Generation control:

- **Objectives**

  Generating & delivering power in an interconnected system as economically and reliably as possible, *while maintaining voltage and frequency within permissible limits.*

- **Control loops**

  Load Frequency Control

  Automatic Voltage Regulator

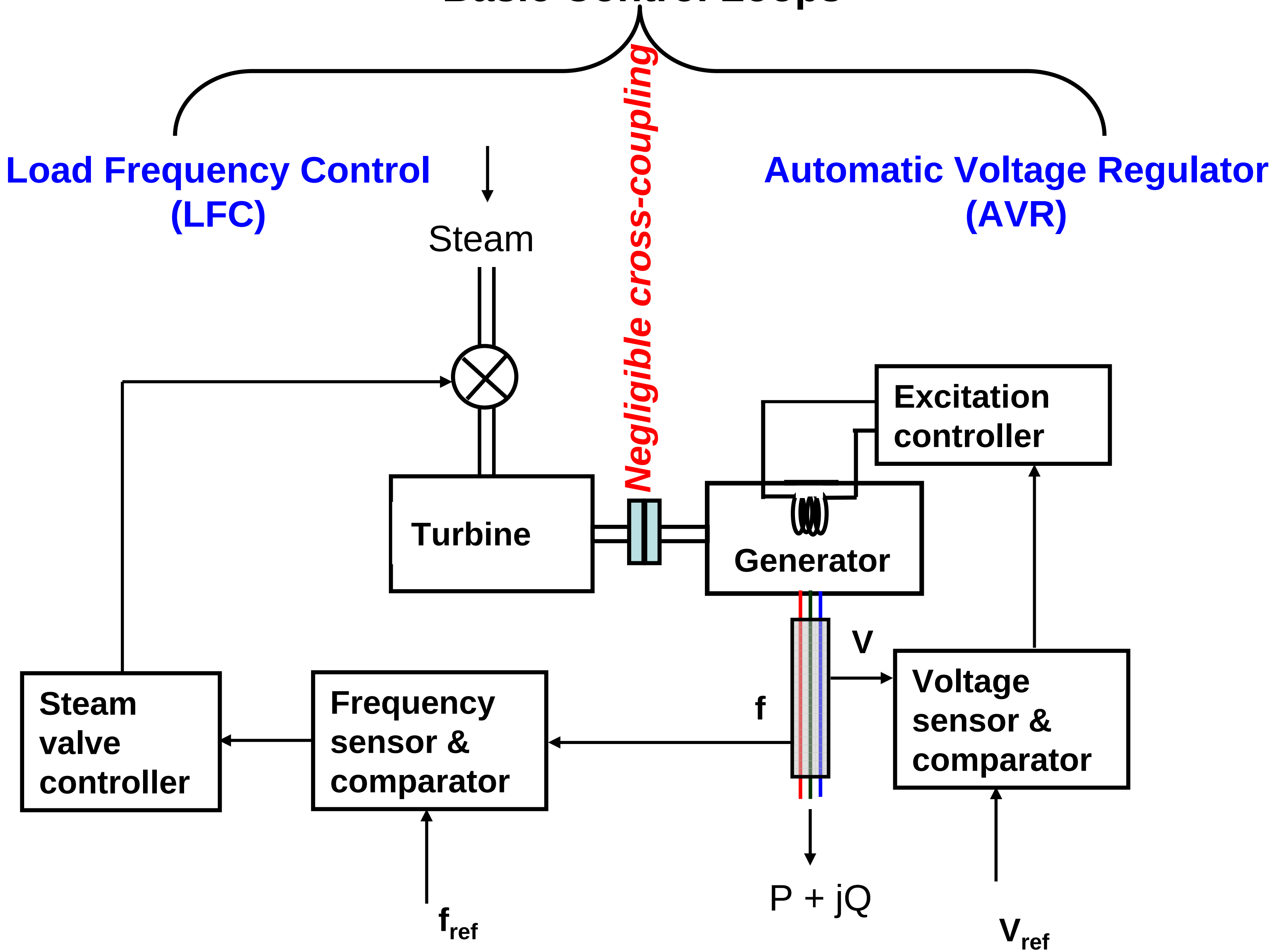
- **Models of sub-systems**

  Load models

  Prime-mover model

  Governor model

Basic Control Loops



Basic Control Loops

Load Frequency Control (LFC)

- Directly controls active power

(indirectly controls frequency)

-Slow acting

Negligible cross-coupling

Automatic Voltage Regulator (AVR)

- Directly controls Excitation (Voltage)

(indirectly controls reactive power)

- **Fast acting**

(low excitation system time constant)

Load frequency control "LFC"

Operating principle:

- Change in frequency and change in rotor angle "δ" are sensed as error signals
- LFC accordingly delivers real power demand signal to the prime-mover

Main Goal:

