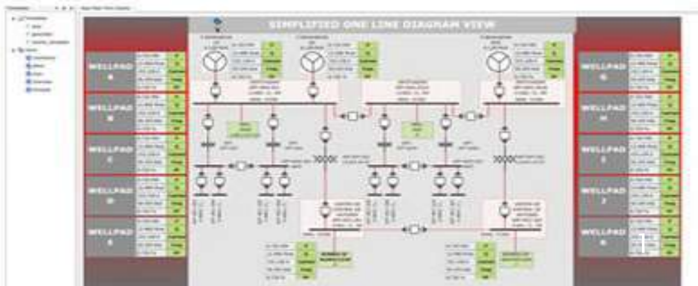
SCADA in electrical power system



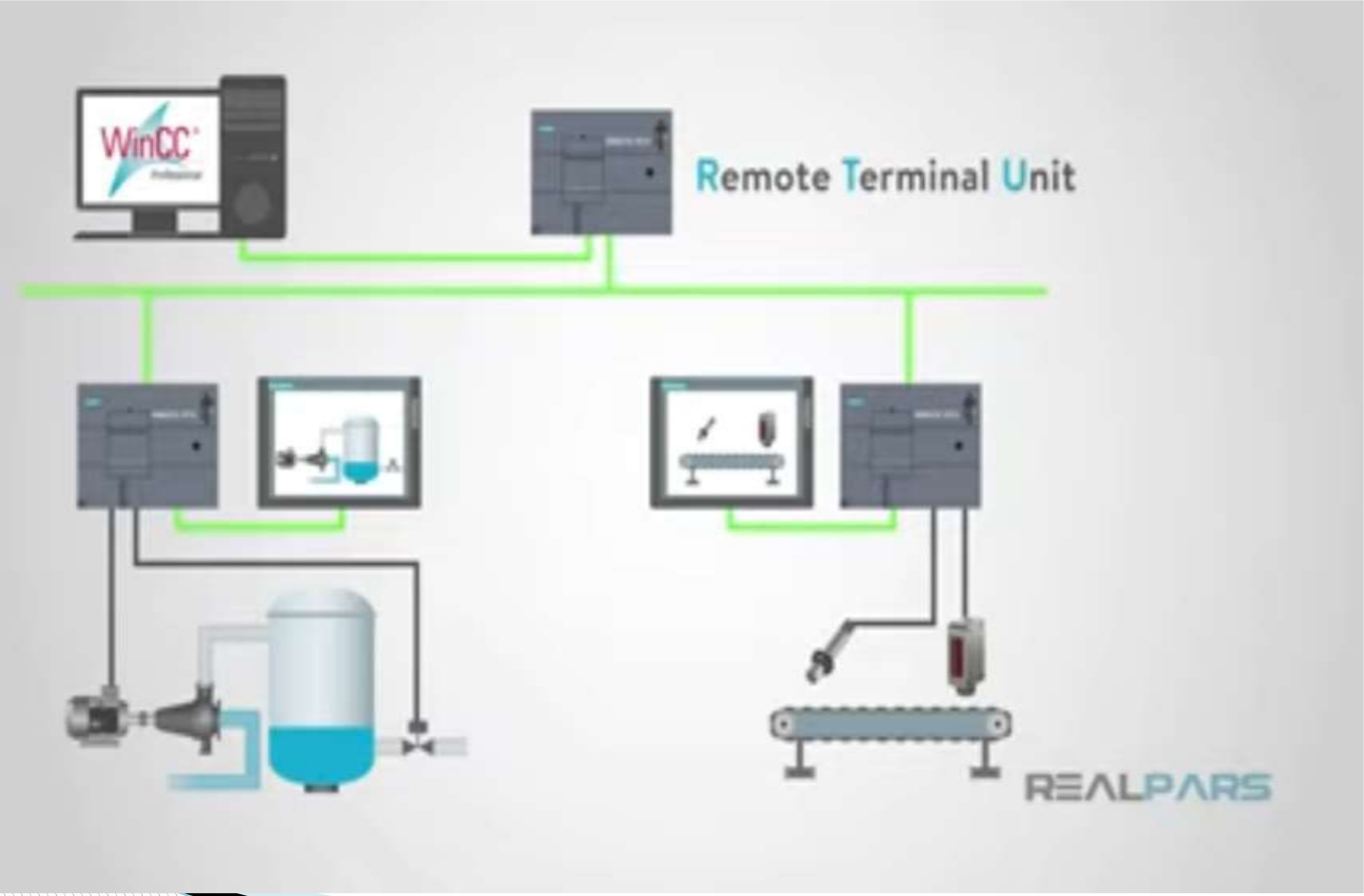
SCADA

- A complex computer based system that uses modern applications to analyse the electric power grid system to acquire data, monitor and control facilities and processes.

- SCADA applications can support dispatchers, operators, engineers, managers, etc. with tools to predict, control, visualize, optimise, and automate the system.

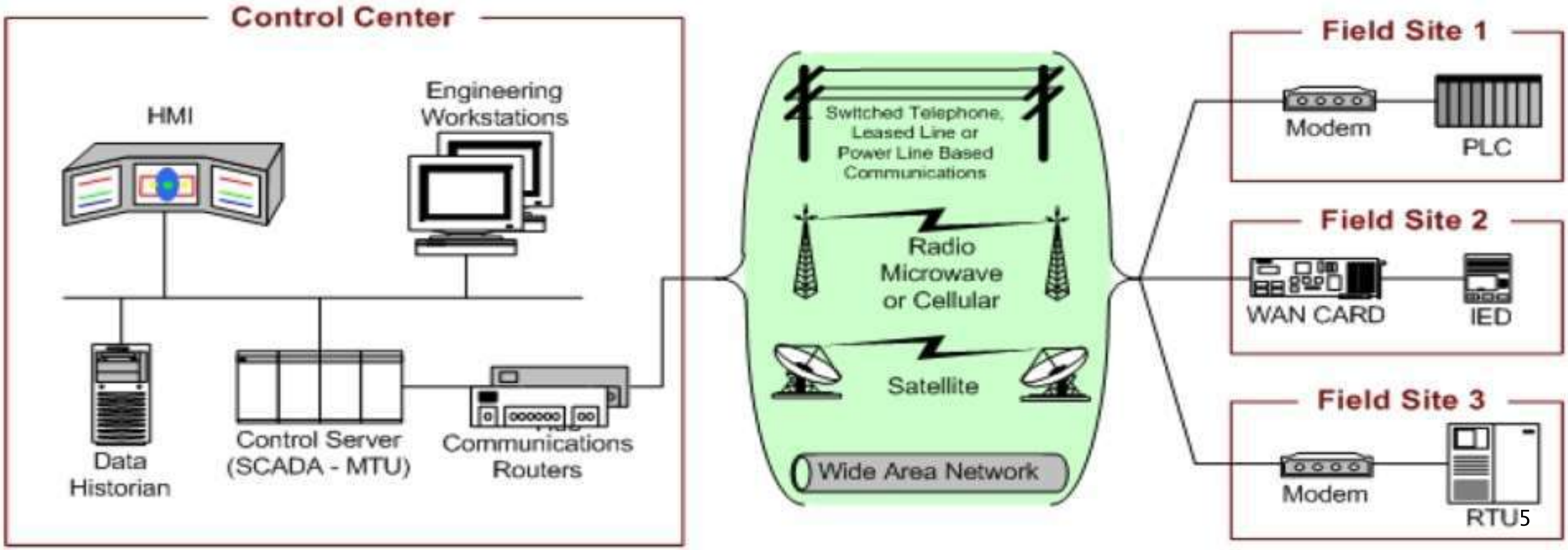
Traditional SCADA Components

- SCADA Master Terminal Unit (MTU): The server that acts as SCADA system
- RTU (remote terminal unit) : remote telemetry data acquisition units located at remote stations
- IED (intelligent electronic devices) smart sensors/actuators with intelligence to acquire data, process it, and communicate
- HMI (human-machine interface) : software to provide for visualisation and interaction with SCADA


WinCC
Professional
Remote Terminal Unit
REALPARS

Overall SCADA System architecture

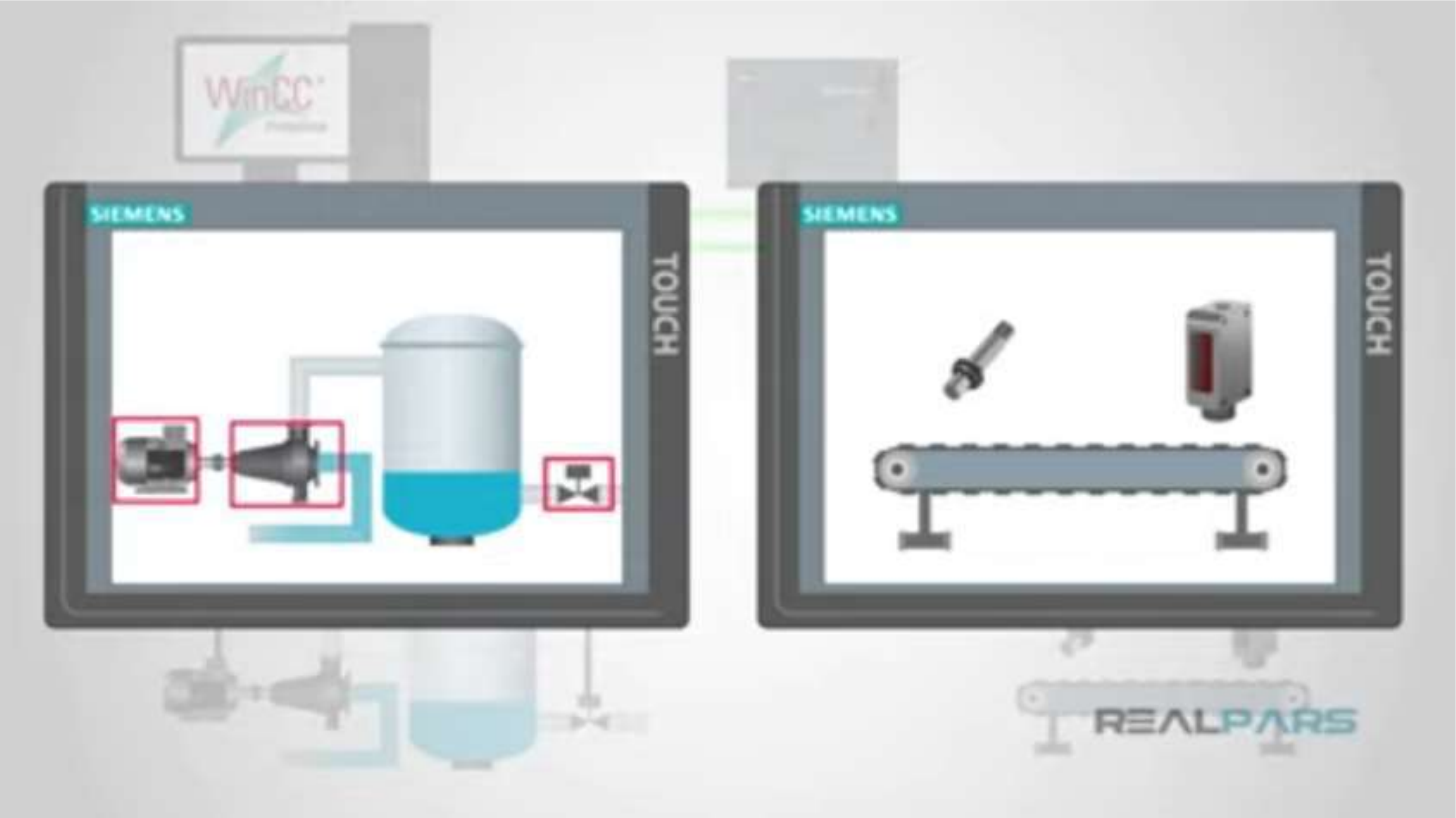
- Can be broken down into 3 categories
- Representation of SCADA system
  - Control Center
  - Communications Network
  - Programmable Logic Controllers(PLCs), Remote Terminal Units (RTUs), IEDs



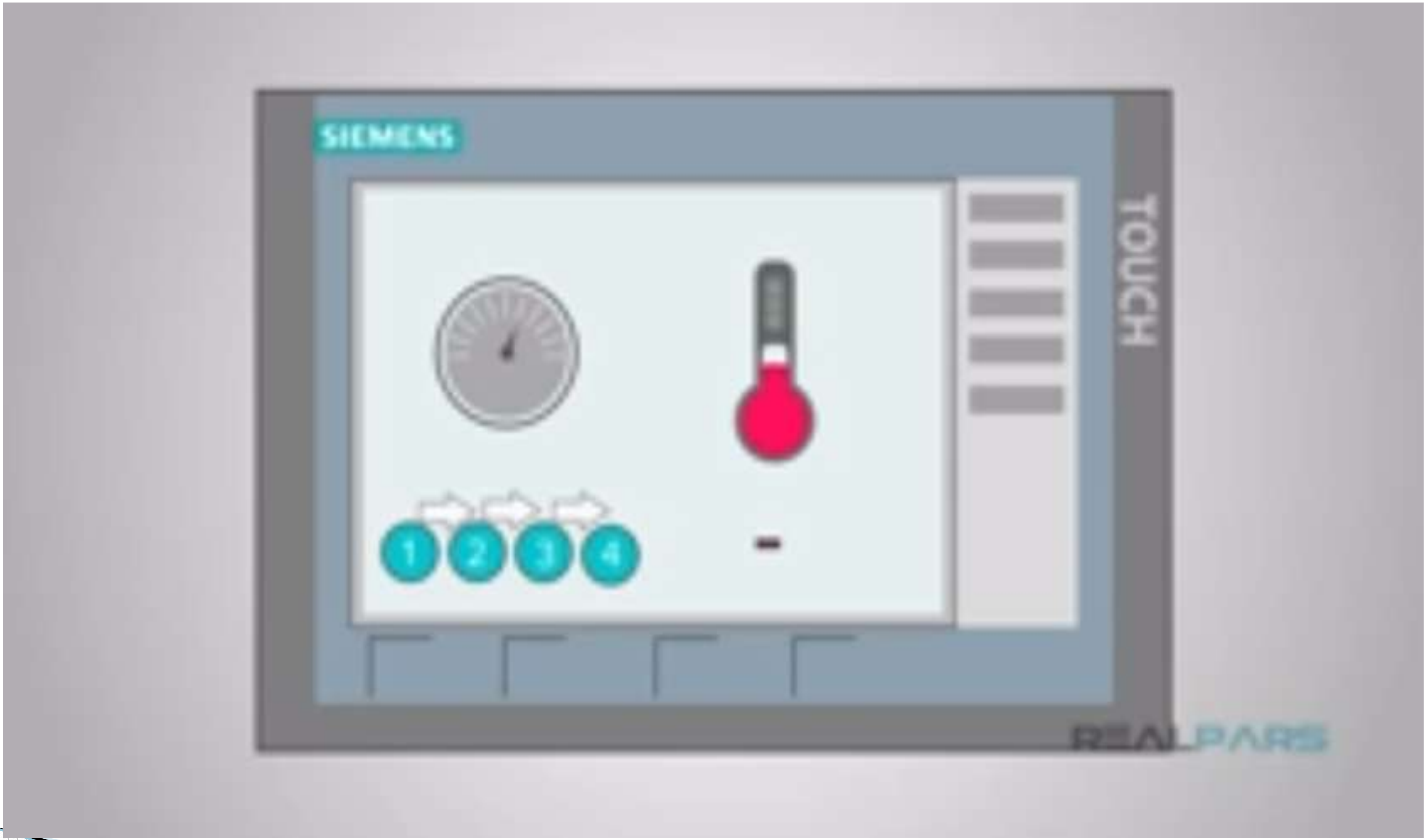
Control Center

- Provides for real-time grid management
- SCADA Server Also known as the MTU (master terminal unit)
- HMI for visualisation and human interaction
- Data historian, a database storage for operational activities
- Control server, hosts software to communicate with lower level control devices

