# Power System Operation & Control

## 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.

# Power Scenario in India

- India – Third highest generating capacity
- Installed Capacity

| | |
|---|---|
| States | 103651.90 MW |
| Private | 174298.02 MW |
| Central | 94026.93 MW |
| Total | 371976.84 MW |

# Power Scenario in India

Installed Capacity of RES

| Small Hydro Power | Wind Power | Bio-Power | Solar Power | Total Capacity |
|---|---|---|---|---|
| 4712.17 MW | 37940.95 MW | 10085.49 MW | 35303.30 MW | 88041.91 MW |

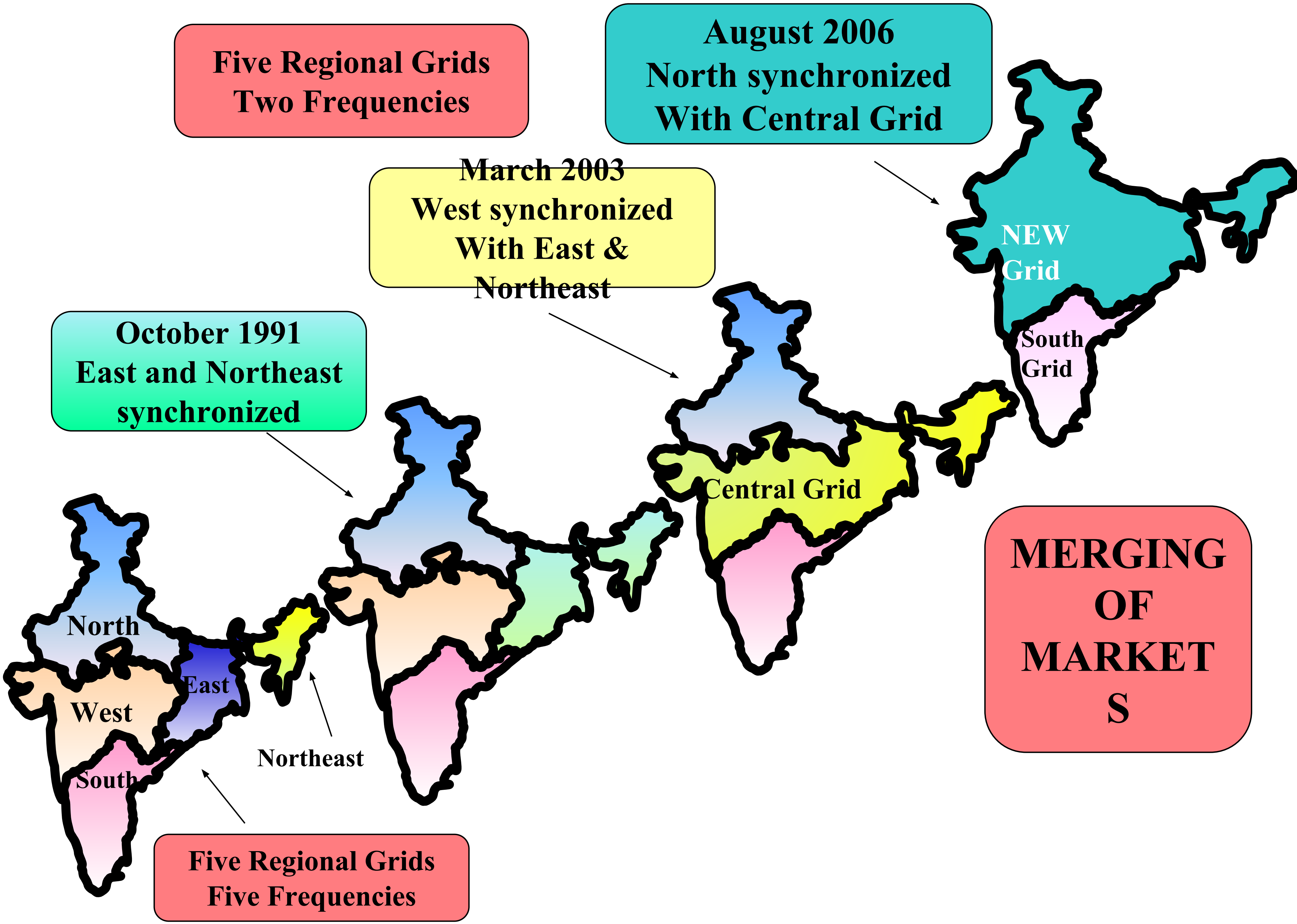
# Power Scenario in India

Power Sector Regions in India

1. Northern Region
2. Western
3. Eastern
4. North Eastern
5. Southern

# Power Transmission in India

- Transmission voltages – 66, 132, 230, 400 & 765 kV.
- Successfully tested 1200 kV transmission.
- HVDC: ±800 kV
- Regional grids are interconnected at 765kV.
- Power supply to Nepal through HVDC line
- Green energy corridors.


