VEMU INSTITUTE OF TECHNOLOGY

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POWER SYSTEM OPERATION AND CONTROL

(20A02701a)

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UNIT I

LOAD ON POWER SYSTEM

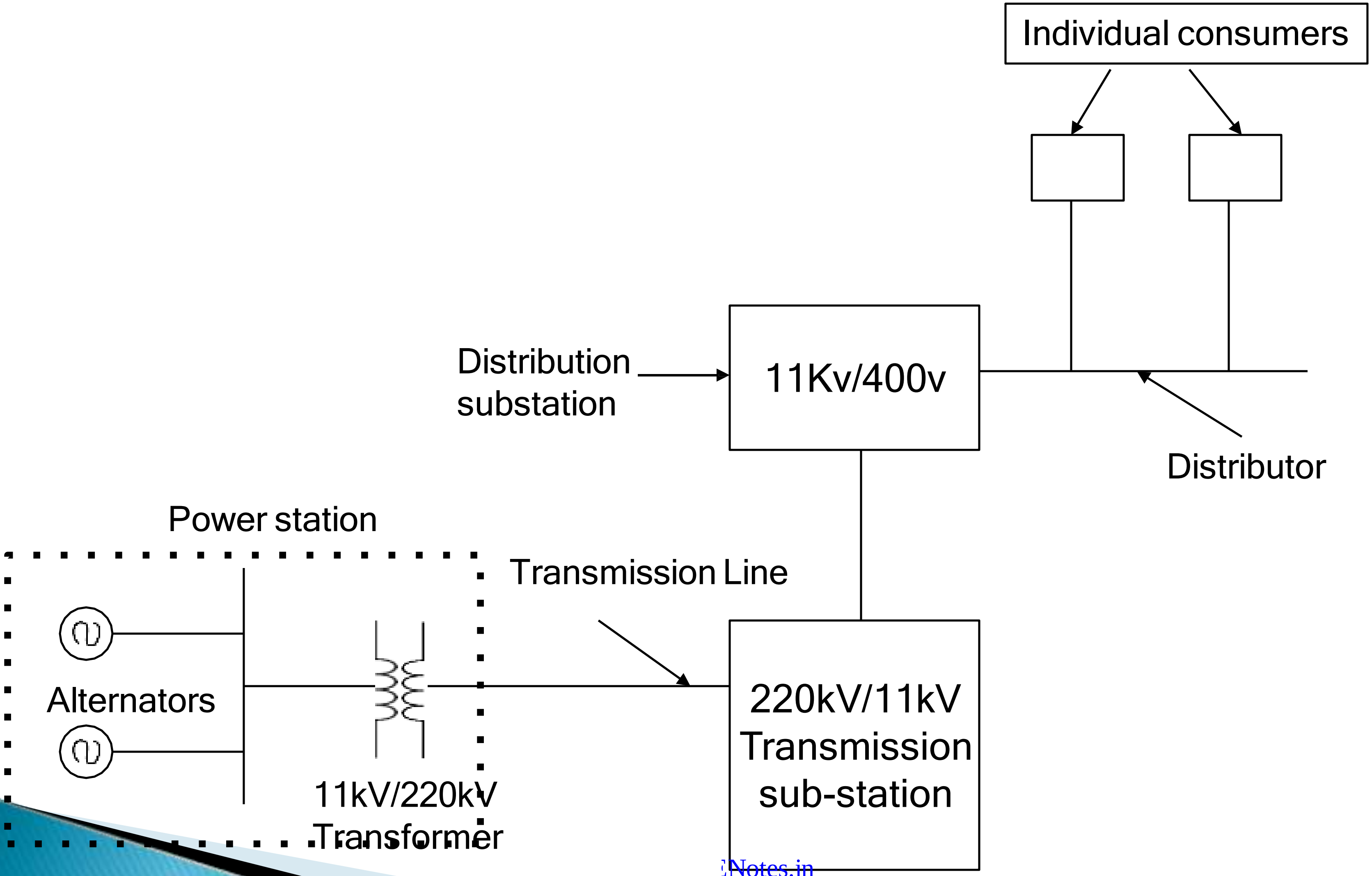
OUTLINE

- Introduction
- Structure of Electric Power system
- Variable load on power stations
- Load curves
- Load Characteristics
- Load duration curves
- Load curves and selection of generating units

Introduction

- The power demands of different consumers vary in accordance with their activities.
- The result of this variation in demand is that load on a power station is never constant rather it varies from time to time

STRUCTURE OF ELECTRIC POWER SYSTEM



Individual consumers

Distribution substation

11Kv/400v

Distributor

Power station

Transmission Line

Alternators

11kV/220kV Transformer

220kV/11kV Transmission sub-station

TYPES OF LOAD

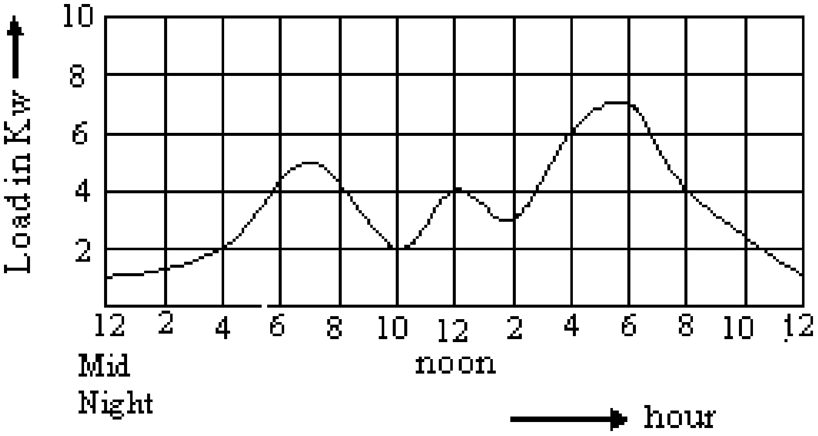
- Domestic load
- Commercial Load
- Industrial Load
- Municipal Load
- Irrigation load
- Traction load

Variable load on power station

LOAD CURVES

Definition:

The curve showing the variation of load on the power station with respect to time



TYPES OF LOAD CURVES

- Daily load curve –Load variations during the whole day
- Monthly load curve – Load curve obtained from the daily load curve
- Yearly load curve - Load curve obtained from the monthly load curve

BASE AND PEAK LOAD ON POWER STATION

BASE LOAD:

The unvarying load which occurs almost the whole day on the station

PEAK LOAD:

The various peak demands of load of the station

BASE AND PEAK LOAD

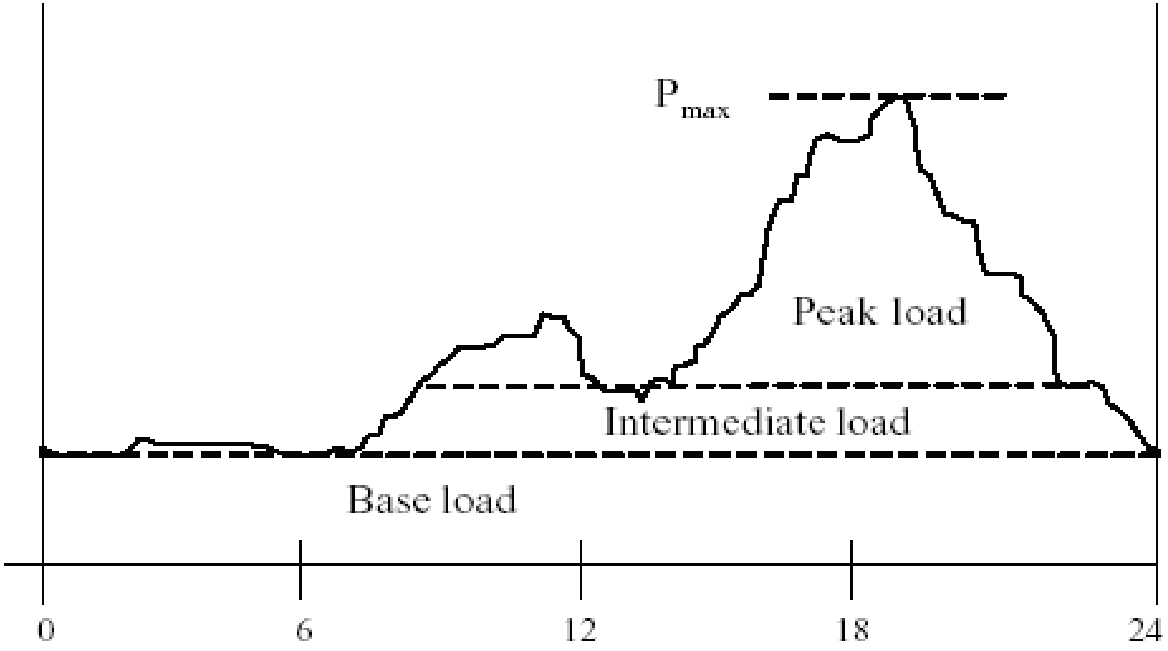


Fig 1. Daily load curve

LOAD CHARACTERISTICS

- Connected load
- Maximum demand
- Average load
- Load factor
- Diversity factor
- Plant capacity factor
- Plant use factor