HMI



HMI:Measurement

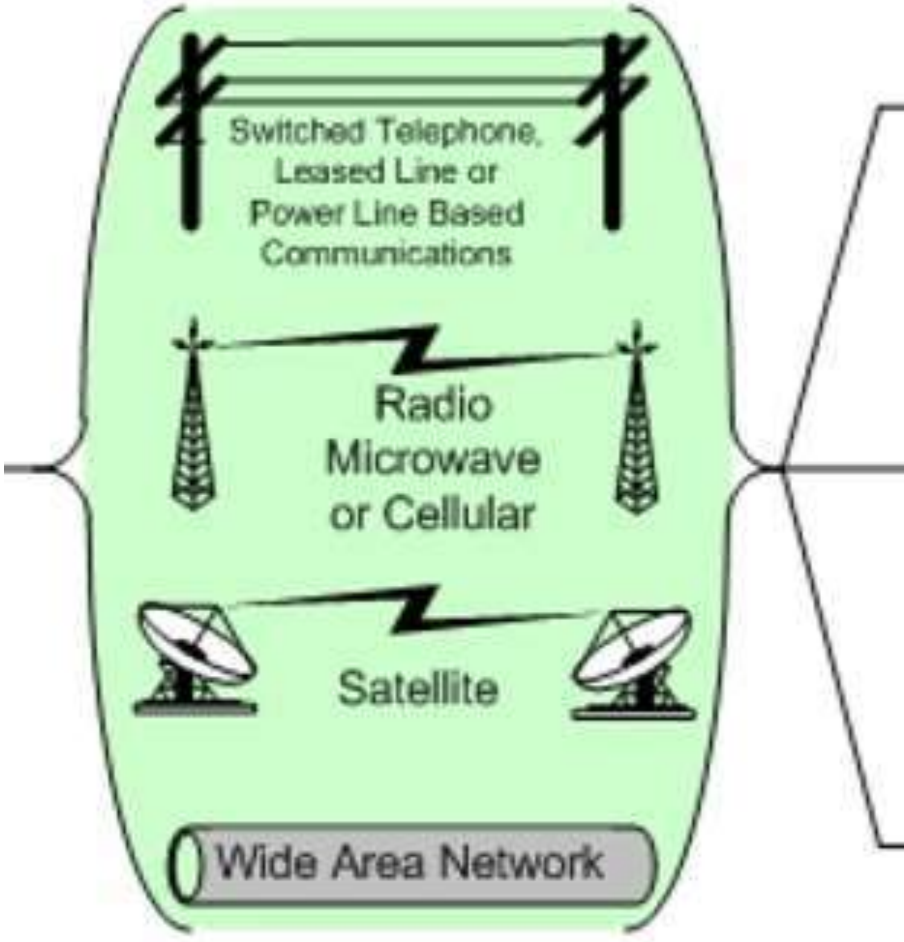


HMI:Trending

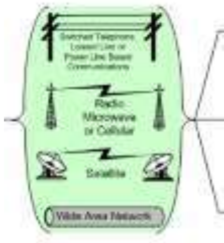
HMI :Latest version

Communication Link

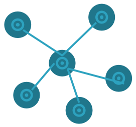
- Phone line/leased line, power line carrier
- Radio
- Cellular network
- Satellite
- Fibre optic



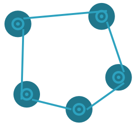
Communication topologies



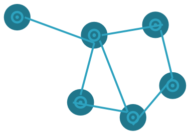
- Star



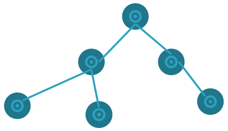
- Ring



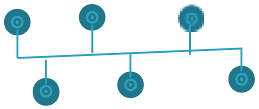
- Mesh



- Tree

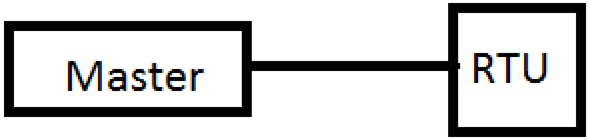


- Bus

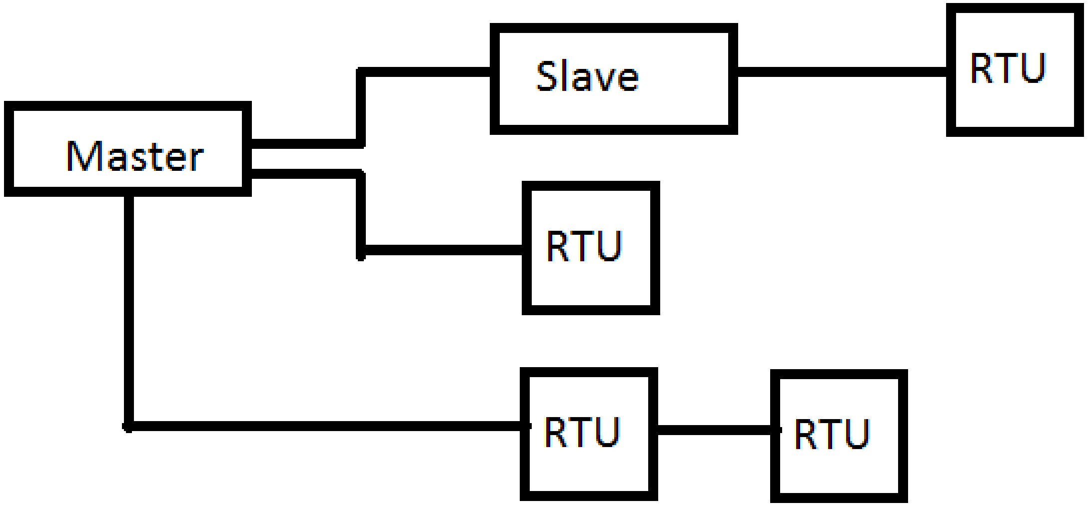


Implementation Examples

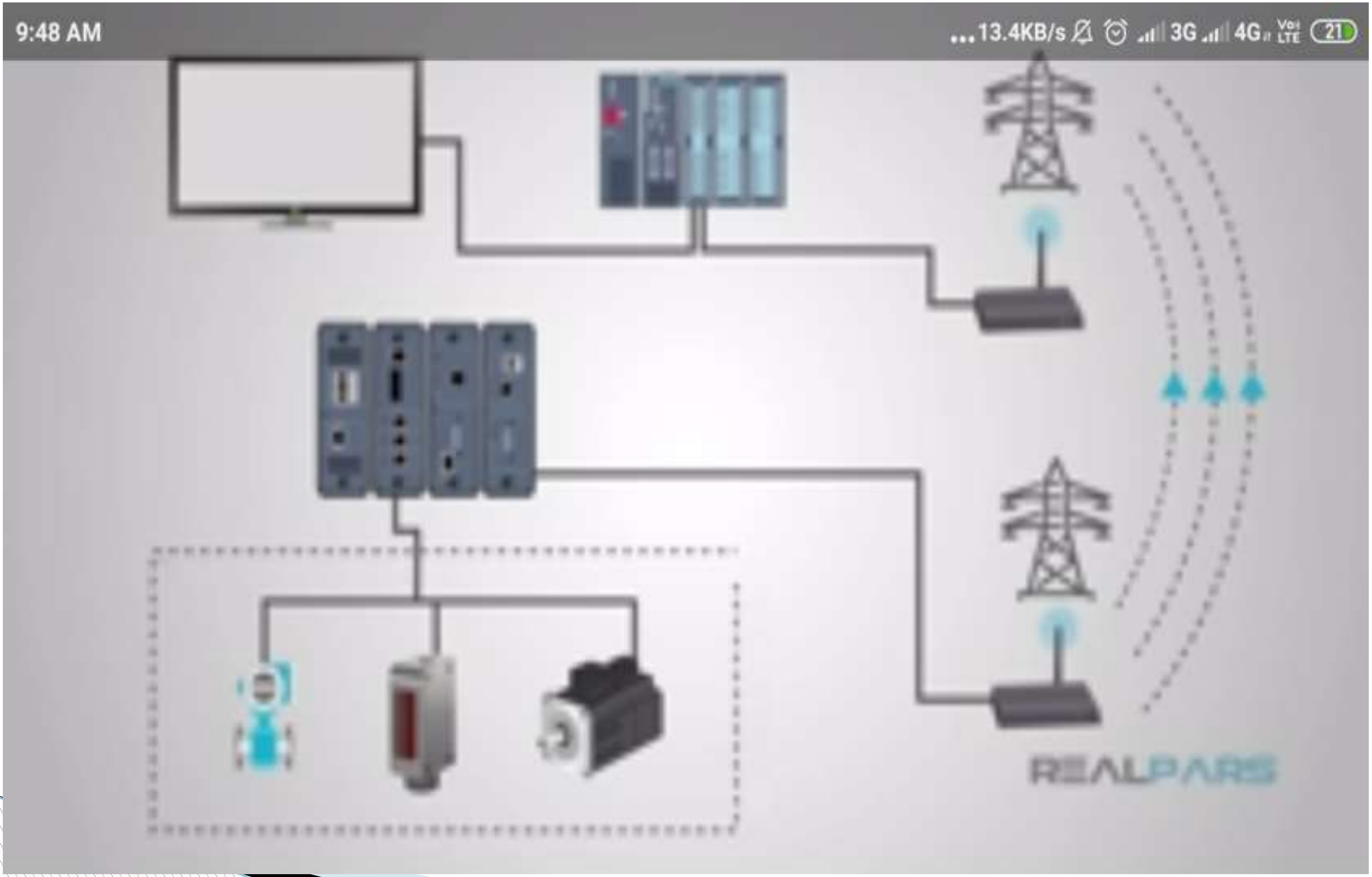
- Many possible topologies
- Direct connection



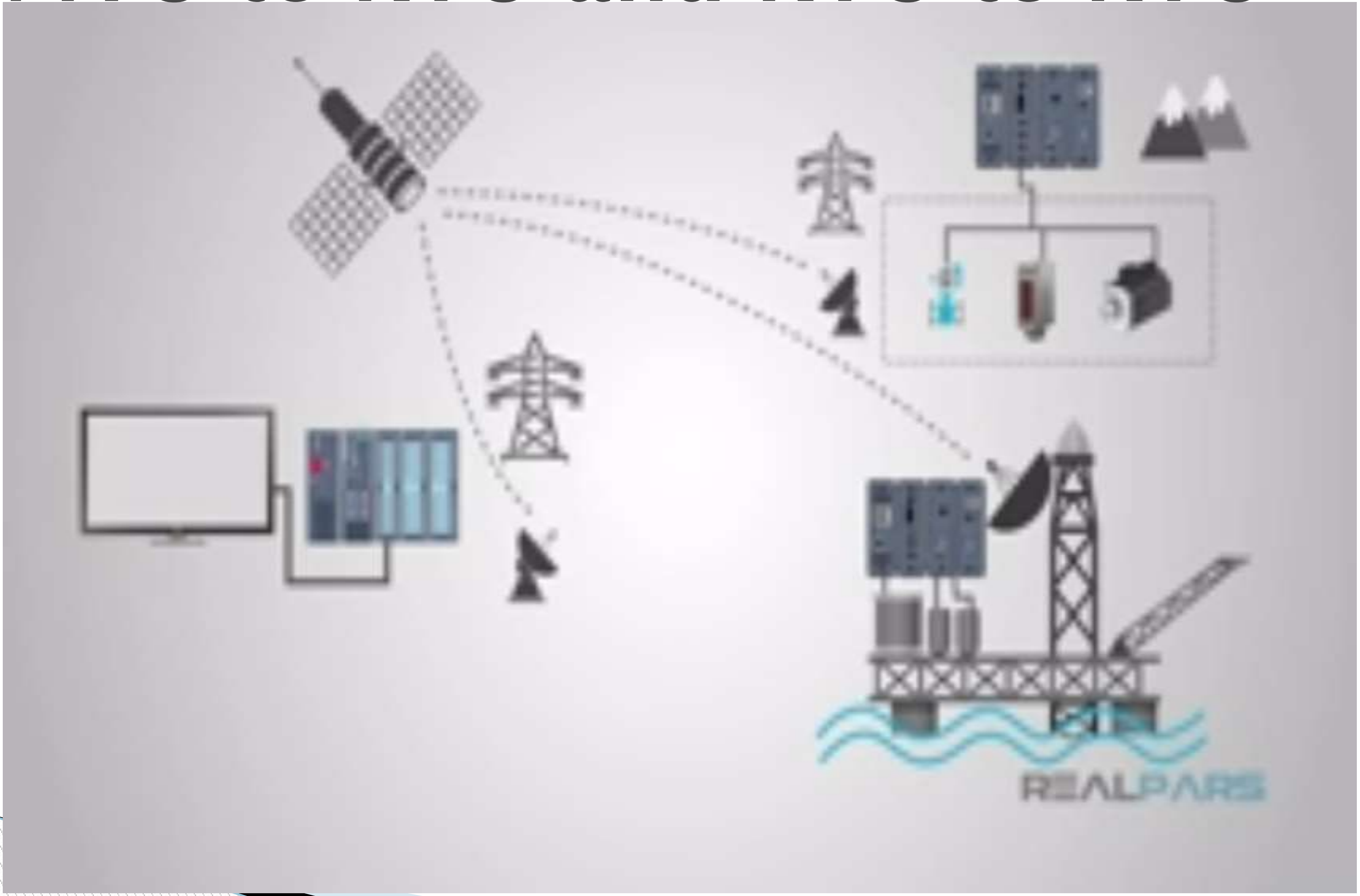
- Connection with slave



MTU to RTU

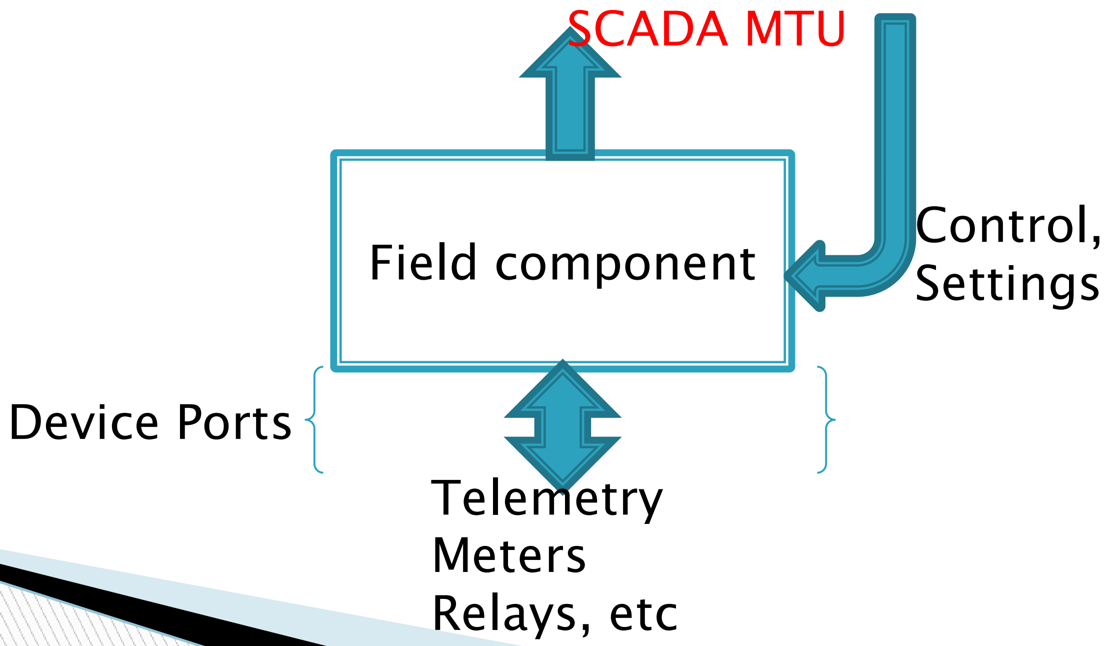


MTU to RTU and RTU to RTU



Field Components

- Acquire telemetry, relay data from system
- Covert it to digital signals if necessary
- Send data to MTU or engineering stations
- Receive control, settings, resets from MTU