Five Regional Grids
Five Frequencies
North
West
East
South
Northeast
October 1991
East and Northeast synchronized
March 2003
West synchronized
With East &
Northeast
Central Grid
Five Regional Grids
Two Frequencies
August 2006
North synchronized
With Central Grid
NEW Grid
South Grid
MERGING OF MARKET
S

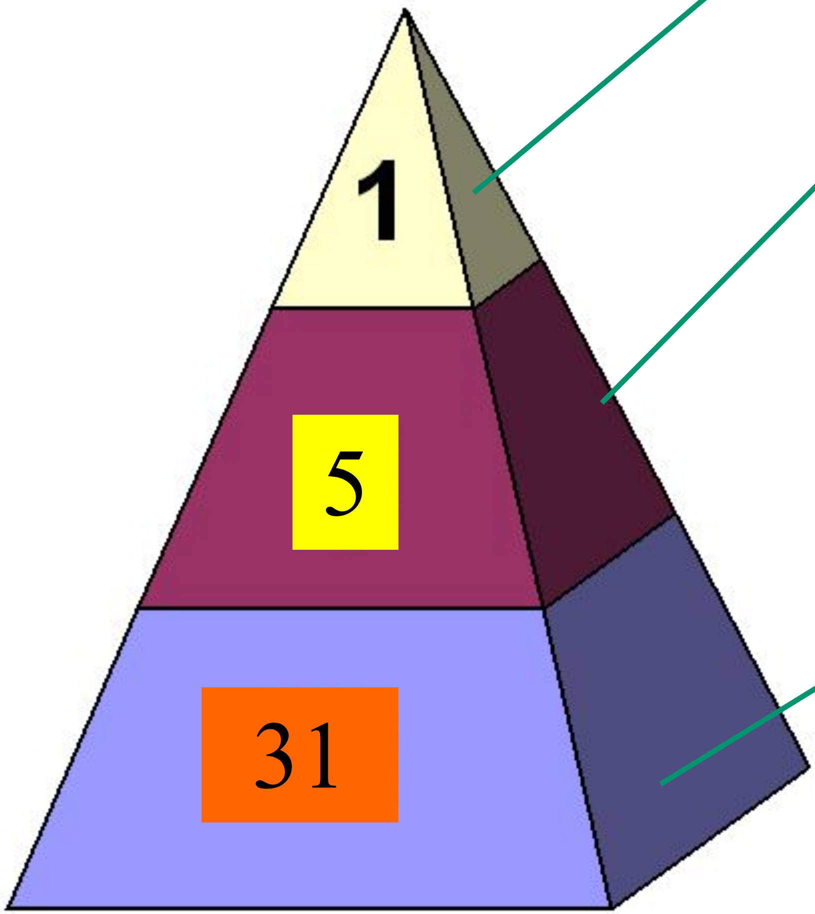
# Development of Load Despatch Centres

- Initial stages
  - a telephone/hotline communication system and a frequency meter
  - Operational only during day-time
  - Acted mainly as an information centre
- State grid interconnections
  - 24x7 operation
  - Rudimentary data acquisition systems
- Central Sector generating stations
  - Interstate scheduling and energy accounting
- Regional Grid formation & CTU
  - Modernization of control centres
- Availability Based Tariff
  - 15-minute scheduling, metering settlement
  - Market operation

# Modernization of Control Centres

- 33 SLDCs, 5 RLDCs, 1 NLDC
- Round-the-clock manning
- Wideband speech and data communication
- Fish as well as bird eye view through SCADA
- Common database in SLDC/RLDC
- Common Information Model (CIM) in NLDC
- Classical data presentation plus alarm processing, exception lists, animation, geographical displays
- Multilayering, Trending
- SoE and replay

