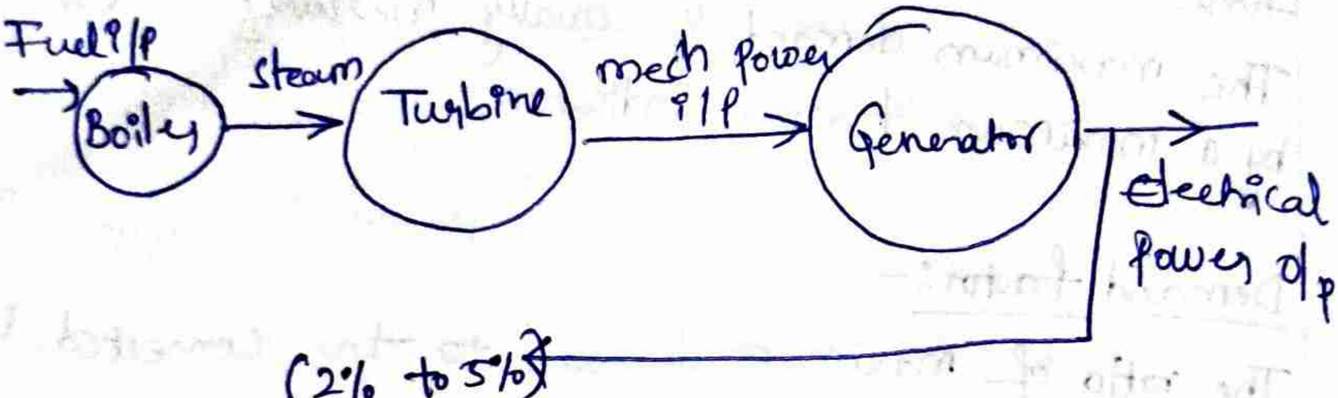
Optimal operation of Generator in Thermal Unit



For supply auxilliary units and boiler feed pumps, converter etc.

Optimal dispatch :-

Scheduling is the process of allocation of generation among different generating units. Economic Scheduling is a cost-effective mode of allocation of generation among the different units in such a way that the overall cost of generation should be minimum. This can also be termed as an optimal dispatch.

Total demand on the station $= P_D$

No. of generating units $= n$.

$P_{G_1}, P_{G_2}, P_{G_3} ---- P_{G_n}$ are the units to supply the demand P_D.

Optimal Allocation of Total load neglecting losses

$$F = \sum_{i=1}^{n} F_i(P_{G_i})$$

where F_i is the cost function of the i^{th} unit.

→ The cost is to be minimized subject to the equality constraint given by

$$P_D = \sum_{i=1}^{n} P_{G_i} \qquad \text{(neglecting losses } P_L = 0\text{)}$$

$$\Rightarrow \sum_{i=1}^{n} P_{G_i} - P_D = 0.$$

where P_{Gi} is the real-power generation of the ith unit.

⇒ To get the soln for optimization problem using Lagrangian multiplier (λ) as

$$F' = F_i - \lambda\left[\sum_{i=1}^{n} P_{Gi} - P_D\right] \quad \mathcal{L} = F_i - \lambda\left(\sum_{i=1}^{n} P_{Gi} - P_D\right)$$

⇒ $\dfrac{dF'}{dP_{Gi}} = 0$ (condition for optimality)

$$\Rightarrow \frac{dF'}{dP_{Gi}} = \frac{dF_i}{dP_{Gi}} - \frac{d}{dP_{Gi}}\left[\lambda\left(\sum_{i=1}^{n} P_{Gi} - P_D\right)\right] = 0$$

$$\Rightarrow \frac{dF'}{dP_{Gi}} = \frac{dF}{dP_{Gi}} - \lambda(1-0) = 0 \quad \frac{\partial \mathcal{L}}{\partial P_{Gi}} = \partial f_i$$

P_D is a constant and is an uncontrolled Variable.

$$\frac{dP_D}{dP_{Gi}} = 0$$

$$\therefore \frac{dF'}{dP_{Gi}} = \frac{dF}{dP_{Gi}} - \lambda = 0$$

$$\Rightarrow \frac{dF}{dP_{Gi}} - \lambda = 0$$

$$\Rightarrow \boxed{\frac{dF_1}{dP_{G1}} = \frac{dF_2}{dP_{G2}} = \frac{dF_3}{dP_{G3}} = \cdots = \frac{dF_n}{dP_{Gn}} = \lambda}$$

It is called a co-ordination equation

$$\frac{dF_1}{dP_{G1}} = a_1 P_{G1} + b_1 = \lambda$$

$$\Rightarrow \lambda = a_1 P_{G1} + b_1$$

$$P_{G1} = \frac{\lambda - b_1}{a_1} \quad \text{(or)} \quad P_{Gi} = \frac{\lambda - b_i}{a_i}.$$

Economic dispatch neglecting losses and including Generator limits.