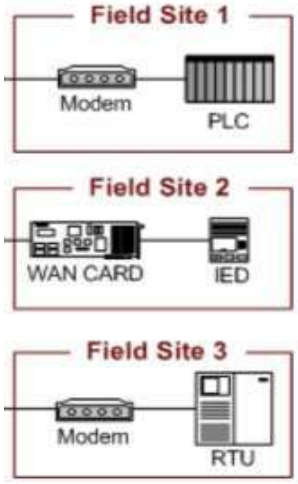
SCADA MTU

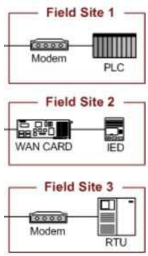
Field component

Control,
Settings

Device Ports

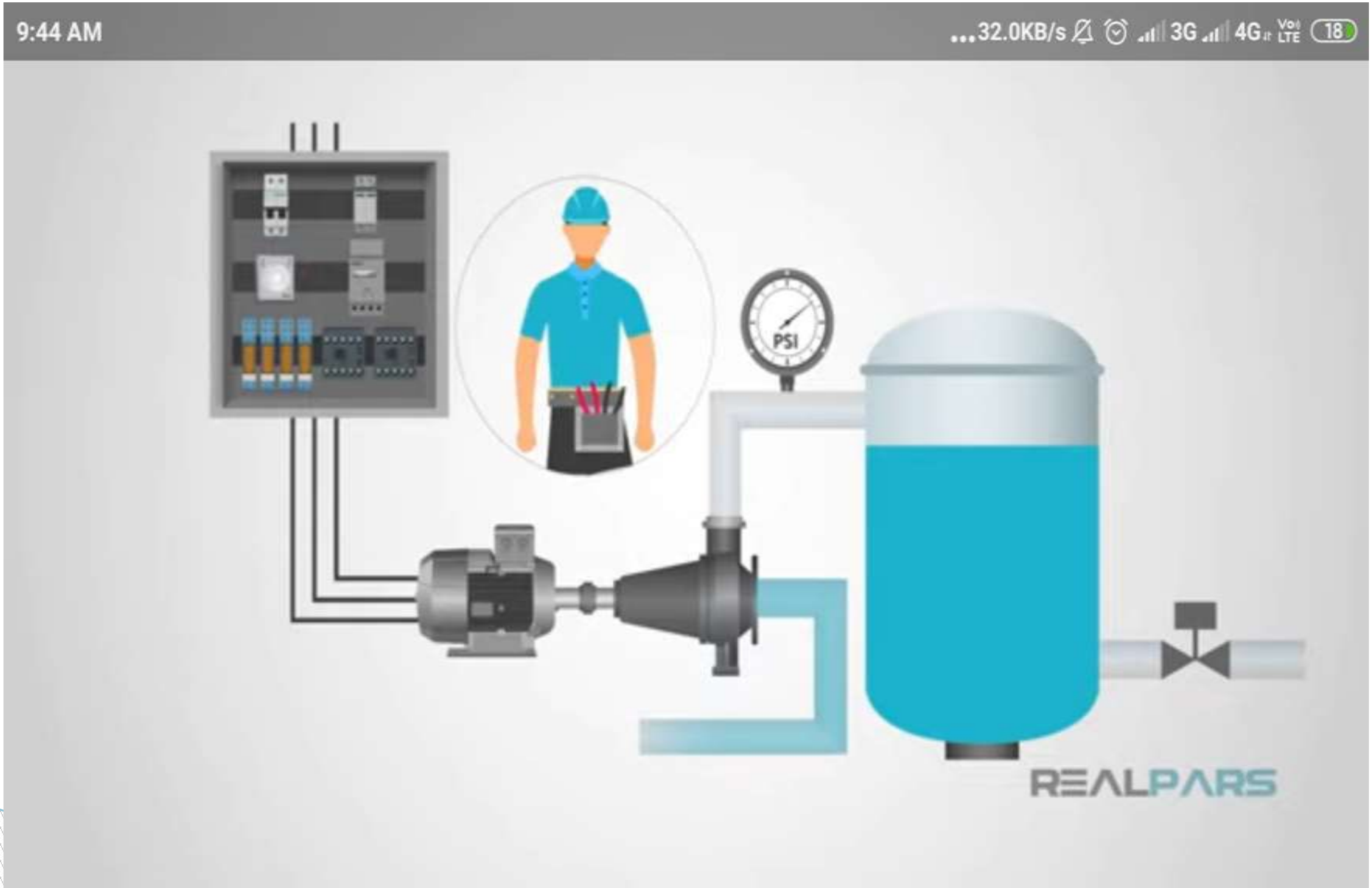
Telemetry
Meters
Relays, etc

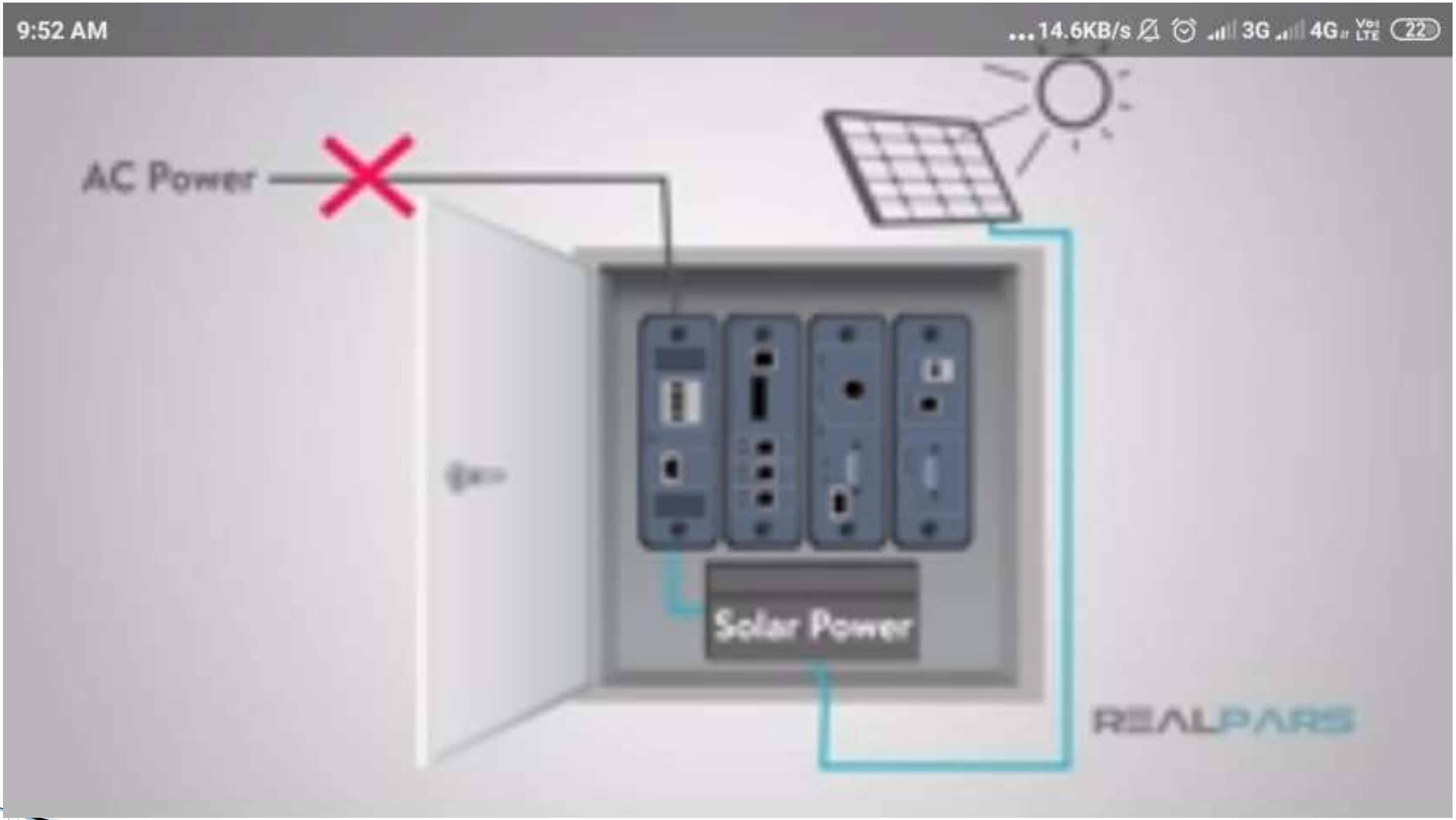


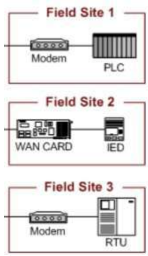


Field Components: RTU

- A Remote Terminal Unit (or RTU) is an electronic device utilizing a microprocessor, which links objects in the physical world with an automation system.
- Reads status and alarms through relay and control circuit auxiliary contacts. Meter reading.
- Manual/remote control e.g. activate alarm. RTU control outputs connected to control relays
- Some PLCs equipped to be RTUs
- Serial communication RS232, RS485


9:44 AM
...32.0KB/s 3G 4G Vo LTE 18
PSI
REALPARS

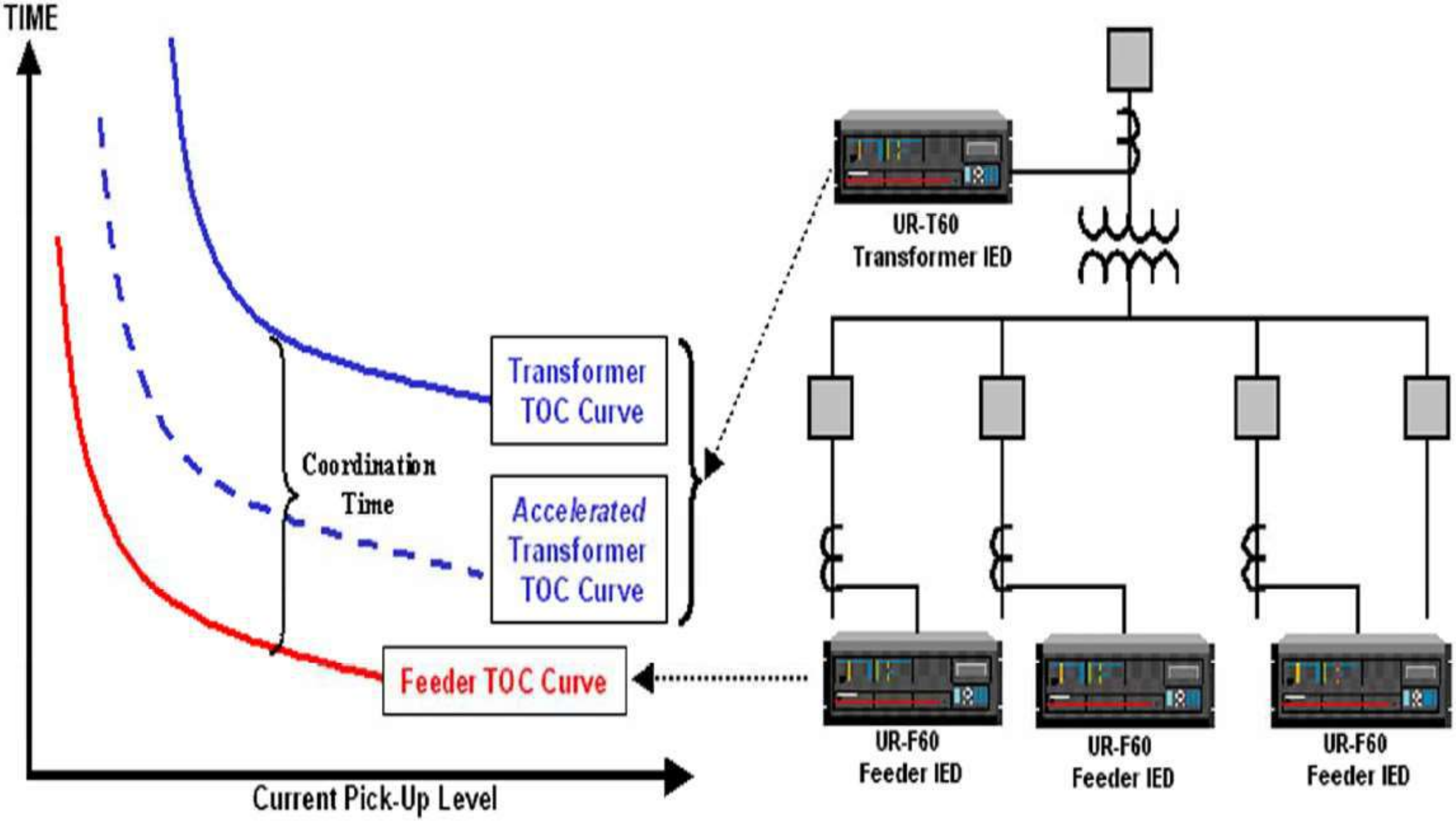

9:52 AM
...14.6KB/s 3G 4G 22
AC Power
Solar Power
REALPARS



Field Components : IED

- Acquires data from electrical devices, e.g. relay or circuit breaker status, switch position.
- Reads meter data such as V, A, MW, MVAR. Some modern meters have IED capabilities, they can communicate their readings with RTU or MTU.
- Control functions include:
  - CB control, voltage regulators, recloser control.
- Newer substations only use modern IEDs
- IEDs can support horizontal communication

IED operation Example



Load –Frequency Control
(Automatic generation control)