To compensate for ***frequency drop*** resulting from ***high demands***

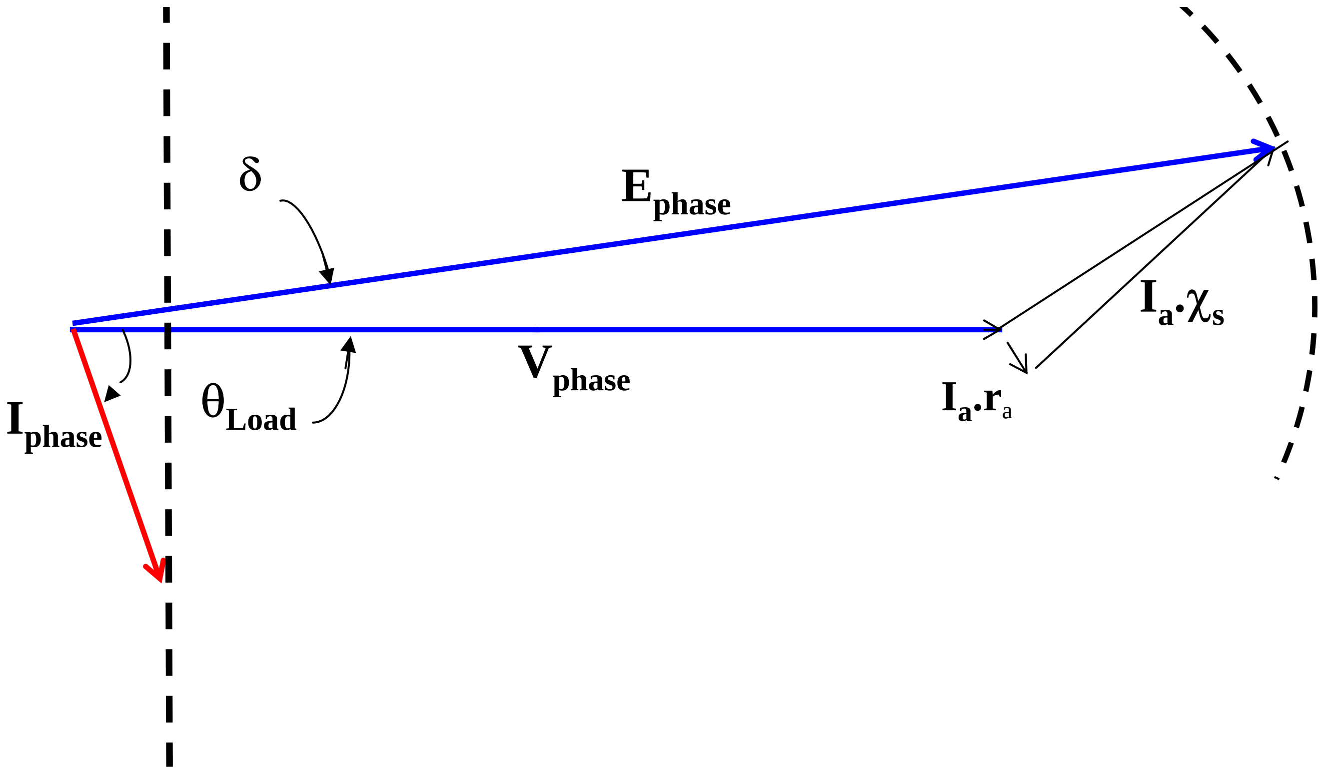
Functions:

- Maintain uniform frequency between specified limits
- Divide the load between paralleled generators
- Control tie-line interchange schedule

Outcomes:

- Ensures constant speed of AC motors
- Preserves power system stability

For generators in large systems: E & V are considered constant



$$From\ Graph: \Rightarrow \quad E\sin\delta \cong IX\cos\theta$$

$$Multiply\ RHS\ \&\ LHS\ by\ \frac{V}{X} \quad \Rightarrow \quad \frac{VE\sin\delta}{X} = VI\cos\theta$$

$$P_{ph} \cong \left(\frac{V_{ph}E_{ph}}{X}\right)\sin\delta$$

Power balance:

At any instant, energy balance exists:

$$\sum P_{mech} = \sum P_{elec} + P_{Losses}$$

If $P_{mech} > P_{elec}$

Excess energy is stored in the machine causing increased velocity (and frequency)

If $P_{mech} < P_{elec}$

The machine decreases its velocity (and frequency) to regain balance condition

Generator model:

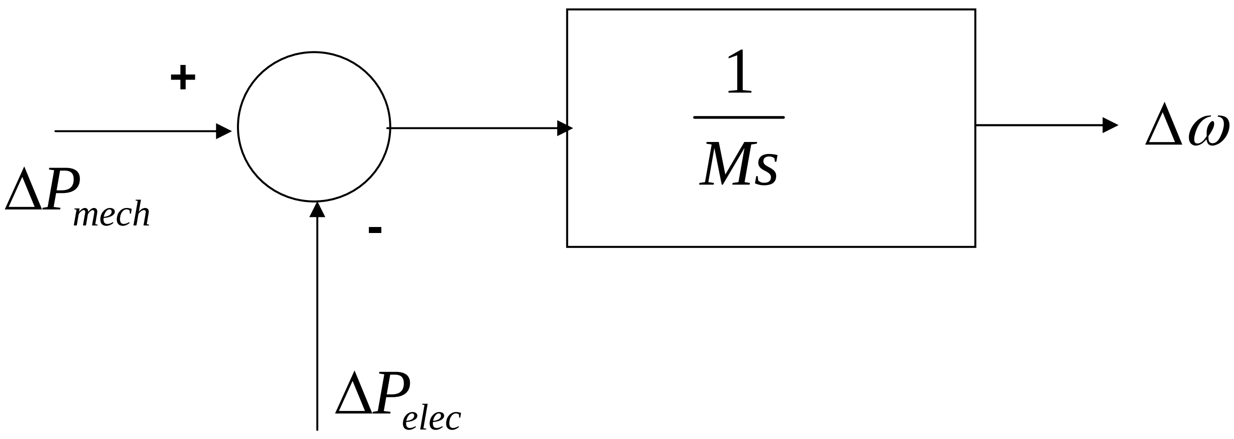
$$\omega = \text{rotational speed (rad/sec)}$$

$$\text{M} = \text{angular moment of machine}$$

$$\text{P}_{\text{mech}} = \text{mechanical input power}$$

$$\text{P}_{\text{elec}} = \text{electrical output power}$$

$$\Delta\text{P}_{\text{mech}} - \Delta\text{P}_{\text{elec}} = M\frac{d}{dt}(\Delta\omega)$$