CONNECTED LOAD

It is the sum of continuous ratings of all the equipment 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.

$$Demand\ \ factor = \frac{\max imum\ \ demand}{connected\ \ load}$$

AVERAGE LOAD

The average of loads occurring on the power station in a given period (day or month or year)

$$Daily\ average\ load = \frac{No.\ of\ units\ (KWh)\ generated\ in\ a\ day}{24\ hours}$$

$$Monthly\ average\ load = \frac{No.\ of\ units\ (KWh)\ generated\ in\ a\ month}{Number\ of\ hours\ in\ a\ month}$$

$$Yearly\ average\ load = \frac{No.\ of\ units\ (KWh)\ generated\ in\ a\ year}{8760\ hours}$$

LOAD FACTOR

The ratio of average load to the maximum demand during a given period .

$$Load\ \ factor = \frac{Average\ load}{Maximum\ demand}$$

If the plant is in operation for T hours,

$$Load\ \ factor = \frac{Average\ load \times T}{Maximum\ demand \times T}$$

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

DIVERSITY FACTOR

The ratio of the sum of individual maximum demands to the maximum demand on power station .

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

PLANT CAPACITY FACTOR

It is the ratio of actual energy produced to the maximum possible energy that could nave been produced during a given period.

$$Plant\ capacity\ \ factor\ = \frac{Actual\ energy\,\mathrm{Pr}odcued}{Max.energy\,that\,could\ have been\ produced}$$

PLANT USE FACTOR

It is the ratio of kWh generated to the product of plant capacity and the number of hours for which the plant was in operation

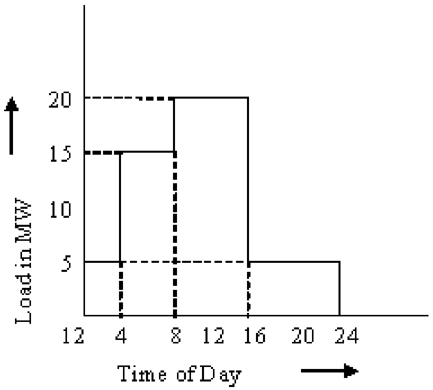
$$Plant\ use\ factor = \frac{Station\ output\ in\ kWh}{Plant\ capacity \times Hours\ of\ use}$$

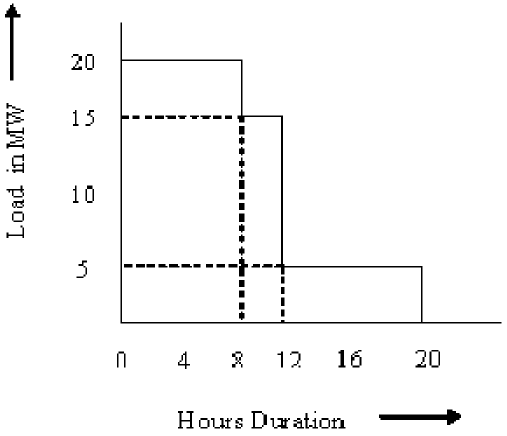
LOAD DURATION CURVE

When the elements of a load curve are arranged in the order of descending magnitudes .

Load curve

Load duration curve





POINTS TO BE NOTED ABOUT LOAD DURATION CURVE

- The load duration curve gives the data in a more presentable form
- The area under the load duration curve is equal to that of the corresponding load curve
- The load duration curve can be extended to include any period of time

SELECTION OF GENERATING UNITS

The number and size of the units are selected in such a way that they correctly fit the station load curve.

Structure of Power System

- Major Components
  - Generators
  - Transmission Network
  - Distribution System
- Interconnection of the elements
- Interconnection of neighboring utilities

Nature of Load

- System load varies continuously with time
- Significant changes from hour to hour, day to day, month to month and year to year
- Typical load curve

Load Forecasting

- Estimating power demand at the various load buses ahead of time
- Required for planning and operational applications.
- Make a statistical analysis of previous load data and set up a suitable model of the demand pattern.
- Utilize the identified load model for making a prediction of the estimated demand for the selected load time.
- Forecasting interval – Few seconds to few years.

Operating Status of Power Systems

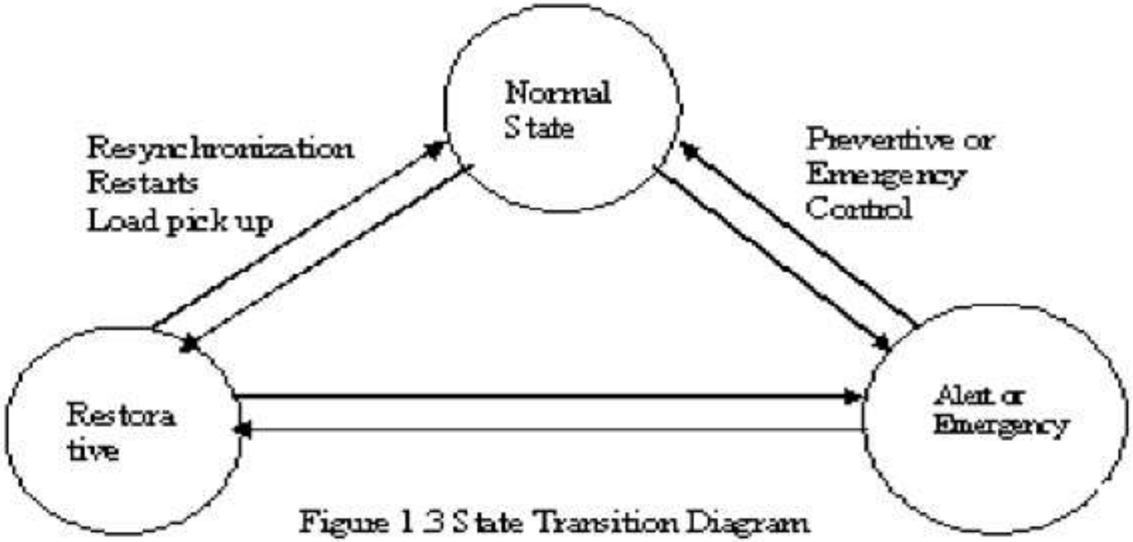


Figure 1.3 State Transition Diagram

Normal State

- All the load demands are met
- Constant frequency
- Bus Voltage magnitude within limits
- No elements are overloaded

Requirement of Constant Frequency Operation

- A.C. motors run at speeds that are directly related to the frequency.
- Generator turbines are designed to operate at a very precise speed
- Better control of overall operation of a power system
- Electrical clocks driven by synchronous motor

MW – Frequency Interaction

- System Generators meet the load and the real transmission loss.
- Energy cannot be stored in electrical form ➔ Electrical Energy production rate must be equal to consumption rate at each moment.
- Power imbalance would enter into or exit from kinetic energy storage.
- As the K.E depends upon generator speed, power imbalance will be translated to change in speed (and frequency).

Necessity of Voltage Regulation

- All equipment in a power system is designed for a certain voltage level.
- If the system voltage deviates, the performance of the device suffers and its life expectancy drops.
- The voltage level of a bus is strongly related to the reactive power injection at the bus.