Chapter-5

Load –Frequency Control

- Objectives of Power system operation and control are

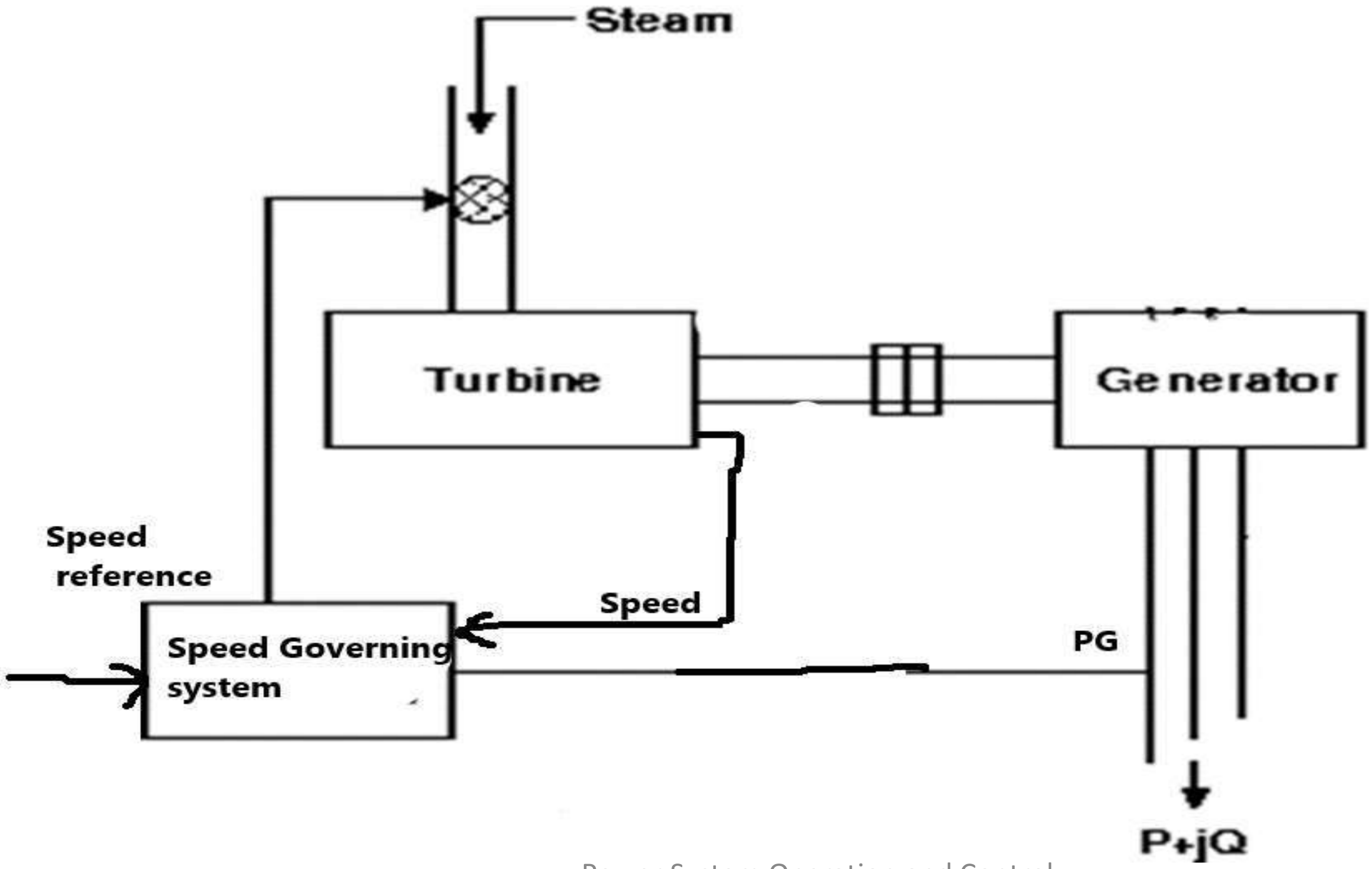
  To supply quality power at

- Constant frequency (5% limits)
- Constant Voltage (5% limits)

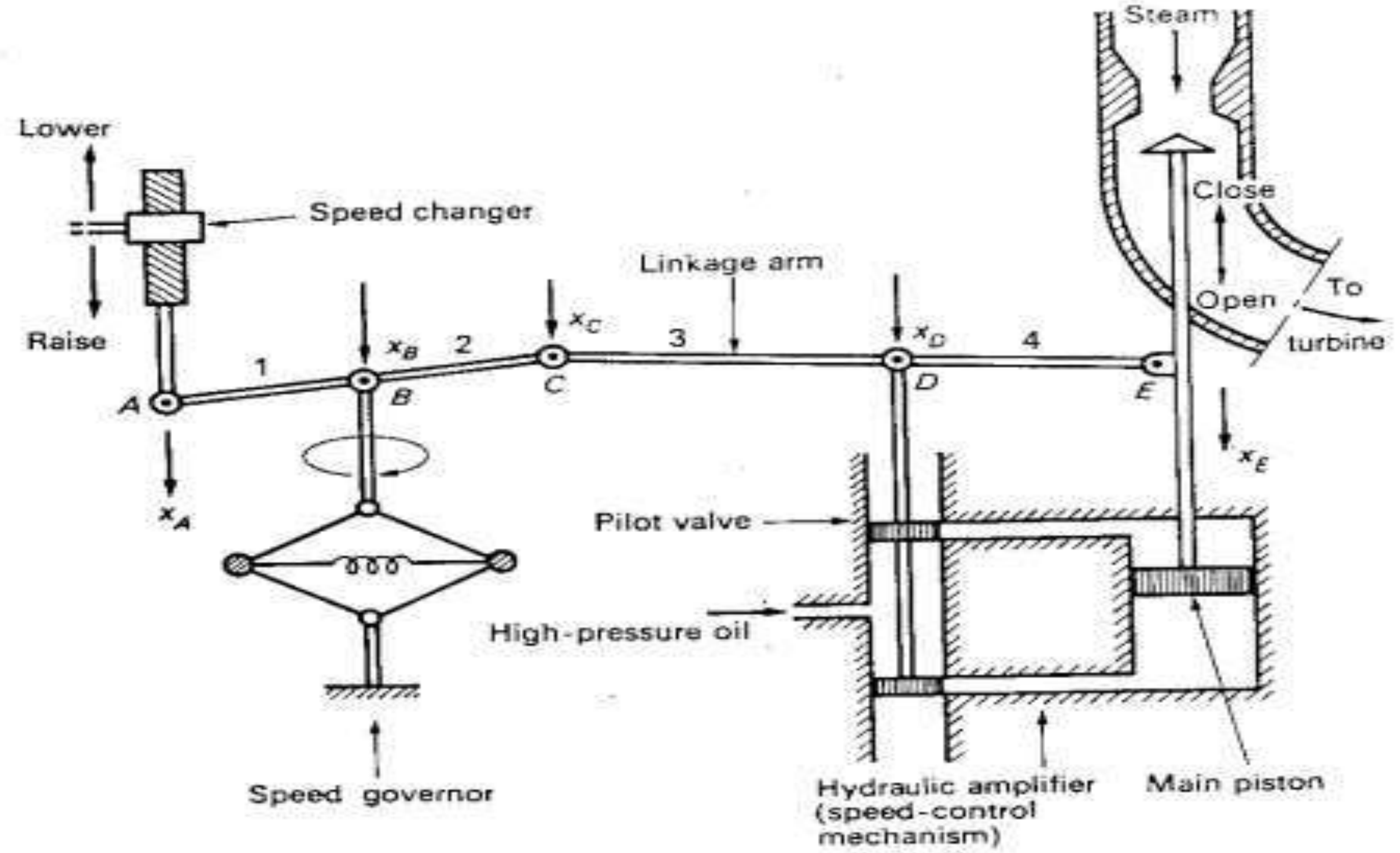
- Active Power and Frequency
  - Balance of load and generation
  - Load-Frequency Control

Load –Frequency Control (Automatic generation control)

Speed governing system



Speed Governing System



The system consists of following components

1.Fly ball governor

2. Hydraulic amplifier

3. Linkage mechanism

4. Speed changer

Fundamentals of Speed Governing System

- The system consists of following components
  - Fly ball governor
  - Hydraulic amplifier
  - Linkage mechanism
  - Speed changer

Fundamentals of Speed Governing System

- **Fly ball speed governor:**
  - This is the heart of the system which senses the change in speed(frequency).
  - As the speed increases the fly ball move outwards and the point B on linkage mechanism moves downwards. The reverse happens when the speed decreases.

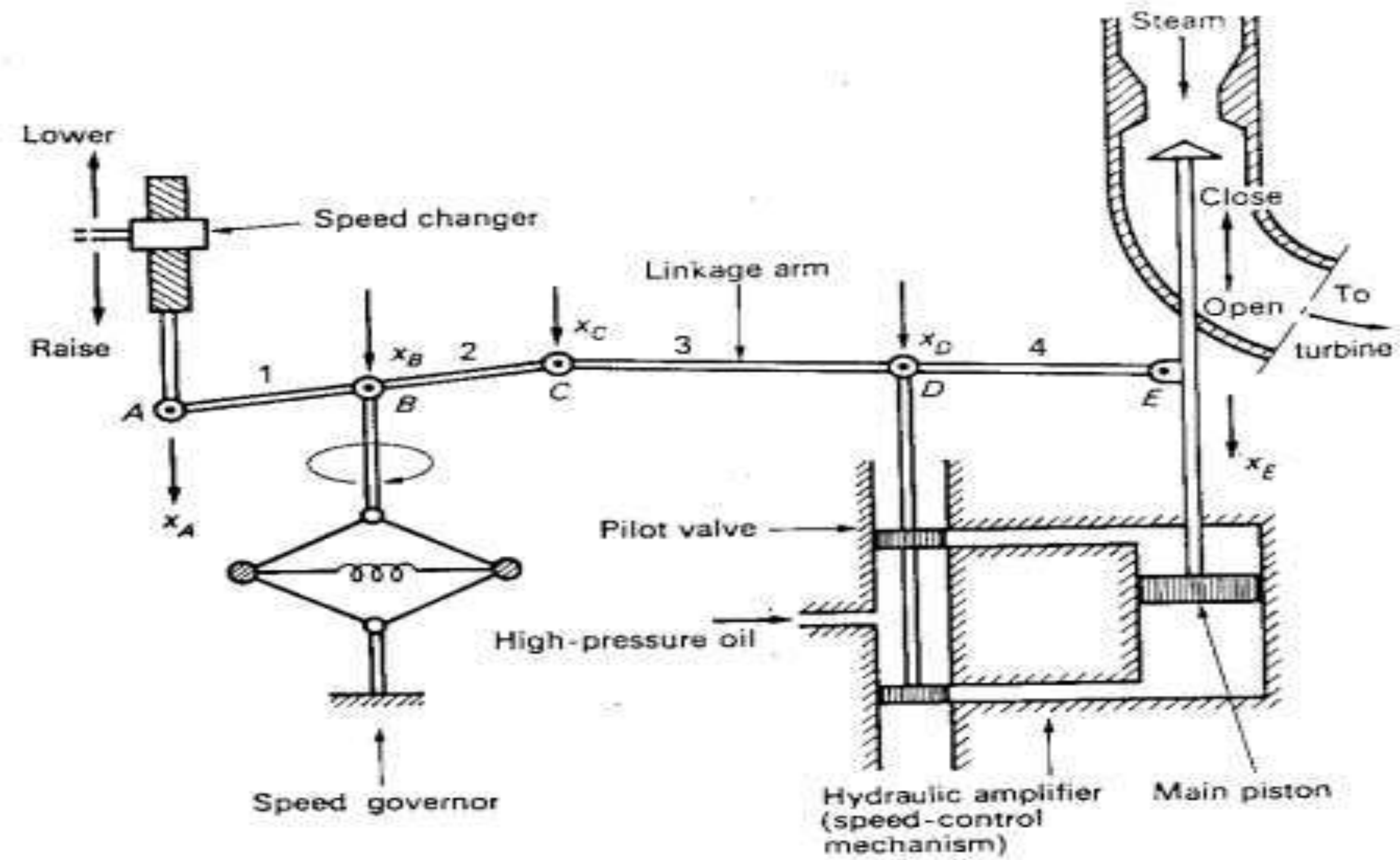
- **Hydraulic amplifier:**
  - It consists of pilot valve and main piston.
  - Low power level pilot valve movement is converted into high power level piston valve movement.
  - This is necessary in order to open or close the steam value against high pressure system.

Fundamentals of Speed Governing System

- **Linkage mechanism:**
  - A,B,C is a rigid link pivoted at B , CDE in another rigid link pivoted at D.
  - This link mechanism provides a movement to control valve in proportion to the change in speed.

- **Speed Changer:**
  - It provides a steady state power output setting for the turbine.
  - Its downward movement opens the upper pilot valve (steam valve) so that more steam is admitted to the turbine under steady state condition.
  - The reverse happens for upward movement of speed changer.

Modeling of Speed Governor system



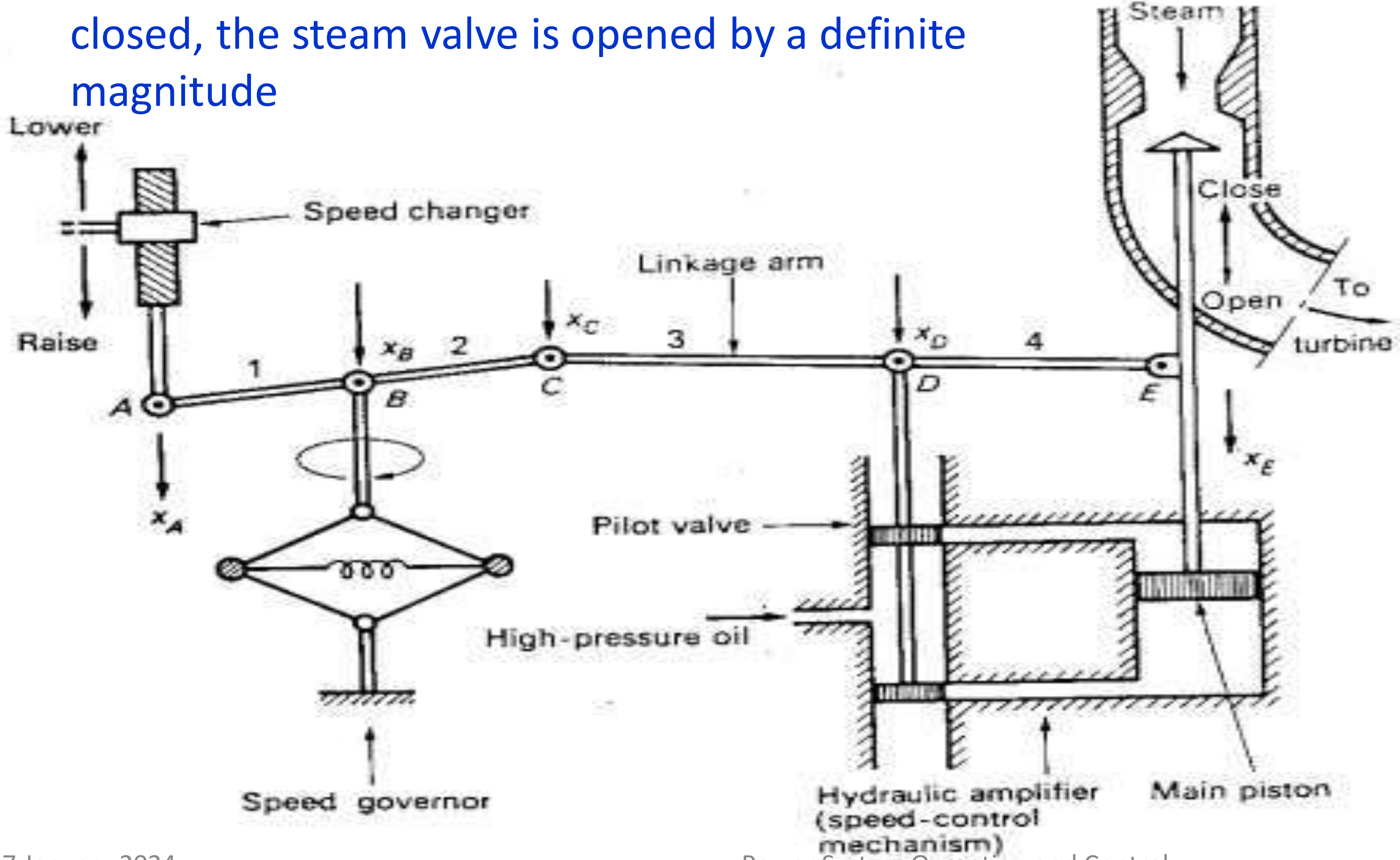
The nominal conditions are

- Power delivered = PG^0
- Turbine Speed = ω^0
- Nominal Frequency = f^0
- Prime mover

  valve position = $X_E{}^0$

Modeling of Speed Governor system

- ✓ Let us assume that the system is operating under steady state condition, i.e.,
- ✓ The linkage mechanism is stationary, pilot valve is closed, the steam valve is opened by a definite magnitude