Load model:

$$\Delta P_{elec} = \underbrace{\Delta P_{Load}}_{\text{Non-frequency sensitive load change}} + \underbrace{D.\Delta\omega}_{\text{Frequency sensitive load change}}$$

Non-frequency sensitive load change — **Frequency sensitive load change**

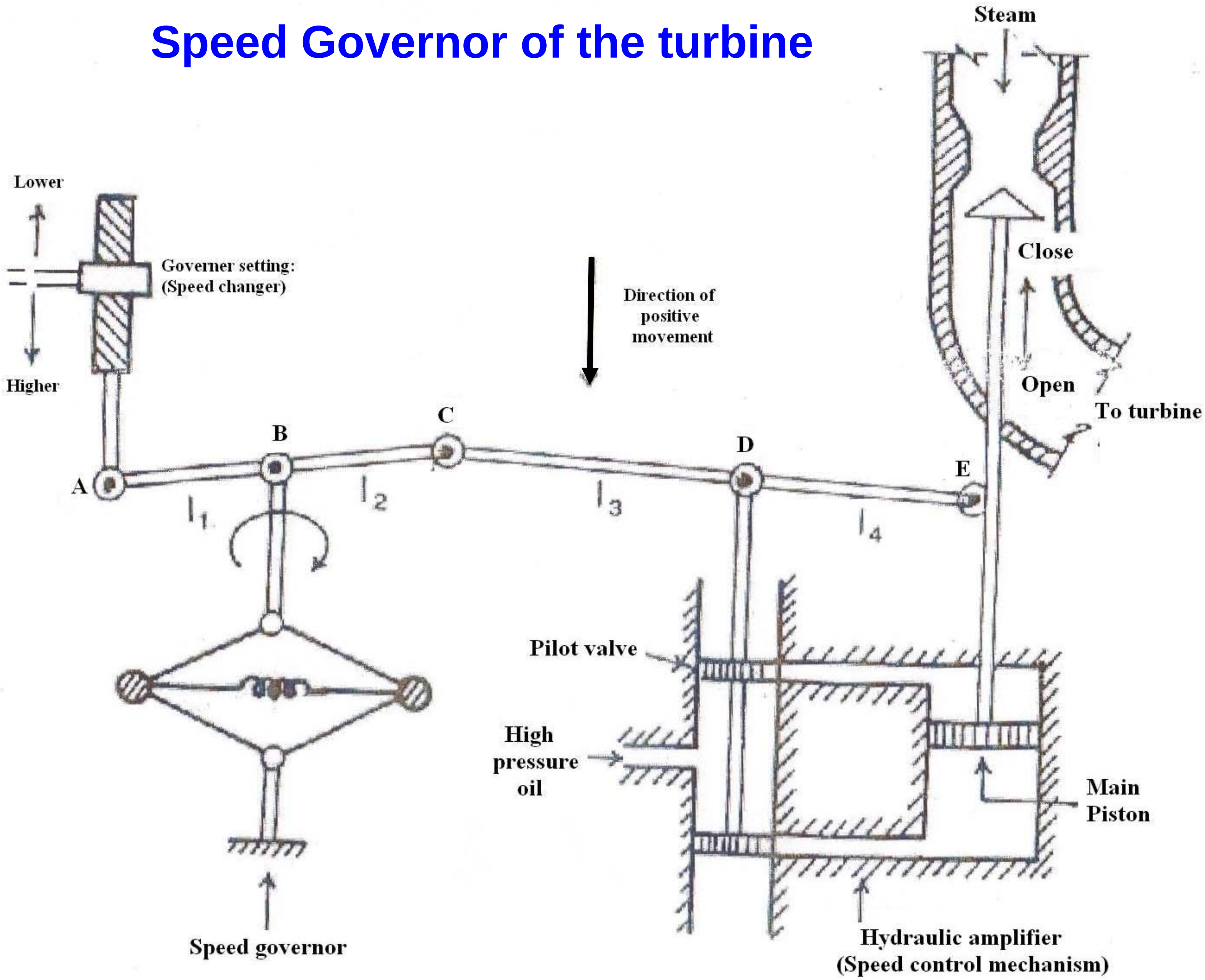
Prime-mover model:

$$\Delta P_{valve} \rightarrow \boxed{\frac{1}{1+sT_{Ch}}} \rightarrow \Delta P_{mech}$$

Where T_{Ch} *is the charging time constant*

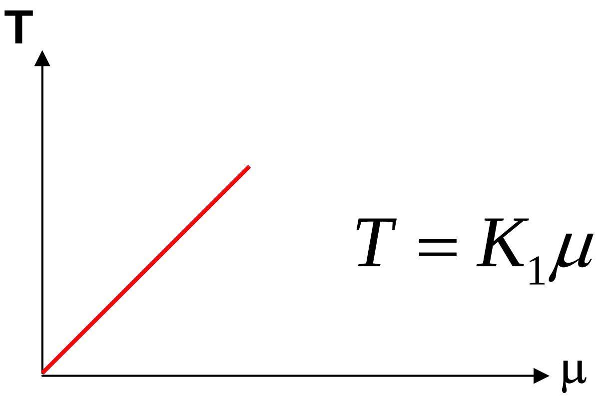
& ΔP_{valve} *is the pu change from nominal in valve position*