Methods of Voltage Control

- Excitation control of generators
- Switched Shunt Capacitors and/or reactors
- Synchronous Condensers
- Tap-Changing of Transformers

Cross – Coupling between P–f and Q – |V|

- Change in MW output of a generator does not result in appreciable change in |V|
- Change in Q input at a bus may affect the real load of the bus in question

Optimal Power System Operation

- Cost of real power generation
- Allocation of real power at generator buses
- Optimum allocation of units – unit commitment
- Optimum allocation of generation to each station – Economic Dispatch

Economic Dispatch

- Determine the economic distribution of load between the various units.
- Fuel Cost is the principal factor in fossil–fuel plants
- Express the variable operating costs of the unit in terms of the power output

$$F_i = a_i P_{gi}^2 + b_i P_{gi} + c_i \quad Rs/hr$$

$$CostFunction \; F_T = \sum_{i=1}^{N} F_i$$

Constraints: i) Real power balance

ii) Generator limits.

Solution Techniques

- Lagrange Multiplier method
- Lamda iteration method
- Gradient method
- Dynamic programming
- Evolutionary Computation techniques

Unit commitment

- Load varies continuously with time
- The daily load pattern exhibit large differences between minimum and maximum demands.
- It is not proper and economical to run all the units at all the time.
- Determine the units of a plant that should operate for a given load– Unit commitment problem.

Continuation

- Solution methods:

  Priority Listing

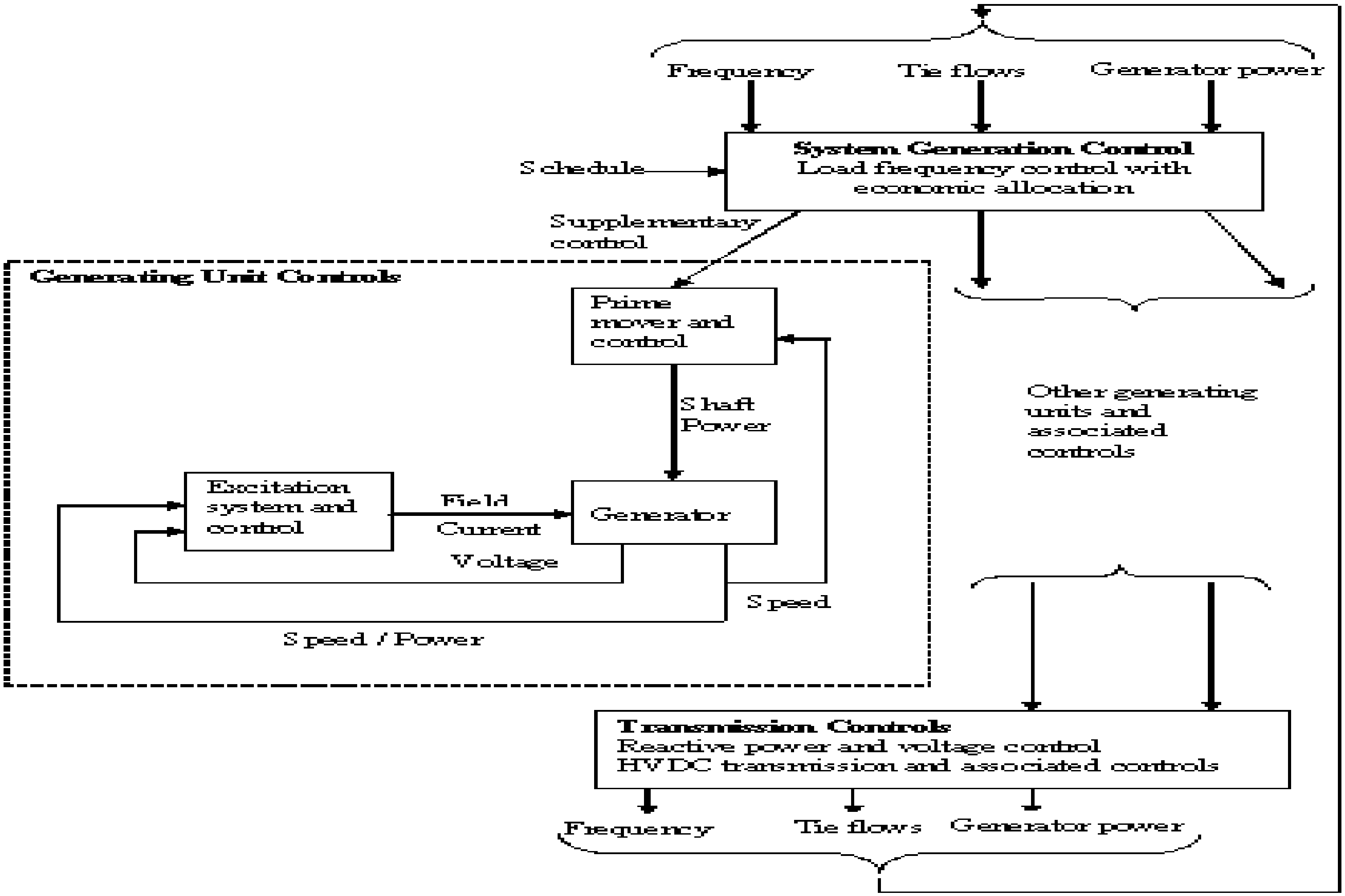
  Dynamic Programming

  Lagrange Relaxation method

  Genetic Algorithm

Power System Control

- Controls to meet the fundamental requirement of "Normal" state.



Levels of Control

- Controllers on individual system elements
  - Prime mover controls
  - Excitation controls
- System – generation control
- Transmission Controls: Power and voltage control devices

Automatic Load Frequency control

- Regulates the MW output and frequency (speed) of the generator.
- Primary loop regulates the steam/hydro flow rate via the speed governor and the control valves to maintain power balance.
- Secondary ALFC loop works in a slow reset mode to eliminate the remaining small frequency errors.
- Secondary loop also controls the power interchange between pool members.

Continuation

- The primary loop response will be over in seconds, whereas the secondary fine adjustment take about one minute.
- In the case of interconnected systems,the secondary ALFC loop also contain the errors in the contracted tie-line powers.

Automatic Voltage Regulator

- Maintains reactive power balance of a generator by maintaining a constant voltage level.
- Measure the bus voltage, after rectification and filtering the output is compared with a reference.
- The resulting error voltage after amplification serve as input to an excitation control system.

Computer Control of Power System

- Increased Complexity in system control.
- Real – time monitoring and control of electric