The nominal conditions are

- Power delivered = PG^0
- Turbine Speed = ω^0
- Nominal Frequency = f^0
- Prime mover

  valve position = $X_E{}^0$

Modeling of Speed Governor system

Let us change the speed changer to command a power increase ΔP_c (ΔP_{ref})

The speed changer movement gives rise to linkage point 'A' moves downwards a small distance ΔX_A

The movement at point A is given by $\Delta X_A = K_C \Delta P_c$ ……..(1)

The link point 'C' will move upward because of linkage (A-B-C) action. (as point B is pivoted)

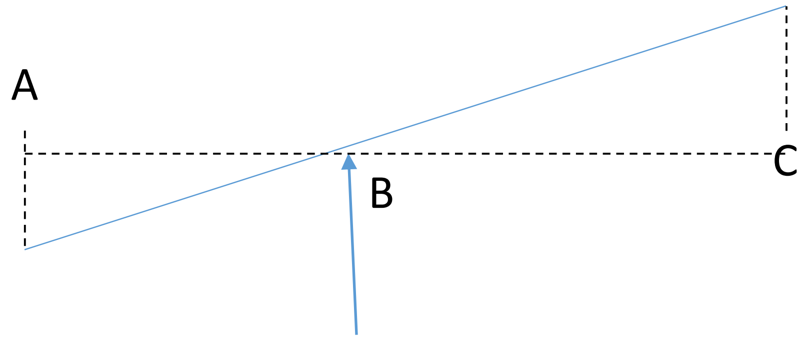
the net movement at point 'C' is produced due to two reasons

1. Due to movement of ΔX_A at point 'A' (+ve)
2. Due to flyball movement caused by increase in frequency . (-ve)

Modeling of Speed Governor system

the net movement at point ‘C’ is given by

$\Delta X_C = \Delta X_C' + \Delta X_C''$

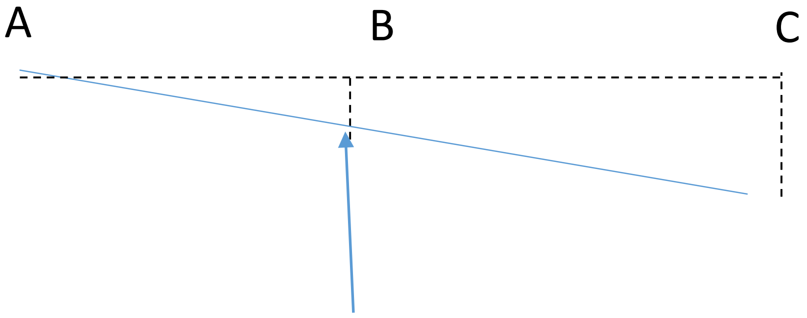


(i) $\Delta X_C' = -K_1 \,.\, \Delta X_A \ (upwards)$

$= -\left(\frac{l_2}{l_1}\right) . \Delta X_A$

$\Delta X_C' = -K_1 . K_c \, \Delta P_C$

(ii) Due to change (increase) in frequency , the point B moves downwards



$\Delta X_B = K_f \,.\, \Delta f$

The movement at point C is given by

$\Delta X_C'' = \left(\frac{l_1+l_2}{l_1}\right) . \Delta X_B$

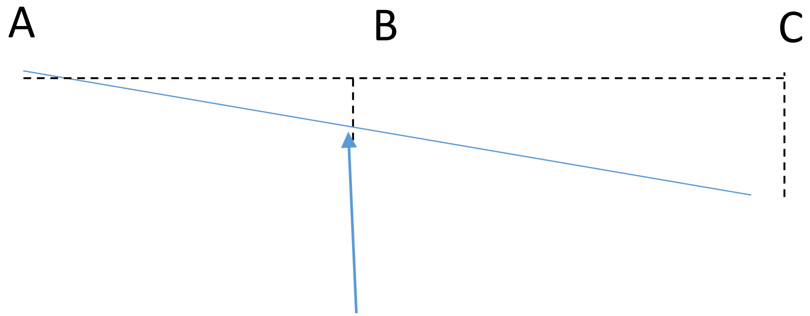
Modeling of Speed Governor system

The movement at point C is given by

$$\Delta X_C" = \left(\frac{l_1+l_2}{l_1}\right) . \Delta X_B$$

$$\Delta X_C" = \left(\frac{l_1+l_2}{l_1}\right) . K_f . \Delta f$$

$$\Delta X_C" = K_2 . \Delta f$$



The net movement at point ‘C’ by both ΔX_A and Δf is given by

$$\Delta X_C = \Delta X_C' + \Delta X_C"$$

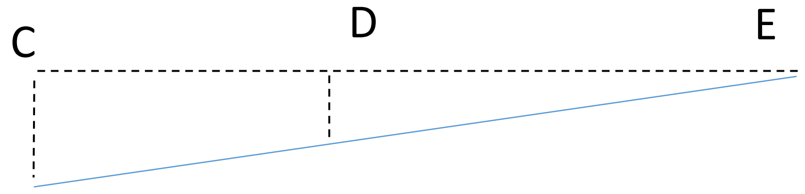
$$\Delta X_C = -K_1 . K_c \, \Delta P_C + K_2 . \Delta f \quad \ldots\ldots\ldots\ldots.. (2)$$

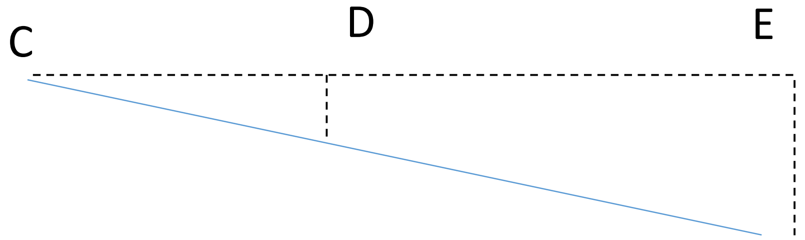
Modeling of Speed Governor system

iii) The movement at point ‘D’ (ΔX_D)

ΔX_D is contributed by ΔX_C and ΔX_E

$\Delta X_D = K_3 \, \Delta X_C + K_4 \, .\Delta X_E \ldots \ldots \ldots \ldots .. (3)$





iv) The movement at point ‘E’ (ΔX_E) (Main piston displacement)

- Rate of flow of oil admitted into the cylinder is proportional to valve opening ΔX_D

  $q = K_q \, \Delta X_D$

- The mass/volume of oil entered into the cylinder is given by

$$V = \int_0^t K_V . q \, dt = \int_0^t K_V . K_q \, \Delta X_D$$

Modeling of Speed Governor system

The displacement of main piston is proportional to mass/volume of oil entered into the cylinder

$$\Delta X_E \ \alpha \ V$$

$$\Delta X_E = -K_5 . \int_0^t \Delta X_D \, \mathrm{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Modeling of Speed Governor system

The equations of speed governor system are

$\Delta X_A = K_C \Delta P_c$ ……..(1)

$\Delta X_C = -K_1 . K_c \Delta P_C + K_2 . \Delta f$ ……………..(2)

$\Delta X_D = K_3 \Delta X_C + K_4 . \Delta X_E$ ……………..(3)

$\Delta X_E = -K_5 . \int_0^t \Delta X_D \, dt$ ………………..(4)

Taking Laplace transform on both sides of equation 1,2,3 and 4

Modeling of Speed Governor system

Taking Laplace transform on both sides of equation 1,2,3 and 4

ΔX_A(s) = K$_C$ ΔP_c(s) ....(1)

ΔX_C(s) = -K$_1$ .K$_c$ ΔP_C(s)+ K$_2$. $\Delta f(s) \ldots \ldots \ldots \ldots . . (2)$

ΔX_D(s) = K$_3$ ΔX_C(s)+ K$_4$.$\Delta X_E(s) \ldots \ldots \ldots \ldots . . (3)$

$\Delta X_E = \frac{-K_5}{s} . \Delta X_D(s)$ ....(4)

Eliminating ΔX_A(s) , ΔX_C(s) , ΔX_D(s)

From (4) → $\Delta X_E(s) = \frac{-K_5}{s} . \Delta X_D(s)$

$$\Delta X_E(s) == \frac{-K_5}{s} . [K_3\, \Delta X_C(s) + K_4\, .\Delta X_E(s)\,]$$

$$\left(1 + \frac{K_5 . K_4}{s}\right) \Delta X_E = \frac{-K_5 . K_3}{s} . \Delta X_C(s)$$

Modeling of Speed Governor system

$$\left(1+\frac{K_5.K_4}{s}\right)\Delta X_E(s)=\frac{-K_5.K_3}{s}.\ \Delta X_C(\mathrm{s})$$

$$\left(1+\frac{K_5.K_4}{s}\right)\Delta X_E(s)=\frac{-K_5.K_3}{s}.\ [-\mathrm{K}_1\ .\mathrm{K}_\mathrm{c}\ \Delta P_C(\mathrm{s})+\ \mathrm{K}_2\ .\ \Delta f(s)]$$

$$\left(1+\frac{K_5.K_4}{s}\right)\Delta X_E(s)=\frac{K_5.K_3.K_1.K_C}{s}.\ [\ \Delta P_C(\mathrm{s})-\ \frac{K_2}{.K_1.K_C}\ .\ \Delta f(s)]$$

$$\Delta X_E(s)=\frac{\frac{K_5.K_3.K_1.K_C}{s}.}{1+\frac{K_5.K_4}{s}}\ [\ \Delta P_C(\mathrm{s})-\ \frac{K_2}{.K_1.K_C}\ .\ \Delta f(s)]$$

$$\Delta X_E(s)=\frac{\frac{.K_3.K_1.K_C}{K_4}.}{\left(\frac{1}{K_5.K_4}\right)s+1}\ [\ \Delta P_C(\mathrm{s})-\ \frac{K_2}{.K_1.K_C}\ .\ \Delta f(s)]$$

Modeling of Speed Governor system

$$\Delta X_E(s) = \frac{\frac{.K_3.K_1.K_c}{K_4}.}{\left(\frac{1}{K_5.K_4}\right)s+1}\left[\ \Delta P_C(\mathrm{s}) - \frac{K_2}{.K_1.K_c}\ .\ \Delta f(s)\right]$$

$$\Delta X_E(s) = \frac{K_{sg}}{T_{sg}.s+1}\left[\ \Delta P_C(\mathrm{s})\ -\ \frac{1}{R}\ .\ \Delta f(s)\right]$$

Where

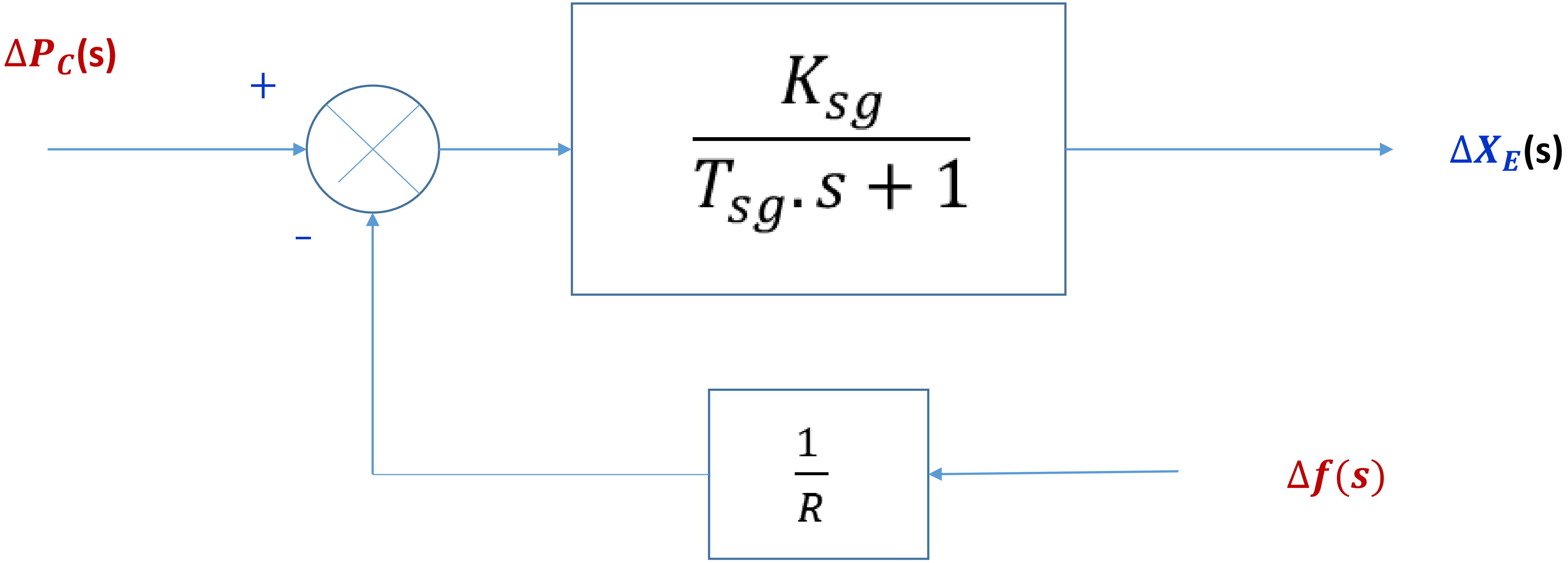
$K_{sg} = \frac{K_3.K_1.K_c}{K_4}$ = gain of the speed governer

$T_{sg} = \frac{1}{K_5.K_4}$ = Time constant of speed governor

R = $\frac{K_1.K_c}{K_2}$ = Speed Regulation.