# Jurisdiction of Load Despatch Centers




**NLDC:**
**Apex body to ensure integrated operation of National Power System**

**RLDC:**
**Apex body to ensure integrated operation of power system in the concerned region**

**SLDC:**
**Apex body to ensure integrated operation of power system in a state**

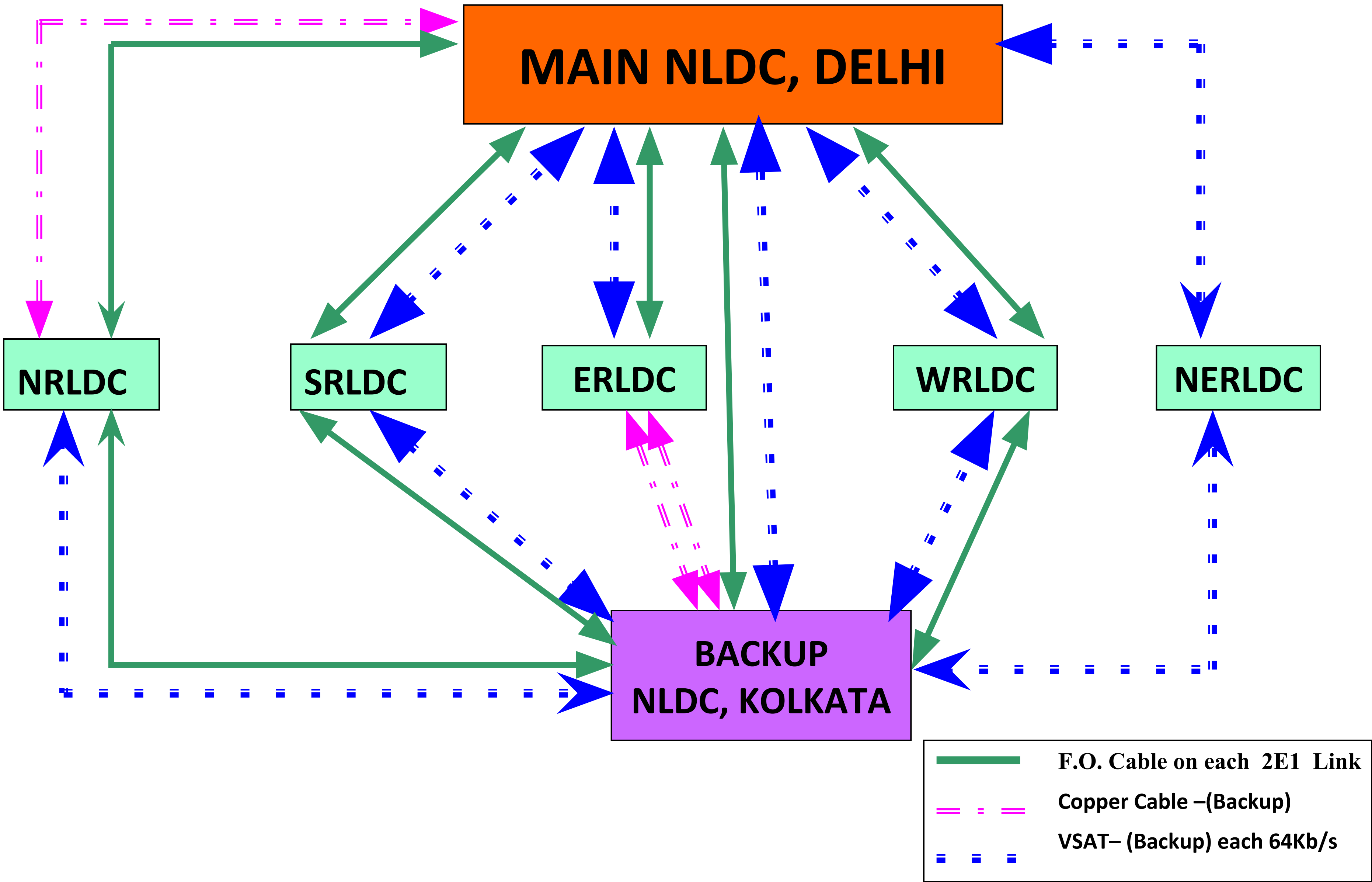
# Jurisdiction of RLDCs/SLDCs

- Control Area
- Scheduling Responsibilities
  - RLDCs
    - State as a whole
    - ISGS /UMPPs,
    - Pvt. Generating Stations > 1000 MW and having > 50% share of state outside home state

#CERC Order 58/2008, Suo Moto

  - SLDCs
    - State Utilities ( SGS / Discoms)
    - Intra-State Entities

# National Load Despatch Center (NLDC)



# Functions of Load Dispatch Centers

- **Optimum scheduling and dispatch of electricity**
- **Monitoring of operations and grid security**
- **Keeping accounts of the quantity of electricity transmitted through the regional grid**
- **Supervision and control over the transmission system**
- **Real time operations for grid control**
- **Dispatch of electricity through secure and economic operation of in accordance with the Grid Standards and the Grid Code**

# Regional Grid Operation: Philosophy

- Operated as loose power pools
- States have full operational autonomy
- State power system treated as notional (flexible) control area
- Very tight control of actual interchange by state utilities & Inter State Generating Stations not mandated
- Deviations from net drawal schedules appropriately priced

# GRID MANAGEMENT FUNCTIONS

- Ex-ante functions
  - **Scheduling**
- Real-time functions
  - **Supervision & control of system parameters**
  - **Facilitating Open Access transactions**
- Post-facto functions
  - **Settlement system operation**
- Interaction with stakeholders

# Basic Requirements of Power System

- Economy
- Reliability
- Quality – Voltage (±5%) & Frequency (±3%)
- Efficiency

# Load & Generation Balance

Match between electric load and generation

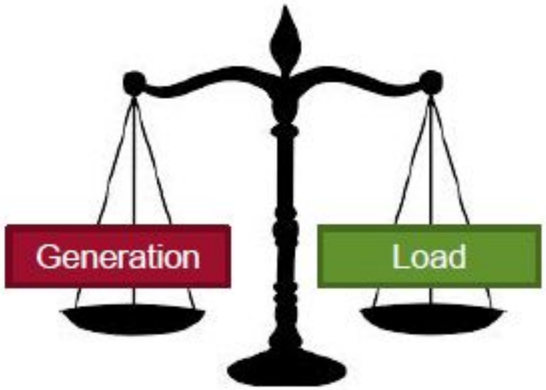
Frequency is an indication

Balanced system, 50/60 Hz

Net power surplus , frequency increases

Net power shortage, frequency decreases

$$\Delta P \longrightarrow \Delta f$$



# Necessity for Voltage Control

- Electric motors will tend to run on over speed when they are fed with higher voltages resulting vibration and mechanical damage.
- Over voltage may also cause insulation failure.
- For a specified power rating, lower voltage results in more current and this results in heating problems. (P=VI)

# Voltage Control

- Control of voltage levels is carried out by controlling the production, absorption, and flow of reactive power
- Generating units provide the basic means of voltage control. synchronous generators
    - can generate or absorb Q depending on excitation
    - automatic voltage regulator continuously adjusts excitation to control armature voltage
    - primary source of voltage support

# Voltage Control

Additional means are usually required to control voltage throughout the system:

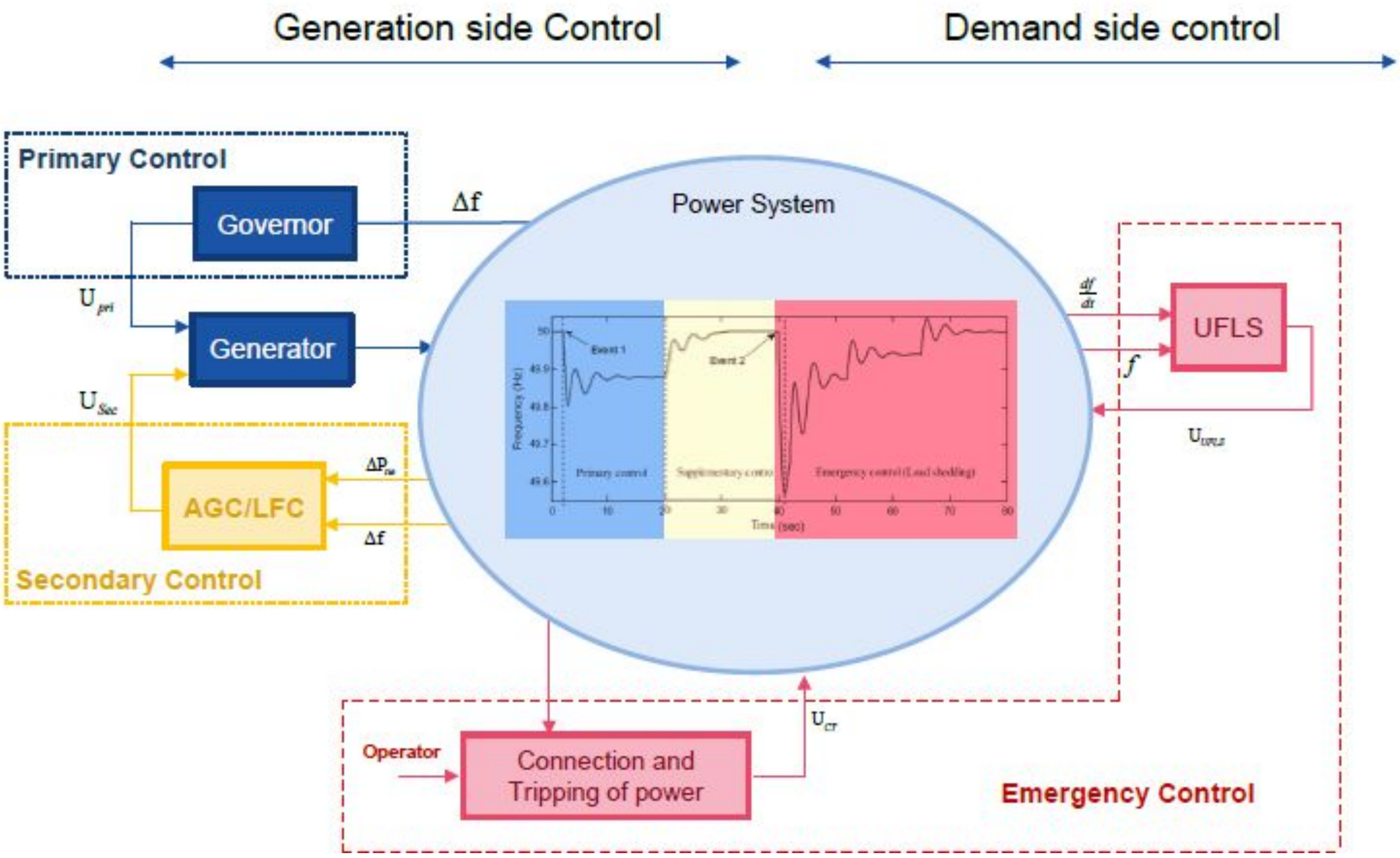
- sources or sinks of reactive power, such as shunt capacitors, shunt reactors, synchronous condensers, and static var compensators (SVCs)
- line reactance compensators, such as series capacitors
- regulating transformers, such as tap-changing transformers and boosters

# Necessity for Frequency Control

- Speed of three phase ac motors proportional to the frequency.

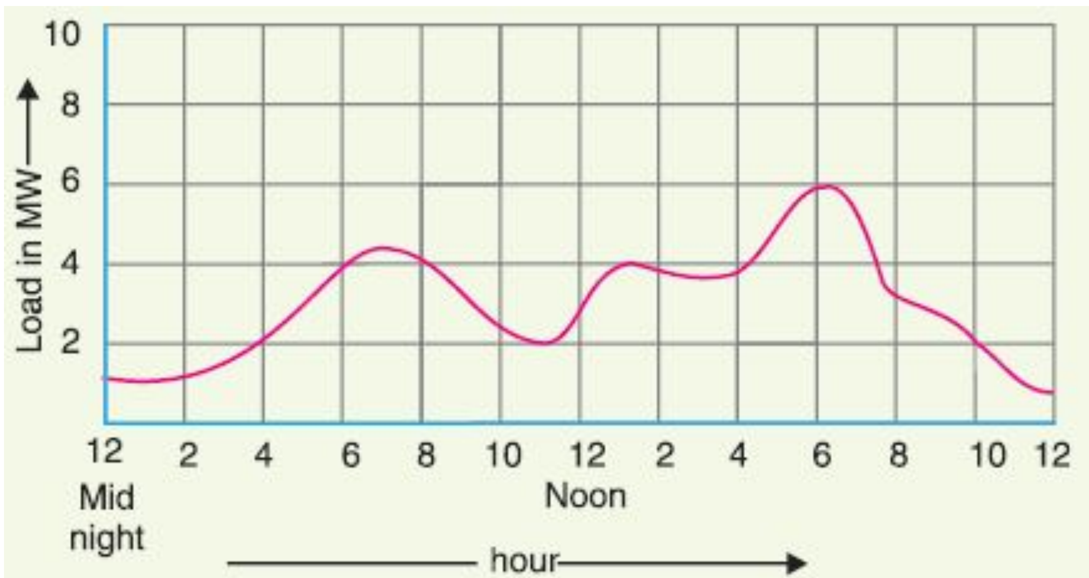
  (N=120f/p)
- The blades of steam and water turbines are designed to operate at a particular speed. Frequency variation leads to speed variation and results in mechanical vibration
- The under frequency operation of the power transformer
- is not desirable
- The system operation at subnormal frequency and voltage leads to loss of revenue
- to the suppliers due to accompanying reduction in load demand

# Frequency Control Actions



# Basics of Load Variation

- Load curve – variation of load w.r.t time
- Daily load curve, weekly, monthly & yearly load curves



# Importance of Load Curve

- The daily load curve shows the variations of load on the power station during different hours of the day.
- The area under the daily load curve gives the number of units generated in the day.
- Units generated/day = Area (in kWh) under daily load curve.
- The highest point on the daily load curve represents the maximum demand on the station on that day.
- The area under the daily load curve divided by the total number of hours gives the average load on the station in the day.

$$\text{Average load} = \frac{\text{Area (in kWh) under daily load curve}}{\text{24 hours}}$$

- The load curve helps in selecting the size and number of generating units.
- The load curve helps in preparing the operation schedule of the station.