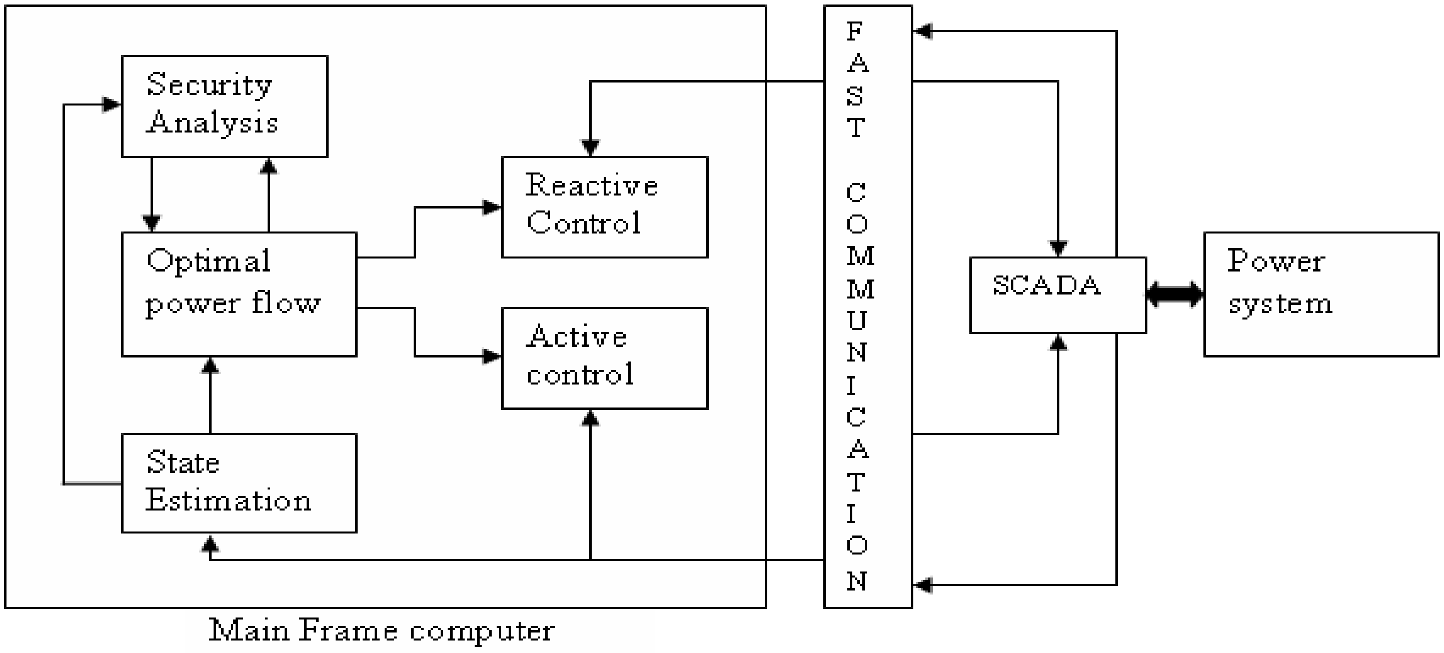


Figure 1.4 Real Time Environment

State Estimation

- Obtain the best possible values of the bus voltage magnitudes and angles by processing the network data.
- Modification to account for the presence of noise.
- Use the method of least-squared error estimation.

Security Analysis

- A power system under normal operating conditions may face a contingency condition.
- Contingencies may result in overloading of some of the power system components and may result in total or partial blockout.
- Analyse the effect of propable contingencies.
- Security– Ability of a power system to face the contingencies without any consequent effects.

References

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- B.M.Weedy and B.J.Cory, Electric Power Systems, Fourth Edition, WSE Publications.
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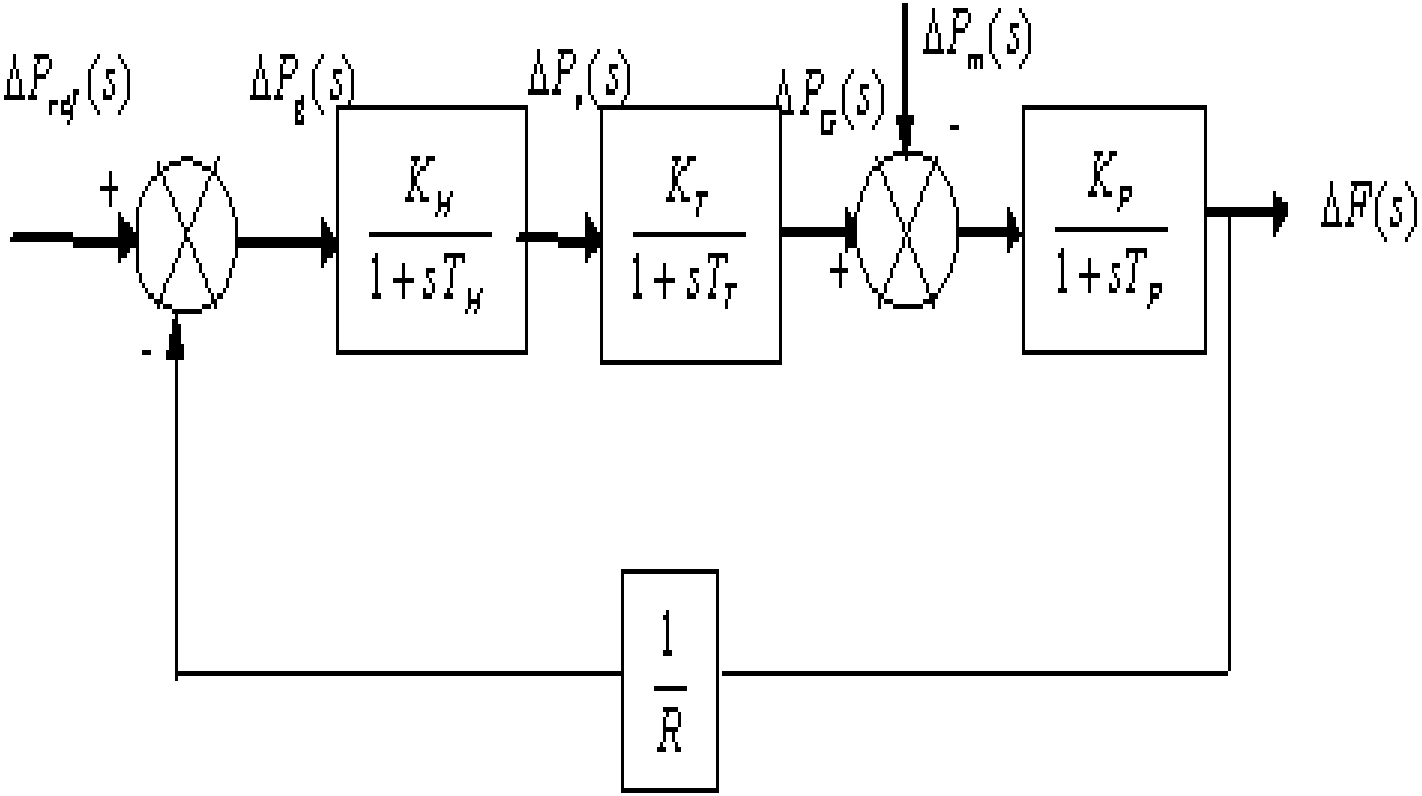
AUTOMATIC GENERATION CONTROL

AGC

- Basic Role of AGC:
  - Maintain desired megawatt output of generator.
  - To assist in frequency control of large interconnection.
  - To keep net interchange of power between pool members at pre-determined values

Complete Block Diagram of Single Area System



CASE I:

- Generator synchronized to a network of very large size i.e. frequency is independent of power output of individual generator (individual network).

$$\therefore \Delta f = 0 \quad \Rightarrow \quad \Delta P_{T,0} = \Delta P_{ref,0}$$

- Direct proportionality between reference setting and turbine power.

CASE II:

- Generator synchronized to a finite size network. Reference power setting is unchanged.

$$\Delta P_{T,0} = -\frac{1}{R}\Delta f_0$$

- For a constant speed changer settings static increase in turbine power is directly proportional to droop in static frequency drop.

STATIC ANALYSIS OF PRIMARY LOOP

- From the block diagram of the AGC loop,

$$\left\{\left[\Delta P_{ref} - \frac{1}{R}\Delta f\right] G_H G_T - \Delta P_D\right\} G_p = \Delta f$$

- If $\Delta P_{ref} = 0$;

$$\Delta f(0) = -\frac{G_p}{1+(1/R)G_P G_H G_T}\Delta P_D(s)$$

- If there is a st nt magnitude “M”,

$$\Delta P_D(s) = \frac{M}{s}$$

- The steady st frequency due to load change is,

$$\Delta f_0 = \lim_{s\to 0}\left[s\Delta f(s)\right] = -\frac{M}{D+(1/R)} = -\frac{M}{\beta}$$

β –Area RC).

Dynamic Analysis of Primary ALFC loop

- The dynamic response of the loop will inform about “tracking” ability and stability of the loop.
- Assumptions: Action of the speed governor plus the turbine generator is “instantaneous” compared with the rest of the power system.

Dynamic Analysis (Continuation)

- The Equation of Change in frequency is:

$$\Delta f(s) = \frac{\dfrac{K_p}{1+sT_P}}{1+\dfrac{1}{R}\cdot\dfrac{K_p}{1+sT_p}}\cdot\frac{M}{s}$$

- For exam 20Hz/pu MW, Tp=20sec, R=2.40 Hz/pu MW, M=0.01 pu MW.

