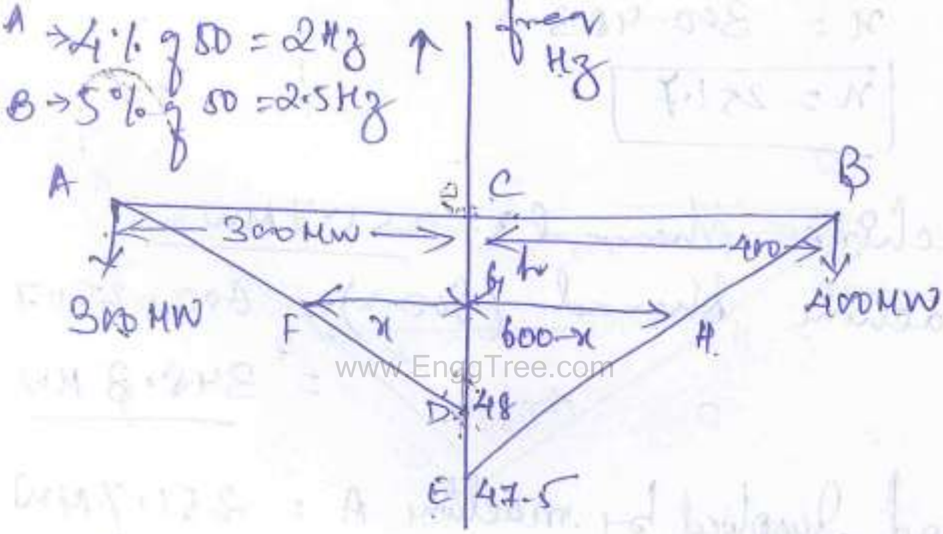
Sol

Let 'x' be the load Shared by machine A

Let '600-x' be the load Shared by machine B

A → 4% of 50 = 2 Hz

B → 5% of 50 = 2.5 Hz



For machine A :-

From

$\triangle ACD$, $\triangle FGD$

$$\frac{AC}{FG} = \frac{CD}{GD}$$

$$\frac{300}{x} = \frac{2}{2-h}$$

$$300(2-h) = 2x$$

$$x = 150(2-h)$$

$$x = 300 - 150h$$

From machine B :-

from

$\triangle BCE$, $\triangle HGD$

$$\frac{BC}{GH} = \frac{CE}{EG}$$

$$\frac{400}{600-x} = \frac{2.5}{2.5-h}$$

$$400(2.5-h) = 2.5(600-x)$$

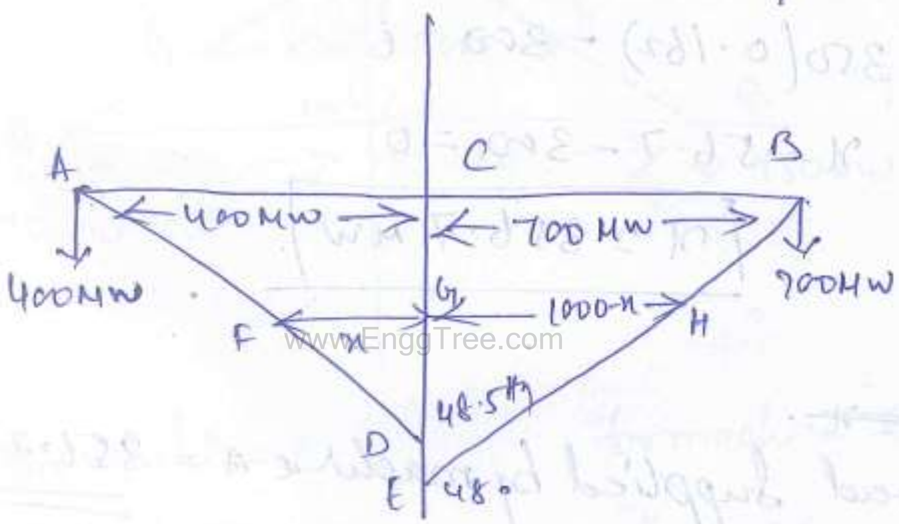
$$160(2.5-h) = 600-x$$

$$400 - 160h = 600 - x$$

$$x = 200 + 160h$$

Q Two generators rated at 400 & 700 MW for operation in ||el. The droop characteristics of governors are 3% & 4% of no-load to full load. Assuming the governor are operated at 50 Hz at no load. How would the load of 1000 MW be shared b/w them. What will be the system freq at this load.

Sol Let 'x' be the load shared by machine A
Let '1000-x' be the load shared by machine B.



3% of 50 = 1.5 Hz = 48.5 Hz

4% of 50 = 2 Hz = 48 Hz

For machine A
from ΔACD, ΔFGD

$$\frac{AC}{FG} = \frac{CD}{DG}$$

$$\frac{400}{x} = \frac{1.5}{1.5-h}$$

$$400(1.5-h) = 1.5x$$

$$266.66(1.5-h) = x$$

$$399.99 - 266.66h = x$$

$$x + 266.66h - 399.99 = 0 \rightarrow (1)$$

For machine B
from ΔBCE, ΔHGE

$$\frac{BC}{HG} = \frac{CE}{EG}$$

$$\frac{700}{1000-x} = \frac{2}{2-h}$$

$$700(2-h) = 2(1000-x)$$

$$350(2-h) = 1000-x$$

$$700 - 350h = 1000 - x$$

$$x - 350h = 300$$

$$x - 350h - 300 = 0 \rightarrow (2)$$

$$x + 266.66h - 399.99 = 0$$

$$x - 350h - 300 = 0$$

$$616.66h - 99.99 = 0$$

$$h = \frac{99.99}{616.66}$$

$$\boxed{h = 0.162}$$

put the value of h in eq ②

$$x - 350(0.162) - 300 = 0$$

$$x - 56.7 - 300 = 0$$

$$\boxed{x = 356.7\ MW}$$

~~1000-x~~

The load supplied by machine A = 356

The load supplied by machine B =

$= 1000 - x$

$= 1000 - 356.7$

$= 643.3\ MW$

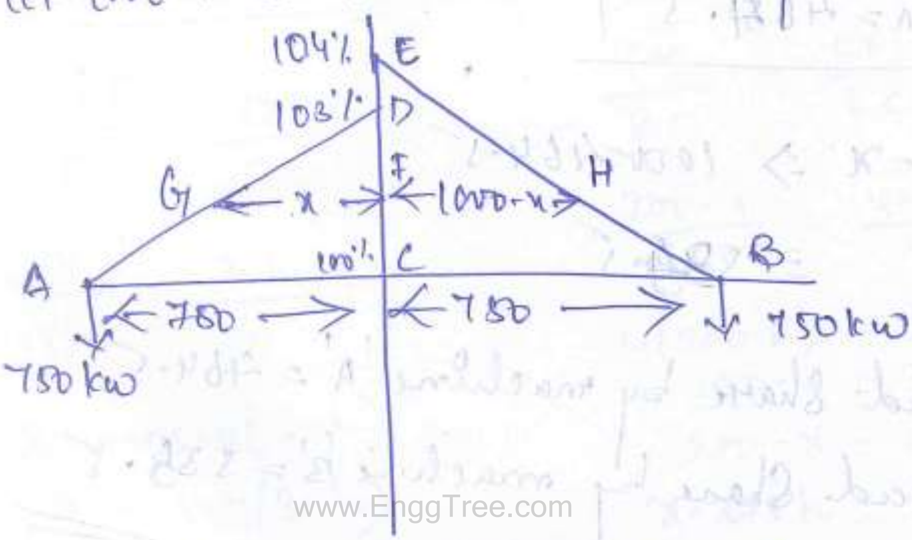
System frequency $= 50 - h$

$= 50 - 0.162$

$\boxed{= 49.838\ Hz}$

Q) Two 750 kW alternator operation parallel. The Speed regulation of 1 set each 100 - 103% from full load to no-load & the other is 100 - 104%. How will the 2 alternators Share a load of 1000 kW

Sol) Let 'x' be the load Shared by machine A
let 1000-x be the load Shared by machine B



For machine A.

ΔACD & ΔGFD

$$\frac{GF}{AC} = \frac{DF}{DC}$$

$$\frac{x}{750} = \frac{3-h}{3}$$

$$3x = 750(3-h)$$

$$x = 250(3-h)$$

$$x = 750 - 250h$$

$$x + 250h = 750 \rightarrow (1)$$

For machine B

$$\frac{FH}{CB} = \frac{EF}{EC}$$

$$\frac{1000-x}{750} = \frac{4-h}{4}$$

$$4(1000-x) = 750(4-h)$$

$$1000 - x = 187.5(4-h)$$

$$1000 - x = 750 - 187.5h$$

$$x - 187.5h = 250 \rightarrow (2)$$

$$x + 250h = 750$$

$$x - 187.5h = 250$$

$$\underline{- \quad + \qquad -}$$

$$437.5h = 500$$

$\boxed{h = 1.142}$

Sub h value in eq ①

$x + \cancel{3}^{1.142}(250) = 750$

$x = 750 - 285.5$

$\boxed{x = 464.5}$

$1000 - x \Rightarrow 1000 - 464.5$

$= 535.5$

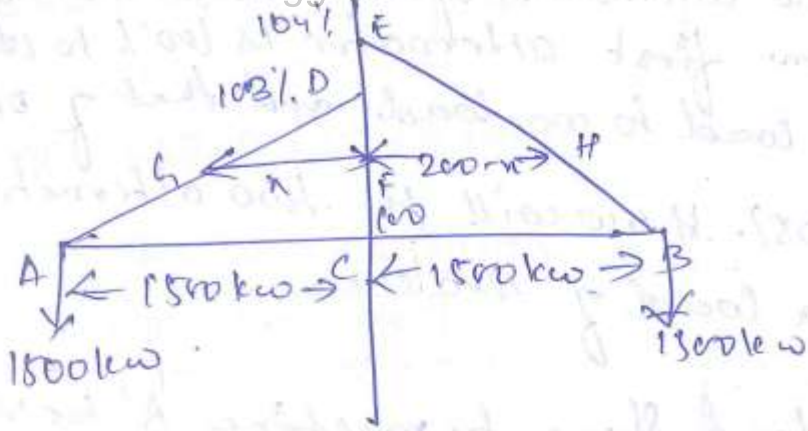
The load share by machine 'A' = 464.5

The load share by machine 'B' = 535.5

2) Two 1500 kW alternator operator in ||el. The speed regulation 1 set come from 100 - 103% from full load to no-load & 100 - 104% for other. How will the alternator share a load of 200 kW.

Let x be the load shared by machine A

Let 200 - x be the load shared by machine B



For machine A

$$\frac{GF}{AC} = \frac{DF}{DC}$$

$$\frac{x}{1500} = \frac{3-h}{3}$$

$$3x = 1500(3-h)$$

$$x = 500(3-h)$$

$$x + 500h = 1500 \rightarrow (1)$$

For machine B

$$\frac{FH}{BC} = \frac{EF}{EC}$$

$$\frac{200-x}{1500} = \frac{4-h}{4}$$

$$4(200-x) = 1500(4-h)$$

$$200-x = 375(4-h)$$

$$200-x = 1500-375h$$

$$x - 375h = -1300 \rightarrow (2)$$

$$x + 500h = 1500$$
$$x - 375h = -1300$$
$$\underline{-\quad + \qquad\quad +}$$
$$875h = 2800$$
$$\boxed{h = 3.2}$$

Put the value of h in eq (1)

$$x + 500(3.2) = 1500$$

$$x = -100$$

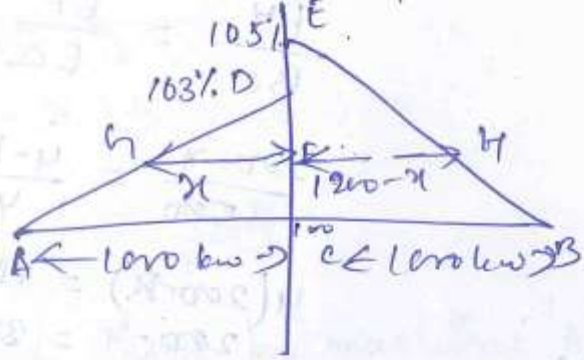
$$200 - x \Rightarrow 200 + 100 \Rightarrow 300$$

The load shared by machine 'A' = -100 kw

" " " " 'B' = 300 kw

Q. Two 1000kw alternators operate in ||el. The s
regulation first alternator is 100% to 10
from full load to no-load and that of o
100% to 105%. How will the two alternato
Share a load of 1200kw.

Let the load Share by machine 'A' be x
let the load Share by machine B be



For machine A :-

$$\frac{GF}{AC} = \frac{DF}{DC}$$

$$\frac{x}{1000} = \frac{3-h}{3}$$

$$3x = 1000(3-h)$$

$$x = 1000 - 333.3h$$

$$x + 333.3h = 1000 \rightarrow (1)$$

For machine B

$$\frac{FH}{BC} = \frac{EF}{EC}$$

$$\frac{1200-x}{1000} = \frac{5-h}{5}$$

$$5(1200-x) = 1000(5-$$

$$1200 - x = 1000 - 200$$

$$x - 200h = 200 \rightarrow (2$$

$$x + 333.3h = 1000$$
$$x - 200h = 200$$
$$-\quad +\qquad -$$
$$533.3h = 800$$
$$h = \frac{800}{533.3}$$
$$\boxed{h = 1.5}$$

Sub h value in eq (1)

$$x + 333.3(1.5) = 1000$$

$$x = 1000 - 499.95$$

$$\boxed{x = 500.05}$$

Let the

$1200 - x \Rightarrow 1200 - 500.05 = 699.95$ KW

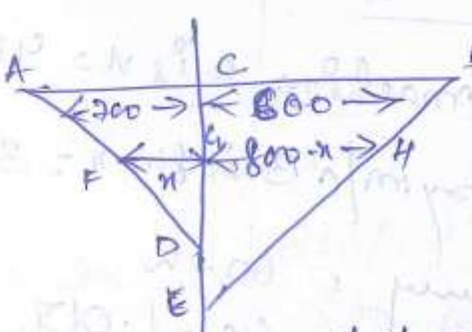
The load share by machine 'A' be 500.05.

The load share by machine B be 699.95 kw

Qus Two synchronous generator operating in ||el. Their capacities 700MW & 600MW. The droop characteristics of their governor are 4% & 5% from noload to full load. Assuming that the generators operating at 60Hz at no load, how would be a load of 800MW share b/w them. what will be the system frequency at this load.

