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Introduction - The successful operation of a power system requirers the folllowing conditions to be fulfilled.

* generation must be adeqruate to meet all the load demand
* system frequency must be maintained within reasonable limits.
* system voltage profile must be maintained
* in case of inter connected operation, the tie line power flows must be maintained at the specified values.

An electrical system normally operates under steady state condition. In this state, it is essential to maintain a power balance in the system. Under steady state operation both the bus voltages and system frequency are maintained at prescribed constant values by ensuring thats their is proper matching between load and demand for both active and reactive power.

In reality, the system is never under steady-state as the active and reactive power load demands of the system are never steady but continously change with increase or fall of demand. Thus the power output of generators must be adjusted at all the times so that the power balance is maintained.

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The active or real power generated (or delievered) by a generator is changed by controlling the mechanical ~~mechanical~~ power output of a prime mover such as steam-turbine

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hydraulic turbine etc. In case of steam and hydraulic turbine, the mechanical power is controlled by controlling the opening or closing of valves thereby regulating steam or water flow into the turbine.

The imbalance in active power is sensed through the change in generator speeds and/or frequency. If there is excessive power generation then the generator will speed up and there will be a rise in frequency. However if there is a deficiency in active power generation then both speed of generator and frequency will decrease. These deviations in speed and/or frequency from normal speed and/or frequency are used to control signals for causing appropriate valve closing or opening automatically. This is known as load frequency control.

Basic Generator Control Loops — In an interconnected power system, load frequency control (LFC) and automatic voltage regulator (AVR) equipment are installed for each generator. The fig. (1) represents the schematic diagram of the load frequency control (LFC) loop and the automatic voltage regulator (AVR) loop.

* 1.) AVR loop — The automatic voltage regulator (AVR) loop controls the magnitude of the terminal voltage V. The voltage magnitude |V| is continously monitored by a potential t/f and rectifier. This dc voltage signal which is proportional to |V| is compared with a d.c ref. voltage

|V|ref. and the error signal voltage Δe is amplified and fed to the exciter as input signal which in turn changes the voltage applied to the field wdg. of the synchronous gen.

2) Load Frequency Control Loop — The LFC loop regulates the active power output and the frequency of the generator. It consists of a fast primary loop and a slower secondary loop. The function of the primary loop is to respond to relatively fast changes in load fluctuations that is sensed through changes in speed. A signal ΔP_C is generated which is amplified and transformed into real power signal ΔP_V which regulates control valves of steam or hydro turbines thereby changing generator real power output.

A secondary loop is a slow acting loop which does fine adjustment of frequency. It is not sensitive to fast changes in load & frequency.