$$\frac{dF_i}{dP_{G_i}} = \lambda \quad \text{for} \quad P_{G_i}(\min) \le P_{G_i} \le P_{G_i}(\max)$$

$$\frac{dF_i}{dP_{G_i}} \le \lambda \quad \text{for} \quad P_{G_i} = P_{G_i}(\max)$$

$$\frac{dF_i}{dP_{G_i}} \ge \lambda \quad \text{for} \quad P_{G_i} = P_{G_i}(\min)$$

cost

fuel weight

$$\mathcal{L} = F_i - \lambda f$$

$$\mathcal{L} = F_i - \lambda(P_{G_i} - P_D)$$

$$\frac{\partial \mathcal{L}}{\partial P_{G_i}} = \frac{\partial F_i}{\partial P_{G_i}} - \lambda(1 - 0)$$

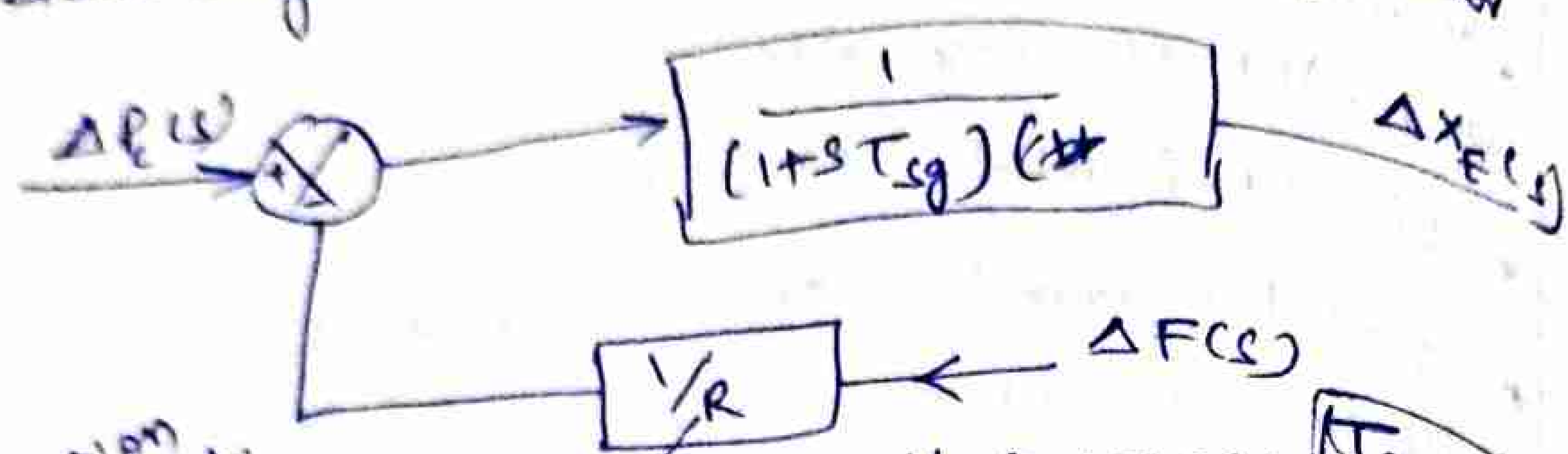
$$\Rightarrow 0 = \frac{\partial F_i}{\partial P_{G_i}} - \lambda$$

$$\frac{\partial F_i}{\partial P_{G_i}} = \lambda$$

Speed governing of system

This topic is submitted in the Assignment.

Block diagram of Simplified turbine governor



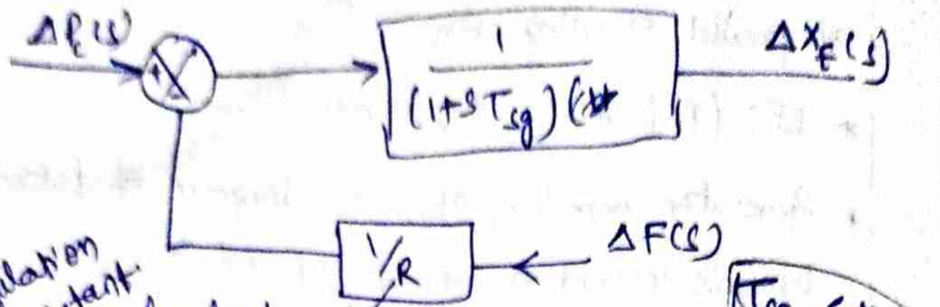
(Regulation constant) $R \rightarrow$ Speed regulation of the governor. $T_{sg} \leq 100$ ms

Block diagram model of a speed-governor system

Speed governing of system

This topic is submitted in the Assignment.

Block diagram of simplified turbine governor



(Regulation constant)

R → Speed regulation of the governor. $T_{sg} \le 100\,ms$

Block diagram model of a speed-governor system

Turbine model :-

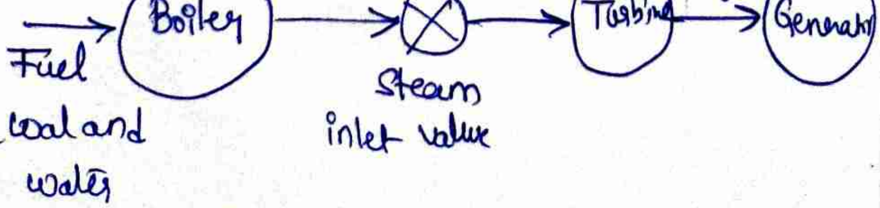
The model requires a relation b/w changes in power output of the steam turbine to changes in it's steam valve opening ΔX_E.