Let x be the load shared by machine 'A'

Let 800-x be the load shared by machine 'B'



$4\% \text{ of } 60 = 2.4$ Hz

$5\% \text{ of } 60 = 3$ Hz

let

For machine A

ΔACD, ΔFGD

$$\frac{AC}{GF} = \frac{CD}{DF}$$

$$\frac{700}{x} = \frac{2.4}{2.4-h}$$

$$700(2.4-h) = 2.4x$$

$$x = \frac{700(2.4-h)}{2.4} \rightarrow (1)$$

For machine B

ΔBCE & ΔEFH

$$\frac{BC}{FH} = \frac{EC}{EF}$$

$$\frac{600}{800-x} = \frac{3}{3-h}$$

$$600(3-h) = 2400-3x$$

$$1800-600h = 2400-3x$$

$$3x = 600(1+h)$$

$$x = 200(1+h) \rightarrow$$

$$200(1+h) = \frac{700(2.4-h)}{2.4}$$

$$4.8(1+h) = 16.8 - 7h$$

$$4.8 + 4.8h = 16.8 - 7h$$

$$11.8h = 12$$

$$\boxed{h = \frac{12}{11.8} = 1.017}$$

$$x = 200(2.017)$$

$$\boxed{x = 403.2}$$

$$\boxed{800 - x = 396.8}$$

Load shared by machine A is $x = 403.2$

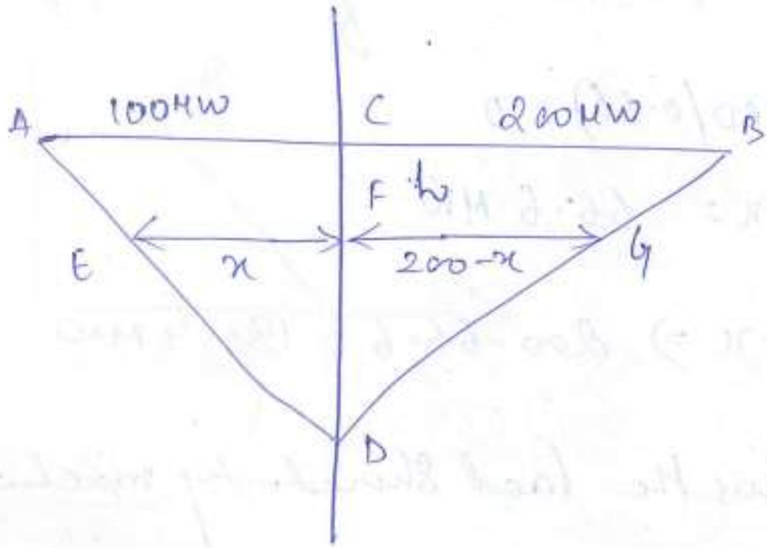
Load shared by m/c B is $800-x = 396.8$

System frequency $= 60 - h$

$= 60 - 1.017$

$= 58.983$ Hz

16(7) Two Sychronous Generator operates in 11^{el} & supplied load of 200 MW. The capacitive of machine was 100MW & 200MW. Both the governor has grouping facilities of no-load to full load. Calculate the load taken by two machines



Let x be the load shared by machine 'A'
Let 200-x be the load shared by machine B.

$$4\% \text{ of } 50 = 2\,Hz.$$

For machine A

$$\frac{AC}{EF} = \frac{CD}{FD}$$

$$\frac{100}{x} = \frac{2}{2-h}$$

$$100(2-h) = 2x$$

$$x = 100 - 50h$$

$$x + 50h = 100 \rightarrow (1)$$

For machine B

$$\frac{CB}{FG} = \frac{CD}{FD}$$

$$\frac{200}{200-x} = \frac{2}{2-h}$$

$$200(2-h) = 2(200-x)$$

$$200 - 100h = 200 - x$$

$$x - 100h = 0 \rightarrow (2)$$

$x + 50h = 100$

$x - 100h = 0$

$\underline{- \quad + \quad\quad -}$

$150h = 100$

$h = 2/3$

$h = 0.66$

Put the value of h in eq (1)

$x - 100(0.66) = 0$

$x = 66.6\ MW$

$200 - x \Rightarrow 200 - 66.6 = 133.4\ MW$

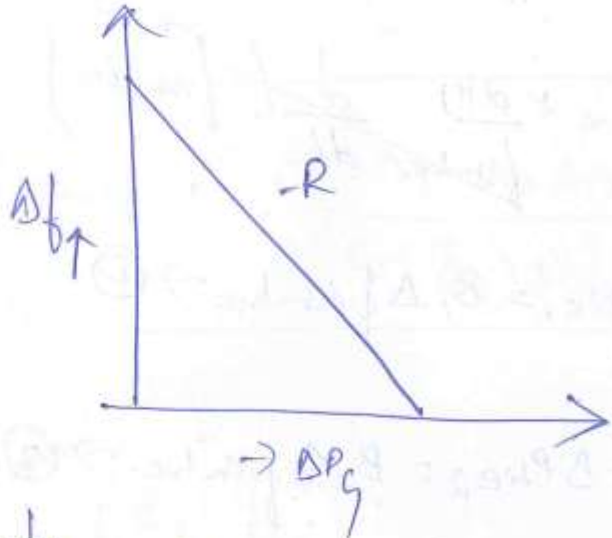
Thus the load shared by machine A is 66.6

Machine B is 133

Static Analysis of two area System (uncontrolled case)

$\Delta P_{C_1} = 0$

$\Delta P_{C_2} = 0$



$$\frac{dy}{dx} = \frac{\Delta f}{\Delta P_G} = -R$$

$$\left.\begin{aligned} \Delta P_{G_1} &= -\tfrac{1}{R_1}\,\Delta f_{1\,static} \\ \text{III}^{ly} \quad \Delta P_{G_2} &= -\tfrac{1}{R_2}\,\Delta f_{2\,static} \end{aligned}\right\} \rightarrow (1)$$

$$(\Delta P_{G_1} - \Delta P_{D_1} - \Delta P_{tie_1})\,\frac{K_{PS1}}{1+sT_{PS1}} = \Delta f_{static}$$

$$(\Delta P_{G_1} - \Delta P_{D_1} - \Delta P_{tie_1})\,\frac{1/B_1}{\left(1+\frac{s2H}{B_1 f_{static}}\right)} = \Delta f_{static}$$

$$(\Delta P_{G_1} - \Delta P_{D_1} - \Delta P_{G_1})\,\frac{1}{\left(B_1 + \frac{2H_1}{f_s}\right)} = \Delta f_{static}$$

$$\Delta P_{G_1} - \Delta P_{D_1} - \Delta P_{tie,1} = \Delta f_{static} \left(B_1 + \frac{2H_1}{f_{static}} \right.$$

$$= B_1 \Delta f_{static} + \frac{2H_1}{f_{static}} \Delta f_{static}$$

$$= B_1 \Delta f_{static} + \cancel{\frac{2H_1}{f_{static}} \frac{d}{dt} \left(f_{static} \right)} \xrightarrow{} 0$$

$$\Delta P_{G_1} - \Delta P_{D_1} - \Delta P_{tie,1} = B_1 \Delta f_{static} \rightarrow (1)$$

III^ly

$$\Delta P_{G_2} - \Delta P_{D_2} - \Delta P_{tie2} = B_2 \Delta f_{static} \rightarrow (2)$$

from eq (1)

$$\boxed{\Delta P_{tie1} = \Delta P_{G_1} - \Delta P_{D_1} - B_1 \Delta f_{static}} \rightarrow$$

from eq (2)

$$\Delta P_{G_2} - \Delta P_{D_2} = B_2 \Delta f_{static} + \Delta P_{tie2}$$

$$= B_2 \Delta f_{static} - a_{12} \Delta P_{tie1}$$

$$\Delta P_{G_2} - \Delta P_D = B_2 \Delta f_{static} - a_{12} \{ \Delta P_{G_1} - \Delta P_{D1} - B_1 \Delta f_{static}$$

from eq (1)

$$-\frac{1}{R_2} \Delta f_{static} - \Delta P_{D_2} = B_2 \Delta f_{static} - a_{12} \left\{ -\frac{1}{R_1} \right.$$

$$- \Delta P_1 - B_1$$

$$-\Delta P_{D_2} - a_{12}\Delta P_{D_1} = \Delta f_{static}\left(B_2 + 1/R_2\right) + \Delta f_{static}\left(a_{12}B \ldots + a_{11}\right.$$

$$= \Delta f_{static}\left[\left(B_2 + 1/R_2\right) + a_{12}\left(B_1 + 1/R_1\right)\right]$$

$$\boxed{\Delta f_{static} = \frac{-\Delta P_{D_2} - a_{12}\Delta P_{D_1}}{\left(B_2 + 1/R_2\right) + a_{12}\left(B_1 + 1/R_1\right)}} \rightarrow (5)$$

Sub

$$\left(B_2 + 1/R_2\right) = \beta_2$$

lly

$$\left(B_1 + 1/R_1\right) = \beta_1$$

$$\boxed{\Delta f_{static} = \frac{-\Delta P_{D_2} - a_{12}\Delta P_{D_1}}{\beta_2 + a_{12}\beta_1}} \rightarrow (6)$$

$$\Delta P_{tie_1} = \Delta P_{G_1} - \Delta P_{D_1} - B_1\Delta f_{static}$$

$$= -1/R_1\,\Delta f_{static} - \Delta P_{D_1} - B_1\Delta f_{static}$$

$$= -\Delta P_{D_1} - \left(B_1 + 1/R_1\right)\Delta f_{static} \rightarrow (7)$$

Sub (6) in (7)

$$\Delta P_{tie_1} = -\Delta P_{D_1} - \left(B_1 + 1/R_1\right)\left\{\frac{-\Delta P_{D_2} - a_{12}\Delta P_{D_1}}{\left(B_2 + 1/R_2\right) + a_{12}\left(B_1 + 1/R_1\right)}\right\}$$

$$\Delta P_{tie_1} = \frac{-\Delta P_{D_1}\left\{(B_2+1/R_2)+a_{12}(B_1+1/R_1)\right\}-(B_1+1/R_1)(-\Delta P_{\ldots}}{(B_2+1/R_2)+(B_1+1/R_1)a_{12}}$$

$$= \frac{-\Delta P_{D_1}(B_2+1/R_2) - a_{12}(B_1+\cancel{1/R_1})\Delta P_{D_1} + \Delta P_{D_2}(B_1 \ldots + a_{12}(B_1+\cancel{1/R_1})\Delta \ldots}{(B_2+1/R_2)+(B_1+1/R_1)a_{12}}$$

$$\boxed{\Delta P_{tie_1} = \frac{-\Delta P_{D_1}\beta_2 + \Delta P_{D_2}\beta_1}{\beta_2 + a_{12}\beta_1}}$$

State variable model

$$\dot{x} = Ax + Bu + CP$$

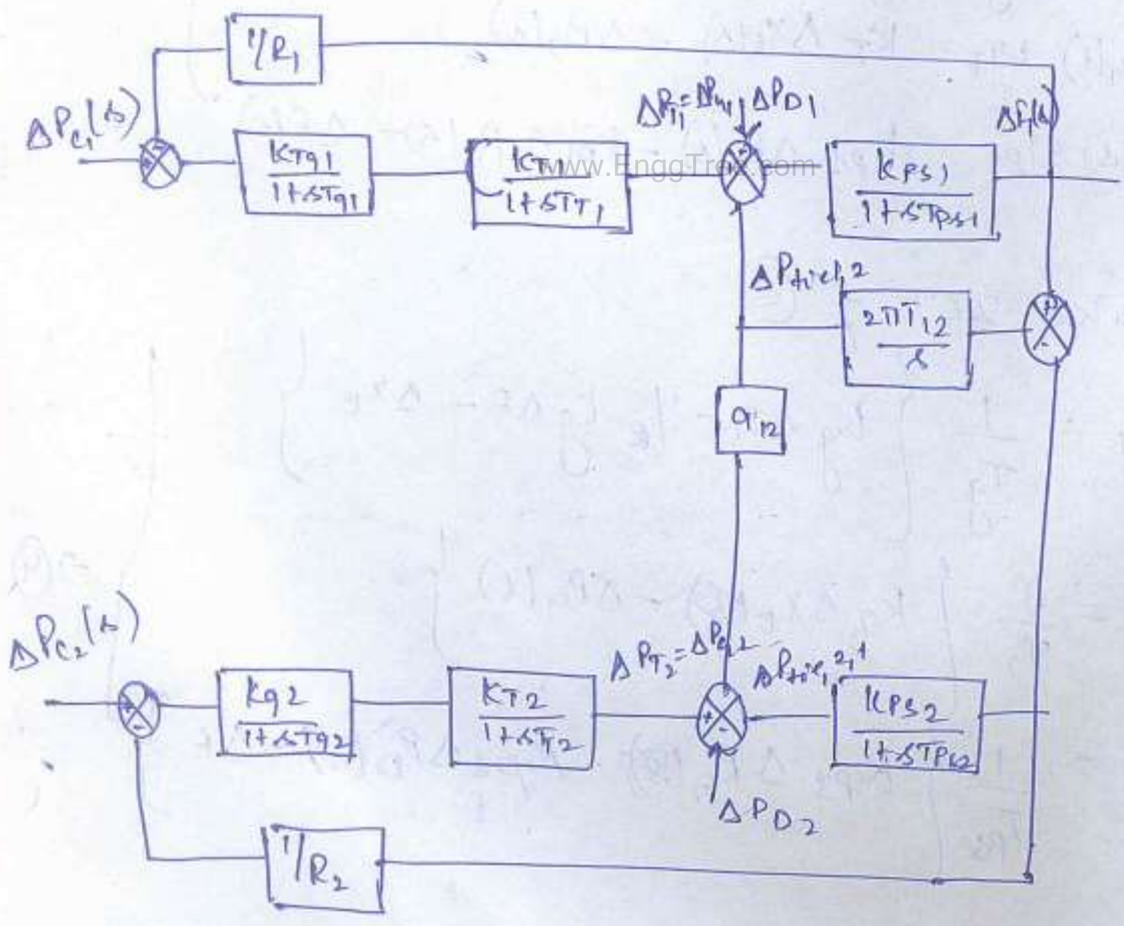
- Ax → State variable → Δx_E, ΔP_g, ΔF
- Bu → Control variable → ΔP_C
- CP → Disturbance variable → ΔP_D

Let $x_1 = \Delta x_E$, $x_2 = \Delta P_g$, $x_3 = \Delta F$

$$\dot{x} = Ax + B\underbrace{u}_{u = \Delta P_C} + C\underbrace{p}_{p = \Delta P_D}$$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} -1/T_g & 0 & -K_g/RT_g \\ K_T/T_T & -1/T_T & 0 \\ 0 & K_{PS}/T_{PS} & -1/T_{PS} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} K_g/T_g \\ 0 \\ 0 \end{bmatrix} \Delta P_C + \begin{bmatrix} 0 \\ 0 \\ \frac{-K_{PS}}{T_{PS}} \end{bmatrix} \Delta P_D$$

State variable model for two area system



$$\Delta X_{E_1}(s) = \left(\frac{K_{g_1}}{1+sT_{g_1}}\right)\Delta P_{c_1}(s) - 1/R_1\, \Delta F_1(s)$$

$$\Delta X_{E_2}(s) = \left(\frac{K_{g_2}}{1+sT_{g_2}}\right)\Delta P_{c_2}(s) - 1/R_2\, \Delta F_2(s)$$

$$\Delta P_{G_1}(s) = \left(\frac{K_{T_1}}{1+sT_{T_1}}\right)\Delta X_{E_1}(s)$$

$$\Delta P_{G_2}(s) = \left(\frac{K_{T_2}}{1+sT_{T_2}}\right)\Delta X_{E_2}(s) \quad \rightarrow (1)$$

$$\Delta F_1(s) = \left(\frac{K_{PS_1}}{1+sT_{PS_1}}\right)\left(\Delta P_{G_1}(s) - \Delta P_{D_1}(s) - \Delta P_{tie1,2}(s)\right)$$

$$\Delta F_2(s) = \left(\frac{K_{PS_2}}{1+sT_{PS_2}}\right)\left(\Delta P_{G_2}(s) - \Delta P_{D_2}(s) + a_{12}\Delta P_{tie1,2}\right)$$

$$\Delta P_{tie1,2} = \frac{2\pi T_{12}}{s}\left[\Delta F_1(s) - \Delta F_2(s)\right]$$

$$\Delta X_{E_1}(s) + \Delta X_{E_1}(s)\, sT_{g_1} = K_{g_1}\Delta P_{c_1}(s) - K_{g_1}\cdot 1/R_1\, \Delta F_1(s)$$

$$\Delta X_{E_2}(s) + \Delta X_{E_2}(s)\, sT_{g_2} = K_{g_2}\Delta P_{c_2}(s) - K_{g_2}\cdot 1/R_2\, \Delta F_2(s)$$

$$\Delta P_{G_1}(s) + \Delta P_{G_1}(s)\, sT_{T_1} = K_{T_1}\Delta X_{E_1}(s)$$

$$\Delta P_{G_2}(s) + \Delta P_{G_2}(s)\, sT_{T_2} = K_{T_2}\Delta X_{E_2}(s)$$

$$\Delta F_1(s) + \Delta F_1(s)\, sT_{PS_1} = K_{PS_1}\Delta P_{G_1}(s) - K_{PS_1}\Delta P_{D_1}(s) - K_{PS_1}\Delta P_{tie1,2}$$

$$\Delta F_2(s) + \Delta F_2(s)\, sT_{PS_2} = K_{PS_2}\Delta P_{G_2}(s) - K_{PS_2}\Delta P_{D_2}(s) + a_{12}\Delta P_{tie1,2}K_{PS_2}$$