Modeling of Speed Governor system

$$\Delta X_E = \frac{K_{sg}}{T_{sg}.s+1}\left[\,\Delta P_C(\mathrm{s}) - \frac{1}{R}.\Delta f(s)\right]$$

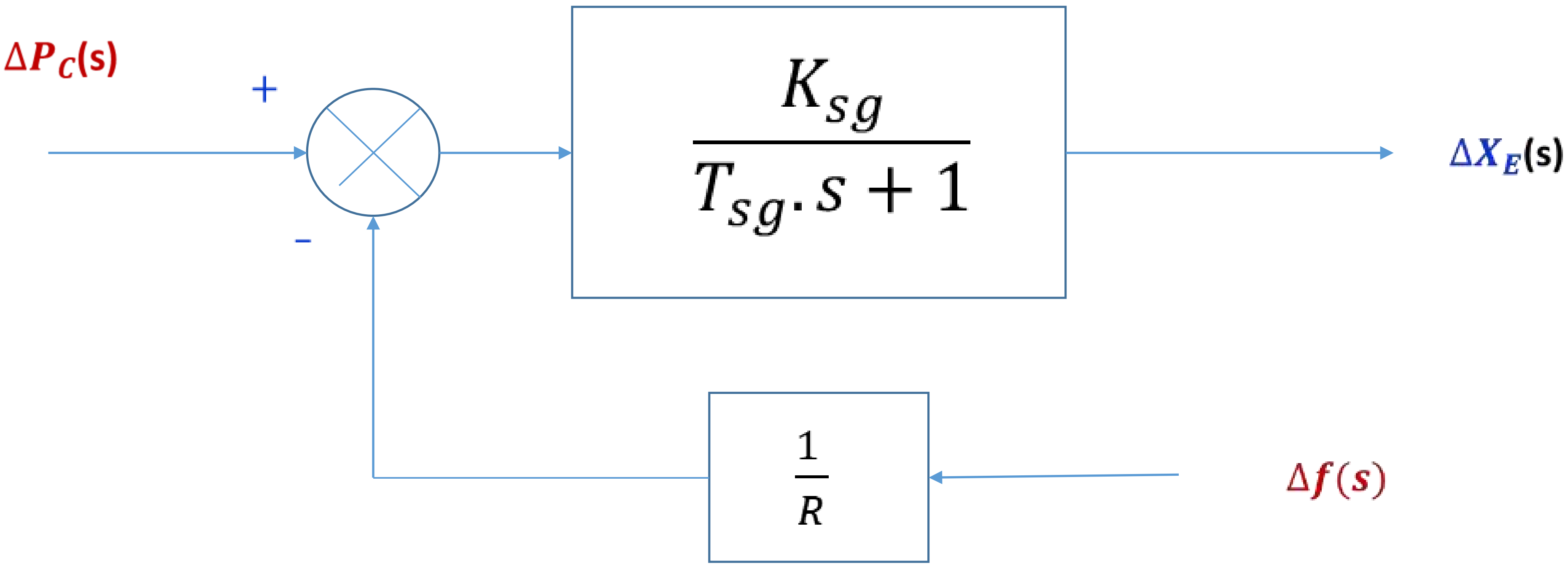


Load –Frequency Control
(Automatic generation control)

Chapter-5

Modeling of Speed Governor system

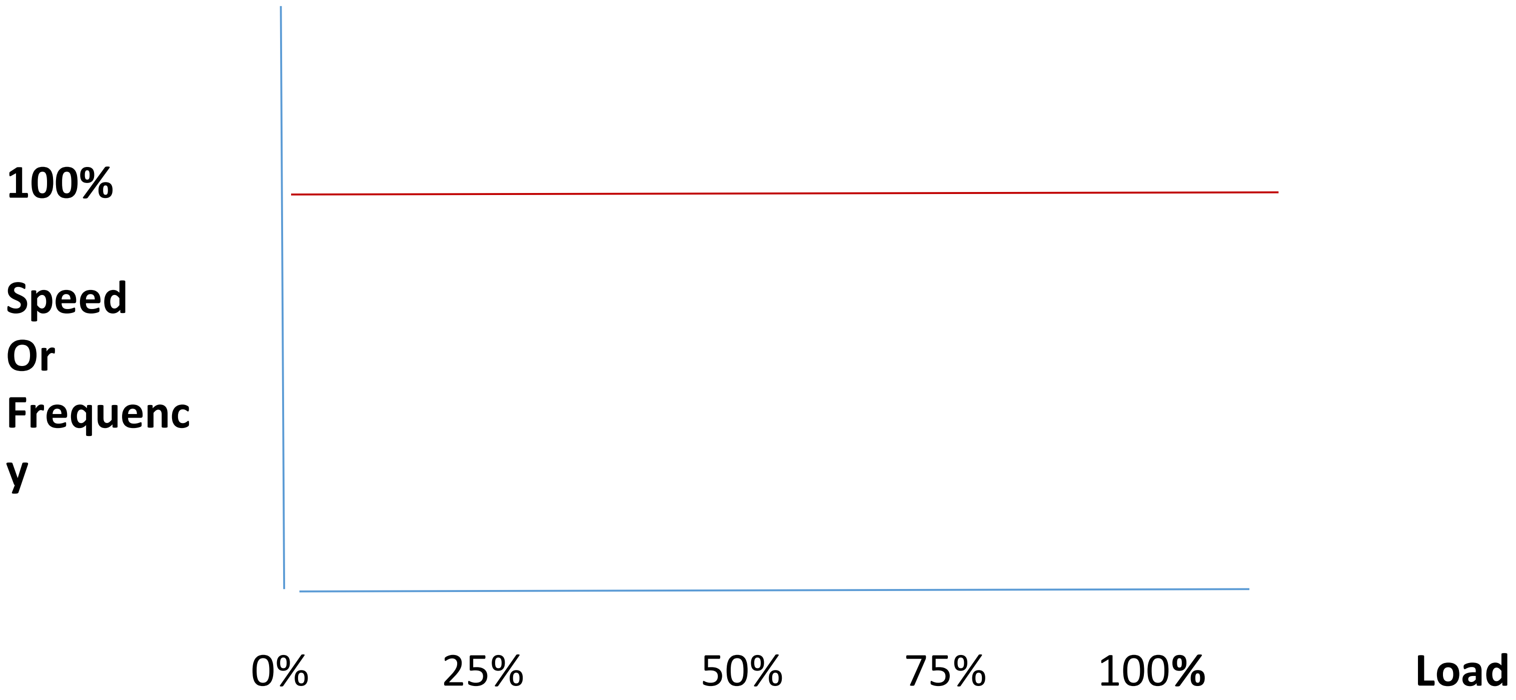
$$\Delta X_E = \frac{K_{sg}}{T_{sg}.s+1}\left[\,\Delta P_C(s) - \frac{1}{R}.\Delta f(s)\right]$$



Modes of Speed Governor operation

ISOCHRONOUS OPERATION:

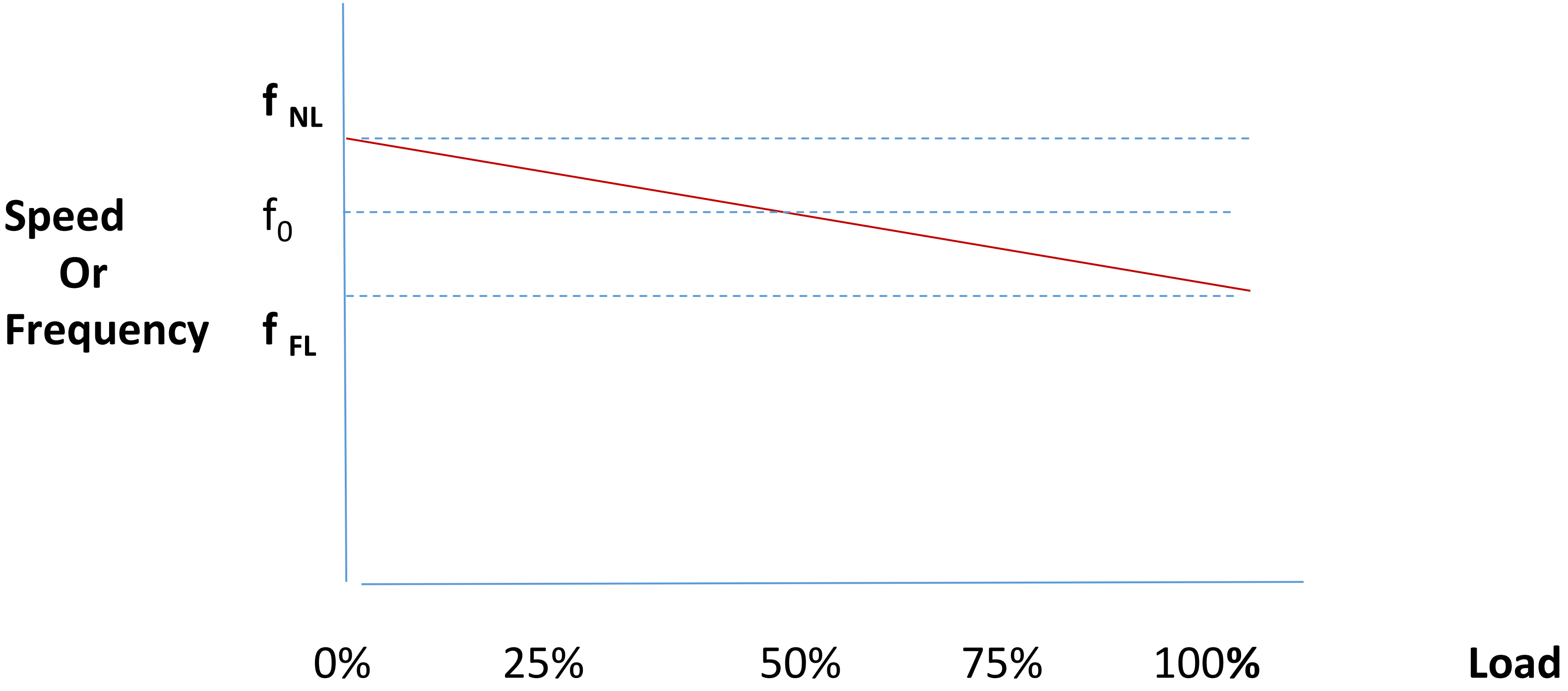
- Governor Maintains a constant speed from No load to full load



Modes of Speed Governor operation

DROOP MODE OPERATION:

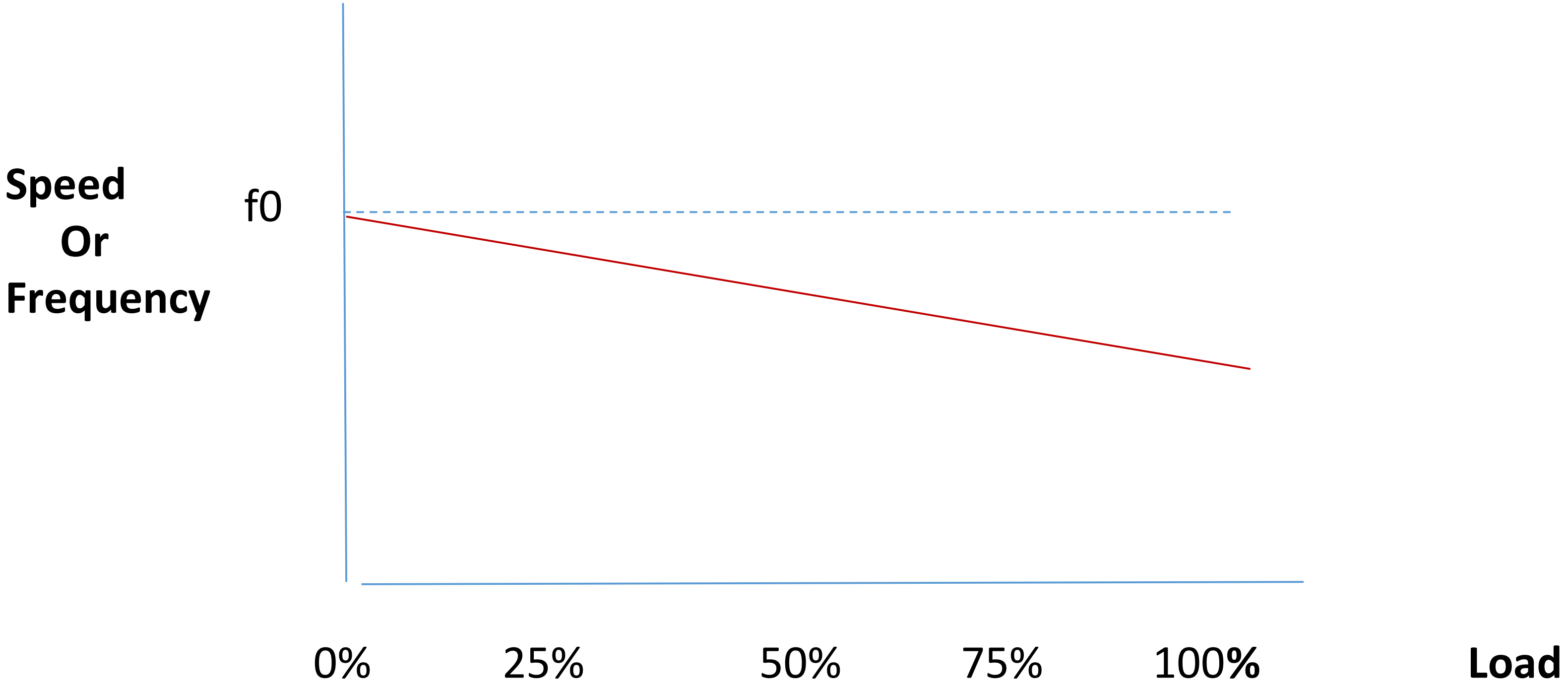
- Decrease in speed as Load increases with a constant slope



Modes of Speed Governor operation

DROOP MODE OPERATION:

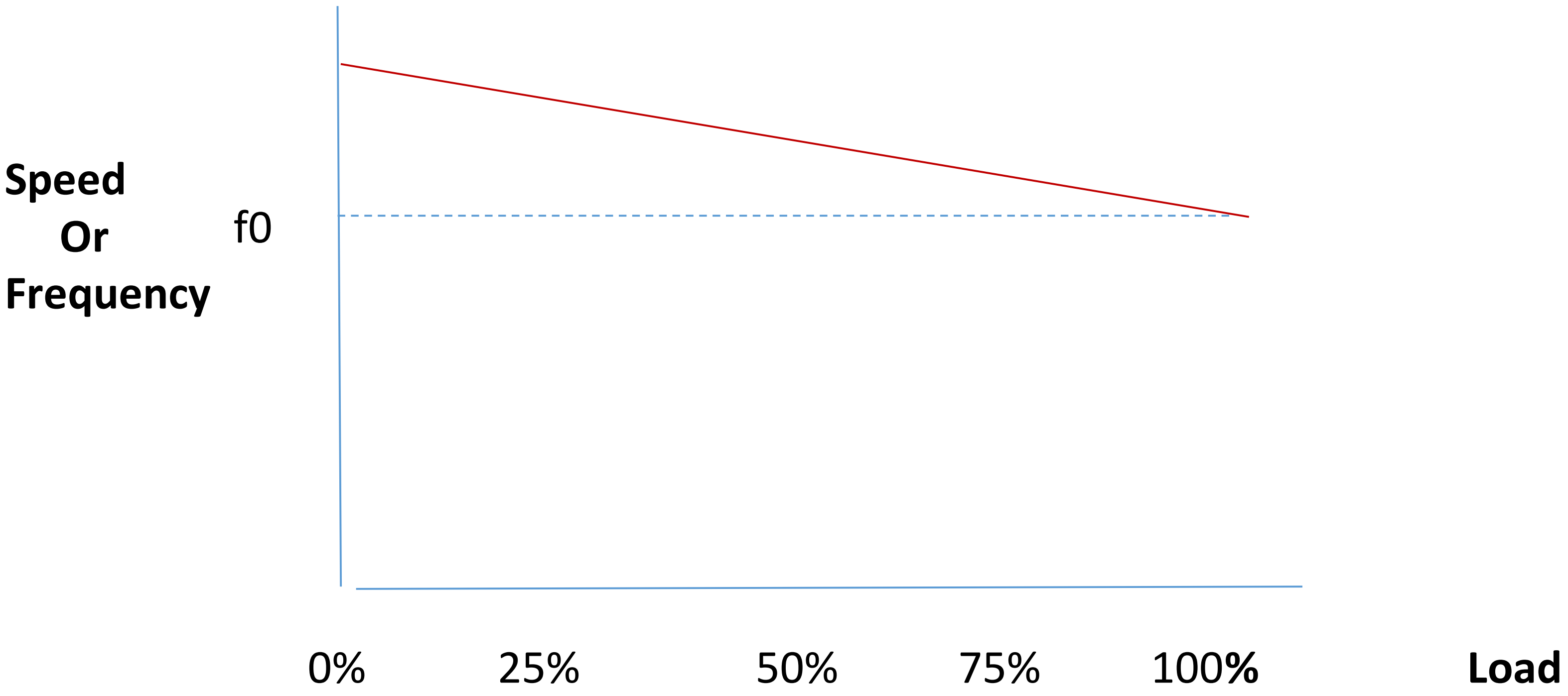
- At no load , the frequency is rated frequency