We consider here non-reheat turbine with a single gain K_T and a single time constant T_t

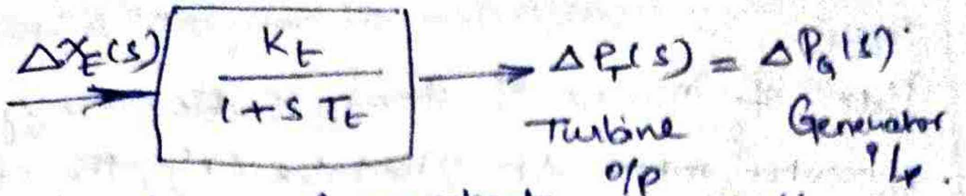
Thus the representation of the T.F is given as

$$G_T(s) = \frac{\Delta P_t(s)}{\Delta X_E(s)} = \frac{K_T}{1+sT_t}$$ (T_t range 0.2 to 2)

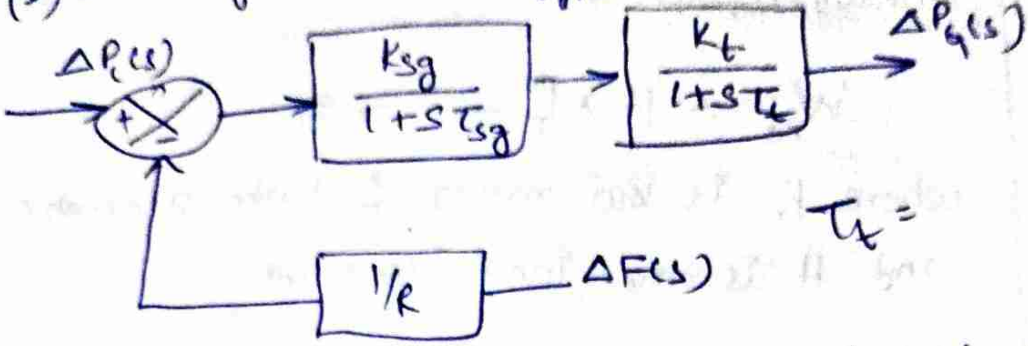
Typically the time constant T_t lies in the range 0.2 to 2.0 sec.



(a) Single stage non-reheat steam turbine



(b) block diagram of non-reheat type steam turbine



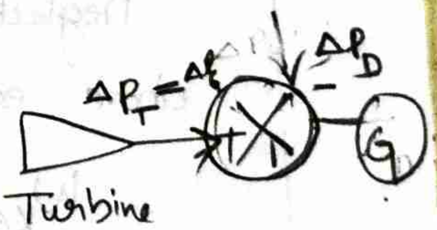
(C) T/F representation of speed control mechanism of a general generator with a non-reheat type steam turbine.

$$\Delta P_G(s) = \frac{K_{sg}K_t}{(1+sT_{sg})(1+sT_t)}$$

Generator Load Model :-

The ~~increas~~ generator-load model gives the relation between the change in frequency (Δf) as a result of the change in generation (ΔP_G) when the load changes by a small amount ΔP_D.

The increment in power input to the generator-load system is

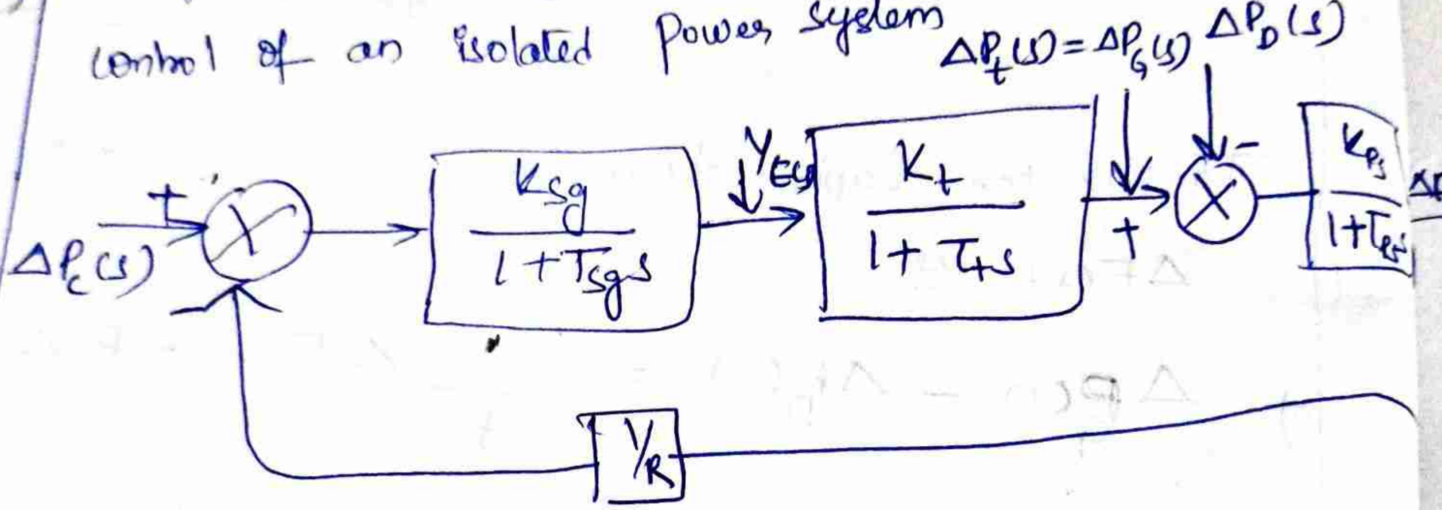


$$\Delta P_G - \Delta P_D \longrightarrow (i)$$

where $\Delta P_G = \Delta P_t$, incremental turbine output (assuming generator incremental loss to be negligible) and ΔP_D is the load increment.