$$\Delta P_{tie1,2}\, s = 2\pi T_{12}\Delta F_1(s) - 2\pi T_{12}\Delta F_2(s)$$

$$\Delta X_{E_1}(s)\, sT_{g_1} = K_{g_1}\Delta P_{c_1}(s) - \Delta X_{E_1} - \frac{K_{g_1}}{R_1}\Delta F_1(s)$$

$$\Delta X_{E_2}(s)\, sT_{g_2} = K_{g_2}\Delta P_{c_2}(s) - \Delta X_E(s) - \frac{K_{g_2}}{R_2}\Delta F_2(s)$$

$$\Delta P_{G_1}(s)\, sT_{T_1} = K_{T_1}\Delta X_{E_1}(s) - \Delta P_{G_1}(s) \quad \rightarrow (2)$$

$$\Delta P_{G_2}(s)\, sT_{T_2} = K_{T_2}\Delta X_{E_2}(s) - \Delta P_{G_2}(s)$$

$$\Delta F_1(s)\, sT_{PS_1} = K_{PS_1}\Delta P_{G_1}(s) - K_{PS_1}\Delta P_{D_1}(s) - \Delta F_1(s) - K_{PS_1}\Delta P_{tie1,2}(s)$$

$$\Delta F_2(s)\, sT_{PS_2} = K_{PS_2}\Delta P_{G_2}(s) - K_{PS_2}\Delta P_{D_2}(s) - \Delta F_2(s) + K_{PS_2}a_{12}\Delta P_{tie1,2}(s)$$

$$\Delta P_{tie1,2}\, s = 2\pi T_{12}\Delta F_1(s) - 2\pi T_{12}\Delta F_2(s)$$

$$\Delta \dot{x}_{E_1} = \frac{1}{T g_1}\left\{ k g_1 \Delta P_{C_1} - \Delta x_{E_1} - \frac{k g_1}{R_1} \Delta F_1 \right\}$$

$$\Delta \dot{x}_{E_2} = \frac{1}{T g_2}\left\{ k g_2 \Delta P_{C_2} - \Delta x_{E_2} - \frac{k g_2}{R_2} \Delta F_2 \right\}$$

$$\Delta \dot{P}_{G_1} = \frac{1}{T_{T_1}}\left\{ K_{T_1} \Delta x_{E_1} - \Delta \dot{P}_{G_1} \right\}$$

$$\Delta \dot{P}_{G} = \frac{1}{T_{T_2}}\left\{ K_{T_2} \Delta x_{E_2} - \Delta P_{G_2} \right\}$$

$$\Delta \dot{F}_1 = \frac{1}{T_{PS1}}\left\{ K_{PS_1} \Delta P_{G_1} - K_{PS_1} \Delta P_{D_1} - \Delta F_1 \right\} - K_{PS_1} \Delta P$$

$$\Delta \dot{F}_2 = \frac{1}{T_{PS_2}}\left\{ K_{PS_2} \Delta P_{G_2} - K_{PS_2} \Delta P_{D_2} - \Delta F_2 + K_{PS_2} a_{12} \Delta P_{tie1,2} \right\}$$

$$\Delta \dot{P}_{tie\,1,2} = 2\pi T_{12} \Delta F_1 - 2\pi T_{12} \Delta F_2$$

Let $x_1 = \Delta x_{E_1}$, $x_2 = \Delta x_{E_2}$

$x_3 = \Delta P_{G_1}$, $x_4 = \Delta P_{G_2}$

$x_5 = \Delta F_1$, $x_6 = \Delta F_2$

$x_7 = \Delta P_{tie\,1,2}$

Determine ALFC parameters for the control area having the following data

i) Total rated area capacity = 2000 MW
ii) Normal operating load = 1000 MW
iii) Interia constant : 5
iv) Speed regulation, R = 2.4 Hz/pu MW

we should assume that load frequency depends linearly.

i.e load would increase by 1% for 1% increase in frequency

Sol

$P_r = 2000$ MW

$P_D = 1000$ MW

$H = 5.0$

$R = 2.4$ Hz/pu.MW

$\uparrow \Delta f = 1\%$, $\Delta P_D = 1\%$

$k_g = k_T = 1$

$T_g = T_T = 0$

$k_{ps} = 1/B$

$$B = \frac{\partial P_D}{\partial f}$$

$$= \frac{\frac{1}{100} \times 1000}{\frac{1}{100} \times 50}$$

Q) An isolated power system has the following

1) Turbine rated O/P = 300 MW
2) Nominal frequency = 50 Hz
3) Governor ~~frequency~~ speed regulation
4) Interia constant = 5
5) Turbine time constant = 0.5 sec
6) Governor time constant = 0.2 sec
7) Speed change = 60 MW

Assume the load varies by 0.8 % for change in frequency.

Determine a steady state frequency deviation

Sol Given data:-

$P_r = 300\,MW$

$H = 5$

$R = 0.05\,pu.$

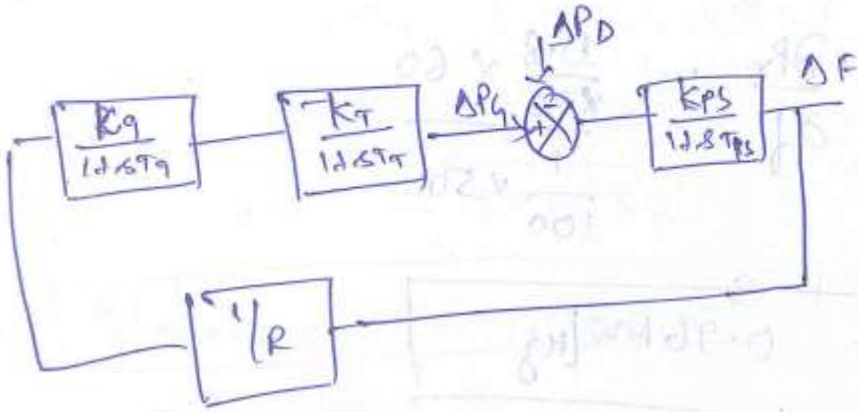
$T_T = 0.5\,sec$

$T_g = 0.2\,sec$

$\Delta P_D = 60\,MW$

$\Delta f \uparrow = 1\%,\ \Delta P_D = 0.8\%$

$$\Delta F_{static} = \underset{s \to 0}{Lt}\ s\,\Delta F(s)$$



$$\frac{\Delta F(s)}{-\Delta P_D(s)} = \frac{G(s)}{1+G(s)H(s)}$$

$$\frac{\Delta F(s)}{-\Delta P_D(s)} = \frac{\frac{K_{ps}}{1+sT_{ps}}}{1+\left[\frac{K_g}{1+sT_g}\right]\left(\frac{K_T}{1+sT_T}\right)\left(\frac{1}{R}\right)\left(\frac{K_{ps}}{1+sT_{ps}}\right)}$$

$$\Delta F(s) = \frac{\frac{K_{ps}}{1+sT_{ps}}}{1+\frac{K_g K_T K_{ps}}{(1+sT_g)(1+sT_T)(1+sT_{ps})}\times\frac{1}{R}} \times \left(\frac{-\Delta P}{s}\right)$$

$$\Delta F_{static} = \underset{s \to 0}{Lt}\ s \cdot \Delta F(s)$$

$$= \underset{s \to 0}{Lt} \cdot \cancel{s} \times \frac{\frac{K_{ps}}{1+sT_{ps}}}{1+\frac{K_{ps}K_T K_g}{(1+sT_g)(1+sT_T)(1+sT_{ps})}\times\frac{1}{R}} \times \left(-\frac{\Delta P}{\cancel{s}}\right)$$

$$\Delta F_{static} = \frac{K_{ps}}{1+\left(K_{ps}\times\frac{1}{R}\right)} \times (-\Delta P)$$

$$K_{ps} = 1/B$$

$$B = \frac{\partial P_r}{\partial f} = \frac{\frac{0.8}{100} \times 60}{\frac{1}{100} \times 50}$$

$$\boxed{B = 0.96\,MW/Hz}$$

$$\boxed{B\,in\,pu = 3.2 \times 10^{-3}\,pu\,MW/Hz}$$

$$T_{ps} = \frac{2H}{Bf}$$

$$= \frac{2(5)}{3.2 \times 10^{-3} \times 50}$$

$$\boxed{T_{ps} = 62.5\,sec}$$

$$K_{ps} = 1/B$$

$$= 1/3.2 \times 10^{-3}$$

$$\boxed{K_{ps} = 0.3125 \times 10^{3}\,Hz/pu\,MW}$$

$$\boxed{K_{ps} = 312.5\,Hz/pu\,MW}$$

$$\Delta P = \frac{60}{300}$$

$$\boxed{\Delta P = 0.2\,pu\,MW}$$

$$\Delta F_{static} = \frac{312.5\,(-0.2)}{1+\left(312.5 \times \frac{1}{0.05}\right)}$$ p.u MW

$$= \frac{-62.5}{1+6250} = \frac{-62.5}{6251}$$

$$\boxed{\Delta F_{state} = -9.99 \times 10^{-3}}$$

Q. Data. Contain to single area power system with linear power frequency.

1) Rated capacity = 2000 MW
2) System load = 1000 MW
3) Interia constant 5
4) Speed reg = 0.3 pu
5) Load damping factor = 1 pu
6) nominal frequency = 50 Hz
7) Assume $T_g = T_t = 0$

For sudden ~~load~~ change in load of 20 MW, determine a steady state frequency deviation & change in generation

Sol

Given data

$P_r = 2000\,MW$

$P_D = 1000\,MW$

$H = 5$

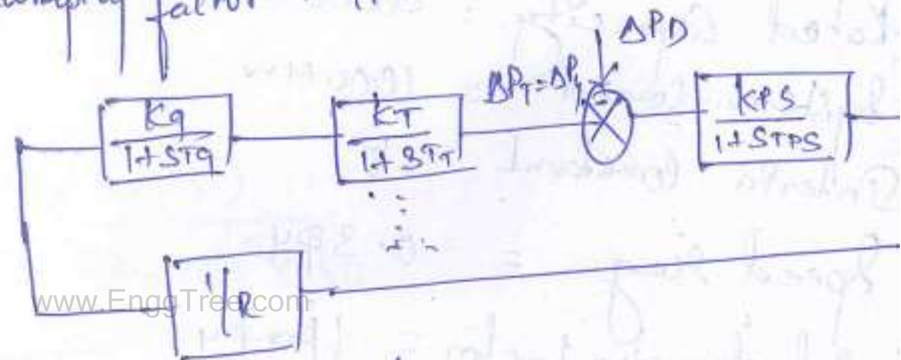
$R = 0.3\,pu$

$f = 50\,Hz$

$T_g = T_T = 0$

$\Delta P_D = 20\,MW$

Load damping factor = 1 pu



$$\Delta F(s) = \frac{\dfrac{K_{PS}}{1+sT_{PS}}}{1 + \dfrac{K_g K_T K_{PS}}{(1+sT_g)(1+sT_T)(1+sT_{PS})R}}$$

$$\Delta F_{static} = \lim_{s \to 0} s\,\Delta F(s)$$

$$= \frac{K_{PS}}{1 + K_{PS}/R} \times (-\Delta P)$$

~~$\Delta F_{static} =$~~

$$B = \frac{\partial P_r}{\partial f} = \frac{20}{50}$$

$B = 0.4$

$B = 0.4 \ MW/Hz$

$$\boxed{B = 4 \times 10^{-4} \ pu \ MW/Hz}$$

$$K_{PS} = \frac{1}{B}$$

$$= 1/4 \times 10^{-4}$$

$$\boxed{K_{PS} = 2500 \ Hz/pu \ MW}$$

$$T_{PS} = \frac{2H}{Bf}$$

$$= \frac{2 \times 5}{4 \times 10^{-4} \times 50}$$

$$\boxed{T_{PS} = 500 \ sec}$$

$$\Delta f_{static} = \frac{K_{PS}(-\Delta P_D)}{1 + K_{PS} \times 1/R}$$

$$= \frac{2500(-0.02)}{1 + 2500/0.03}$$

$$\Delta f_{static} = \cancel{-0.00239} \ -5.99 \times 10^{-4}$$

$$\Delta P_g = -\frac{1}{0.03} \times (-5.99 \times 10^{-4})$$

$$\boxed{\Delta P_g = 0.019 pu}$$

UNIT III REACTIVE POWER – VOLTAGE CONTROL

Function of excitation system

1. It act as the control circuit for the generator i.e it regulates the o/p of generator terminal

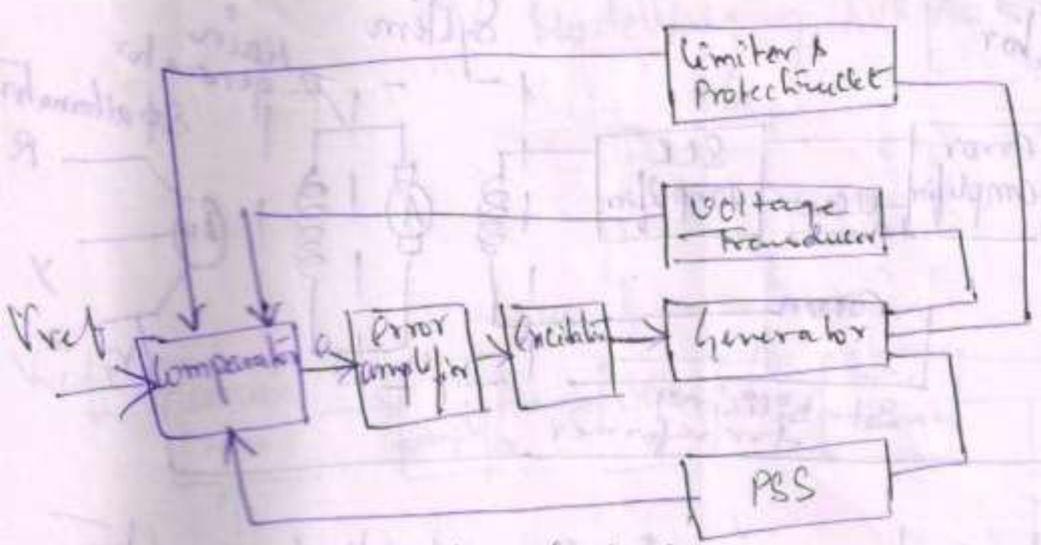
2. It serves as a protection ckt of a generator It ensures the capacitive limits of the generator

Types of excitation system

DC excitation system -
here DC generator is use to give DC supply to the field winding.