# Important terms and factors

- **Connected load.** *It is the sum of continuous ratings of all the equipments connected to supply system.*
- **Maximum demand** : *It is the greatest demand of load on the power station during a given period.*
- **Demand factor.** *It is the ratio of maximum demand on the power station to its connected load*

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

- The value of demand factor is usually less than 1.
- **Average load.** *The average of loads occurring on the power station in a given period* (*day or month or year*) *is known as* **average load** *or* **average demand.**

- **Load factor.** *The ratio of average load to the maximum demand during a given period is known as* **load factor.**

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

If the plant is in operation for T hours,

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

$$= \frac{\text{Units generated in T hours}}{\text{Max. demand} \times \text{T hours}}$$

- The load factor may be daily load factor, monthly load factor or annual load factor if the time period considered is a day or month or year.
- The load factor plays key role in determining the overall cost per unit generated.
- Higher the load factor of the power station, lesser will be the cost per unit generated.

- **Diversity factor.** *The ratio of the sum of individual maximum demands to the maximum demand on power station is known as* **diversity factor. (Greater than 1).**

$$\text{Diversity factor} = \frac{\text{Sum of individual max. demands}}{\text{Max. demand on power station}}$$

- The greater the diversity factor, the lesser is the cost of generation of power.

- **Plant capacity factor.** *It is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period.*

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

$$= \frac{\text{Average demand} \times T}{\text{Plant capacity} \times T}^{**}$$

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

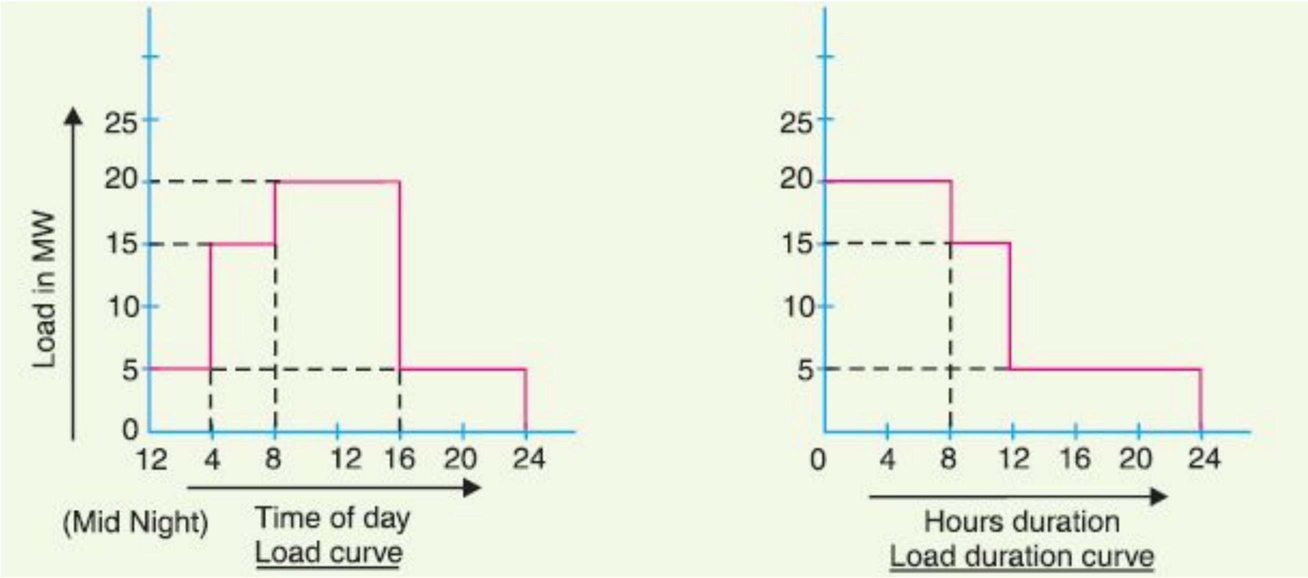
$$\text{Annual plant capacity factor} = \frac{\text{Annual kWh output}}{\text{Plant capacity} \times 8760}$$

- **Plant use factor.** *It is ratio of kWh generated to the product of plant capacity and the number of hours for which the plant was in operation.*

$$\text{Plant use factor} = \frac{\text{Station output in kWh}}{\text{Plant capacity} \times \text{Hours of use}}$$

# Load Duration Curve

- *When the load elements of a load curve are arranged in the order of descending magnitudes, the curve thus obtained is called a* **load duration curve.**



# Load Forecasting

- Estimation of load on the power system in advance
- Estimation of both demand and energy requirements is crucial to effective system planning
- Demand prediction – to determine generating capacity, T & D additions
- Used to establish procurement policies for construction of generating stations
- Capital energy forecasts are required to determine the future fuel requirements
- The variation of load does exhibit certain daily and yearly pattern repetitions

# Purpose of Load Forecasting

- Proper planning of power system
- Planning of transmission and distribution facilities
- Power system operation
- Financing
- Manpower development
- Grid formation
- Electrical power sales