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

→ Complete block diagram representation of load frequency control of an isolated power system.



Block diagram model of load-frequency control (Isolated power system)

A complete block diagram representation of an isolated power system comprising turbine, generator, governor and load is easily obtained by combining the block diagram of individual components.

Control Area Concept:-

In real practice, the system of a single generator that feeds a large and complex area has rarely occured.

→ Several generators connected in parallel, located also at different locations, will meet the load demand of such geographically large area.

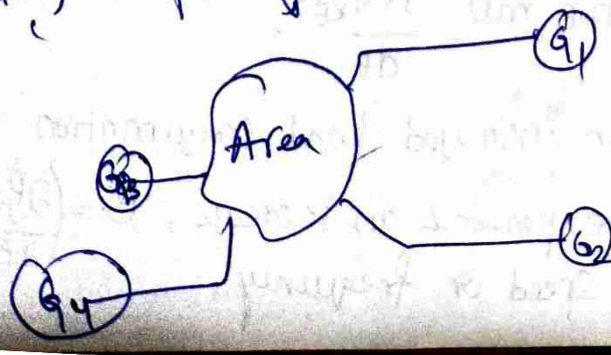
→ All the generators may have the same response characteristics to the changes in load demand.

→ So the large power system is divided into sub-areas, in which all the generators are tightly coupled such that they swing in unison (simultaneously) with change in load due to a speed-changer setting.

→ Such an area, where all the generators are running cohererently is termed as a $\boxed{\text{control area}}$.

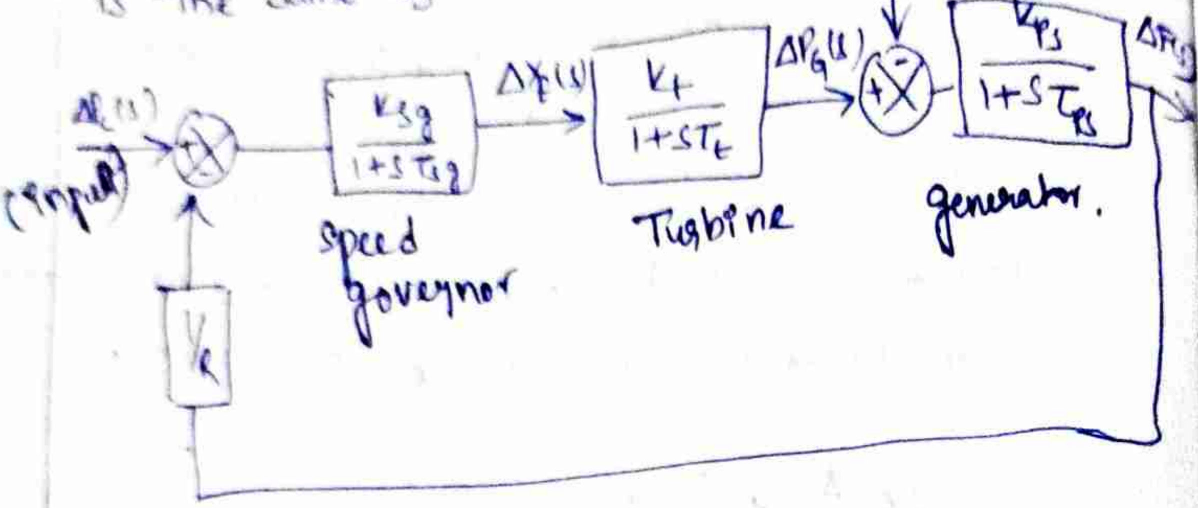
→ In this area, frequency may be same in steady state and dynamic conditions.

→ For developing a suitable control strategy, a control area can be reduced to a single generator, a speed governor, and a load system.



Block diagram representation of a single area

The block diagram of an isolated power system, which in essence is a single-area system, is the same as the block diagram.



Single-Area - Steady State Analysis :-

The block diagram of an LFC of an isolated power system of a third-order model is represented in the above block diagram.

There are two incremental inputs to the system are

(i) The change in the speed-changer position, (ΔP_c) (speed change

(ii) The change in load-demand, ΔP_D.
(Load demand)

Dynamic Analysis (Uncontrolled case)