Speed Governor of the turbine

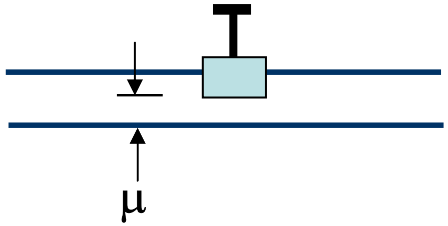


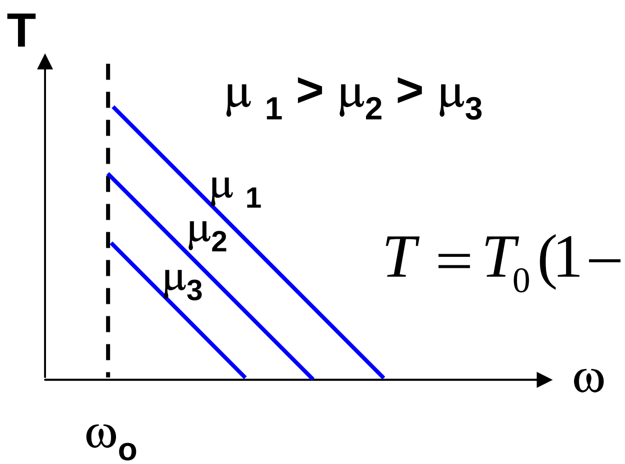
Governor Torque –Speed characteristics

Torque depends on "μ", and speed "ω" at constant power



$$T = K_1 \mu$$



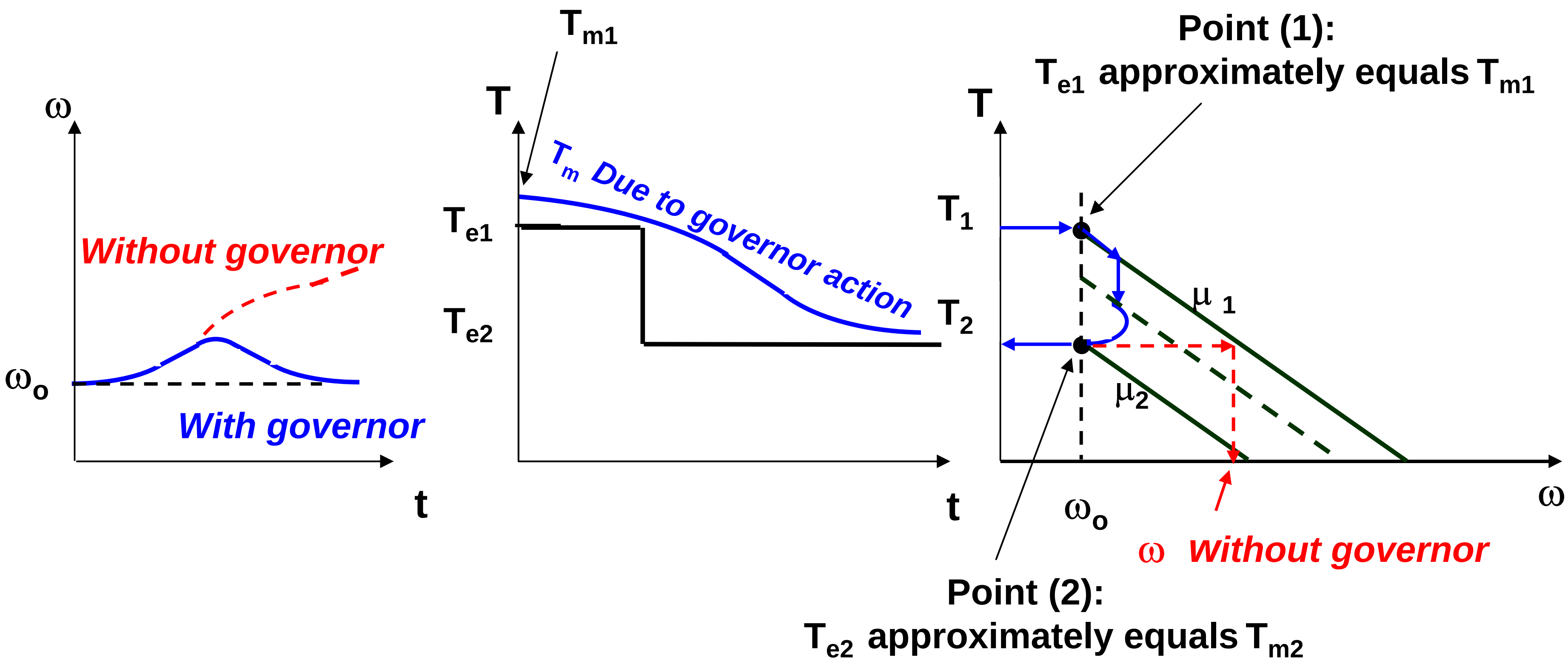


$$T = T_0(1 - K_2 \omega)$$

The governor transfers the operating point from a certain curve (μ) to another, keeping the speed constant.

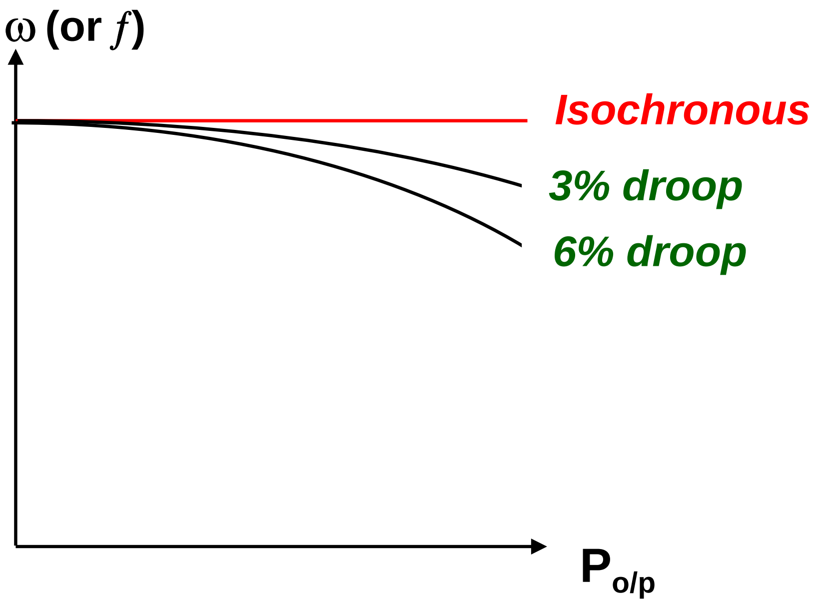
Torque is maximum at synchronous speed "ω_o"