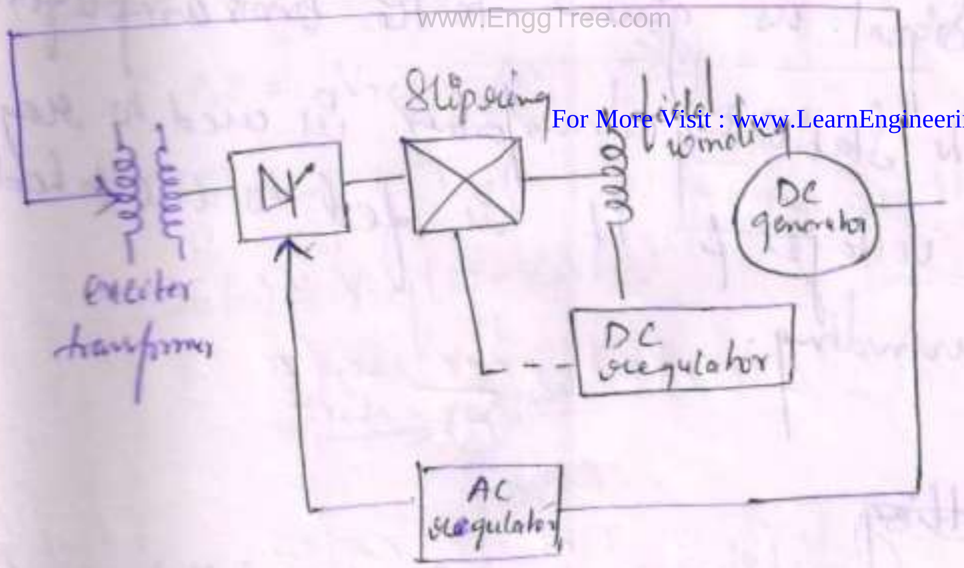
AC excitation system :-
Here an alternator is use to produce a require AC supply. This AC supply is converted into DC with the help of slip ring & then fed

Basic block diagram of excitation



Examples of excitation system:-

Rectifier controller excitation system

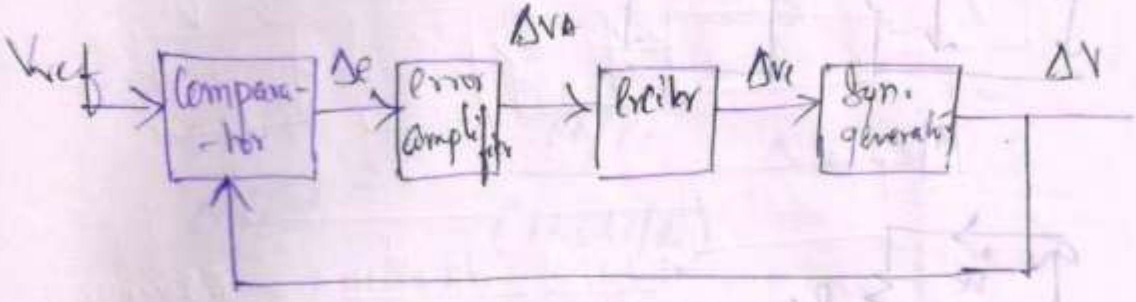


i) The exciter transformer is used as a protective device

ii) The AC regulator regulates the AC voltage & it given to converter & it is fed to the field

Modelling of excitation system (or)

Modelling of AVR [Automatic voltage regulator]

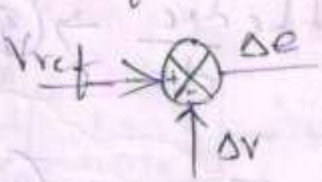


i) Modelling of Comparator

$$\Delta e = V_{ref} - \Delta V \quad \rightarrow (1)$$

Taking L.T

$$\Delta E(s) = V_{ref}(s) - \Delta V(s)$$

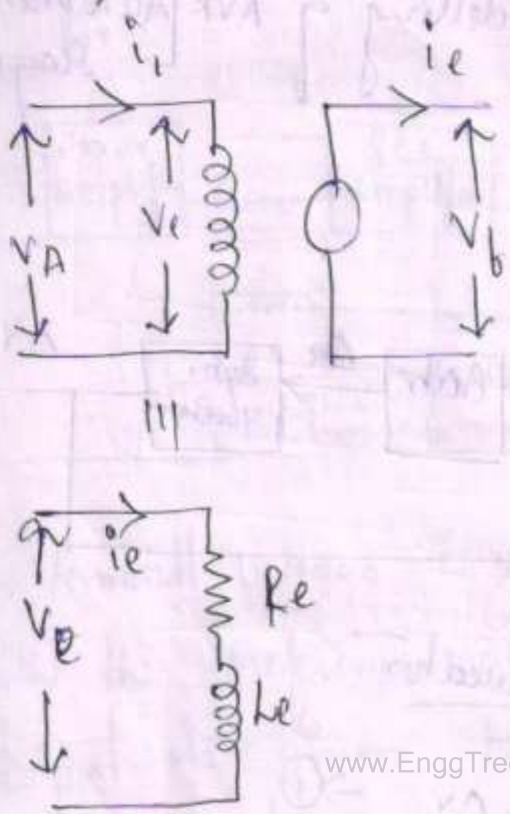


ii) Modelling of Error amplifier

$$\Delta V_A \propto \Delta e$$

$$\boxed{\Delta V_A = K_A \Delta e} \rightarrow (2)$$

iii) Modelling of Exciter :-



i/p equation :-

$$\Delta v_e = \Delta i_e R_e + L_e \frac{di_e}{dt} \rightarrow (3)$$

Taking L.T of eq (3)

$$\boxed{\Delta V_e(s) = \Delta I_e(s) R_e + L_e\, s I_e(s)}$$

o/p equation

$\Delta v_1 \propto \Delta i_e$

$$\frac{\Delta V_F(s)}{\Delta V_e(s)} = \frac{K_e \, \Delta I_e(s)}{\Delta I_e(s) R_e + L_e s \Delta I_e(s)}$$

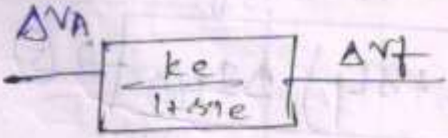
$$\frac{\Delta V_F(s)}{\Delta V_e(s)} = \frac{K_e \cancel{\Delta I_e(s)}}{\cancel{\Delta I_e(s)} R_e \left(1 + \frac{L_e s}{R_e}\right)}$$

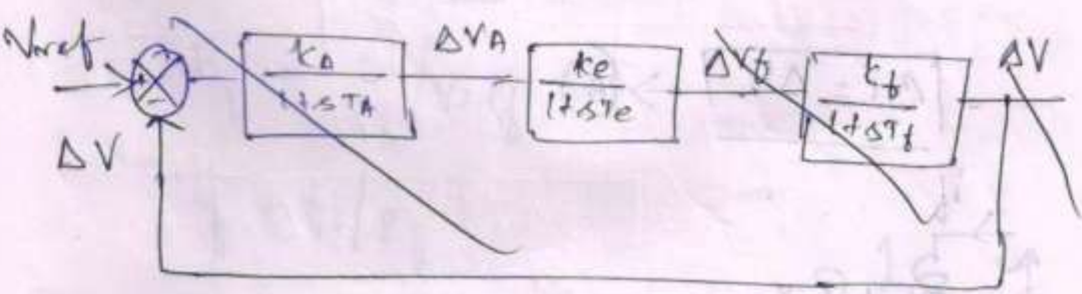
$$\frac{\Delta V_F(s)}{\cancel{\Delta V_e(s)}} = \frac{K_e/R_e}{(1 + s L_e/R_e)} \Delta V_e(s)$$

$$\boxed{\Delta V_F(s) = \frac{K_e}{1 + sT_e} \Delta V_e(s)}$$

$K_e = K_e/R_e$

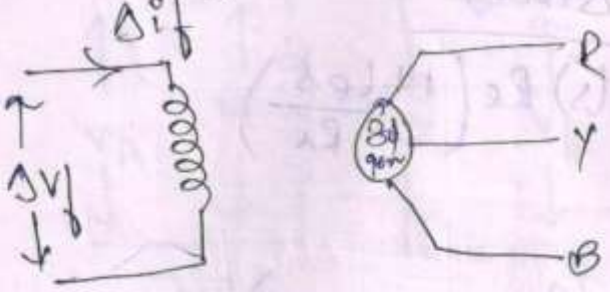
$T_e = L_e/R_e$

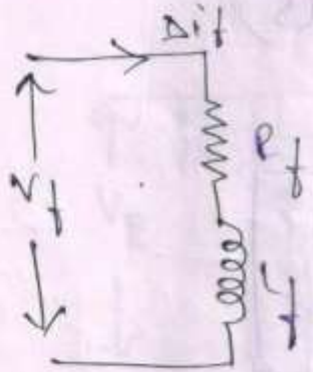




Modelling of AVR :-

Modelling of Synchronous gen :-





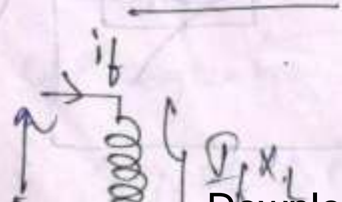
$$\Delta v_f = R_f \Delta i_f + L_f \frac{d \Delta i_f}{dt}$$

Take L.T

$$\Delta V_F(s) = R_F \Delta I_{F(s)} + L_f \, s I_F(s)$$

$$\boxed{\Delta V_F(s) = (R_F + sL_f)\, \Delta I_{F(s)}} \rightarrow 5$$

$$\boxed{\Delta E = \Delta V} \rightarrow 6$$



$$\Delta I_f = \frac{\sqrt{2}\,\Delta E}{L\omega}$$

$$\boxed{\Delta I_f = \frac{\sqrt{2}\,\Delta V}{L\omega}} \rightarrow (7)$$

~~Modelling eq~~

Sub eq (7) in eq (5)

$$\Delta V_F(s) = (R_F + sL_f)\frac{\sqrt{2}\,\Delta V}{L\omega}$$

$$\frac{\Delta V}{\Delta V_F(s)} = \frac{L\omega}{\sqrt{2}(R_F + sL_f)}$$

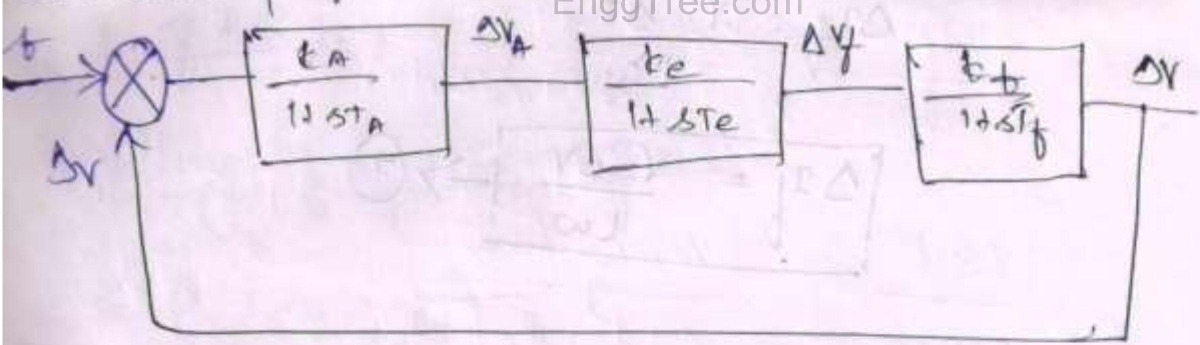
$$\boxed{\frac{\Delta V}{\Delta V_F(s)} = \frac{L\omega}{\sqrt{2}R_F\left(1 + \frac{sL_f}{R_f}\right)}}$$

$$\boxed{\frac{\Delta V}{\Delta V_F} = \frac{K_f}{1 + sT_f}}$$

$K_f = L\omega / \sqrt{2}R_f$

$T_f = L_f / R_f$

rall modelling of A...



$$T.F = \frac{G(s)}{1+G(s)H(s)}$$

$$\frac{\Delta V}{\Delta V_{ref}} = \frac{\frac{K_A K_e K_f}{(1+sT_A)(1+sT_e)(1+sT_f)}}{1+\frac{K_A K_e K_f}{(1+sT_A)(1+sT_e)(1+sT_f)} \times 1}$$

$$\frac{\Delta V}{\Delta V_{ref}} = \frac{K_A K_e K_f}{(1+sT_A)(1+sT_e)(1+sT_f)+(K_A K_e K_f)}$$

Steady State Response of AVR

O/P reaches ss as $t \to \infty$

$$\Delta V = \lim_{s \to 0} s \cdot \Delta V(s) \rightarrow (1)$$

So $T.F = \frac{G(s)}{\ }$

$$\frac{\Delta V}{\Delta V_{ref}} = \frac{K_A K_e K_f}{(1+sT_A)(1+sT_e)(1+sT_f) + K_A K_e K_f}$$

If $\Delta V_{ref}(s) = 1/s$

$$\Delta V = \frac{K_A K_e K_f}{(1+sT_A)(1+sT_e)(1+sT_f) + K_A K_e K_f} \times 1/s \rightarrow (2)$$

Sub (2) in (1)

$$\Delta V = \lim_{s \to 0} s \cdot \frac{K_A K_e K_f}{(1+sT_A)(1+sT_e)(1+sT_f) + K_A K_e K_f} \times 1/s$$

$$\Delta V = \frac{K_A K_e K_f}{1 + K_A K_e K_f}$$

$$\boxed{\Delta V(s) = \frac{K}{1+K}}$$

Dynamic Response of AVR

o/p changes wrt time

$\Delta V(t) = ? \rightarrow$ 3

$$\Delta V(s) = \frac{K_A K_e K_f}{(1+sT_A)(1+sT_e)(1+sT_f) + K_A K_e K_f} \times \frac{1}{s}$$

ICT

$\Delta V(s) = k_1 e^{s_1 t} + k_2 e^{s_2 t} + k_2 e^{s_3 t}$ — rule are real p

$\Delta V(t) = A e^{at} \sin(\alpha + \beta) t \Rightarrow$ complex

Stability Compensation

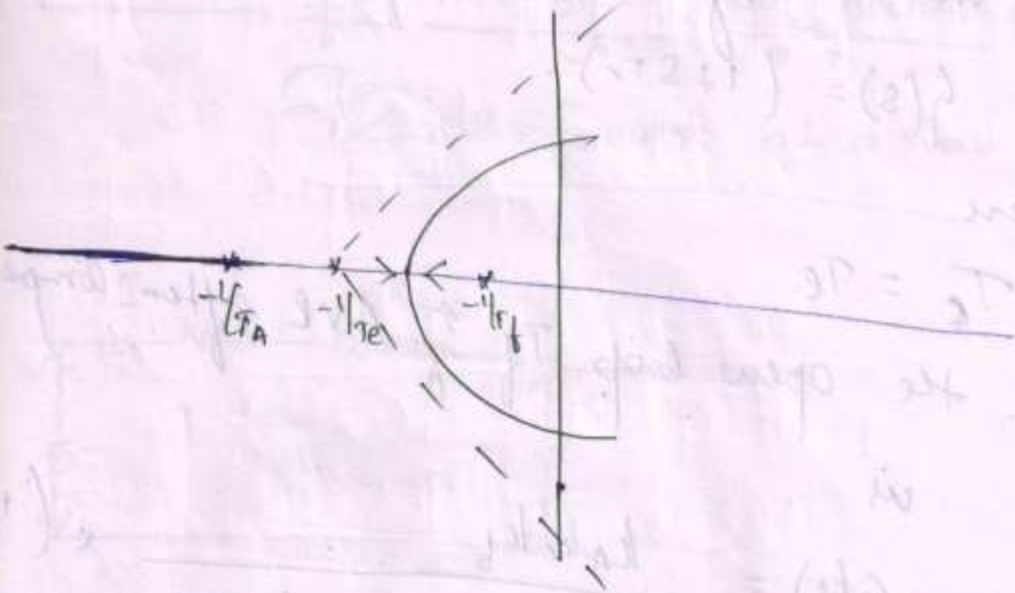
Consider open loop TF of AVR.

$$G(s) = \frac{K_A K_e K_f}{(1+sT_A)(1+sT_e)(1+sT_f)}$$

No. of zeros $= n = 0$

poles $= m = 3$

$m - n = 3 - 0 = 3$



If we take a test point b/w $-1/\tau_A$ & ∞, ~~the~~ to right of test point, there is odd no. of zeros & poles ~~to means, therefore the region b/w $-1/\tau_A$ & ∞ are~~

the test point is considr $-1/\tau_e$ & $-1/\tau_f$, the root locus from the both the poles collide each other move to the right half of the s-plane thus making the system unstable.