# Classification of Load Forecasting

- Demand Forecast:
  - used to determine the reserve capacity of the generation, transmission and distribution systems
  - demand can be predicted on the basis of rate of growth of demand from past history and government policy
  - This will give the expected rate of growth of load
- Energy Forecast:
  - used to determine the type of facilities required, i.e., future demand requirements

# FORECASTING PROCEDURE

- Short-term technique
- Medium-term (intermediate) technique
- Long-term technique

# Short-term Forecast

- Done for day to day operations
- To ensure enough generation capacity for a week and for maintaining the required spinning reserve
- It is usually done 24 hours ahead when the weather forecast for the following day becomes available
- The final estimate is arrived at after accounting for the transmission and distribution losses of the system

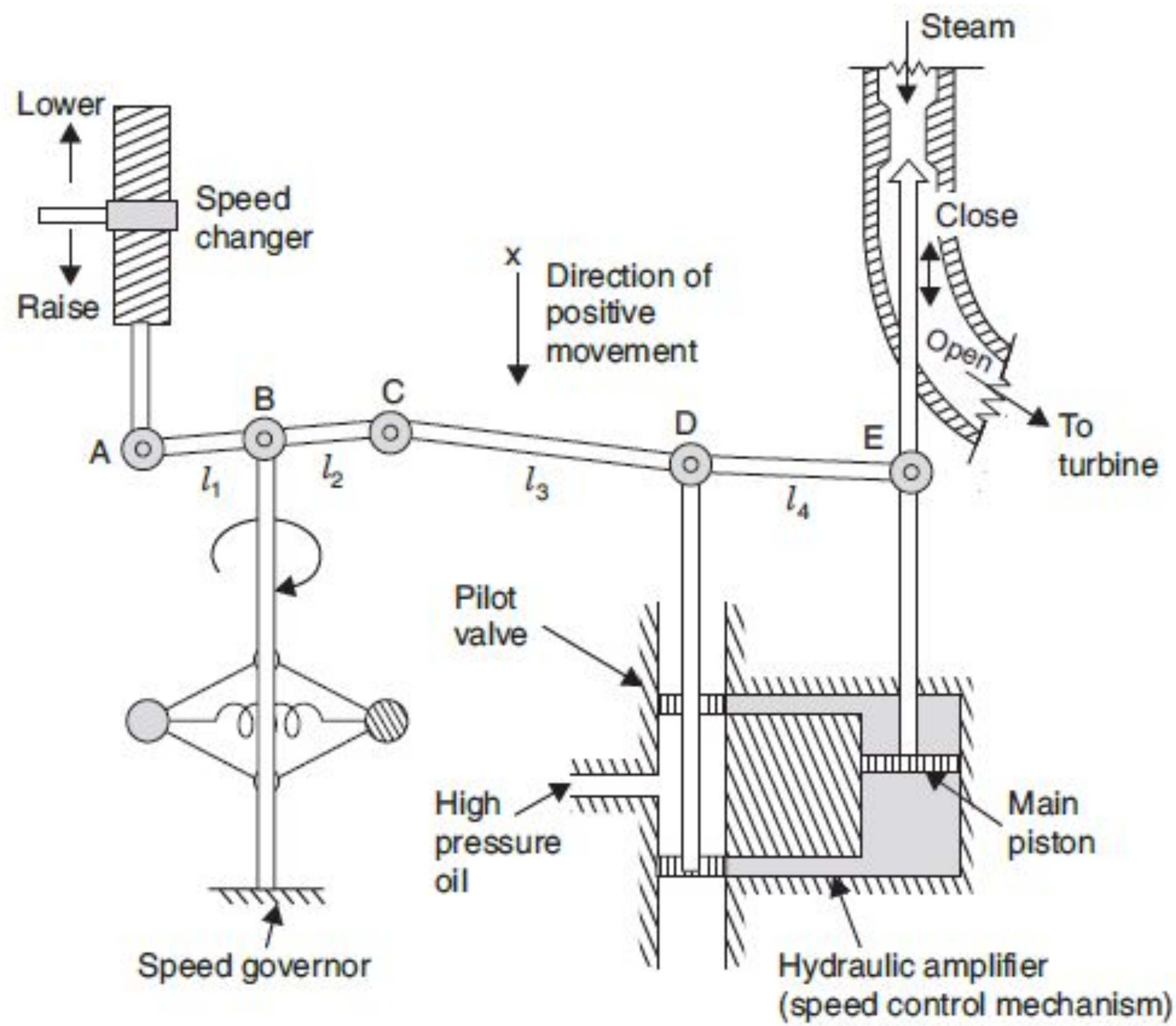
# Medium-term Forecast

- Done for 5 or 6 years
- Plays a major role while planning the size of a power plant, and for the construction and installation of the equipment in power plants.
- For the estimation of fuel (coal, diesel, water, etc.)
- For the estimation of peak power and energy requirement for each month of the coming year

# Long-term Forecast

- May extend over a period of 20 years or even more
- Preparation of maintenance schedules of the generating units
- Plan for future expansion of the generating capacity
- Enter into agreements for energy interchange with neighbouring utilities
- **Peak Load Approach:** extrapolate the trend curve, which is obtained by plotting the past values of annual peaks against years of operation.
- **Energy Approach:** the annual energy sales is forecasted to different classes of customers like residential, commercial, industrial, etc., which is then converted to annual peak demand using the annual load factor.

# Speed Governing System



# *Model of Speed Governing System*

- frequency of the system is $f^0$
- generator output $P_{G0}$
- steam valve setting $X_E^0$
- Let the point $A$ of the speed changer lower down by an amount $\Delta X_A$

increase in power is $\Delta P_c$ then $\Delta X_A = K_1 \Delta P_c$.