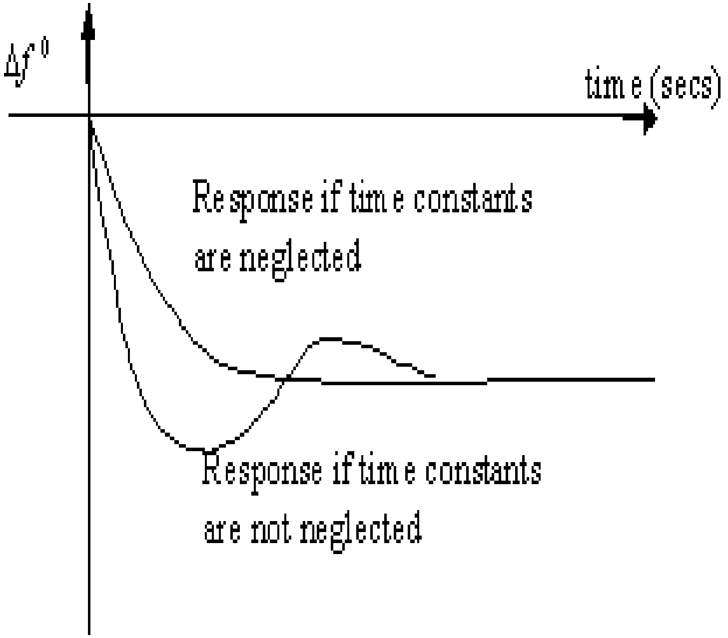
- The approximate time response is therefore purely e

$$\Delta f(s) = -0.0235\left(\frac{1}{s}-\frac{1}{s+2.55}\right)$$

$$\Delta f(t) = -0.0235\left(1-e^{-2.55t}\right)$$

$\Delta f(t) = -0.0235(1 - e$

Dynamic Response of Single area system



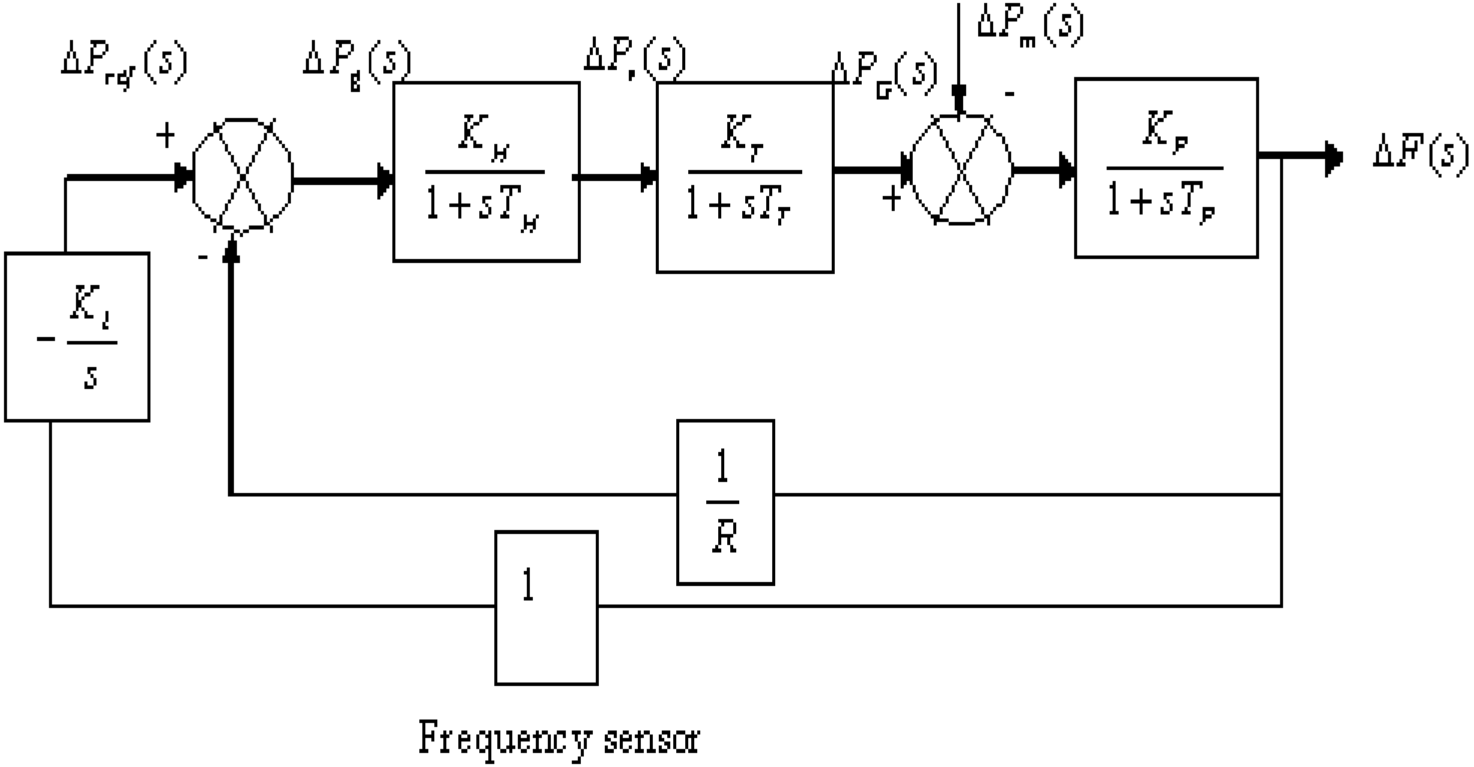
Dynamic Analysis (Continuation)

- The system can be made still faster by reducing R, that is by increasing the static loop gain.
- Reduction of R also increases the static frequency error.
- By considering the time responses causes larger transient dips.

SECONDARY CONTROL LOOP

- The system could undergo intolerable dynamic frequency changes with changes in load.
- It forces the frequency error to zero by the adjusting the contr input.
- **SPECIFICATIONS:**
  - Loop stability
  - Isochronous control (i.e.) Δf is 0.
  - Integral of frequency error should be minimized.
  - Economical sharing of loads between the individual generators in the control area.

Secondary ALFC Loop



SECONDARY ALFC Loop

$$\Delta F(s) = \frac{K_p}{\left(1 + sT_p\right) + \left(\frac{1}{R} + \frac{K_i}{s}\right) \times \frac{K_p}{\left(1 + sT_t\right)}} \times \frac{\Delta P_D}{s}$$

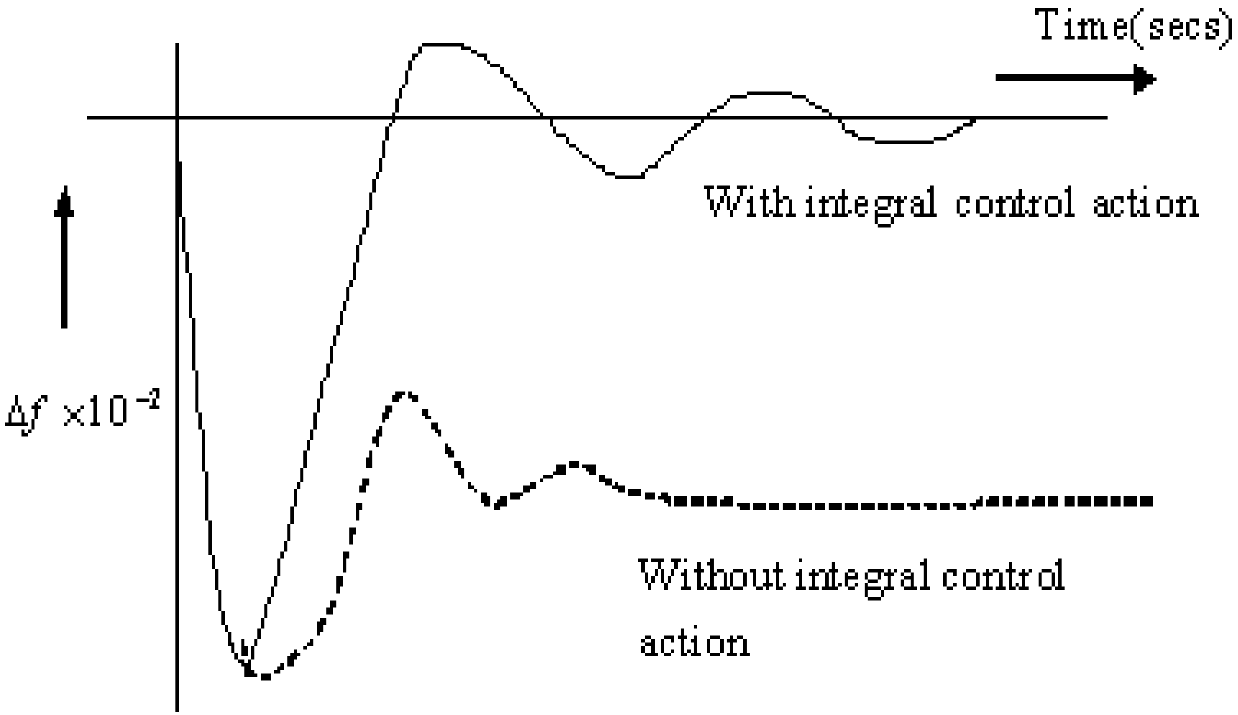
$$\Delta f \;\left|steady\ state = \underset{s \to 0}{s}\ \Delta F(s) = 0\right.$$