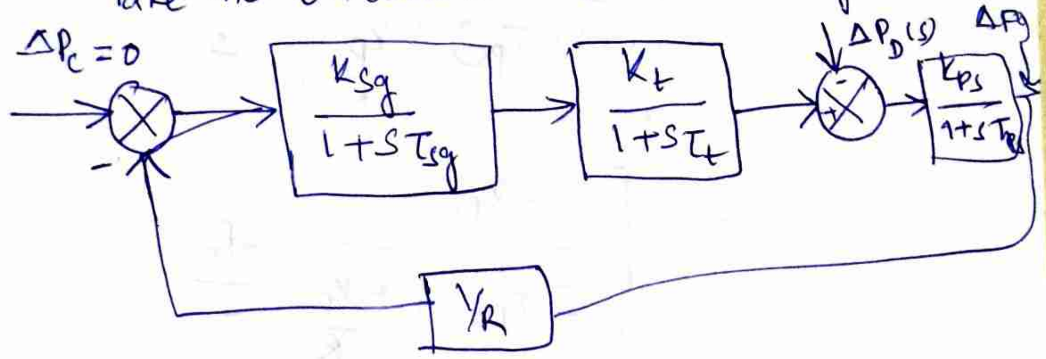
The meaning of dynamic response is how the frequency changes as a function of time "immediately after disturbance before it reaches the new steady-state condition." $f(t)$

The analyzation of dynamic response requires the "solution of dynamic equation of the system for a given disturbance." $t=0^-$ to $t=0^+$ 0^- 0^+

D.R → D.E

The solution involves of different equations representing the dynamic behavior of the system.

Take the uncontrolled case block diagram



For the above block diagram

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

For a practical LFC system

$$T_{sg} << T_t << T_{ps}$$

Typical values are $T_{sg} = 0.4s$

$T_t = 0.5s$

$T_{ps} = 20s.$

Load frequency control of two area system

→ An extended power system can be divided into a number of load frequency control (LFC) areas, which are interconnected by tie lines. Such an operation is called "pool operation".

→ A power pool is an interconnection of the power systems of individual utilities.

→ Each power system operates independently within it's own jurisdiction, but the internal system exchanges of power through the tie lines to maintain system frequency.

The basic principle of a pool operation in the normal steady state provides.

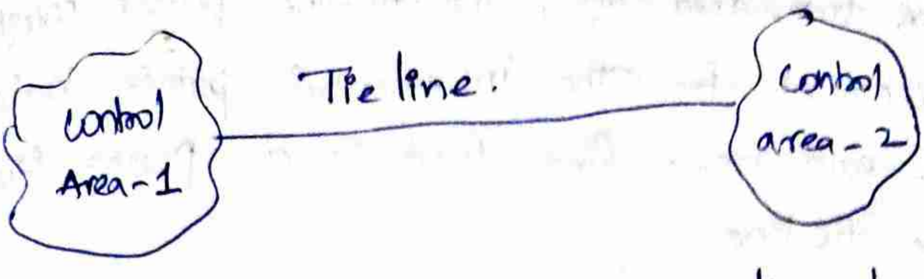
(i) Maintaining of scheduled interchanges of tie-line power:

The interconnected areas share their reserve power to handle load peaks and unanticipated generator outages.

(ii) Absorption of own load change by each Area:

The interconnected areas can tolerate larger load changes with smaller frequency deviations than the isolated power system areas.

IV
2nd



Two control areas interconnected through a single tie line.

For analyzing the dynamics of the LFC of n area power system, consider 2-area systems.

Here the control is to regulate the frequency of each area and to simultaneously regulate the power flow through the tie line according to an interarea power arrangement.

In the case of an isolated control area, the zero steady-state error in frequency ($\Delta f_{\text{steady state}} = 0$) can be obtained by using PPI controller,

where as in two-control area case, PPI will be installed to give zero steady-state error in a tie line power flow, in addition to zero steady-state error.

For the sake of convenience, each control area can be represented by turbine, generator and governor system.

In case of ΔP single area, the incremental power $(\Delta P_G - \Delta P_D)$ was considered by the rate of increase of stored KE and increase in frequency.

$$\Delta P_G - \Delta P_D = \frac{dW_{KEi}}{dt} + B\Delta f$$

Response of a Two-area System - Uncontrolled case

For Uncontrolled case $\Delta P_{c_1} = \Delta P_{c_2} = 0$.

i.e., Speed changes positions are fixed.

Static Respons :-

The changes or deviations, which result in the frequency and tie-line power under Steady-state conditions following Sudden Step changes in the loads in two areas

$\Delta P_{D_1}, \Delta P_{D_2} \longrightarrow$ incremental step changes in the loads of control area-1 & 2.

$\Delta P_{G_1}, \Delta P_{G_2} \longrightarrow$ are incremental Changes in generation of Area 1 and Area 2.

$\rightarrow$ Δf is Change in freq.

Incremental Change in generation of 1

$$\Delta P_{G_1} = -\frac{\Delta f}{R_1} \longrightarrow (1)$$

and (2) $\Delta P_{G_2} = \frac{-\Delta f}{R_2} \longrightarrow (2)$

$$\left(\Delta P_{G_1} - \Delta P_{D_1}\right) = \frac{2H_1}{f^0} \cdot \underbrace{\frac{d}{dt}(\Delta f_1)}_{=0} + B_1(\Delta f_1) + \Delta P_{TL1} \longrightarrow (3)$$

$$\left(\Delta P_{G_2} - \Delta P_{D_2}\right) = \frac{2H_2}{f^0} \underbrace{\frac{d}{dt}(\Delta f_2)}_{=0} + B_2 \Delta f_2 + \Delta P_{TL2} \longrightarrow (4)$$

Module

Load frequency And Economic Dispatch controls :-

Load frequency control with integral controller achieves zero steady state frequency error and a fast dynamic response, but it excercises no control over the relative loadings of various generating stations of the control area.