- The movement of linkage point $A$ causes small position changes $\Delta X_C$ and $\Delta X_D$ of the linkage points $C$ and $D$.

Let the point $A$ of the speed changer lower down by an amount $\Delta X_A$ as a result the commanded increase in power is $\Delta P_c$ then $\Delta X_A = K_1 \Delta P_c$. The movement of linkage point $A$ causes small position changes $\Delta X_c$ and $\Delta X_D$ of the linkage points $C$ and $D$. With the movement of $D$ upwards by $\Delta X_D$ high pressure oil flows into the hydraulic amplifier from the top of the main piston thereby the steam valve will move downwards a small distance $\Delta X_E$ which results in increased turbine torque and hence power increase $\Delta P_G$. This further results in increase in speed and hence the frequency of generation. The increase in frequency $\Delta f$ causes the link point $B$ to move downward a small distance $\Delta X_B$ proportional to $\Delta f$. We assume that the movements are positive if the points move downwards.

Two factors contribute to the movement of *C*:

(*i*) Increase in frequency causes $B$ to move by $\Delta X_B$ when the frequency changes by $\Delta f$ as then the fly-ball moves outward and $B$ is lowered by $\Delta X_B$. Therefore, this contribution is positive and is given by $K_1 \Delta f$.

(*ii*) The lowering of the speed changer by an amount $\Delta X_A$ lifts the point $C$ upwards by an amount proportional to $\Delta X_A$, *i.e.*, let this be $K_2' \Delta X_A$ or $K_2 \Delta P_c$.

$$\Delta X_C = K_1 \Delta f - K_2 \Delta P_c$$

The positive constants $K1$ and $K2$ depend upon the length of the linkage arms $AB$ and $BC$ and upon the proportional constants of the speed changer and the speed governor.
The movement of $D$ is contributed by the movement of $C$ and $E$. Since $C$ and $E$ move downwards when $D$ moves upwards, therefore,

$$\Delta X_D = K_3 \Delta X_C + K_4 \Delta X_E$$

The positive constants $K_3$ and $K_4$ depend upon the length of the linkage $CD$ and $DE$.

Assuming that the oil flow into the hydraulic cylinder is proportional to position $\Delta XD$ of the pilot valve, the value of $\Delta XE$ is given by

$$\Delta X_E = K_5 \int_0^t -(\Delta X_D)\, dt$$

The constant $K5$ depends upon the fluid pressure and the geometries of the orifice and the cylinder.

Taking Laplace transform of equations

$$\Delta X_C(s) = K_1\,\Delta F(s) - K_2\,\Delta P_c(s)$$

$$\Delta X_D(s) = K_3\,\Delta X_C(s) + K_4\,\Delta X_E(s)$$

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

Eliminating the variables $\Delta X_C$ and $\Delta X_D$, we obtain

$$\Delta X_E(s) = \frac{K_2K_3\Delta P_c(s) - K_1K_3\Delta F(s)}{K_4 + s/K_5}$$

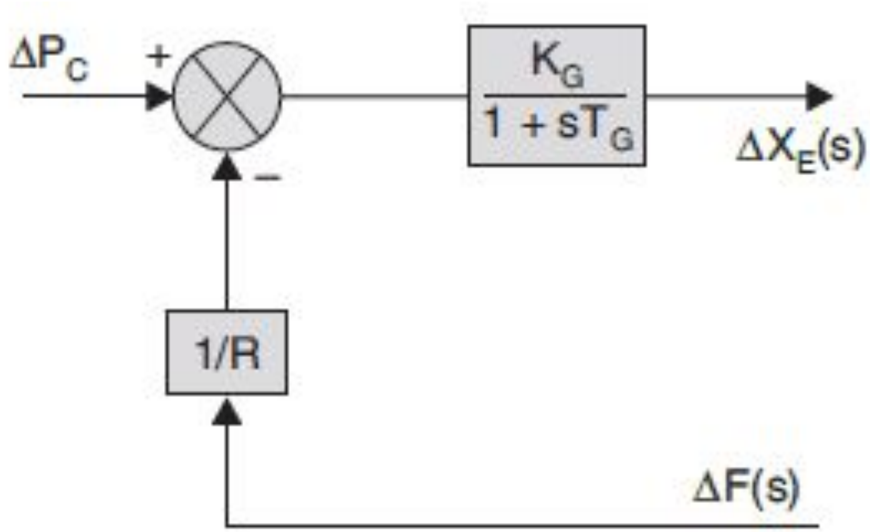
$$= \frac{K_G}{1+sT_G}\left[\Delta P_c(s) - \frac{1}{R}\Delta F(s)\right]$$

where $R = \dfrac{K_2}{K_1}$ speed regulation of the governor.