Δf

In central load frequency control of a given control area, the change in frequency is known as Area Control Error (ACE).

In the above scheme AEC being zero under steady state conditions, a logical design criterion is the minimization of dt for a step disturbance.

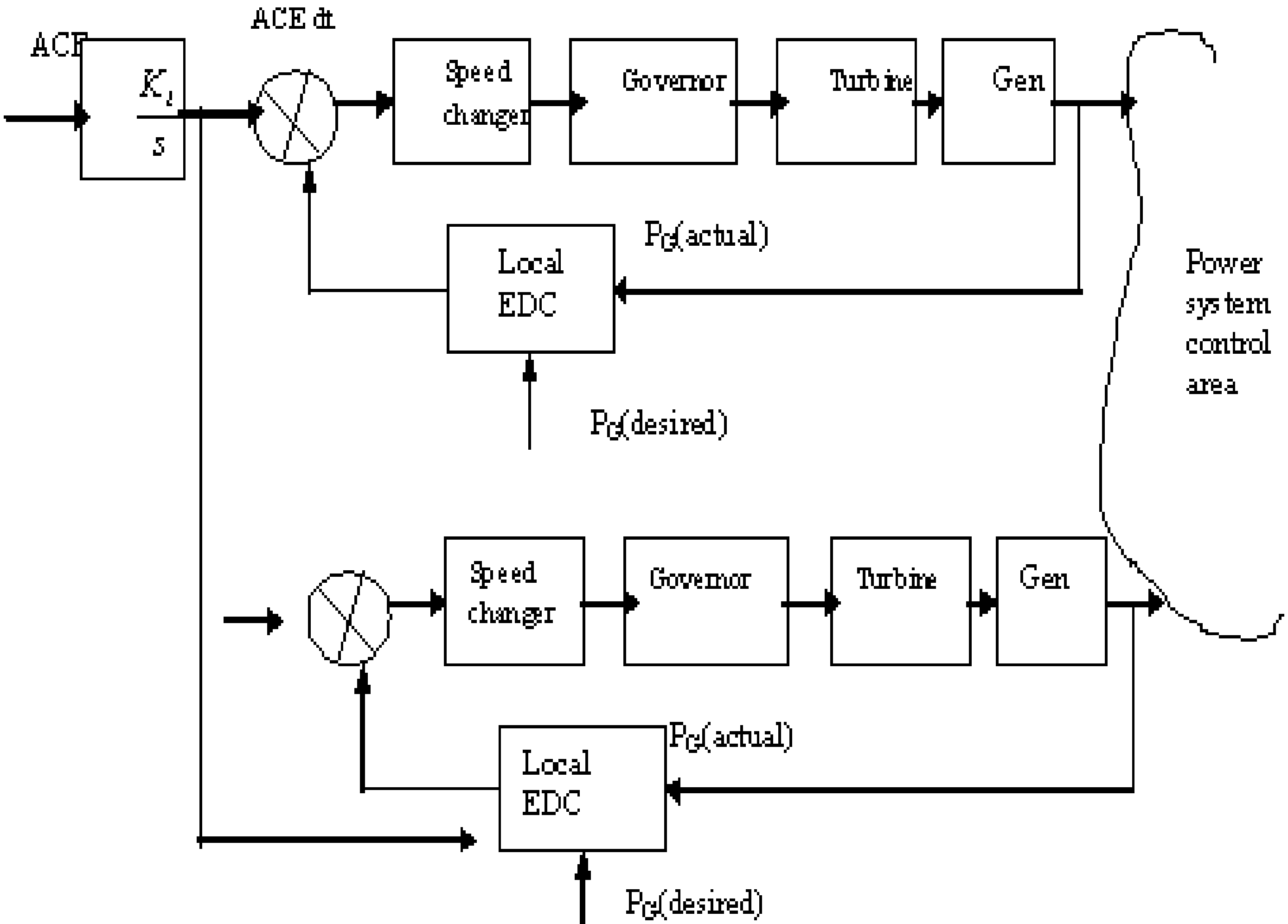
Dynamic response of the load frequency controller with and without integral control action



LFC with Economic Dispatch Control

- Load frequency control with integral controller exercises no control over the relative loadings of various generating stations (i.e., economic dispatch) of the control area.
- Economic dispatch control can be viewed as an additional tertiary control loop.
- The function of the Economic Dispatch Control (EDC) Program is to calculate the economic loading point for the various generating units.
- 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 central economic dispatch controller

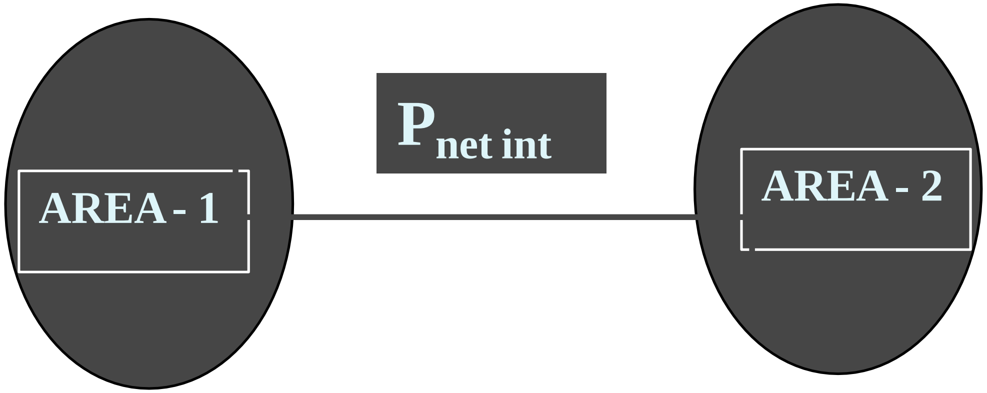
Control Area Load Frequency Control and Economic Dispatch Control



CONCEPT OF CONTROL AREA

- If there are several generators in an area, the lumped behavior of the generators can be got if:
  - ➢Controls of the generators are in unison. This can be justified if individual control loops have same parameters of regulation (R).
  - ➢ Turbine response characteristics are identical.

CONTROL AREA



$P_{\text{net int}}$ = total actual net interchange (+ : power leaving;
- : power entering)

$\Delta P_{\text{net int}}\ (= \Delta P_{12}) = P_{\text{net int}} - P_{\text{net int schd}}$

$P_{\text{net int schd}}$ = scheduled or desired value of interchange;

ΔP_{L1} = Load change in area 1; ΔP_{L2} = Load change in area 2;

LOAD FREQUENCY CONTROL ACTIONS

Δf	**$\Delta P_{net\ int}$**	**LOAD CHANGE**	**CONTROL ACTION**
–	–	$\Delta P_{L1} > 0$ $\Delta P_{L2} = 0$	Increase P_{gen1}.
+	+	$\Delta P_{L1} < 0$ $\Delta P_{L2} = 0$	Decrease P_{gen1}
–	+	$\Delta P_{L1} = 0$ $\Delta P_{L2} > 0$	Increase P_{gen2}
+	–	$\Delta P_{L1} = 0$ $\Delta P_{L2} < 0$	Decrease P_{gen2}

MULTI–AREA SYSTEMS

Multi-Area Systems

- Basic Operating Principles:

  1.Each pool member or control area should strive to carry its own load.