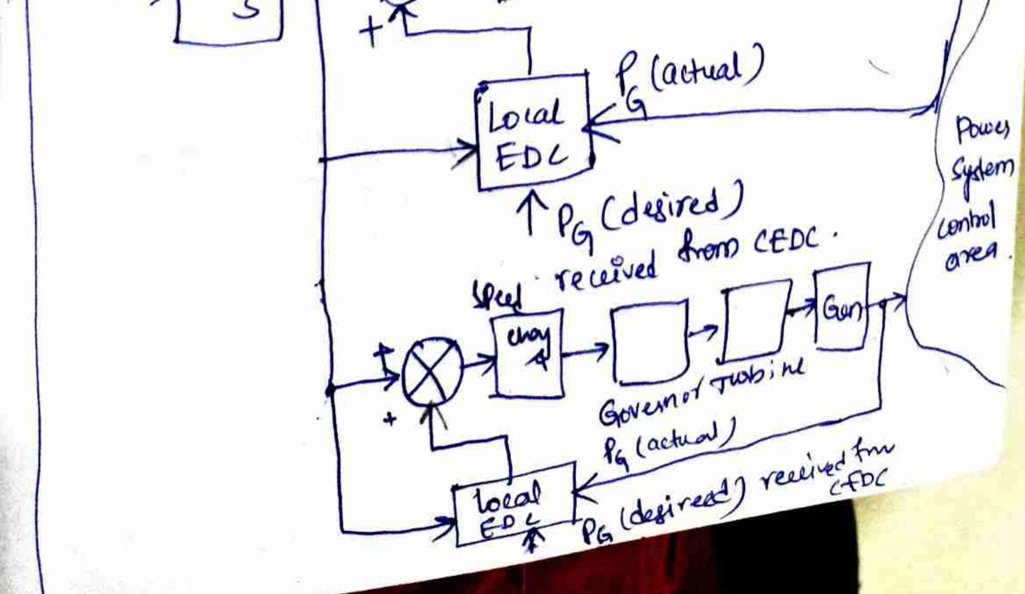
For ex, if a sudden small increase in load (say 1%) occurs in the control area, the LFC changes the speed changer settings of the governors of all generating units of the area so that, together, these units match the load and the frequency returns to the schedule value.

→ However, in the process of this change the loadings of various generating units change in a manner independent of economic loading considerations.

→ In fact, some units may even get overloaded.

→ A satisfactory solution is achieved by using independent controls for load frequency and economic dispatch.

→ while load frequency controller is a fast acting control, and regulates the system around an operating point; the economic dispatch controller is a slow acting control, which adjusts the speed changer setting every minute in accordance with a command signal generated by the CEDC (central economic dispatch computer)

→ 

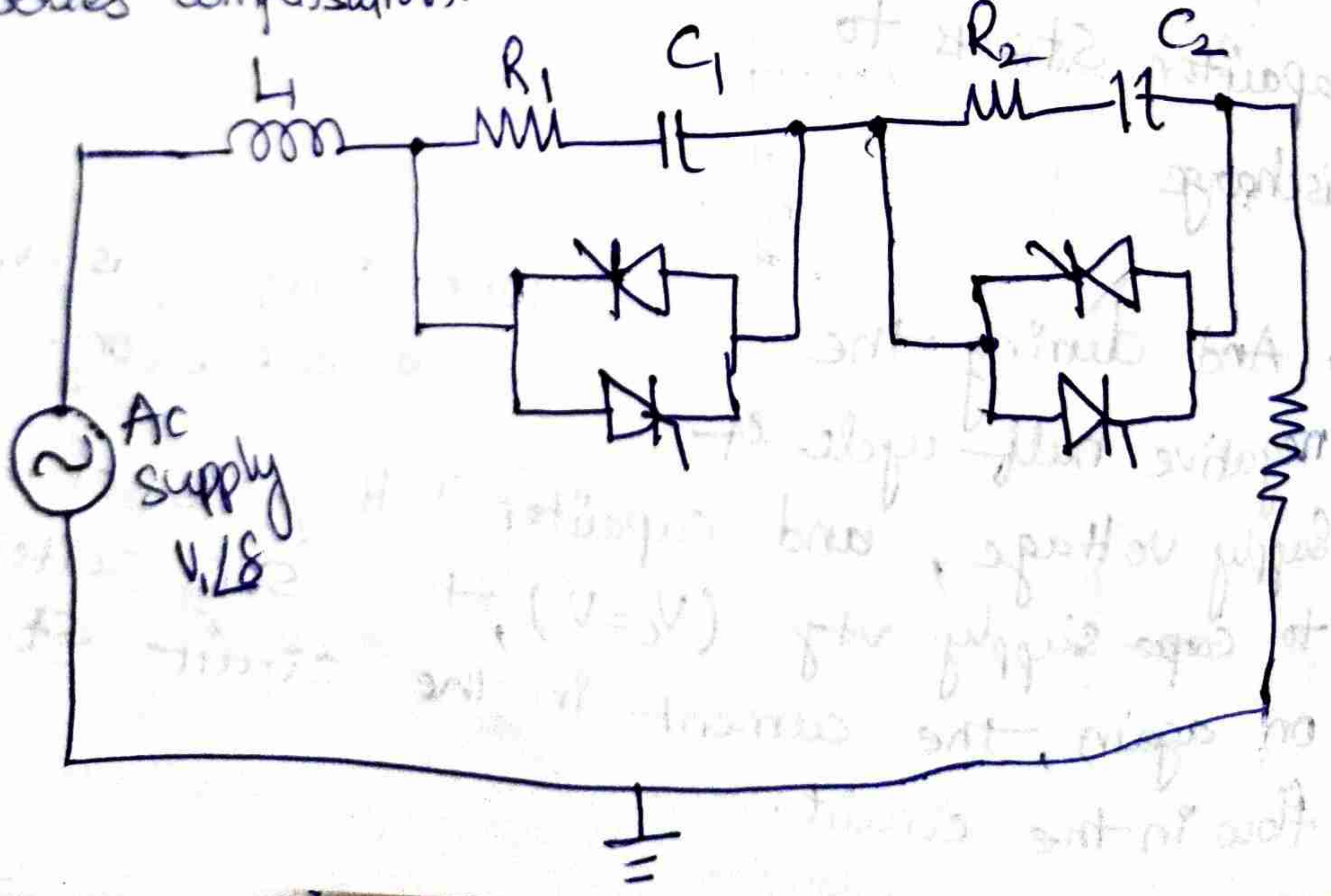
The above schematic diagram of both these controls for two typical units of a control area.