Let the TF of Series Compensator be

$$G(s) = (1+sT_c).$$

Here

$$T_c = T_e.$$

$\therefore$ the open loop Tf of AVR after Compensation is

$$G(s) = \frac{K_A K_e K_f}{(1+sT_A)\cancel{(1+sT_e)}(1+sT_f)} \times \cancel{(1+sT_e)}$$

$$G(s) = \frac{K_A K_e K_f}{(1+sT_A)(1+sT_f)}$$

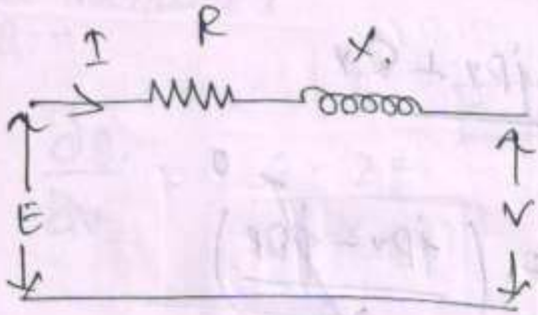
no. of zeros = 0

no. of poles 'm' = 2

$$m-n = 2-0 = 2$$

$$T_f > T_A = -1/T_f > -1/T_A$$

Relation b/w Voltage, Real power & Reactive power at a node



$$V = f(P, Q)$$

$$dv = \frac{\partial v}{\partial p} \cdot dp + \frac{\partial v}{\partial Q} dQ$$

$$\Delta V = \frac{dP}{\left(\frac{\partial P}{\partial v}\right)} + \frac{dQ}{\left(\partial Q / \partial v\right)}$$

$$E = V + \text{drop}$$

$$E = V + IZ$$

$$E = V + I(R + jX)$$

$$S = VI^*$$

$$S^* = V^* I$$

$$I = \frac{S^*}{V^*} = \frac{P - jQ}{}$$

$$E - V = \left(\frac{P - jQ}{V}\right)(R + jX)$$

$$= \frac{PR - jQR + jPX - j^2 QX}{V}$$

$$= \frac{PR - jQR + jPX + QX}{V}$$

$$E - V = \left(\frac{PR + QX}{V}\right) + \cancel{\left(\frac{jPX - jQR}{V}\right)}^{0}$$

$$EV - V^2 = PR + QX$$

$$\frac{EV - V^2 - QX}{R} = P$$

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

$$\frac{EV - V^2 - PR}{X} = Q.$$

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

$$\Delta V = \frac{dP}{(\partial P/\partial V)} + \frac{dQ}{\left(\frac{\partial Q}{\partial V}\right)}$$

$\Delta V = \frac{dP}{\ }$

Case 1 :-

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

If we increase the Q reactive power for that we decrease the inductance X

Case 2 :-

$$\boxed{E = V}.$$

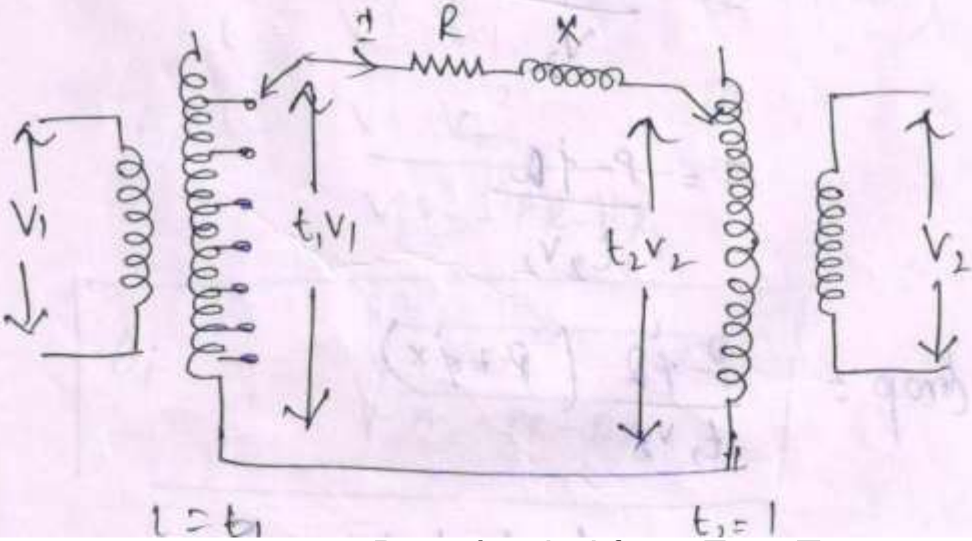
$$\frac{\partial Q}{\partial V} = \frac{E - 2E}{X}$$

$$= \frac{-E}{X}$$

$$= -I$$

OLTC :-

Tap changing transformer :-



$1 : t_1$ $t_2 : 1$

Let V_1 & V_2 be the primary & secondary voltage of OLTC

Let t_1 & t_2 be the tap ~~changer of the transformer~~ ratio of the OLTC.

Assume

$$t_1 t_2 = 1 \Rightarrow \boxed{t_1 = 1/t_2} \rightarrow (1)$$

$$V_1 = V_2 + \text{drop}$$

$$t_1 V_1 = t_2 V_2 + \text{drop}$$

$$\text{drop} = IZ$$
$$= I(R + jX)$$

WKT,

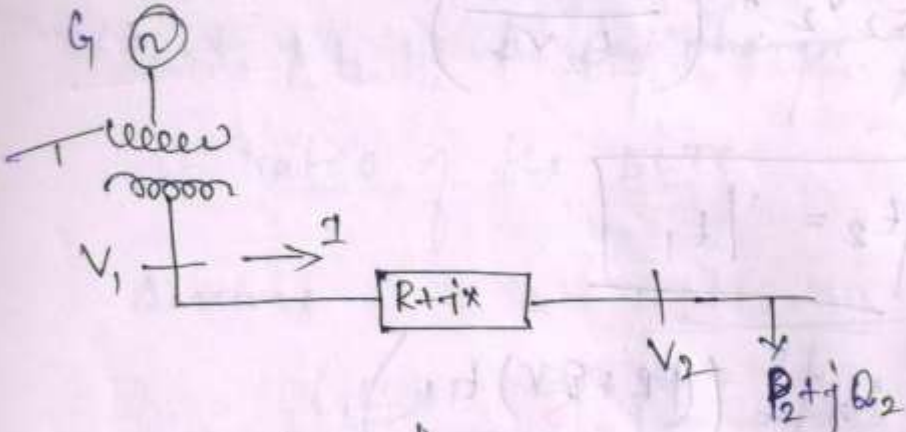
$$I = \frac{P - jQ}{V_2}$$

$$I = \frac{P - jQ}{t_2 V_2}$$

$$\text{drop} = \frac{P - jQ}{t_2 V_2}(R + jX)$$

$t_1 V_1 = t_2 V_2$ ...

Reactive Power Balance & it's effects



$V_1 = V_2 + \text{drop}$

$= V_2 + IZ$

$= V_2 + I(R+jx)$

WKT

$S = P_2 + jQ_2$

$V_1 I_1^* = P_2 + jQ_2$

$I_1^* = \dfrac{P_2 + jQ_2}{V_1}$

$I = \dfrac{P_2 - jQ_2}{V_1^*}$

$$\boxed{I = \frac{P_2 - jQ_2}{V_1}}$$

$V_1 = V_2 + \left(\dfrac{P_2 - jQ_2}{V_1}\right)(R+jx)$

The OLTC control the o/p voltage approx there is only 20% variation in the voltage.

If the voltage variation increase beyond 20%, OLTC has to used along with any one of the devices which inject reactive power.

Here the o/p voltage can controll by using OLTC along with Syn. Condenser as shown in fig above

$V_1 = V_n + \text{drop}$

$= V_n + IZ$

$= V_n + I(R + jX)$

$= V_n + \left(\frac{P_2 - jQ_2}{V_n}\right)(R + jX)$

$= V_n + \left(\frac{P_2R + jPX - jQ_2R - j^2Q_2X}{V_n}\right)$

$= V_n + \left(\frac{P_2R + jPX - jQ_2R + Q_2X}{V_n}\right)$

$= V_n + \left(\frac{P_2R + Q_2X}{V_n}\right) + j\left(\frac{PX - Q_2R}{V_n}\right)$

$$\delta V = \frac{P_2 X - Q_2 R}{V_n}$$

If Resistance is neg,

$$\Delta V = Q_2 X / V_n$$

$$\delta V = P_2 X / V_n$$

; Resistance is neg,

$$V_1 = V_n + \frac{Q_2 X}{V_n} + \frac{j P_2 X}{V_n}$$

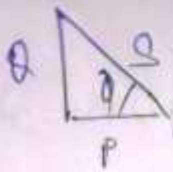
$$Q_2 = Q_2 - Q_C$$

$$V_1 = \sqrt{\left(V_n + \frac{Q_2 X}{V_n}\right)^2 + \left(\frac{P_2 X}{V_n}\right)^2}$$

$$V_1^2 = \left(V_n + \frac{Q_2 X}{V_n}\right)^2 + \left(\frac{P_2 X}{V_n}\right)^2$$

Sub, $Q_2 = Q_2 - Q_C$

$$V_1^2 = \left(V_n + \frac{(Q_2 - Q_C) X}{V_n}\right)^2 + \left(\frac{P_2 X}{V_n}\right)^2$$



$$\tan\phi = \frac{Q}{P}$$

$$Q = P\tan\phi$$

$$\cos\phi = 0.8$$

$$\phi = 36.86^\circ$$

$$\tan\phi = 0.75$$

$$Q_2 = P_2 \times 0.75$$

$$= 8.333 \times 0.75$$

$$Q_2 = 6.247\ MW$$

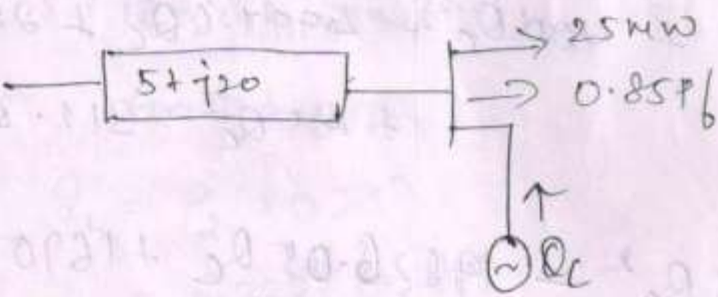
$$V_2 = 33/\sqrt{3}$$

$$\boxed{V_2 = 19.05\ V}$$

$$0 = P_2^2R^2 + (Q_2 - Q_c)^2X^2 + 2V_2^2\left(P_2R + (Q_2 - Q_c)X\right) + P_2^2X^2 + (Q_2 - Q_c)^2R^2$$

$$0 = P_2^2R^2 + (Q_2^2X^2 + Q_c^2X^2 - 2Q_2Q_cX^2 + 2V_2^2(P_2R + (Q_2 - Q_c)) + P_2^2X^2 + (Q_2^2 + Q_c^2 - 2Q_2Q_c)R^2$$

A 3ϕ overhead line has resistance and reactance of 5 & 20 ohms resp. The load at the receiving end is 30MW, 0.85pf lagging at 33kV. Find the voltage at the sending end. What will be the kVAR rating of the compensating equipment inserted at the received end so as to maintain a voltage of 33kV at each end? Find also the max load that can be transmitted.



$V_1 = V_2 + \text{drop}$

~~$V_1 = V_2 + IR$~~

$\text{drop} = IZ$

$= I(R+jX)$

$= \left(\dfrac{P_2 - Q_2 j}{V_2}\right)(R+jx)$

$$\text{drop} = \frac{P_2R + jP_2x - Q_2Rj + Q_2x}{V_2}$$

$$= \frac{(P_2R + Q_2x) + j(P_2x - Q_2R)}{V_2}$$

$$= \frac{P_2R + Q_2x}{V_2} + j\frac{(P_2x - Q_2R)}{}$$

Sub ② in ①

$$V_1 = V_2 + \Delta V + j\delta V$$

$$V_1^2 = V_2^2 + (\Delta V + j\delta V)^2$$

$$V_1^2 = (V_2 + \Delta V)^2 + (j\delta V)^2$$

$$= \left(V_2 + \left(\frac{P_2R + Q_2X}{V_2}\right)\right)^2 + \left(\frac{P_2X - Q_2R}{V_2}\right)^2$$

$$\cancel{V_1^2V_2^2 = V_2^2 + (P_2R + Q_2X)^2 + 2(P_2R + Q_2X)V_2^2 + (P_2X)^2 + (Q_2R)^2 - 2P_2XQ_2R}$$

$$V_1^2V_2^2 = \left(V_2^2 + (P_2R + Q_2X)\right)^2 + (P_2X - Q_2R)^2$$

$$V_1^2V_2^2 = V_2^4 + (P_2R + Q_2X)^2 + 2V_2^2(P_2R + Q_2X) + (P_2X)^2 + (Q_2R)^2 - 2P_2XQ_2R$$

$$V_1^2V_2^2 = V_2^4 + (P_2R)^2 + (Q_2X)^2 + \cancel{2(P_2R)(Q_2X)} + 2V_2^2(P_2R + Q_2X) + (P_2X)^2 + (Q_2R)^2 - \cancel{2P_2XQ_2R}$$

From the problem

$V_1 = V_2$

$$V^4 = \cancel{V_2^4} + (P_2R)^2 + (Q_2X)^2 + 2V_2^2(P_2R + Q_2X) + (P_2X)^2 + (Q_2R)^2$$

$R = 5\Omega$

$X = 20\Omega$

$P_2 = 30/3 = 10\,MW$

$Q_2 = P_2 \tan\phi$

$= 10 \tan(31.78)$

$Q_2 = 6.195$

$$0 = (P_2 R)^2 + (Q_2 - Q_c)^2 x^2 + 2V_2^2 \left(P_2 R + (Q_2 - Q_c) x\right) + P_2^2 x^2 + (Q_2^2 + Q_c^2 - 2Q_2 Q_c) R^2$$

$$0 = (P_2 R)^2 + (Q_2^2 + Q_c^2 - 2Q_c Q_2) x^2 + 2V_2^2 (P_2 R + Q_2 x - Q_c x) + P_2^2 x^2 + Q_2^2 R^2 + Q_c^2 R^2 - 2Q_2 Q_c R^2$$

$$= (10 \times 5)^2 + (6.195^2 + Q_c^2 - 2(6.195) Q_c)(20)^2 + 2(19.05)^2 \left(50 + (6.195)20 - Q_c(20)\right) + (10^2 \times 20^2) + (6.195^2 \times 5^2) + (Q_c^2 (5)^2) - 2(6.195) Q_c (5)^2$$

$$= 2500 + (38.378 + Q_c^2 - 12.39 Q_c)400 + 725.805(173.9 - 20 Q_c) + 500 + 959.45 + 25 Q_c^2 - 309.75 Q_c$$

$$= \cancel{25}\ 2500 + 15351.2 + 400 Q_c^2 - 4956 Q_c + 126217.49 - 14516.1 Q_c + 1459.45 + 25 Q_c^2 - 309.75 Q_c$$

$$= 425 Q_c^2 + 145528.14 - 19781.85$$

$t_1 = 0.64$

$t_1 = 1/t_2$

$t_2 = 1/t_1$

$t_2 = 1.5625$

A 132kV line is fed through an 11/132kV transformer from a constant 11kV supply. At the load end of the line the voltage is reduced by another transformer of nominal ratio 132/11 kV. The total impedance of the line & transformer at 132kV is $25 + j66\,\Omega$

Both transformer are equipped with tap changing facilities which are arranged so that the product of the two off-nominal settings is unity. If load on the system is 100MW at 0.9pf lagging. Calculate the setting of tap changer required to maintain the voltage of the load busbar at 11kV. Use base MVA of 100MVA.

$$Z_{pu} = \frac{KV_A^2}{MVA} = \frac{11^2}{100} = 1.21$$

$$= \frac{132^2}{100} = 174.24$$

$$PF_2 = \frac{1/0.00388}{1/0.003124 + 1/0.00388 + 1/0.0964}$$

$PF_2 = 0.378$

$\Delta P_2 = 50 \times 0.378$

$\Delta P_2 = 18.90$

$P_2 = 334.6 + 18.90$

$\boxed{P_2 = 353.5\,MW}$

$$PF_3 = \frac{1/0.0964}{1/0.003124 + 1/0.00388 + 1/0.0964}$$

$\boxed{PF_1 = 0.152}$

$\Delta P_3 = 7.60$

$P_3 = 122.2 + 7.60$

$P_3 = 122.2 + 7.60$

$\boxed{P_3 = 129.8\,MW}$

$$\frac{\partial L_i}{\partial P_{gi}} = \frac{\partial F_T(P_{gi})}{\partial P_{gi}} + 0 + \lambda \frac{\partial P_{Li}}{P_{gi}} - \lambda = 0$$

$$\boxed{\frac{\partial F_T(P_{gi})}{\partial P_{gi}} + \lambda \frac{\partial P_{Li}}{\partial P_{gi}} = \lambda} \rightarrow (3)$$