Modes of Speed Governor operation

DROOP MODE OPERATION:

- At full load , the frequency is rated frequency

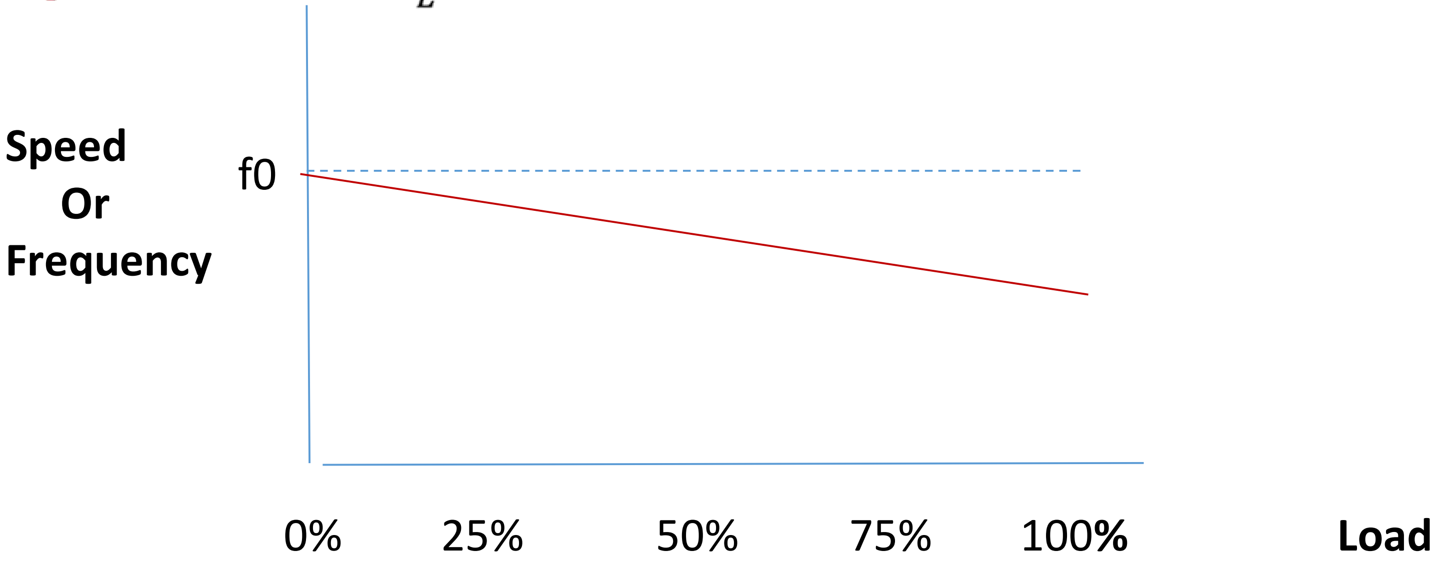


Speed Regulation (R)

- The steady state speed regulation is given by

$$R = \frac{Change\ in\ speed\,(frequency)\ in\ p.u}{change\ in\ the\ load\ \ in\ p.u} = \frac{\Delta f}{\Delta P_L}$$

$$R = \frac{\frac{\Delta f}{f}}{\frac{\Delta PL}{P_L}}$$



- Ex:1 A machine of 500 MW capacity has a speed droop characteristics of 5% . The frequency is 50 Hz on the full load.

Plot the speed droop characteristics and find the frequency

a)when the load is 0 MW.

b)when the load is 300 MW.

Given data:

Full load frequency = f_{FL} = 50 Hz

Load, P_{FL} = 500 MW

No load, P_0 = 0 MW

Change in Load $\Delta P = 0 - 500 = -500\ MW$

Change in frequency $\Delta f = f_0 - 50 = ?$

(i) When P = 0 MW ; P_{FL} = 500 MW

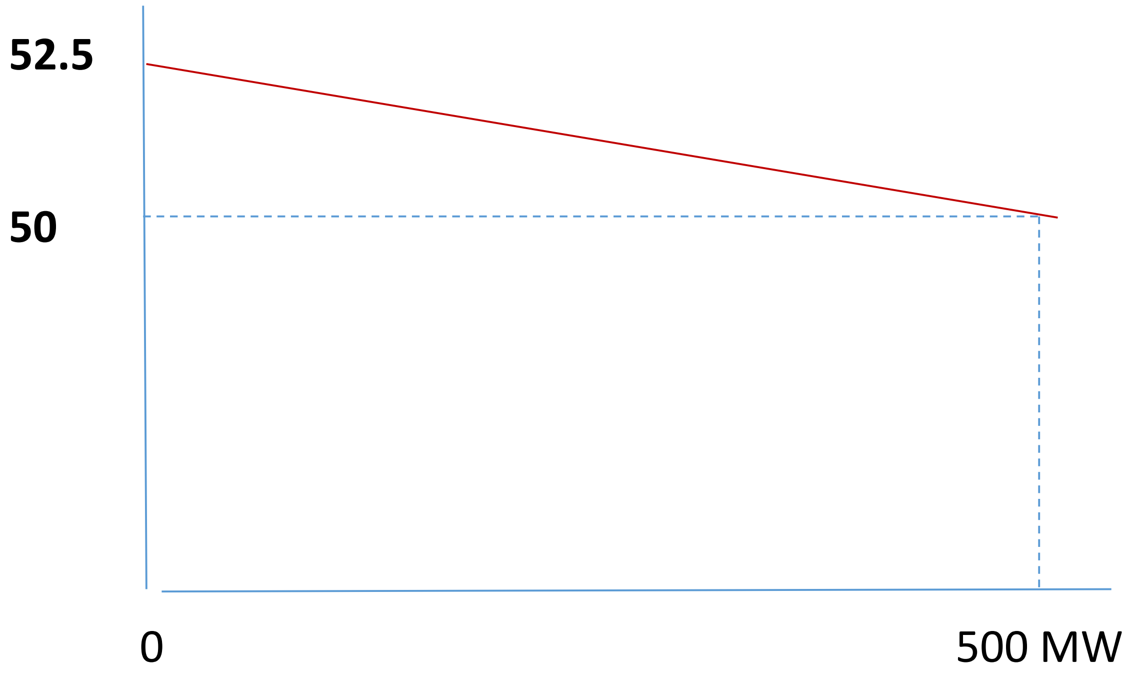
- Speed regulation, $R = \dfrac{\frac{\Delta f}{f}}{\frac{\Delta PL}{P_L}}$

$$0.05 = \frac{\frac{\Delta f}{50}}{\frac{500}{500}}$$

$$0.05 = \frac{\Delta f}{50}$$

Change in frequency

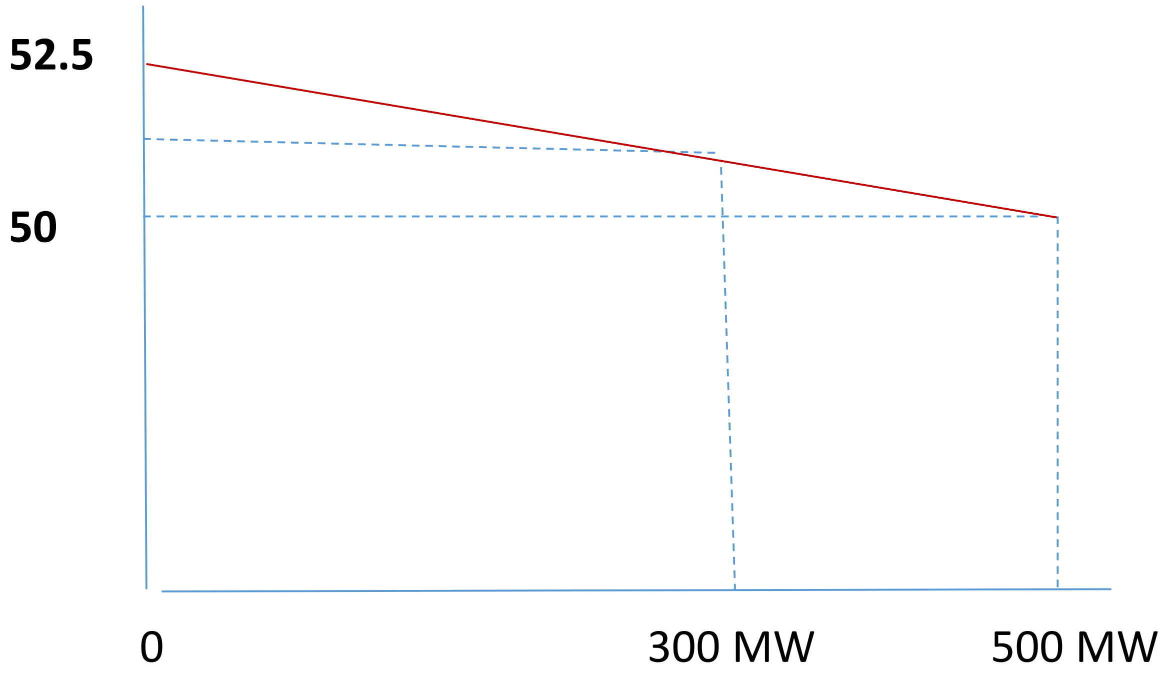
$$\Delta f = 2.5\ Hz$$



(ii) When P_L = 300 MW ; P_{FL} = 500 MW

$$\Delta P = 300 - 500 = -200\ MW$$

Speed regulation, $R = \dfrac{\frac{\Delta f}{f}}{\frac{\Delta PL}{P_L}}$



$$0.05 = \frac{\frac{\Delta f'}{50}}{\frac{200}{500}}$$

Change in frequency

$$\Delta f' = 0.05 * 0.4 * 50 = 1\ Hz$$

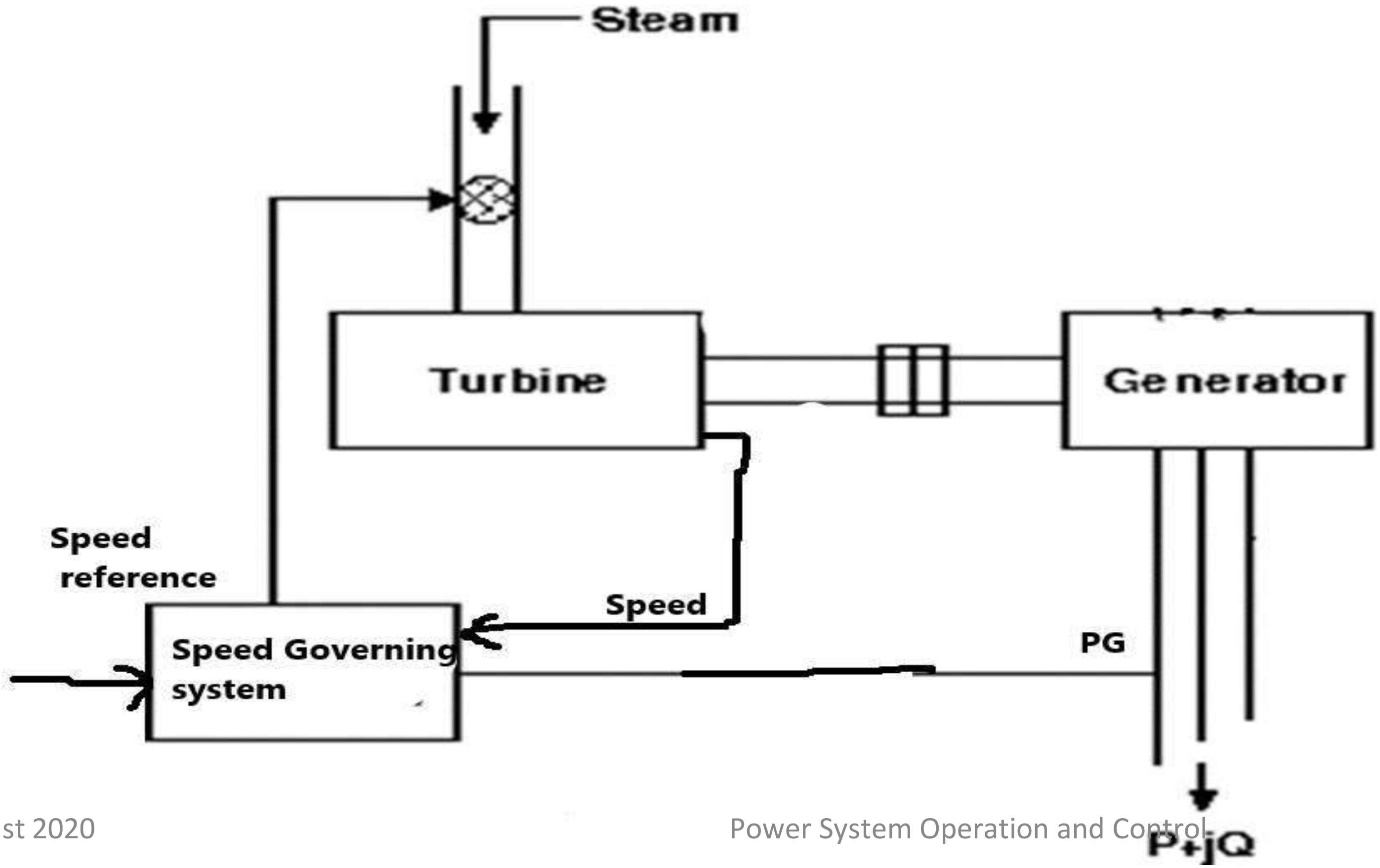
Load –Frequency Control
Modelling of turbine