  2.Each control area must agree upon adopting regulating and control strategies and equipment that are mutually beneficial under both normal and abnormal situations.

Modeling the Tie-line

- In normal operation the power on the tie-line is given by,

$$P^0_{12} = \frac{|V^0_1||V^0_2|}{X}\sin\left(\delta^0_1 - \delta^0_2\right)$$

- Where

$$\Delta P_{12} \approx \frac{|V^0_1||V^0_2|}{X}\cos\left(\delta^0_1 - \delta^0_2\right)\left(\Delta\delta_1 - \Delta\delta_2\right) \quad MW$$

$$T^0 \cong \frac{|V^0_1||V^0_2|}{X}\cos\left(\delta^0_1 - \delta^0_2\right) \quad MW/rad$$

Continuation

- The tie-line power deviation then takes of the following form $\Delta P_{12} = T^{0}\left(\Delta\delta_1 - \Delta\delta_2\right) \quad MW$
- The frequency deviation is related to the reference angle by the formula,

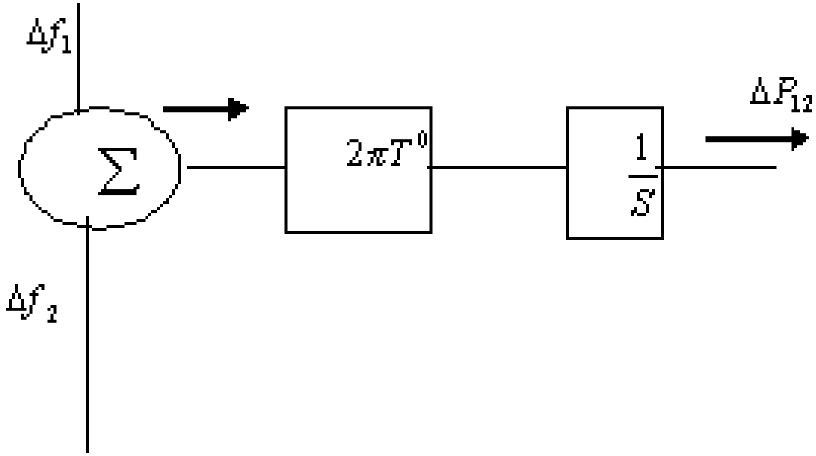
$$\Delta f = \frac{1}{2\pi}\frac{d}{dt}\left(\delta^{0} + \Delta\delta\right) = \frac{1}{2\pi}\frac{d}{dt}\left(\Delta\delta\right) \qquad Hz$$

$$\Delta\delta = 2\pi\int^{t}\Delta f \; dt \qquad rad$$

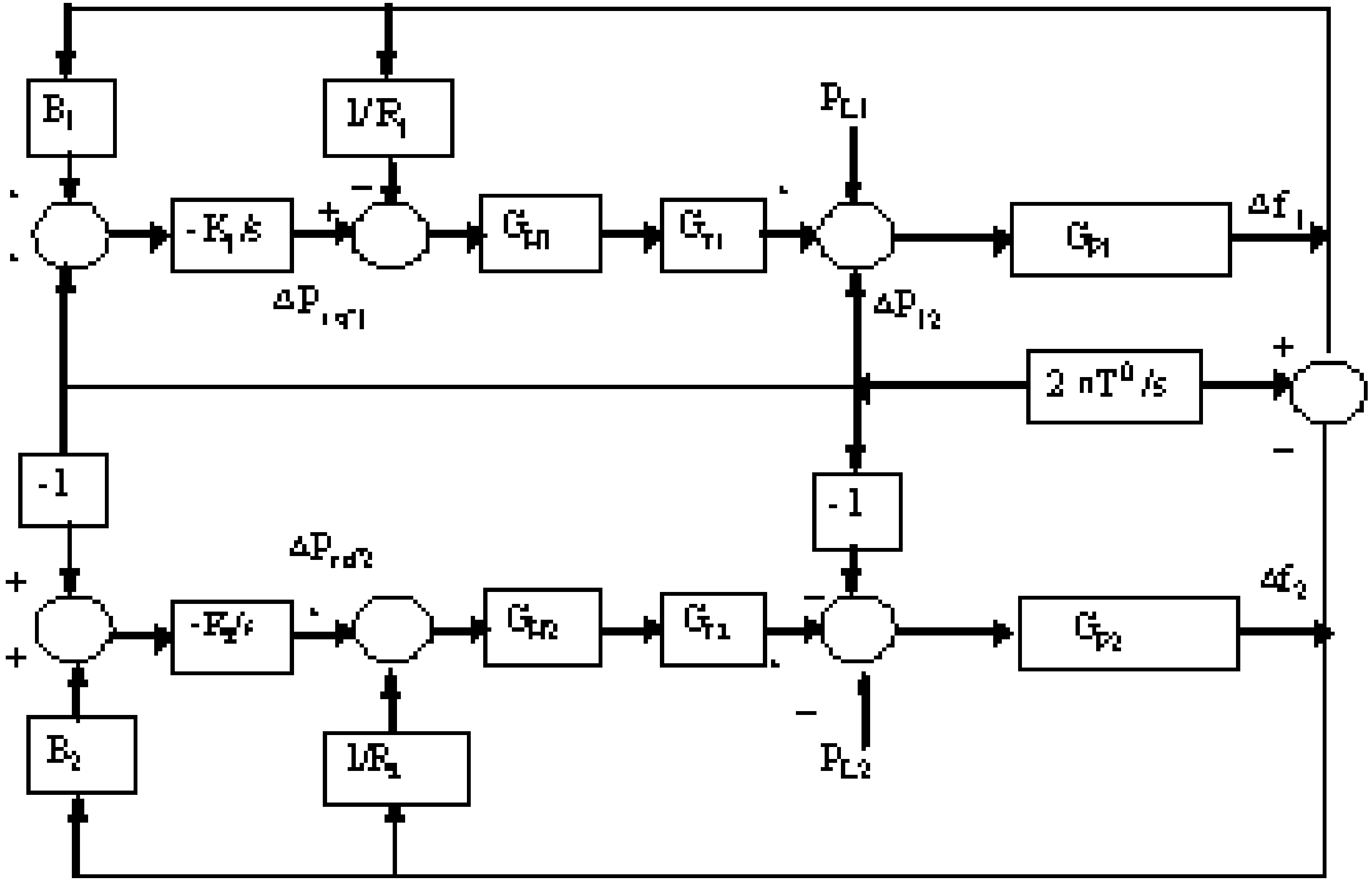
- Tie-line p

$$\Delta P_{12} = 2\pi T^{0}\left(\int^{t}\Delta f_1\, dt - \int^{t}\Delta f_{2\,dt}\right) \qquad MW$$

Linear Representation of Tie-line



BLOCK DIAGRAM FOR TWO AREA CONTROL SYSTEM



IMPLEMENTATION OF CONTROL MECHANISM

TIE-LINE BIAS CONTROL:

- The control error for each area is a linear combination of (biased/weighted) frequency error and the net interchange error,

$$ACE_1 = \Delta P_{net\ int1} + B_1\ \Delta f_1$$

$$ACE_2 = \Delta P_{net\ int2} + B_2\ \Delta f_2$$

- If K_{I1} and K_{I2} are integrator gains, speed-changer commands are given b

$$\Delta P_{ref,1} = -K_{I1} \int \left(\Delta P_{net,int1} + B_1\ \Delta f_1 \right) dt$$

$$\Delta P_{ref,2} = -K_{I2} \int \left(\Delta P_{net,int2} + B_2\ \Delta f_2 \right) dt$$