Theory of operation of Governor



Governor Speed ⁄ Power drooping characteristics

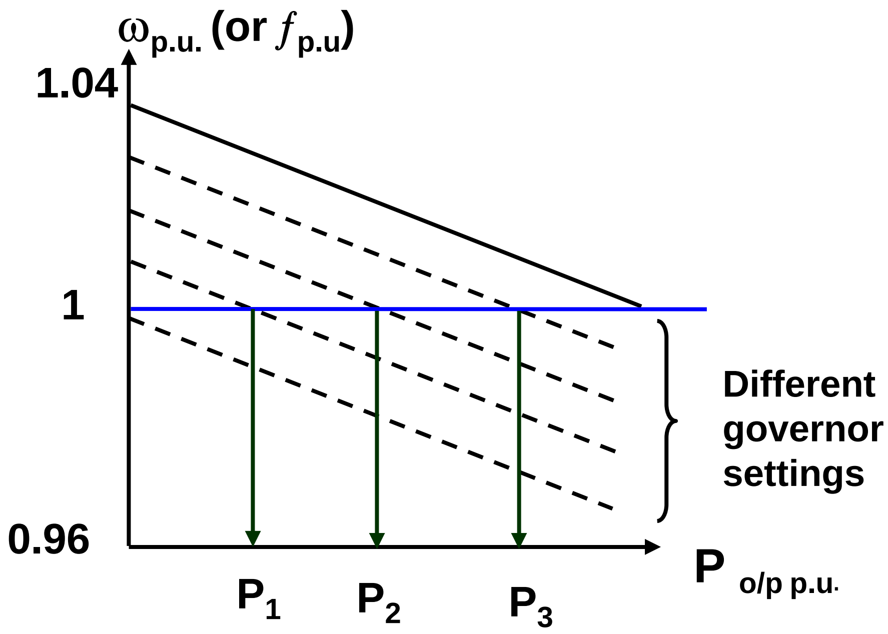
Different types of governors:



Isochronous type is ***forbidden*** with parallel operated generators

Different settings of a certain governor:

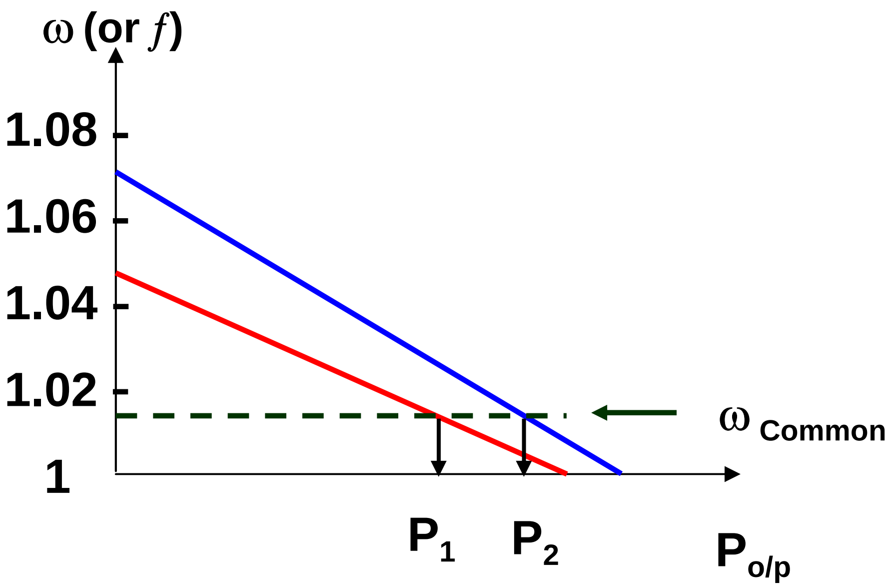
(***drooping characteristics assumed straight lines***)



Paralleled generators sharing active power of load

For two paralleled machines 1 & 2:

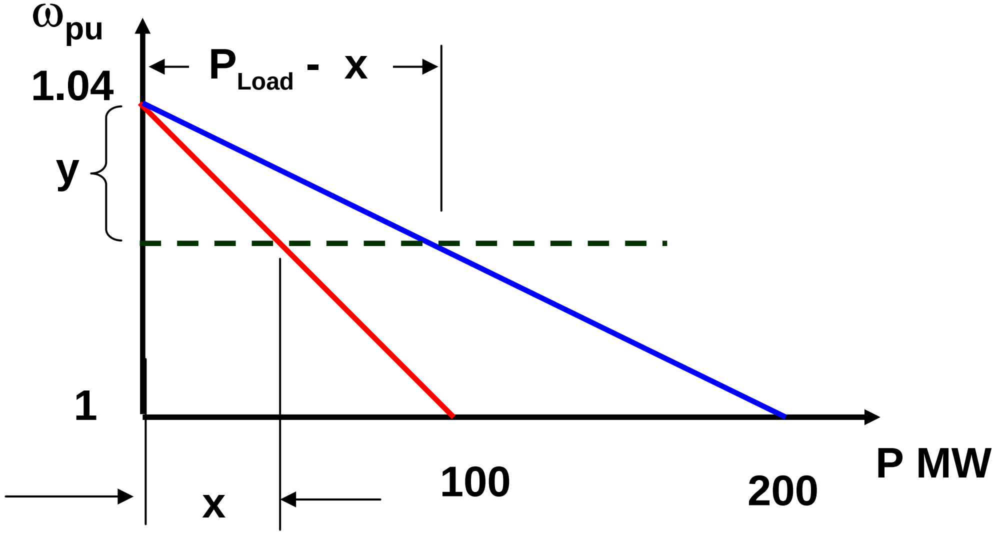
The power will be shared by a ratio determined by the drooping characteristics of the governors of both machines. By adjusting the governors' settings, the power-speed curves are transmitted to parallel locations, thus controlling the active power sharing of load between both generators