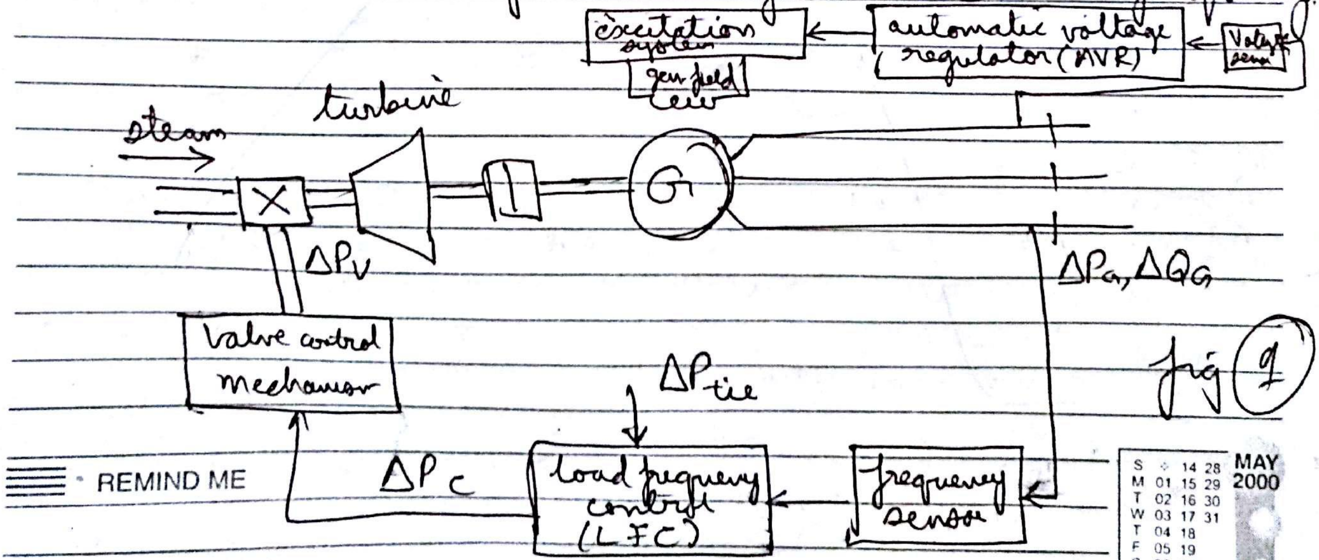

fig 9

The controllers (for LFC & AVR) are set for a particular operating condition and take care of small changes in load demand to maintain the frequency and voltage magnitude within the specified limits. Small changes in real power are mainly dependent on changes in rotor angle δ and thus frequency whereas the reactive power is mainly dependent on the voltage magnitude (i.e. on generator excitation).

The time constant of excitation system is much smaller than the prime mover time constant and its transient decay much faster without affecting LFC dynamic. Thus the cross-coupling between LFC and AVR loops is negligible and hence LFC and AVR can be analyzed independently.

Load Frequency Control (LFC) – The operation objectives of the LFC are to maintain reasonably uniform frequency, to divide the load between generators, and to control the tie-line interchange schedules. The change in frequency and tie line real power are sensed, which is a measure of the change in rotor angle δ i.e. the error Δδ is to be corrected. The error signal Δf and ΔP_{tie} are amplified, mixed and transformed into a real power command signal ΔP_V, which is sent to the prime mover to call for an increment in torque.

The first step in the analysis and design of a control system is mathematical modeling of the system. The two most common methods are the transfer function method and the state variable approach. The state variable approach can be applied to

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linear as well as non-linear system. However for transfer model, the non linear system must first be linearized. The transfer function model is obtained for the following components.

Generator Model — The swing equation of a synchronous machine is given by

$$\frac{H}{\pi f_0}\frac{d^2\delta}{dt^2} = P_m - P_e \quad [P_m \text{ and } P_e \text{ are in pu}]$$

If there is a small changes in power developed then we have

$$\frac{2H}{\omega_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e \quad [\omega_s = 2\pi f_0]$$

or in terms of small deviation in speed

$$\frac{2H}{\omega_s}\frac{d\Delta\omega}{dt} = \Delta P_m - \Delta P_e$$

$$\text{or} \quad \frac{d\,\Delta\omega/\omega_s}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \quad \left[\frac{d\omega}{dt} = \frac{d^2\delta}{dt^2}\right]$$

If speed is expressed in per unit then we have

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e)$$

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Taking Laplace transform of eq. (1) gives

$$\Delta\Omega(s) = \frac{1}{2Hs}\left[\Delta P_m(s) - \Delta P_e(s)\right]$$

or $$\frac{\Delta\Omega(s)}{(\Delta P_m(s) - \Delta P_e(s))} = \frac{1}{2Hs} \Rightarrow \text{transfer function}$$

The resulting block dig. for generator is given by fig (2)

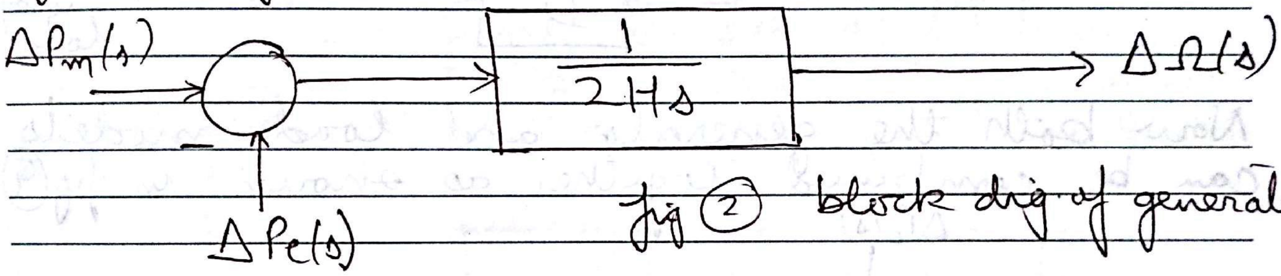

fig (2) block dig. of generator

Load Model — In the case of a power system the load consists of a variety of electrical devices among which some are resistive loads which are independent of frequency and some loads like motor loads are sensitive to the changes in frequency. The speed load characteristics of a composite load is approximated by