Chapter-5

Modelling of turbine

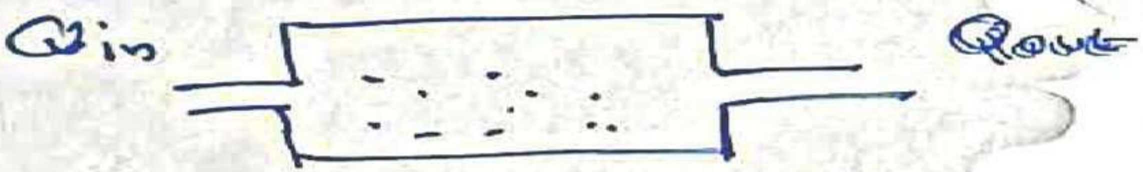
- The prime mover driving a generator unit may be a steam turbine or a hydro turbine.
- The models for the prime mover must take account of the steam supply characteristics

in the case of steam turbine on the penstock for a hydro turbine



Modeling of Turbine

Let us consider a small steam vessel

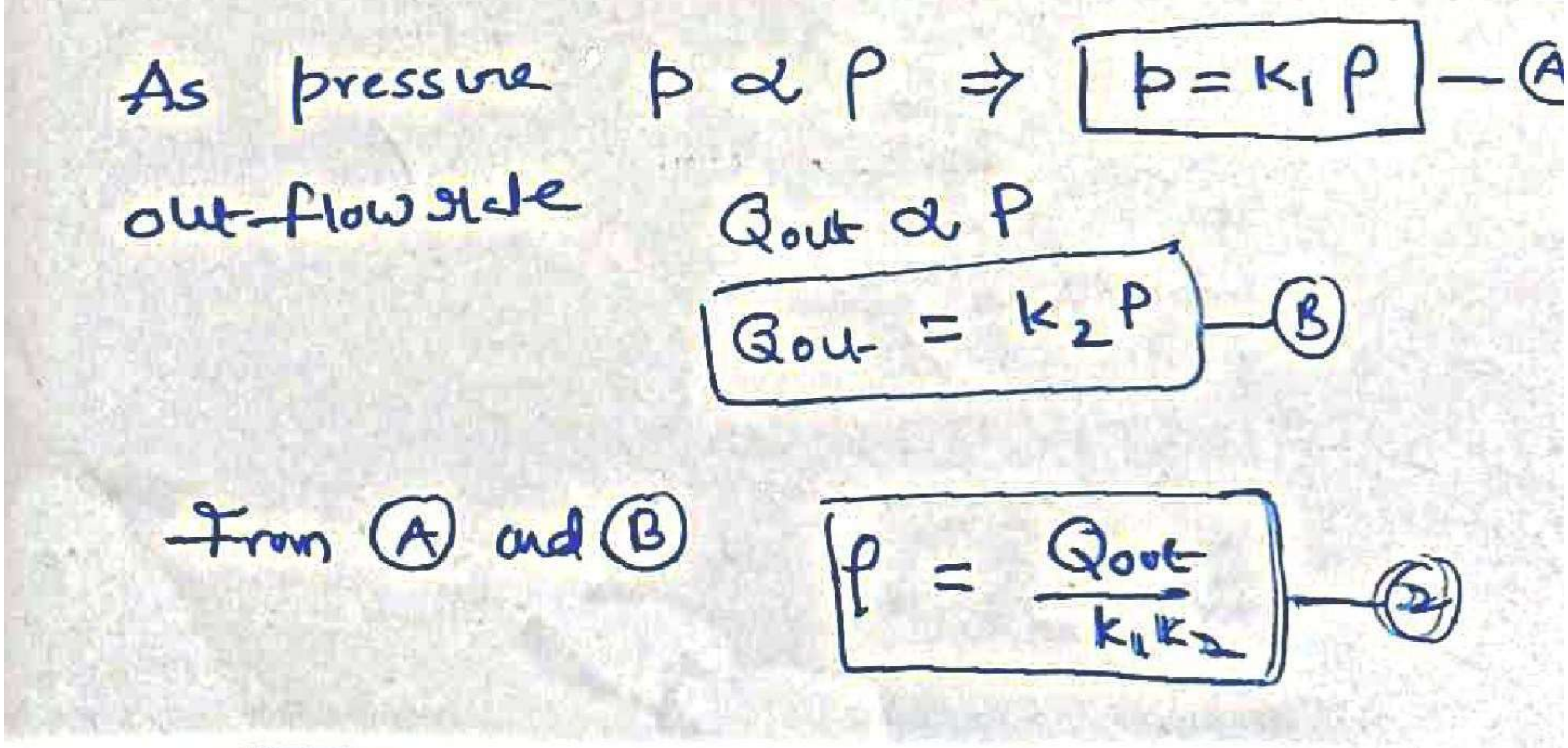


Q_{in} = steam inflow Kg/sec
Q_{out} = steam outflow Kg/sec
W = weight of the steam kg
$= V.\rho$
V = volume in m^3
ρ = density of steam

~~From~~ Continuity Equation (Mass balance)

$$\boxed{Q_{in} - Q_{out} = \frac{d}{dt} W} \quad \text{———} \; ①$$

$$Q_{in} - Q_{out} = V.\frac{d\rho}{dt}$$

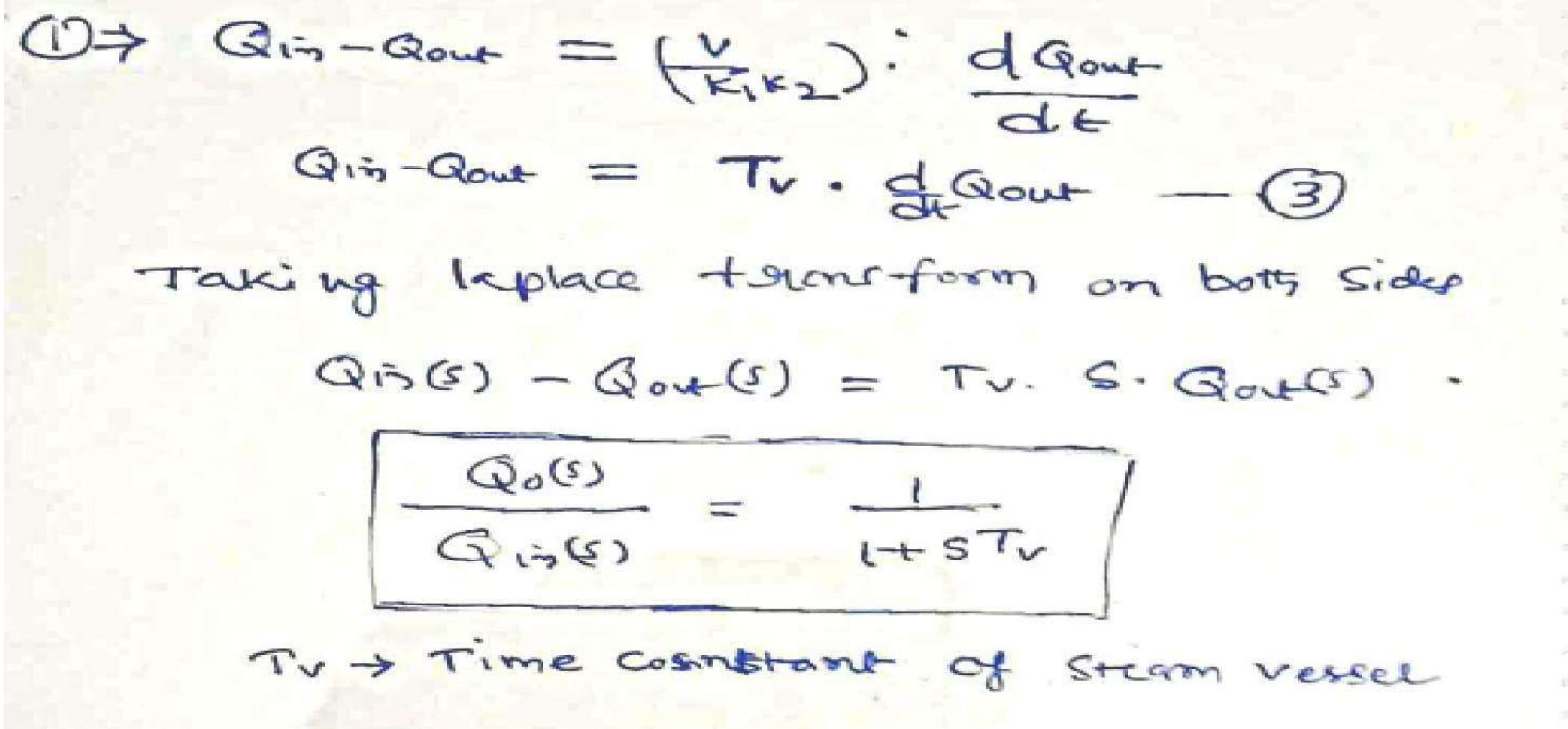


As pressure $p \propto \rho \Rightarrow \boxed{p = k_1 \rho}$ — Ⓐ

out-flow rate $Q_{out} \propto P$

$\boxed{Q_{out} = k_2 P}$ — Ⓑ

From Ⓐ and Ⓑ $\boxed{\rho = \frac{Q_{out}}{k_1 k_2}}$ — ②



① → $Q_{in} - Q_{out} = \left(\frac{V}{K_1 K_2}\right) \cdot \frac{dQ_{out}}{dt}$

$$Q_{in} - Q_{out} = T_v \cdot \frac{d}{dt} Q_{out} \quad \text{— ③}$$

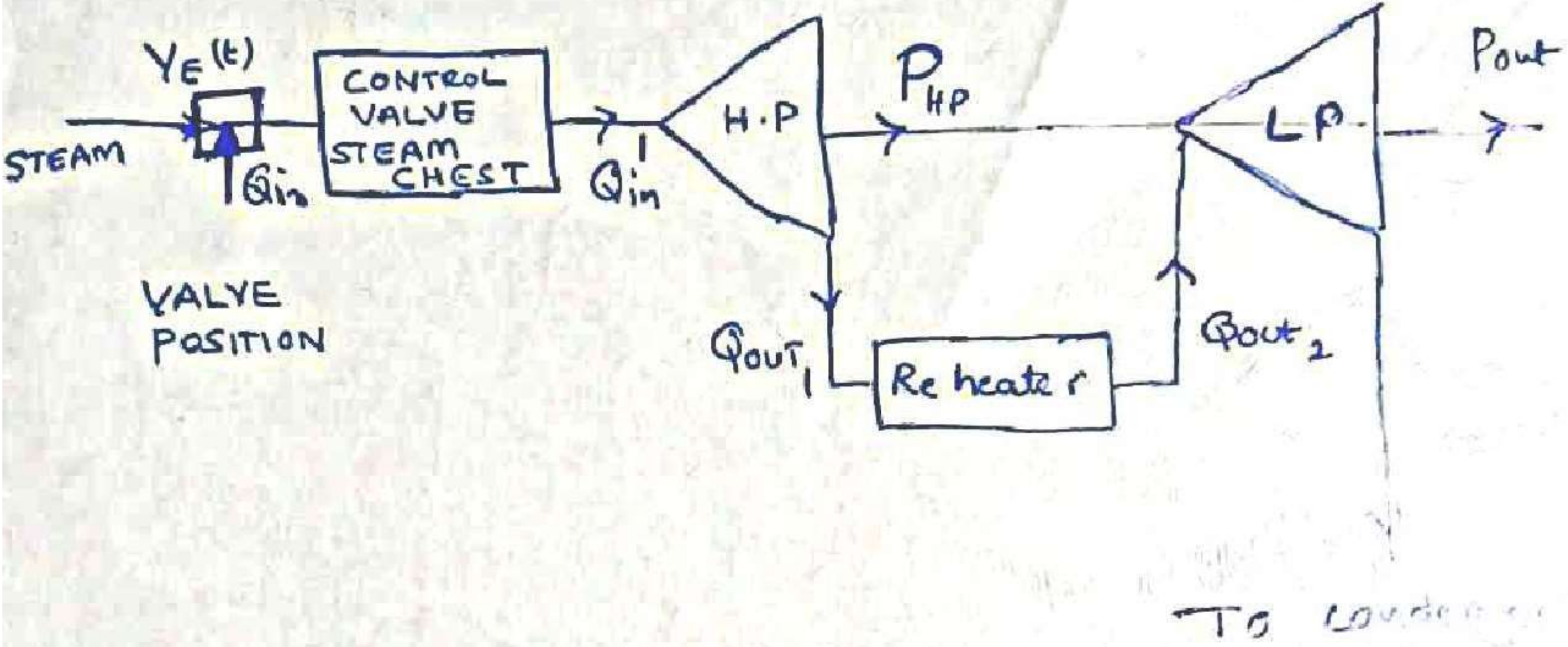
Taking laplace transform on both sides

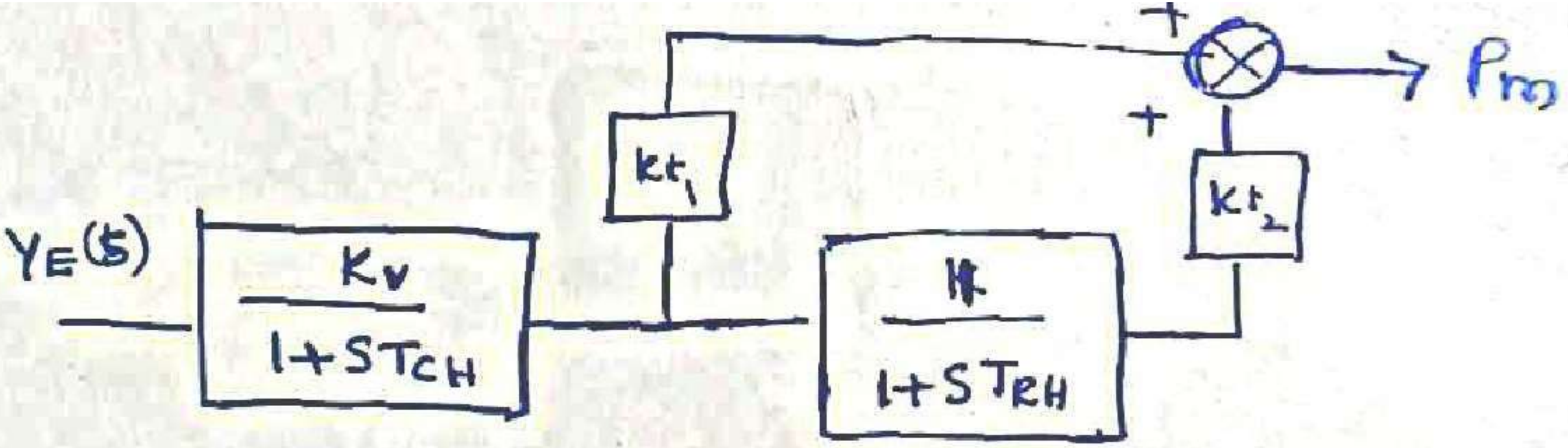
$$Q_{in}(s) - Q_{out}(s) = T_v \cdot s \cdot Q_{out}(s) .$$

$$\boxed{\frac{Q_o(s)}{Q_{in}(s)} = \frac{1}{1 + sT_v}}$$

T_v → Time constant of steam vessel

Modelling of Steam Turbine





K_v → gain of control valve

T_{CH} → Time constant of steam chest including H-P-stage of Turbine

T_{RH} → Time constant of Reheater

$$P_m(s) = \frac{Kt_1 K_v}{1+sT_{CH}} \cdot Y_E(s) + \frac{K_v \cdot Kt_2}{(1+sT_{CH})(1+sT_{RH})} Y_E(s)$$

Modeling of Turbine

$$P_m(s) = \frac{K_t}{T_t.s+1} \times \Delta X_E(\mathrm{s})$$