The signal to change the speed changer setting is constructed in accordance with economic dispatch error [P_G (desired) − P_G (actual)], is suitably modified by the signal representing integral ACE at that instant of time.

The P_G (desired) is computed by the central economic dispatch computer (CEDC) and is transmitted to the Local economic dispatch controller (EDC) installed at each station.

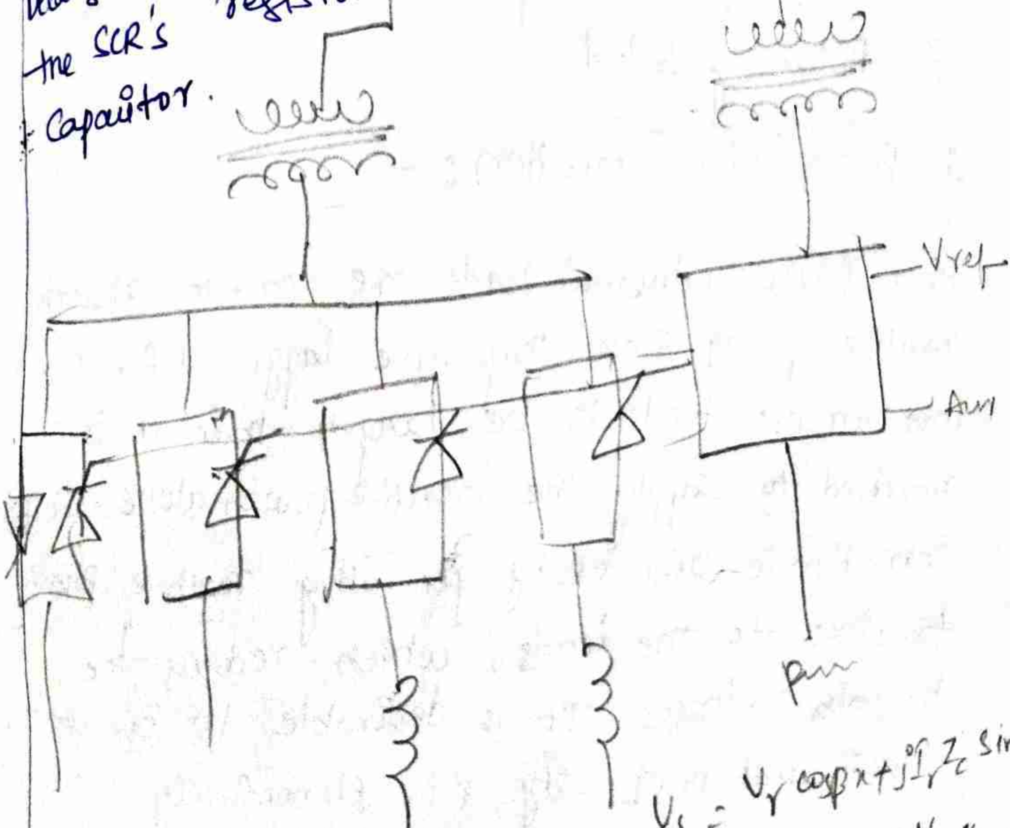
Series Compensator :-

In the TSC scheme, increasing the number of capacitor banks in Series Controls the degree of Series compensation.



to accomplish this, each capacitor bank is controlled by a thyristor bypass Switch or Valve.