$$\Delta P_e = \Delta P_L + D\Delta\omega \quad \text{——} \quad (2)$$

where $\Delta P_L \rightarrow$ non-frequency sensitive load change

$D.\Delta\omega \rightarrow$ frequency sensitive load change

where D is expressed as

$$D \triangleq \frac{\%\ \text{change in load}}{\%\ \text{change in frequency}}$$

Taking Laplace transform of eq (2) we get

$$\Delta P_e(s) = \Delta P_L(s) + D\,\Delta\Omega(s)$$

The block dig of load is given by fig (3)

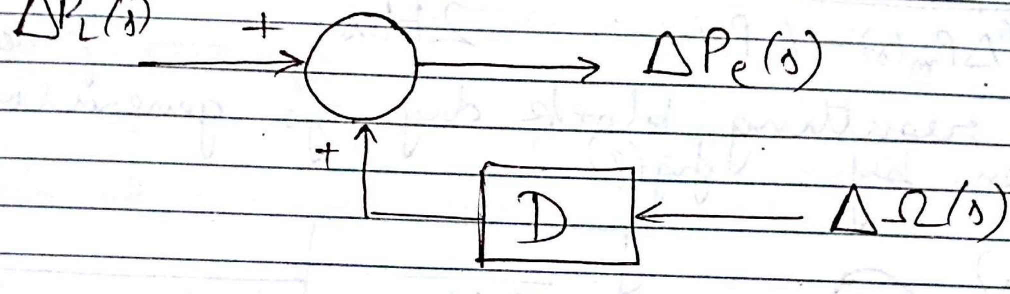

fig (3) block dig of load

Now both the generator and load models can be combined together as shown in fig (4)

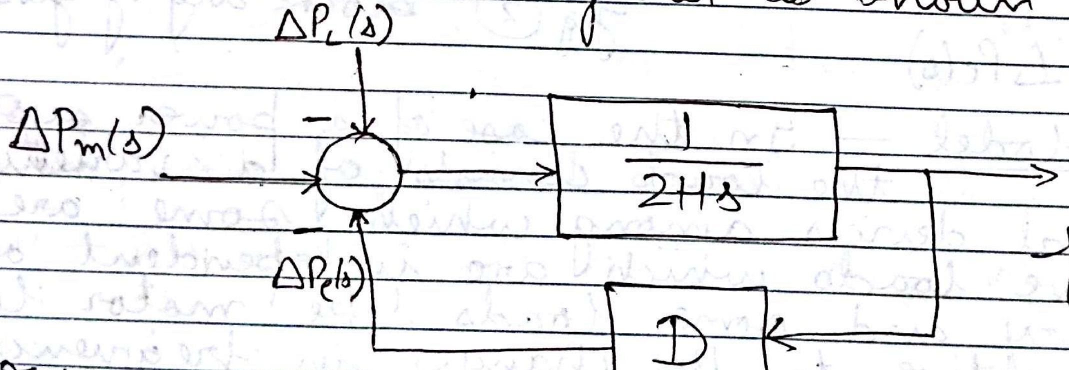

fig (4) gen. & load combined

Eliminating the feedback loop using block reduction technique we finally get the combined generator - load model as shown in fig (5)

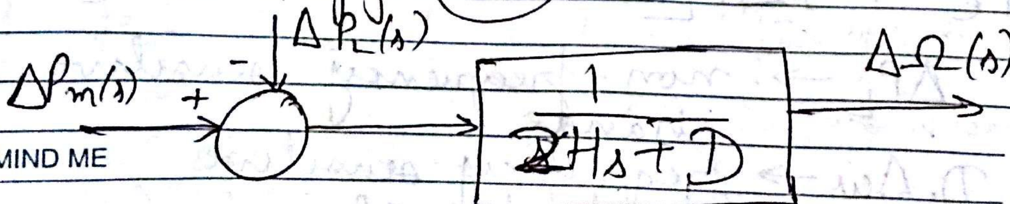

fig (5)