Solution of economic dispatch using λ-iteration method (with losses)

$$\frac{\partial F_T(P_{G1})}{\partial P_{gi}} + \frac{\lambda P_{Li}}{\partial P_{gi}} = \lambda$$

Step1:- Set iteration count $k=0$, Assume the value of λ

Step(2) - Substitute the value of λ is co-ordinates

eqn & hence obtain $P_{G1}, P_{G2}, P_{G3}, \ldots P_{Gn}$

$$P_m = \frac{1 - \frac{\beta_m}{\lambda} - \sum_{\substack{i=1 \\ \neq m}}^{n} 2B_{mn}P_n}{\frac{\gamma_m}{\lambda} + 2B_{mm}}$$

Step 3:- $\sum_{i=1}^{n} P_{gi} = P_D + P_L$

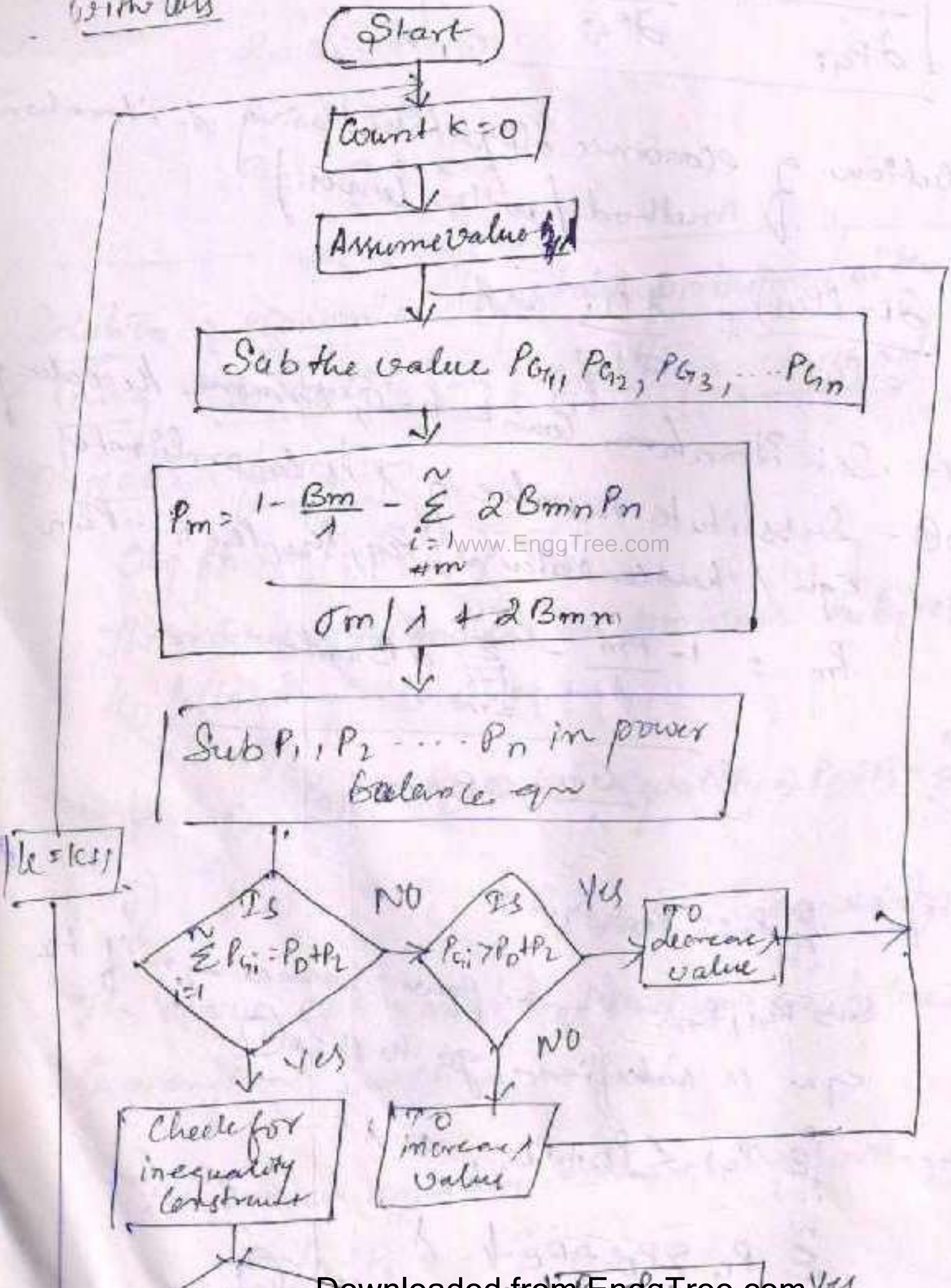
Sub $P_{G1}, P_{G2} \ldots P_{G3}$ in power balance eqn if the eqn is satisfied go to step(4)

$$\sum_{i=1}^{n} P_{gi} < P_D + P_L, \uparrow \lambda$$

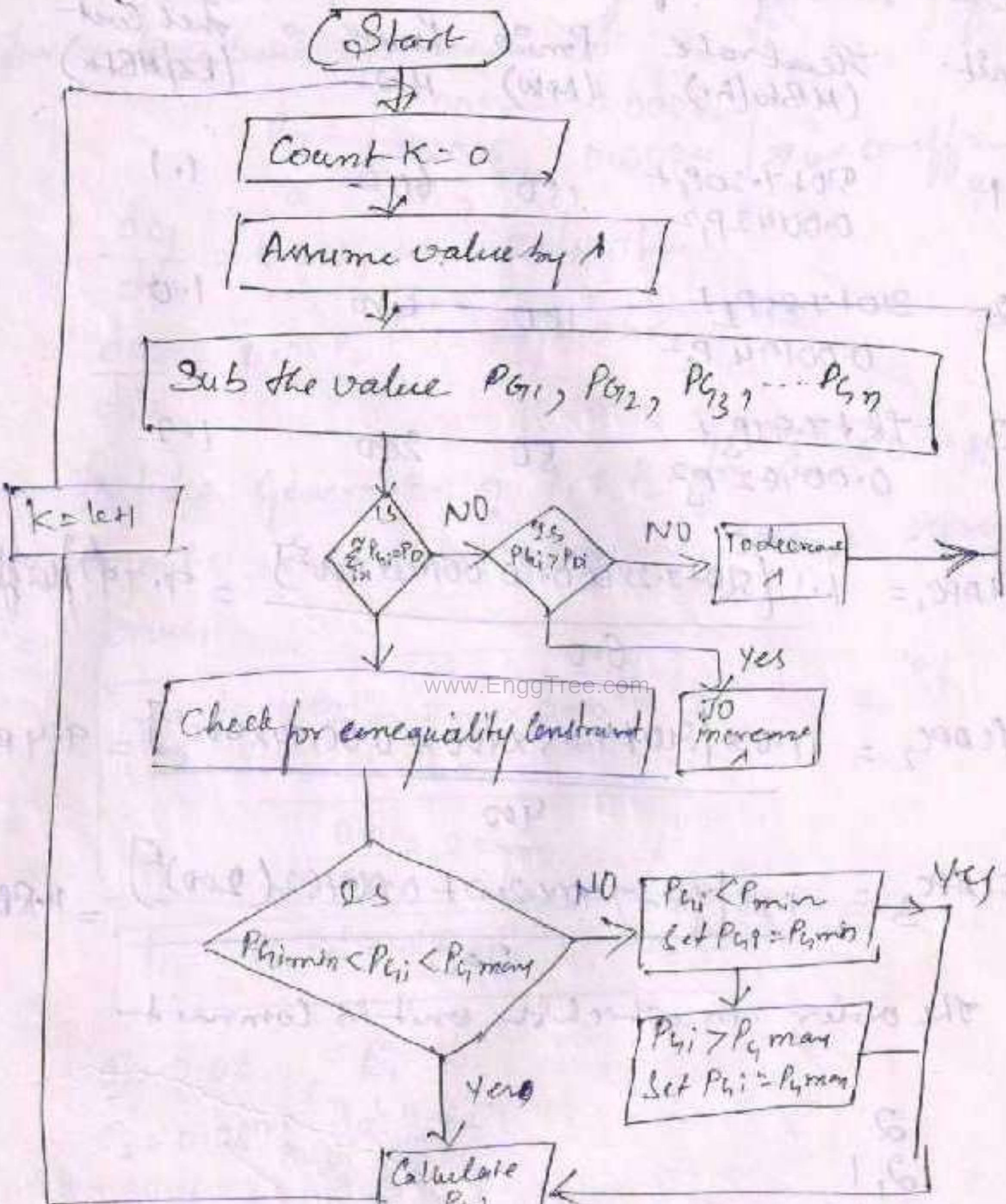
For a 2 unit plant a power loss is given by

$$\boxed{P_L = B_{11} P_1^2 + 2 B_{12} P_1 P_2 + B_{22} P_2^2}$$

with loss



Without loss



Qn Construct the priority list for the units given below

Unit	Heat rate (MBtu/hr)	P_{min} (MW)	P_{max} MW	Fuel Cost (Rs/MBtu)
1	$510+7.20P_1+0.00142P_1^2$	150	600	1.1
2	$310+7.85P_2+0.00194P_2^2$	100	400	1.0
3	$78+7.97P_3+0.00482P_3^2$	50	200	1.2

$$FLAPC_1 = \frac{1.1\left[510+7.2\times600+0.00142\times600^2\right]}{600} = 9.79\ \text{Rs/MWhr}$$

$$FLAPC_2 = \frac{1.0\times\left[310+7.85\times400+0.00194\times400^2\right]}{400} = 9.4\ \text{Rs/MWhr}$$

$$FLAPC_3 = \frac{1.2\times\left[78+7.97\times200+0.00482(200)^2\right]}{200} = 11.88\ \text{Rs/MWhr}$$

The order in which the unit is commit

2
2, 1
2, 1, 3

$1-\frac{B_{mn}}{\lambda}-\sum_{i=1}^{n}2B_{mn}P_n$

$1-\frac{B_{mn}}{\lambda}, 2B_{mn}$

$\frac{B_{mn}}{\lambda}-\sum_{i=1}^{n}2B_{mn}P_n$

P_n

$1-\frac{B_{mn}}{\lambda}-\sum_{i=1}^{n}2B_{mn}P_n$

$\frac{B_{mn}}{\lambda}, 2B_{mn}$

for a two unit system the loss co-efficient, for

~~for a two unit system the los~~

$$B_{11} = \begin{bmatrix} 0.001 & -0.0005 \\ -0.0005 & 0.0024 \end{bmatrix} \rightarrow \text{loss co-efficient matrix}$$

$$\frac{dc_1}{dp_1} = 0.08P_1 + 16 \text{ Rs/MWhr}$$

$$\frac{dc_2}{dP_2} = 0.08P_2 + 12 \text{ Rs/MWhr}$$

find the Generation of P_1 & P_2 for $\lambda = 50$ & also compute the transmission loss & resultant power

$$\boxed{P_m = \frac{1 - \frac{B_m}{\lambda} - \sum_{\substack{i=1 \\ \neq m}}^{N} 2B_{mn}P_n}{\frac{\sigma_m}{\lambda} + 2B_{mm}}}$$

$$\boxed{P_L = B_{11}P_1^2 + 2B_{12}P_1P_2 + B_{22}P_2^2}$$

$\sigma_1 = 0.08$, $\beta_1 = 16$

$\sigma_2 = 0.08$, $\beta_2 = 12$

$$P_1 = \frac{1 - \frac{B_1}{\lambda} - 2B_{12}P_2}{\frac{\sigma_1}{\lambda} + 2B_{11}}$$

$$= 0.68 + 0.001P_2$$

$$P_2 = \frac{1 - \frac{B_2}{\lambda} - 2B_{21}P_1}{\frac{\sigma_2}{\lambda} + 2B_{22}}$$

$+32.89 + 0.043P_1$

$2221.78 + 0.043P_1$

$P_1 - 0.043P_1$

$P_1(0.957$

$$P_2 = \frac{1 - \frac{12}{50} - 2(-0.0005)P_1}{\frac{0.08}{50} + (2 \times 0.0024)}$$

$$P_2 = \frac{0.76 + 0.001P_1}{6.4 \times 10^{-3}}$$

$$\boxed{P_2 = 118.75 + 0.156P_1}$$

$(188.88 \times 0.277 P_2$

$118.75 + (29.46 + 0.0432 P_2$

$0.956 P_2$

Iteral	P_1	P_2
0	0	0
1	188.89	148.21
2	229.94	154.62
3	231.7	154.89
4	231.77	154.9

$P_1 = 231.7$, $P_2 = 154.9$

$$P_L = B_{11}P_1^2 + 2B_{12}P_1P_2 + B_{22}P_2^2$$

$$= 0.001(231.79)^2 + 2(-0.0005 \times 231.79 \times 154.9) + (0.0024(\cancel{154}\ 154.9)^2$$

$$\boxed{P_L = 75.4\ \text{MW}}$$

$B_m - \sum 2B_{mn}P_n$

$$\boxed{P_2 = 45.45 + 0.113 P_1}$$

k	P_1	P_2
0	0	0
1	33.33	49.21
2	41.54	50.19
3	41.70	50.16
4	41.70	50.16

$P_1 = 41.7\ MW$

$P_2 = 50.16\ MW$

$$P_L = B_{11} P_1^2 + 2 B_{12} P_1 P_2 + B_{22} P_2^2$$

$$= (0.001)(41.7)^2 + 2(-0.0005)(41.7)(50.16) + (0.0024)(50.16)^2$$

$$\boxed{P_L = 5.68\ MW}$$

$P_G - P_L = P_D$

$41.7 + 50.16 - 5.68 = 86.18\ MW$

↑ the λ value from 3

$$\boxed{\lambda = 2\cancel{7}}$$

$$P_m = \frac{1 - \frac{\beta_m}{\lambda} - \sum_{\substack{i=1 \\ \neq m}}^{n} 2 B_{mn} P_n}{\frac{\gamma_m}{\lambda} + 2 B_{mm}}$$

$$P_1 = \frac{1 - 20/27 - 2(-0.0005)P_2}{\frac{0.1}{27} + 2(0.001)}$$

$$P_1 = \frac{0.26 + 0.001P_2}{0.0037 + 0.002}$$

$$P_1 = \frac{0.26 + 0.001P_2}{0.0057}$$

$$\boxed{P_1 = 45.61 + 0.175P_2}$$

$$P_2 = \frac{1 - \frac{\beta_2}{\lambda} - 2B_{21}P_1}{\frac{\sigma_2}{\lambda} + 2B_{22}}$$

$$= \frac{1 - \frac{15}{27} - 2(-0.0005)P_1}{\frac{0.1}{27} + 2(0.0024)}$$

$$= \frac{0.44 + 0.001P_1}{0.0037 + 0.0048}$$

$$= \frac{0.44 + 0.001P_1}{0.0085}$$

$$\boxed{P_2 = 52.23 + 0.117P_1}$$

K	P_1	P_2
0	0	0

$P_L = B_{11}P_1^2 + 2B_{12}P_1P_2 + B_{22}P_2^2$

$= 8.117\ MW$

$P_L(P)$ $P_1 + P_2 - P_L = P_D$

$58.76 + 58.75 - 8.117 = 100$

$106.3 > 100$

$\lambda = 25 - \frac{25-27}{86.18-106.3}(100-86.18)$

$\boxed{\lambda = 26.37}$

$P_m = \dfrac{1 - \frac{\beta_m}{\lambda} - \sum_{\substack{n=1 \\ \neq m}}^{n} 2B_{mn}P_n}{\frac{\sigma_m}{\lambda} + 2B_{mm}}$

$P_1 = \dfrac{1 - \frac{\beta_1}{\lambda} - \sum 2B_{12}P_2}{\frac{\sigma_1}{\lambda} + 2B_{11}}$