$$P_{Load} = P_1 + P_2$$

Example:

Two paralleled synchronous generators supply a total load of 200 MW. The capacities of both machines are 100 and 200 MW respectively, and both machines have governor droop characteristics of 4% from no load to full load. Find the active power load share of each machine assuming free governor action.



Assume $x = P_1$

$$\frac{0.04}{100} = \frac{y}{x} \qquad \ldots\ldots\ldots (1)$$

$$\frac{0.04}{200} = \frac{y}{200 - x} \qquad \ldots\ldots\ldots (2)$$

$P_1 = x = 66.65$ MW

$P_2 = 200 – x = 133.35$ MW

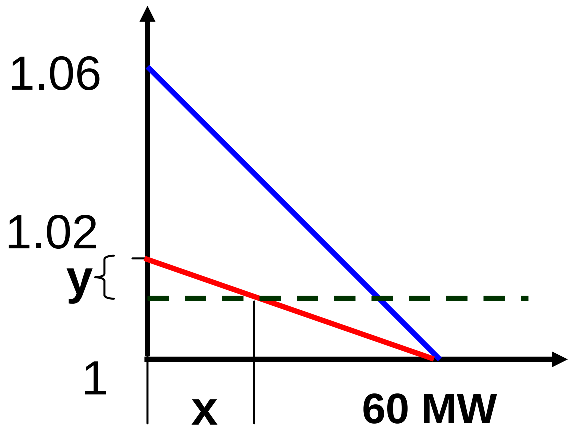
$\omega_{common} = 1.01334$ p.u.

<u>Conclusion:</u> When governors' drooping characteristics are the same, generators share the active power load in proportion to their capacities.

Two identical 60 MW synchronous generators are operated in parallel. Their governors have droops from no load to full load of 2% and 6% respectively. Find the following:

- The share of each machine if the total load was 100 MW

- The governor's setting (in terms of % adjustment in no-load speed) needed to force both machines to share the load equally.

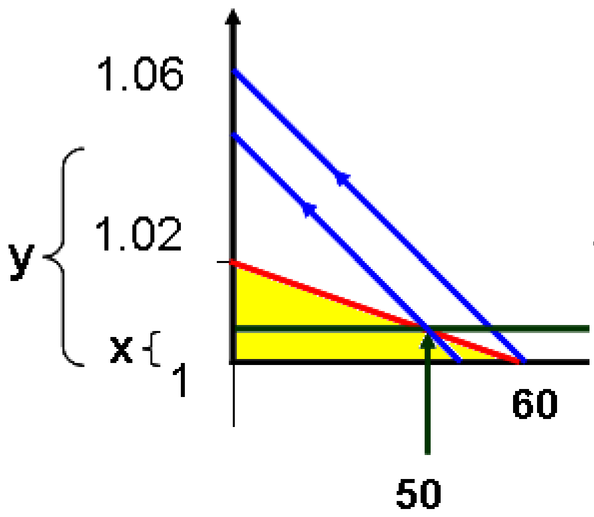


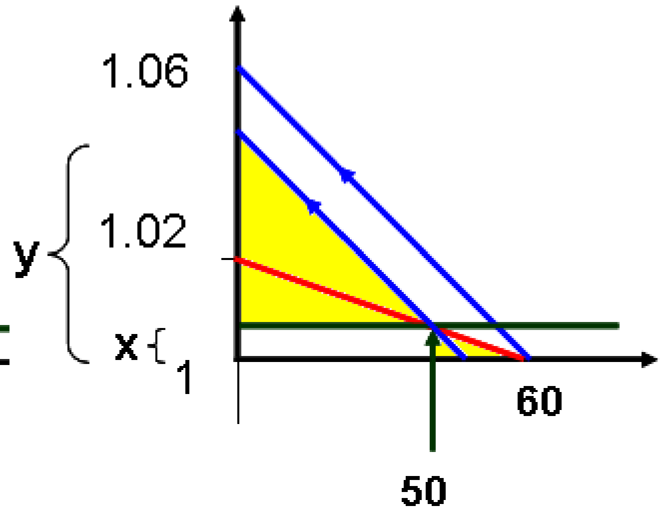
$$\frac{0.02}{60} = \frac{y}{x} \quad \cdots\cdots\cdots (1)$$