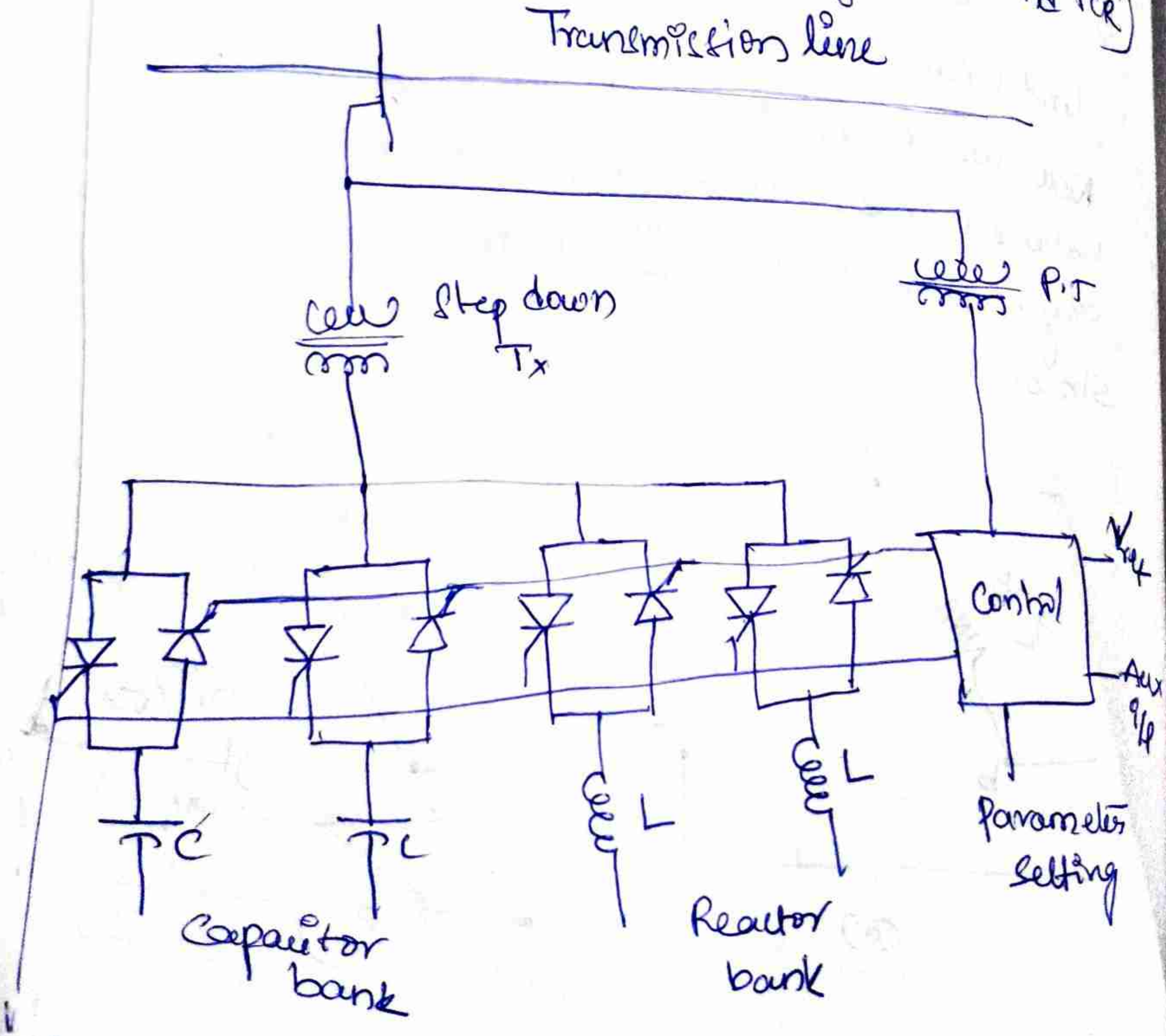
- The operation of the thyristor switches is co-ordinated with voltage and current zero-crossing;
- The thyristor switch can be turned on to bypass the capacitor bank
  And when the applied AC voltage crosses zero, and its turn-off to be initiated prior to current zero, at which it can recover it's voltage blocking capability to activate capacitor bank.
- Initially, capacitor is charged to some voltage while switching the SCR's, they may get damaged because of the initial voltage. In order to protect the SCR's resistor is connected in series with capacitor.



$$V_s = V_r \cos\beta x + j I_r Z_c \sin\beta x$$

$$I_r = I_r \cos\beta x + j \frac{V_r}{Z_c} \sin\beta x$$

Shunt Compensator (Static VAR compensator using TSCs and TCR)



A shunt connected static VAR compensator, composed of TSCs and TCRs. With proper co-ordination of the capacitor switching and reactor control, the VAr output can be varied continuously.

Between the capacitive and inductive rating of the equipment. The compensator is normally operated to regulate the voltage of the transmission system at a selected terminal.

Specifications of load compensates

* Maximum and continuous reactive power requirement in terms of absorbing as well as generation
* Overload rating and duration.
* Rated Voltage and limits of Voltage between which the reactive power rating must not be exceeded.
* Frequency and it's variation.
* Accuracy of voltage regulation requirement
* Maximum harmonic distortion with compensation in Series.
* Accuracy of Voltage regulation equipment.
* Response time of the compensator for a specified disturbance.
* Emergency procedure and precautions
* Reliability and redundancy of components.

Necessity of maintaining frequency constant

1) Ac motors require consta freny of supply to
2) continuous process Industry, it effecs maintain speed
csupply
3) synchronous operation of various units in power system
4) Freny amount of power transfd through the line $P = \frac{EV}{X} \sin\delta$
5) Electrical clocks → synchronous
aum ↳ freny → nxf → loss or gain of
time by elu