$= \dfrac{1 - \frac{20}{26.37} - 2(-0.0005)P_2}{\frac{0.1}{26.37} + 2(0.001)}$

$= \underline{0.24 + 0.001\,P_2}$

$$P_2 = \frac{1 - \frac{\beta_2}{\lambda} - 2B_{21}P_1}{\frac{\gamma_2}{\lambda} + 2B_{22}}$$

$$= \frac{1 - {15}/{26.37} - 2(0.0005)P_1}{\frac{0.1}{26.37} + 2(0.0024)}$$

$$= \frac{0.43 + 0.001P_1}{0.0037 + 0.0048}$$

$$= \frac{0.43 + 0.001P_1}{0.0085}$$

$$\boxed{P_2 = 50.58 + 0.1176P_1}$$

k	P_1	P_2
0	0	0
1	41.45	54.96
2	50.85	56.05
3	51.04	56.08
4	51.04	56.08

$P_1 = 55.76\,MW$

$P_2 = 55.75\,MW$

$P_L = B_{11}P_1^2 + 2B_{12}P_1P_2 + B_{22}P_2^2$

$= 7.21\,MW$

$P_D = P_1 + P_2 - P_L = 51.04 + 56.08 - 7.21$

$\boxed{P_D = 99.91\,MW}$

Base point & participation factor :-

if the demand is increases means, the un also participation to fullfill the demand

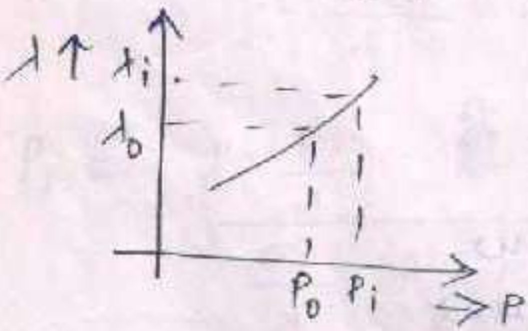
The Change in the demand load is equal to the unit power which are all participates & make equal to 1

$$PF = \frac{\Delta P_i}{\Delta P_D}$$

$$= \frac{\Delta P_1}{\Delta P_D} + \frac{\Delta P_2}{\Delta P_D} + \cdots + \frac{\Delta P_D}{\Delta P_D}$$

$$= \frac{\Delta P}{\Delta P_D}$$

$$= 1$$



wkt ...

$$F_{T_i} = a_i P_i^2 + b_i P_i + C_i \quad ₹/hr$$

$$\frac{\partial F_{T_i}}{\partial P_i} = 2a_i P_i + b_i = \lambda$$

from the fig, $\frac{dy}{dx} = \frac{d}{dx}\left(\frac{\partial F_i}{\partial P}\right) = \frac{d}{dx}(F_i')$

$$\sum_{i=1}^{n} \Delta P_i = \frac{\Delta\lambda}{F_i''}$$

$$\Delta P_1 = \frac{\Delta\lambda}{F_1''} \quad , \quad \Delta P_2 = \frac{\Delta\lambda}{F_2''}$$

$$\Delta P_n = \frac{\Delta\lambda}{F_n''}$$

$$\Delta P_1 + \Delta P_2 + \cdots + \Delta P_n = \frac{\Delta\lambda}{F_1''} + \frac{\Delta\lambda}{F_2''} + \cdots + \frac{\Delta\lambda}{F_n''}$$

$$= \Delta\lambda\left(1/F_2'' + 1/F_2'' + \cdots + 1/F_n'' \right)$$

$$\boxed{\Delta P_D = \Delta\lambda\left(\sum_{i=1}^{n} 1/F_i'' \right)}$$

Participation factor (PF)

$$PF_1 = \frac{\Delta P_1}{\Delta P_D} = \frac{\Delta\lambda / F_i''}{\Delta\lambda\left(\sum_{i=1}^{n} 1/F_i''\right)}$$

$$PF_2 = \frac{\Delta P_2}{\Delta P_D} = \frac{\Delta\lambda / F_i''}{\Delta\lambda\left(\sum_{i=1}^{n} 1/F_i''\right)}$$

$$PF_i = \frac{\Delta P_i}{\Delta P_D} = \frac{\Delta\lambda / F_i''}{\Delta\lambda\left(\sum_{i=1}^{n} 1/F_i''\right)}$$

in general

$$\boxed{PF_i = \frac{1/F_i''}{\sum_{i=1}^{n} 1/F_i''}}$$

$= 574 + 0.58(1.3)$

$$\boxed{\lambda = 575.5}$$

$P_1 = 72.73\ MW$

$P_2 = 36\ MW$

$P_3 = 91.25\ MW$

Solution of economic dispatch problem (with losses) using co-ordination equation method

Objective function

Obj fn : min $F_T(P_{Gi}) \to (1)$

The above optimaisation problem subjected to the following constraints

i) $\sum_{i=1}^{n} P_{Gi} = P_D + P_L$ - equality $\Rightarrow P_D + P_L - \sum_{i=1}^{N} P_{Gi}$

ii) $P_{min} \le P_{Gi} \le P_{Gimax}$ - inequality $\Big\} \to (2)$

The above optimaisation problem is solved by Lagrangian function method

The above equality constraint can written as

$$P_D + P_L - \sum_{i=1}^{m} P_{Gi} = 0$$

UNIT – IV ECONOMIC OPERATION OF POWER SYSTEM

Spinning reserve describes total generation obtain for all the units synchronized to power system minus ~~the~~ total demand minus total losses

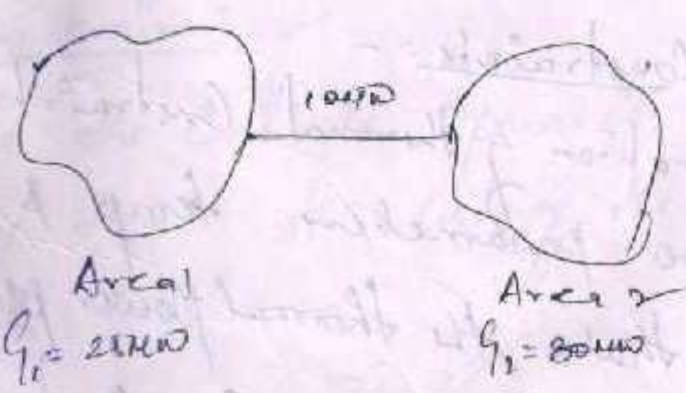
Usually 10 - 15% of peak demand is taken as spinning reserve.

Spinning reserves supply power for the following two condition

i) Temporary loss of 1 or 2 units in P.S

ii) loss of heavily loaded unit.

Bottling of reserves



Consider two areas A_1 & A_2 generates

But since the line capacity of is 10 MW it is not possible to transfer the storage of power in Area 2

eventhough there is circulate amount of power lost ~~due~~ in Area 1 due to limitation in tie line capacity the ~~excess~~ ~~of~~ power is not able to be transfer the area A2 in

This ~~control~~ condition is prevailling called as bottling of reserve.

Off line reserve:-

This type of reserves is mainly used for maintainance purpose

Thermal Constraints:-

The Operation of thermal Constraints depends upon two parameters temp & pressure. Based on that, the thermal power plant is subjected to the following Constraints

i) Min up time

ii) Min down time:-

One the unit is de-committed in order to recommit the same unit it requires some time. This time required is min. down time

iii) Crew Constraints:-

For simultaneous operation of two or more unit in power system one its require more member to operators

STATUS

Hydro Constraints

Here the hydro units are given MUST RUN STATUS that is the unit is allow to operate through out the day.

fuel Constraints -

Here, the unit is operated in such a way that the cost of the fuel is maintained at ~~fuel~~ minimum

6

... two approaches to heating the thermal plant 1) Cooling
2) Banking

In the 1st case, the plant is allowed to cool to a lower temp. & then heated up to its operating temperature

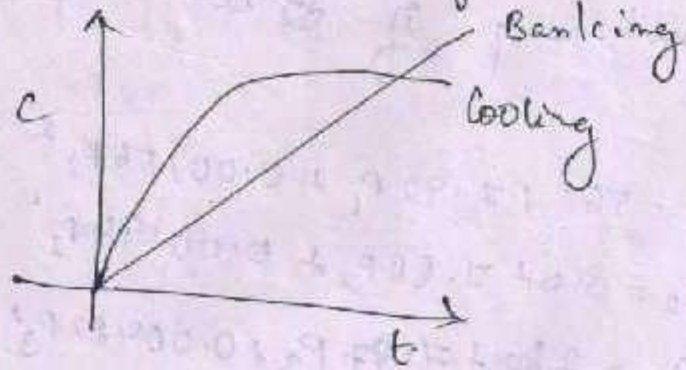
In 2nd case the plant is heated directly to its operating temperature.

Start up cost for cooling:-

$$C = C_c(1-e^{-t/\alpha})F + C_f$$

Start up cost for banking

$$C = C_c \times t \times F + C_f$$



Consider a 3unit plant who cost equation is given below

$$C_1 = 561 + 7.92P_1 + 0.00156P_1^2$$

$$C_2 = 310 + 7.85P_2 + 0.000194P_2^2$$

$$C_3 = 78...$$

priority list method.

A unit commitment problem by a priority list method by calculating FLAPC (full load Average production cost) the unit with least FLAPC is turned 'ON' first & the same procedure is carried for remaining unit.

To decommit, the unit with highest FLAPC is turned ON first.

The solution of unit commitment problem by priority list method can be better explain as

The cost eq of 3 unit plant is given below

(i)

$C_1 = 561 + 7.92 P_1 + 0.00156 P_1^2$

$C_2 = 310 + 7.85 P_2 + 0.00194 P_2^2$

$C_3 = 280 + 7.97 P_3 + 0.00482 P_3^2$

(ii)

unit	P min	P max
1	150	600
2	100	400
3	50	200

(iii)

$$FLAPC = \frac{C_i(P_i)}{P_i(F_L)}$$

$$FLAPC_1 = \frac{C_1(P_1)}{P_1(F_L)} = \frac{5874.6}{600} = 9.791 \text{ Rs/MW}$$

$$FLAPC_2 = \frac{C_2(P_2)}{P_2(F_L)} = \frac{3760.4}{400} = 9.401 \text{ Rs/MW}$$

loads ϕ

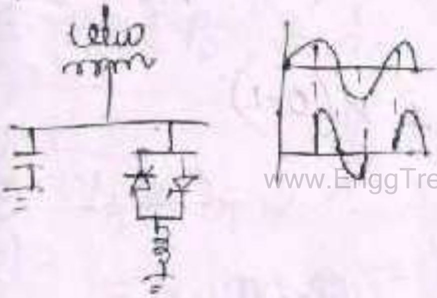
MVAR injection of switched capacitor to maintain acceptable voltage profile and a minimize losses:-

Static VAR Compensator:-

Located in receiving substation & distribution system

Adv

① For stepless variation of reactive
- Transient stability can be improved
- System transmission capacity can be increased



Solution of economic dispatch problem (without losses) using co-ordination equation method.

objective function

obj fn: $F_T(P_{Gi}) \to ①$

The above optimization problem

Subjected to the following constraints

i) $\sum_{i=1}^{n} P_{Gi} = P_D$ → power balance; Equality constraints $\to ②$

The above equality constraint can written as

$$P_D - \sum_{i=1}^{N} P_{Gi} = 0$$

Therefore Langrangian

$$\mathcal{L} = \text{obj fn} + \lambda\,(\text{Eq. Constraint})$$

$$= F_T(P_{Gi}) + \lambda\left(P_D - \sum_{i=1}^{N} P_{Gi}\right)$$

$$\frac{\partial \mathcal{L}}{\partial P_{Gi}} = \frac{\partial F_T(P_{Gi})}{\partial P_{Gi}} + \lambda(0-1)$$

$$\frac{\partial \mathcal{L}}{\partial P_{Gi}} = 0$$

$$0 = \frac{\partial F_T(P_{Gi})}{\partial P_{Gi}} - \lambda$$

$$\boxed{\lambda = \frac{\partial F_T(P_{Gi})}{\partial P_{Gi}}} \rightarrow (3)$$

Eq 3 is known as co-ordination eqn (without losses)

Solution of co-ordination eqn using λ-iteration Method (without losses)

$\lambda = \frac{\partial F_T(P_{Gi})}{\partial P_{Gi}}$

Step1:- Set iteration count $k=0$, Assume the value of λ.

Step2: Substitute the value of λ in co-ordinates eqn & hence obtain $P_{G1}, P_{G2}, P_{G3} \cdots P_{Gn}$

Step3: Sub $P_{G1}, P_{G2} \cdots P_{G3}$ in power balance eqn

if the eqn is satisfied go to step (4)

$\sum_{i=1}^{n} P_G < P_D, \uparrow \lambda$

$\sum_{i=1}^{n} P_G > P_D, \downarrow \lambda.$

go to Step (4).

Step4:- Check for inequality constraint.

$P_{Gi\,min} \leq P_{Gi} \leq P_{Gi\,max}$

If satisfied go to 1 ($\uparrow$ iteration)

else

Set $P_{Gi} = P_{Gi\,min}$

Set $P_{Gi} = P_{Gi\,max}$

go to (1)

Step3 :-

$$\sum_{i=1}^{n} P_{G_i} = P_D \quad , \quad i = 1,2,3$$

$$P_{G_1} + P_{G_2} + P_{G_3} = P_D$$

$$65 + 5 + 85.71 = 200$$

$$155.7 \neq 200$$

$$< 200$$

Increase λ by 2

$$\boxed{\lambda = 30}$$

$$\lambda = \frac{\partial C_1}{\partial P_1} = 0.1 P_1 + 21.5 = 30 \Rightarrow P_1 = 85 \text{ MW}$$

$$\lambda = \frac{\partial C_2}{\partial P_2} = 0.2 P_2 + 27 = 28 \Rightarrow P_2 = 15 \text{ MW}$$

$$\lambda = \frac{\partial C_3}{\partial P_3} = 0.1 P_3 + 16 = 28 \Rightarrow P_3 = 100 \text{ MW}$$

$$P_1 + P_2 + P_3 = 200$$

$$200 = 200$$

Equality constraints is satisfy

Step4: Check for inequality constraint

$$P_{Gi\,min} \leq P_{Gi} \leq P_{Gi\,max}$$

Now the plant is reduced by 2 unit

$P_D = 200 - 39 = 161 MW$

$P_1 + P_3 = 161 MW$

$P_1 = P_3 = \frac{161}{2} = \boxed{80.5 MW}$

put $P_1 = 80.5$,

$\frac{\partial C_1}{\partial P_1} = 0.1P_1 + 21.5 = 30$

$\frac{\partial C_3}{\partial P_3} = 0.14P_3 + 16 = 30$

Sub $\lambda = 30$

~~OR~~ $\boxed{\begin{array}{l} P_1 = 85 MW \\ P_2 = 100 MW \end{array}}$

$P_1 + P_3 = 161$

$185 > 161$

$\downarrow \lambda$ by 2

$\boxed{\lambda = 28}$

Subs $\lambda = 28$ in co-ordinate

$\Rightarrow 0.1P_1 + 21.5 = 28 \Rightarrow \boxed{P_1 = 65 MW}$

$\Rightarrow 0.14P_3 + 16$ ...