$$\frac{0.06}{60} = \frac{y+0.04}{100-x} \quad \cdots\cdots\cdots (2)$$

$$P_1 = 45MW,\ P_2 = 55MW$$

$$y = 0.015 \Rightarrow \omega_1 = 1.005\,pu$$





$$\frac{0.02}{x} = \frac{60}{60-50} \quad \cdots\cdots\cdots (1)$$

$$x = 2\times 10^{-3}$$

$$\frac{y-x}{0.06} = \frac{50}{60} \quad \cdots\cdots\cdots (2)$$

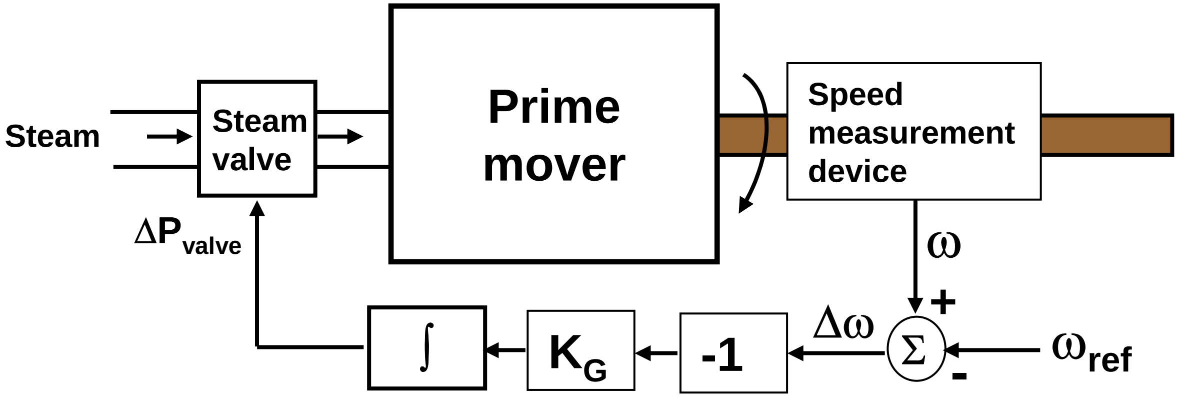
$$y = 0.052$$

$$\omega_2 = 1.052 \Rightarrow adjustment = 1.06 - 1.052 = 0.008$$

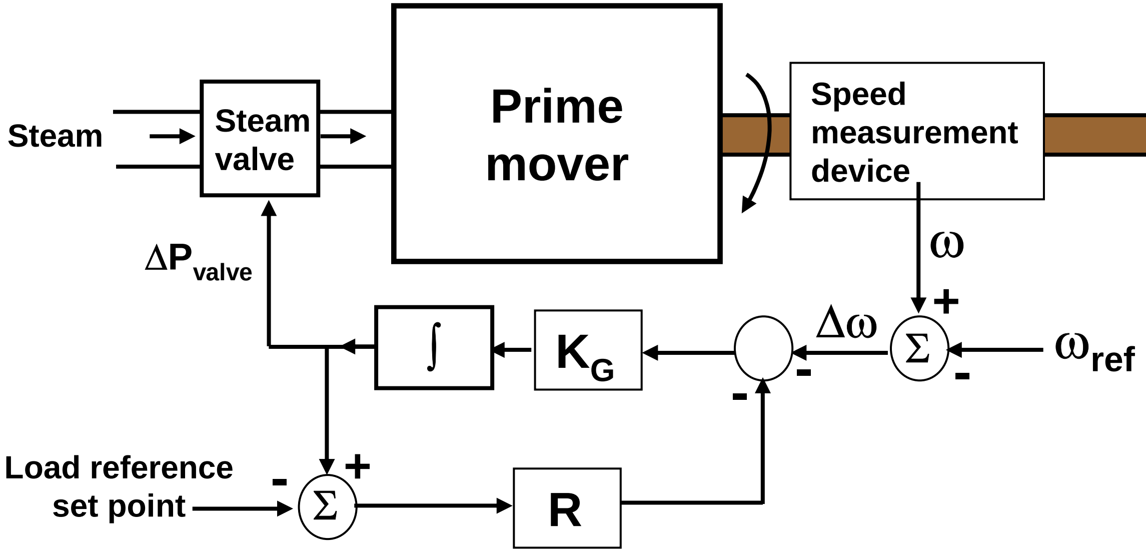
$$\%\ adjustment = 0.8\%$$

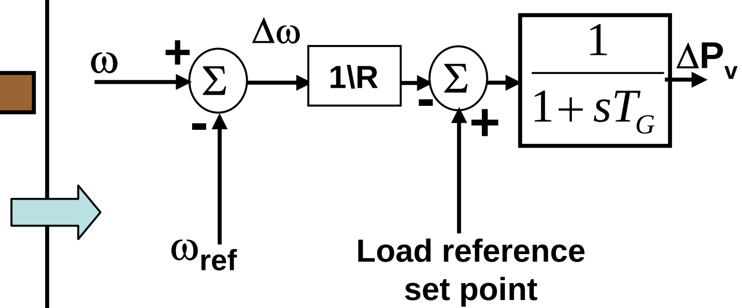
Governor Models

Isochronous (constant speed)