$$K_G = \frac{K_2K_3}{K_4} = \text{gain of speed governor}$$

$$T_G = \frac{1}{K_4K_5} = \text{time constant of speed governor}$$

Block diagram representation of speed governing system for steam turbine

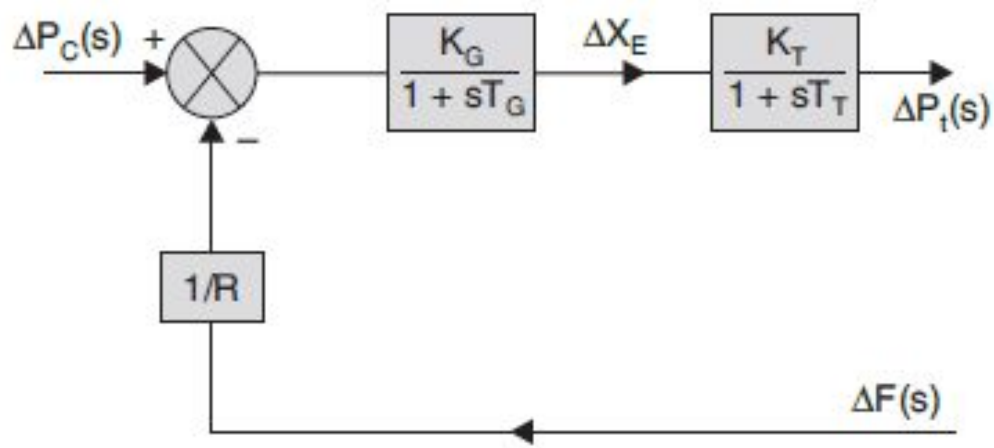


# *Turbine Model*

The model requires a relation between changes in power output of the steam turbine to changes in its steam valve opening $\Delta X_E$. We consider here a non-reheat turbine with a single gain factor $K_T$ and a single time constant $T_T$ and thus in the crudest model representation of the turbine the transfer function is given as

$$G_T(s) = \frac{\Delta P_t(s)}{\Delta X_E(s)} = \frac{K_T}{1 + sT_T} \tag{20.8}$$

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



# *Generator-load Model*

- The model gives relation between the change in frequency as a result of change in generation when the load changes by a small amount
- Let $\Delta PD$ be the change in load, as a result the generation also swings by an amount $\Delta PG$. The net power surplus at the bus bar is $\Delta PG - \Delta PD$ and this power will be absorbed by the system in two ways:

($i$) By increasing the kinetic energy of the generator rotor at a rate $\frac{dW}{dt}$, where $W$ is the new value of kinetic energy. Let $W^0$ be the K.E. before the change in load occurs when the frequency is $f^0$ and let $W$ be the K.E. when the frequency is $f^0 + \Delta f$. Since the K.E. is proportional to square of the speed of the generator, therefore, the two kinetic energies can be correlated as

$$W = W^0 \left( \frac{f^0 + \Delta f}{f^0} \right)^2 \tag{20.9}$$

$$W = W^0 \left( 1 + \frac{2\Delta f}{f^0} \right) \tag{20.10}$$

neglecting the higher terms as $\frac{\Delta f}{f^0}$ is small.

$$\therefore \qquad \frac{dW}{dt} = \frac{2W^0}{f^0} \cdot \frac{d}{dt} \cdot (\Delta f) \tag{20.11}$$

(*ii*) The load on the motors increases with increase in speed. The load on the system being mostly motor load the rate of change of load with respect to frequency can be regarded as nearly constant for small changes in frequency, *i.e.*, $D = \dfrac{\partial P_D}{\partial f}$, where $D$ can be obtained empirically. Therefore, the net power surplus at the bus bar is given by

$$\Delta P_G - \Delta P_D = \frac{2W^0}{f^0} \frac{d}{dt}(\Delta f) + D \cdot \Delta f \ldots \qquad (20.12)$$

If $H$ is the inertia constant of the generator in MW-sec/MVA and $P$ is the rating in MVA, then $W_0 = HP$.

Rewriting the balance equation (20.12)

$$\Delta P_G - \Delta P_D = \frac{2HP}{f^0}\frac{d}{dt}(\Delta f) + D \cdot \Delta f \ldots \tag{20.13}$$

Dividing throughout by $P$ we get

$$\Delta P_G(\text{p.u.}) - \Delta P_D\,(\text{p.u.}) = \frac{2H}{f^0}\, s\Delta F(s) + D(s)\Delta F(s)$$

$$= \Delta F(s)\left[\frac{2H}{f^0}s + D(s)\right]$$

or

$$\Delta F(s) = \frac{\Delta P_G(s) - \Delta P_D(s)}{\dfrac{2H}{f^0}s + D(s)}$$

or

$$\Delta F(s) = [\Delta P_G(s) - \Delta P_D(s)]\frac{K_P}{1 + sT_P} \tag{20.15}$$

where $T_p = \dfrac{2H}{Df^0}$ = power system time constant

and $K_p = \dfrac{1}{D}$ = power system gain

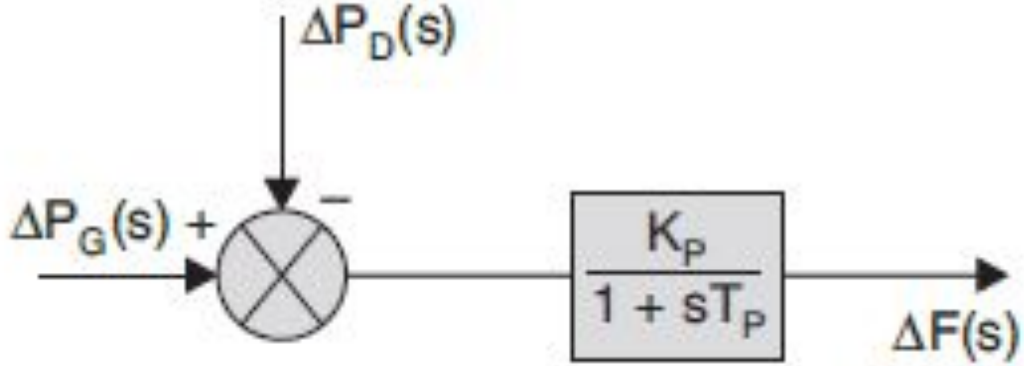



**Fig. 20.8** Generator load model.

# Load Frequency Control – Block Diagram