$\lambda_1 = 26,\ \lambda_0 = 30,\quad P_1 = 150.7\ ,\ P_0 = 185$

$$\lambda_1 + \frac{\lambda_1 - \lambda_0}{P_1 - P_0}(P_D - P_1)$$

$$= 28 + \frac{28 - 30}{(150.2 - 185)}(161 - 150.2)$$

$$= 28 + 0.6$$

$$\boxed{\lambda = 28.6}$$

Sub $\lambda = 28.6$ into co-ordination eqn

$\lambda = \frac{\partial C_1}{\partial P_1} = 0.1P_1 + 21.5 = 28.6 \Rightarrow P_1 = 71\,MW$

$P_3 = 70\,MW$

$P_2 = 39\,MW$

For the above problem calculate, the net saving by economic load sharing by compare to equal load sharing

$C_1 = 0.05P_1^2 + 21.5P_1 + 500$

$C_1 = 2158.64\ Rs/hr$

$C_2 = 0.1P_2^2 + 27P_2 + 500$

$= 2744.52\ Rs/hr$

$C_3 = 0.07P_3^2 + 16P_3 + 900$

$= 2277.86\ Rs/hr$

$C_1 = 122.91$ M

$C_2 = 1039.47$ M

$C_3 = 628.45$ M

$C_1 = \ \ 0.05P_1^2$

$0.2P_2 + 40 = 50$

$P_2 = 50$

$166.67 < 200$

$\boxed{\lambda = 55}$

λ is increase by 5

$0.3P_1 + 15 = 55$

$\boxed{P_1 = 133.33 \text{ MW}}$

$0.2P_2 + 40 = 55$

$\boxed{P_2 = 75 \text{ MW}}$

$208.33 > 200$

λ is decrease by 1

$0.3P_1 + 15 = 54$

$\boxed{P_1 = 130 \text{ MW}}$

$0.2P_2 + 40 = 54$

$\boxed{P_2 = 70 \text{ MW}}$

$P_1 + P_2 = 200$

$200 = 200$

$\boxed{\text{Then } \lambda = 54}$

A power plant has 3 units with following I/P, O/P

Characteristics

$Q_1 = 0.002P_1^2 + 0.86 P_1 + 20$ tonnes/hr

$Q_2 = 0.004P_2^2 + 1.08P_2 + 20$ tonnes/hr

$Q_3 = 0.0028P_3^2 + 0.64P_3 + 36$ tonnes/hr

if the fuel cost is 500 Rs/tonnes the max & min generation level each unit 120MW & 36 MW respectively. ~~for loading~~ find the optimum scheduling for the total load of 200 MW

Sol Fuel cost is 500 Rs/tonnes.

Multiply the cost fuel is ~~to~~ all eqn.

$C_1 = 1P_1^2 + 430P_1 + 10000$

$C_2 = 2P_2^2 + 540P_2 + 10000$

$C_3 = 1.4P_3^2 + 320P_3 + 18000$

Step 1

Assume, λ

$P_1 + P_2 + P_3 = 200$

$P_1 = P_2 = P_3 = \frac{200}{3} = 66.67$ MW

WKT

$\lambda = \frac{\partial F_1}{\partial P_1} = \cancel{0.004}\,2P_1 + 430$

Step 2:-

$i = 1, 2, 3$

Co-ordination eq

$\lambda = \frac{\partial C_1}{\partial P_1} = 2P_1 + 430 = 563$, $\boxed{P_1 = 66.5 MW}$

$\lambda = \frac{\partial C_2}{\partial P_2} = 4P_2 + 540 = 563$, $\boxed{P_2 = 5.75 MW}$

$\lambda = \frac{\partial C_3}{\partial P_3} = 2.8P_3 + 320 = 563$, $\boxed{P_3 = 86.78 MW}$

Step 3

$\sum_{i=1}^{n} P_{Gi} = P_D$, $i = 1, 2, 3$

$P_{G1} + P_{G2} + P_{G3} = P_D$ 484.29

$66.5 + 5.75 + 86.78 = 200$ 1.157

$159.03 < 200$

increase λ by 5

$\lambda = \frac{\partial C_1}{\partial P_1} \Rightarrow 2P_1 + 430 = 568$, $\boxed{P_1 = 69 MW}$

$\frac{\partial C_2}{\partial P_2} \Rightarrow 4P_2 + 540 = 568$, $P_2 = 7 MW$

$\frac{\partial C_3}{\partial P_3} \Rightarrow 2.8P_3 + 320 = 568$, $P_3 = 88.57$

$164.57 < 200$

$P_1 + P_2 + P_3 = 200$

$87 + 16 + 101.42 \neq 200$

$204.42 > 200$

Step 5

λ decrease by 4

$\frac{\partial C_1}{\partial P_1} = \boxed{P_1 = 85MW}$

$\frac{\partial C_2}{\partial P_2} = \boxed{P_2 = 15MW}$

$\frac{\partial C_3}{\partial P_3} = \boxed{P_3 = 100MW}$

$200 = 200$

Equality condition is satisfied.

Step 6 Check for inequality constraint

$P_{G_i min} \leq P_{G_i} \leq P_{G_i max}$

$P_{G_i min} = 36MW$

$P_{G_i max} = 120MW$

$P_1 = 85MW$

$P_2 = 15MW$ = set as P_2 = 36 MW

$P_3 = 100MW$

$P_1 = 82\,MW$

$\frac{\partial C_1}{\partial P_1} = 2P_1 + 430 = \cancel{266}\ 594$

Sub $\lambda = \cancel{3000}\ \cancel{266}\ 594$

$\frac{\partial C_1}{\partial P_1} = 2P_1 + 430 = 594$, $P_1 = 82\,MW$

$\frac{\partial C_3}{\partial P_3} = 2.8P_3 + 320 = 594$, $P_3 = 97.8$

$P_1 + P_3 = 164$

$82 + 97.8 = 164$

$179.8 > 164$

λ is decrease by 10

$\frac{\partial C_1}{\partial P_1} = 2P_1 + 430 = 584$; $\boxed{P_1 = 77\,MW}$

$\frac{\partial C_3}{\partial P_3} = 2.8P_3 + 320 = 584$, $P_3 = 94.28\,MW$

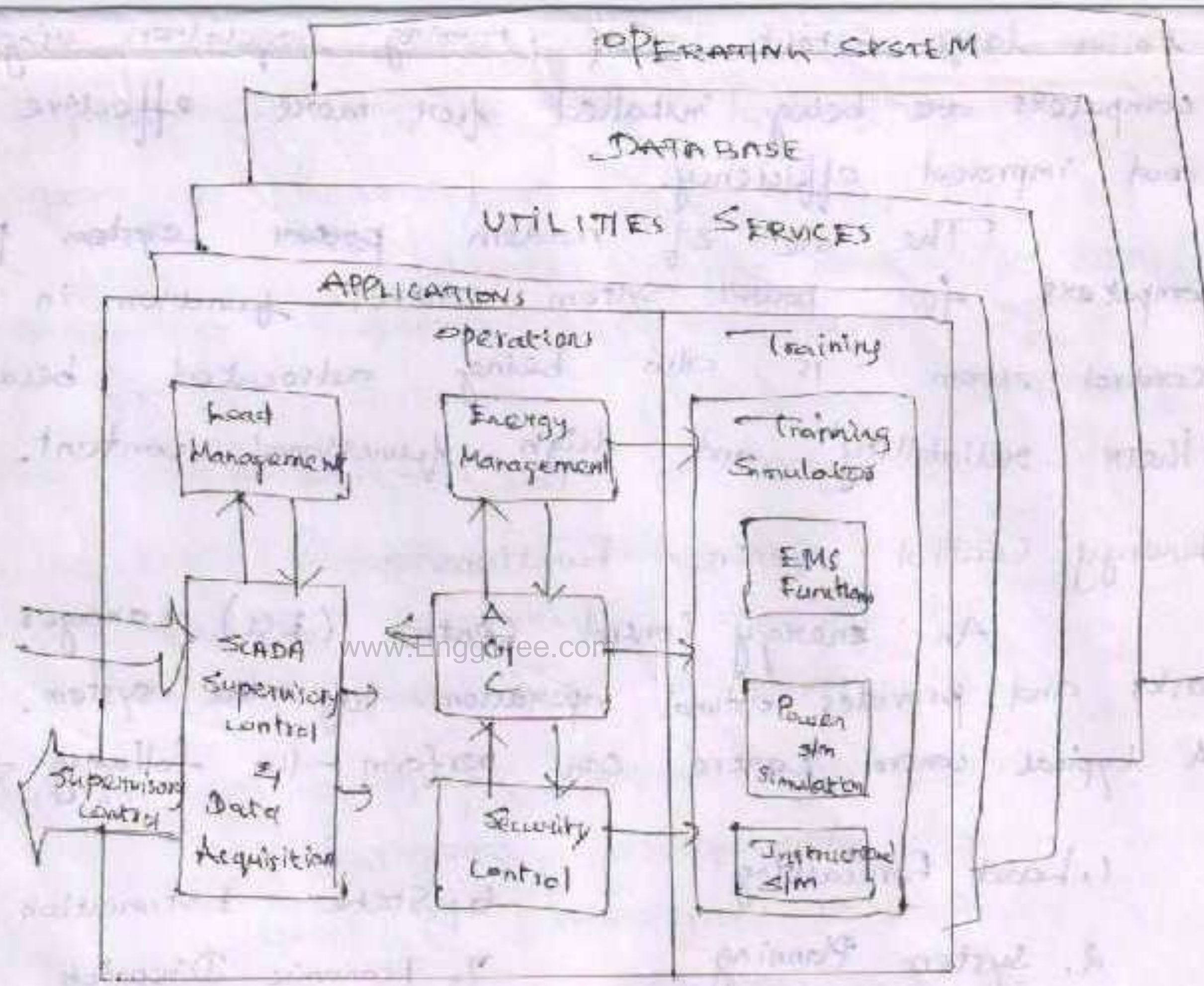
$171.8 > 164$

λ is decrease by 10

$\frac{\partial C_1}{\partial P_1} = 2P_1 + 430 = 574$, $\boxed{P_1 = 72\,MW}$.

$\frac{\partial C_3}{\partial P_3} = 2.8P_3 + 320 = 574$, $\boxed{P_3 = 90.71\,MW}$.

UNIT 5 - COMPUTER CONTROL OF POWER SYSTEM



EMS consists of energy management, AGC, security control, SCADA, load management etc.

Introduction :

The use of computers nowadays encompasses al[l] phases of power system operation :

1. Planning 2. Forecasting 3. Scheduling

4. Security & 5. Power s/m control

With in the power stations, automation is taking o[n] to a large extent. Self - tuning regulators using pe[r] computers are being installed for more effective con[trol] and improved efficiency.

The use of modern ~~power system~~ person[al] computers for power system control function in a control room is also being advocated, because [of] their reliability and high functional content.

Energy Control Centre Functions :-

An Energy Control Centre (ECC) manages thes[e] tasks and provides optimal operation of the system. A typical control centre can perform the following functi[ons]

1. Load Forecasting
2. System Planning
3. Unit Commitment
4. Maintanance Scheduling
5. Security Monitoring
6. State Estimation
7. Economic Dispatch
8. Load Frequency contro[l]

Real time computer control of power system :

The computer system involves dual confi with external interfaces to monitor the data.

The first one is a process computer linke by telechannels to various generating and sub-sta for data acquisition.

The second one is a larger one where ma calculations are carried out and is linked to the process computer.

For a real time computer control of power systems, the following ~~data~~ basic components are needed:

1. System Wide instrumentation
2. High Speed digital telemetry
3. Central Processing Unit
4. Memory & bulk Storage
5. Interactive display &
6. Software (operating & Application)

The real time ~~control~~ computer consists of mo and interfaces, CPU, memory and bulk storage & i/p o/p devices like display devices, card-reader, Local Control centre :

A no of control functions can be performed locally at power generating stations and substation using local equipment and automatic devices. LCC have the following functions.

1. Local monitoring & control
2. Protection
3. Auto - Reclosure
4. Voltage Regulation
5. Capacitor Switching
6. Feeder Synchronization
7. Load shedding &
8. Network restoratio

Area Load dispatch Centre :

A group of generating stations & sub-statio along with the associated n/w and loads may considered as a unit for control under an area load dispatch centre.

The area control centre receives inform and process it for appropriate control actio

Fourth level (Top level) Inter connected power systems Regional control centre.

Supervisory Control and Data Acquisition (SCADA)

SCADA system is an arrangement which consists many equipments which performs controlling and monitoring of a power system or a part of a power system.

Locations of SCADA

1. Master Control Centre (National Grid control)
2. Zonal (Regional) control centre
3. District (State EB) control centre
4. Control rooms of generating stations & Large substations

SCADA requires two-way communication channels the master control centre and remote control centre through

(i) Microwave
(ii) Cables (separate)
(iii) Carrier Communication (PLC)

Features of SCADA systems :

1. Data collection (Data Acquisition)
2. Data Transmission (Telemetry)
3. Scanning, Indication, Monitoring, Logging
4. Execution of operating commands :
   ON / OFF, RAISE / LOWER
5. Network, supervision, alarms & report any uncommon change of state
6. Control & Indication
7. Ensure sequential Events

Various types of SCADA systems

Type 1 : Small distribution systems, small hydro sta
HVDC links.

Type 2 : Medium sized power systems, powe
stations, HVDC links distribution syste

Type 3 : Regional Control Centre

Type 4 : National & Regional control Centre

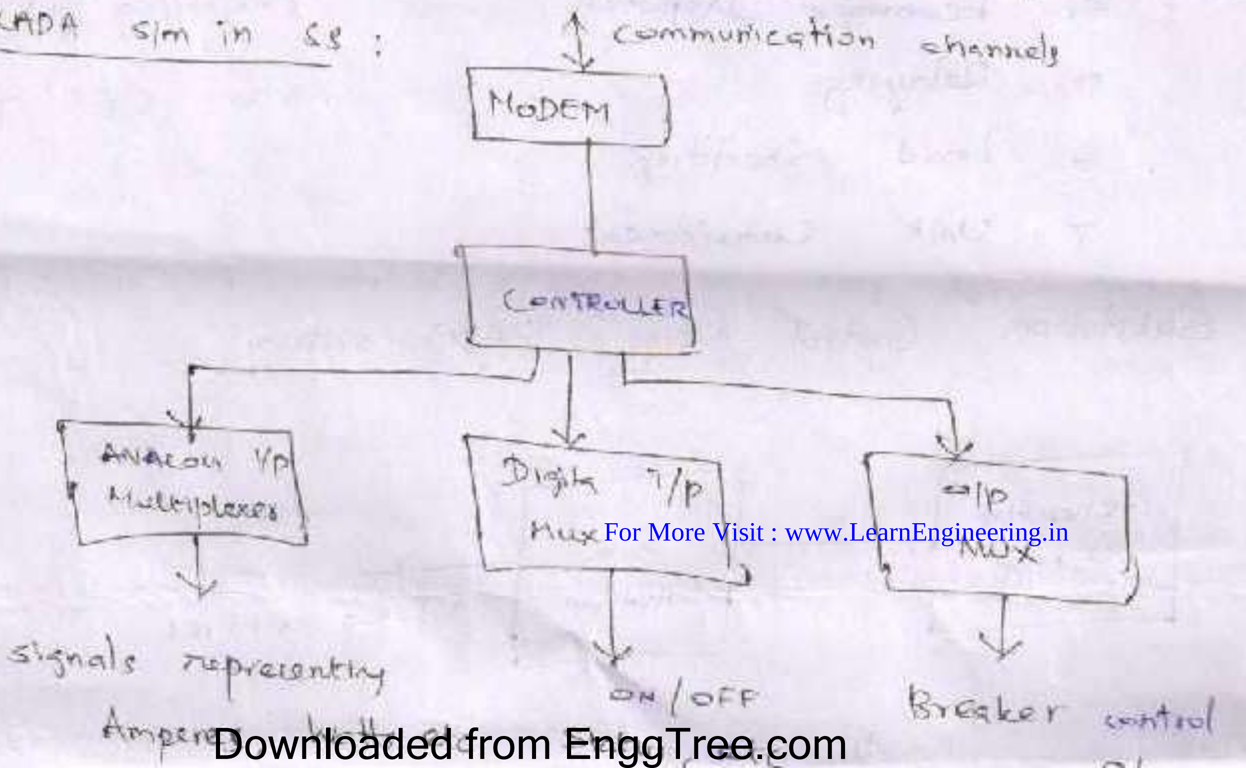
from same location
instruction / information

from Remote
Instruction / Inform

operation with the aid of analogue and digital control systems in the plant.

The breakers can be operated by remote control from the control room. During faults and abnormal conditions, the breakers are operated by protective relays automatic. Thus the primary control in SS is of 2 cate

SCADA s/m in SS :



Unit Level

From this level, the lines, t/fs are contro[lled]

& supervised. The equipment is divided into a no.

of independent units. This division improves the

operating reliability & simplifies future extensi[on]

such as additional lines.

The fns are

1. Line protection, Breaker Failure Protection

2. Auto - Reclosing

3. Synchronising check

4. Energy Metering

5. Collection of position indication &

measured values.

6. Execution of commands from substation leve[l]

computer.

7. Back -up control