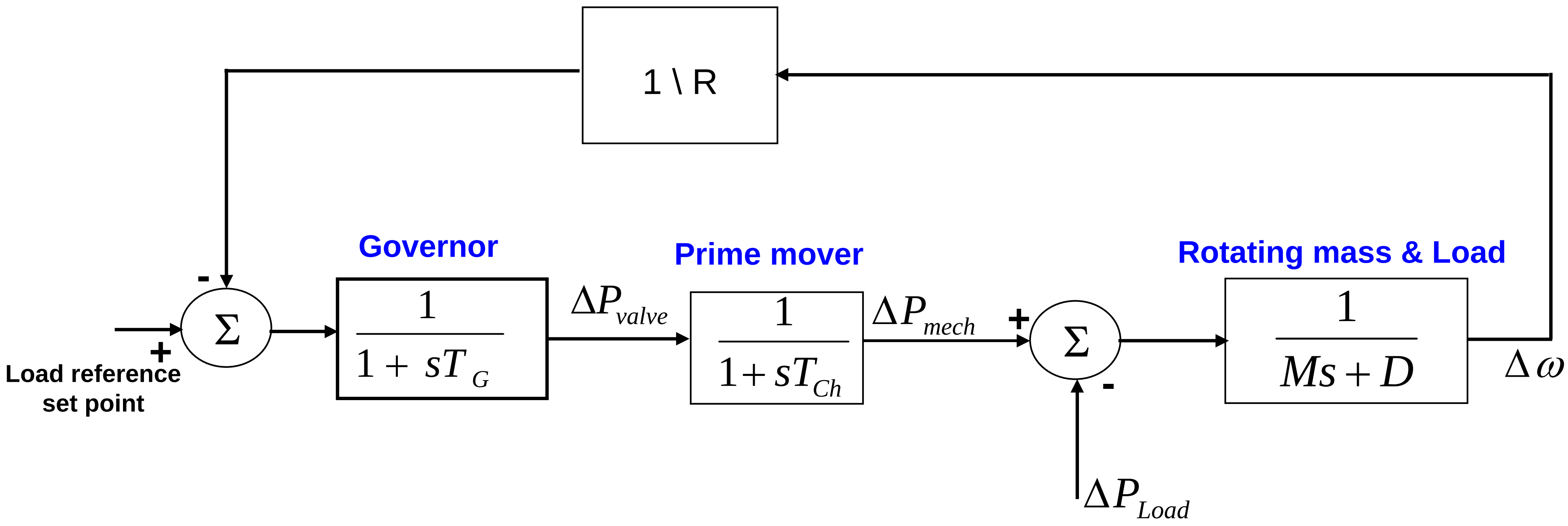


Governor with speed droop feed-back loop

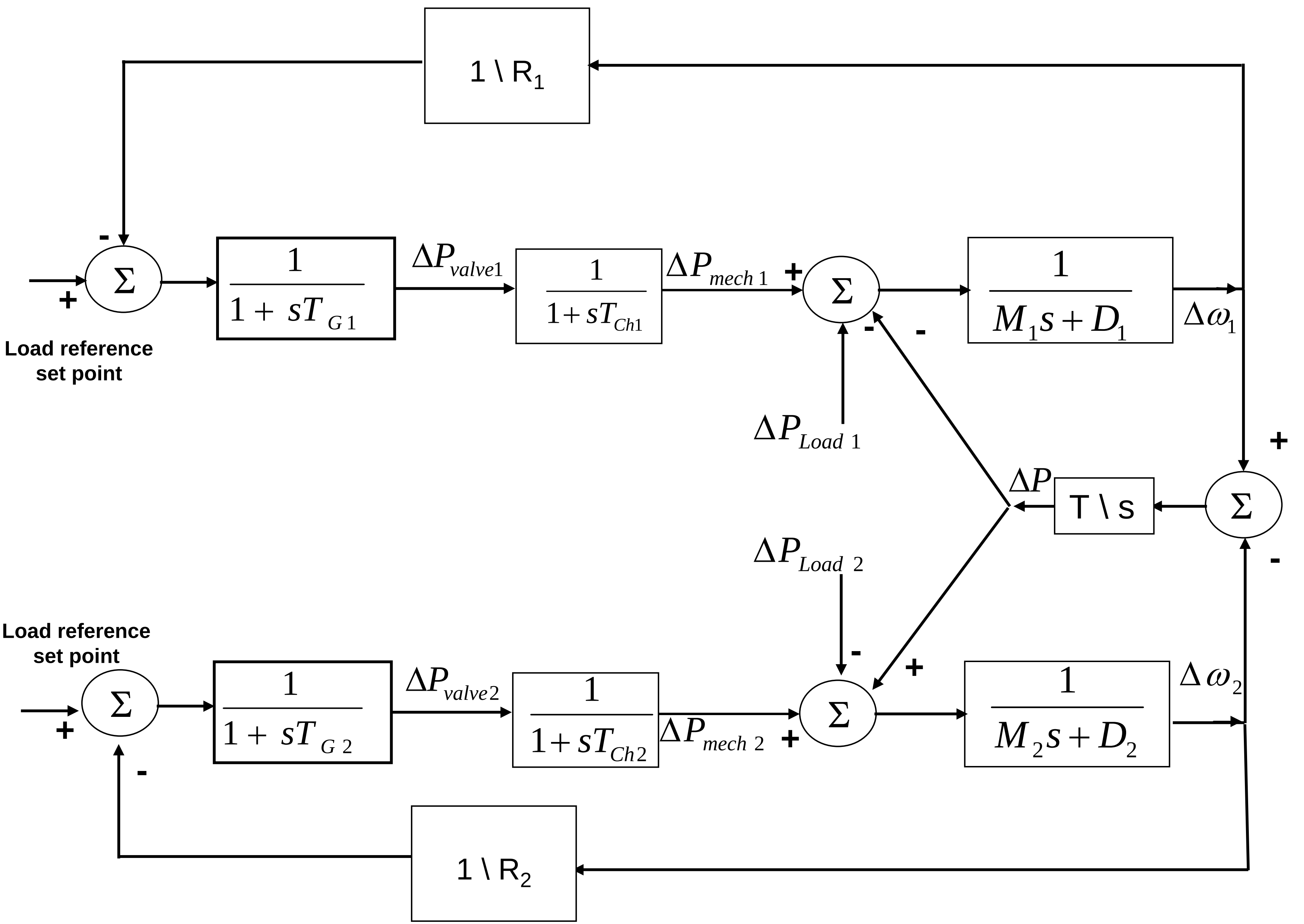




$$\text{Governor time constant}: T_G = \frac{1}{K_G R}$$



Entire Generator's Block Diagram



Paralleled Generator's Block Diagram