- Negative sign indicates the increase in generation for a decrease in Δf or $\Delta P_{net,int}$.
- Our aim is to drive Δf and $\Delta P_{net,int} \longrightarrow 0$. when steady state is reached, speed changer settings would have to be zero. Hence,

$$\Delta P_{12,0} + B_1\ \Delta f_0 = 0\ ;\ \Delta P_{21,0} + B_2\ \Delta f_0 = 0$$

Static Response of Two-area System

- The response of the two-area system with fixed speed changer positions is:

$$\Delta P_{ref,1} = \Delta P_{ref,2} = 0$$

- The incremental increase in turbine dynamics in this static case is determined by the static loop gains.

$$\Delta P_{T1,0} = -\frac{1}{R_1}\Delta f_0$$

$$\Delta P_{T2,0} = -\frac{1}{R_2}\Delta f_0$$

$$-\frac{1}{R_1}\Delta f_0 - M_1 = D_1 \ \Delta f_0 + \Delta P_{tie1,\ \ 0}$$

$$-\frac{1}{R_2}\Delta f_0 - M_2 = D_2 \ \Delta f_0 - \Delta P_{tie1,\ \ 0}$$

$$\Delta f_0 = -\frac{M_1 + M_2}{\beta_1 + \beta_2} \qquad Hz$$

$$\Delta P_{tie1,\ 0} = -\Delta P_{tie2,\ 0} = \frac{\beta_1 M_2 - \beta_2 M_1}{\beta_1 + \beta_2} \qquad puMW$$

- Equation of changes in frequency and tie-line power is:

$$\Delta f_0 = -\frac{M_1 + M_2}{2\beta} \quad Hz$$

$$\Delta P_{tie1,\ 0} = -\Delta P_{tie2,\ 0} = \frac{M_2 - M_1}{2} \quad pu\,MW$$

Dynamic Response of Two-Area System

Assumptions:

- Consider the case of two equal areas.
- Consider the turbine controller fast relative to the inertia part of the systems, i.e., we set GH=GT=1.
- Neglect the system damping. This means that we assume the load not to vary with frequency; i.e., we set D1=D2=0.

$$\Delta P_{tie1}(s) = \frac{\pi f^0 T^0}{H} \frac{\Delta P_{D2}(s) - \Delta P_{D1}(s)}{s^2 + \left(f^0 / 2RH\right)s + 2\pi f^0 T^0 / H}$$

The above expression gives some of the following important facts:

1. The denominator being of the form

$$s^2 + 2\alpha s + \omega^2 = (s+\alpha)^2 + \omega^2 - \alpha^2$$

where α and ω^2 are both positive, hence the system is stable and damped.

2. Following a disturbance, the system will oscillate at the damped angular frequency.

$$\omega^0 = \sqrt{\omega^2 - \alpha^2} = \sqrt{\frac{2\pi f^0 T^0}{H} - \left(\frac{f^0}{4RH}\right)^2}$$

EXCITATION SYSTEM

EXCITATION SYSTEM

- An excitation system is the source of field current for the excitation of a principle electric machine, including means for its control.

FUNCTIONS OF EXCITATION SYSTEM

- To provide direct current to the synchronous machine field winding.
- To perform control and protective functions essential to the satisfactory performance of the power system by controlling the field voltage and thereby the field current.

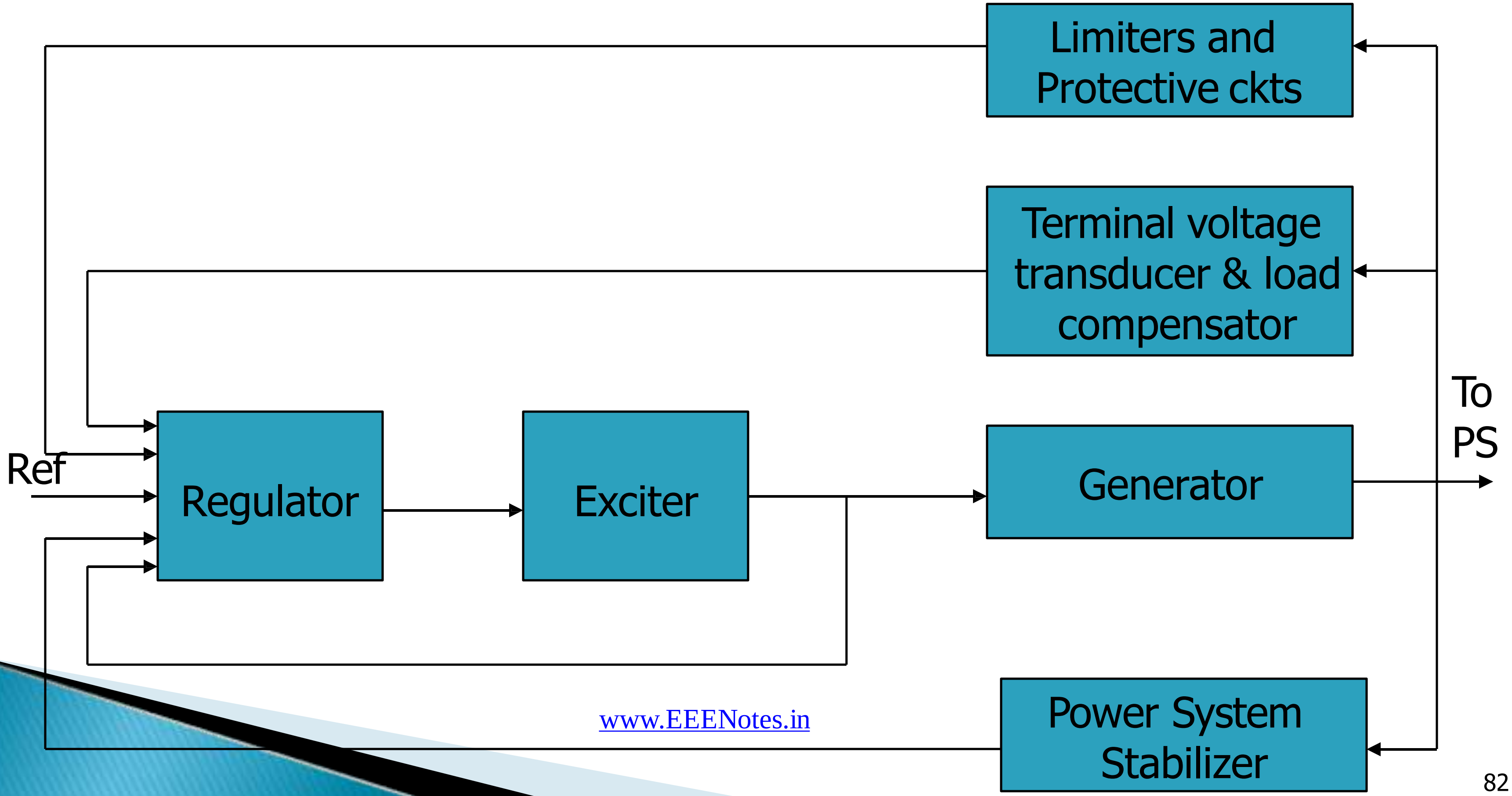
REQUIREMENTS OF EXCITATION SYSTEM

- To meet specified response criteria.
- To provide limiting and protective functions.
- To meet specified requirements for operating flexibility.
- To meet the desired reliability and availability.

TYPES OF EXCITATION SYSTEMS

- DC excitation systems
- AC excitation systems
- Static excitation systems

ELEMENTS OF EXCITATION SYSTEM



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ELEMENTS OF EXCITATION SYSTEM

- Exciter

  Provide dc power to the synchronous machine field winding.

- Regulator

  Process and amplifies input control signals to a level and form appropriate for control of the exciter.

ELEMENTS OF EXCITATION SYSTEM

- Terminal voltage transducer and load compensator

  Senses generator terminal voltage, rectifies and filters it to dc quantity and compares it with a reference which represents desired terminal voltage.

- Power system stabilizer

  Provides additional input signal to the regulator to damp power system osc

- Limiters & protective circuits

  Include a wide array of control and protective functions which ensure that the capability limits of the exciter and synchronous generator are not exceeded.

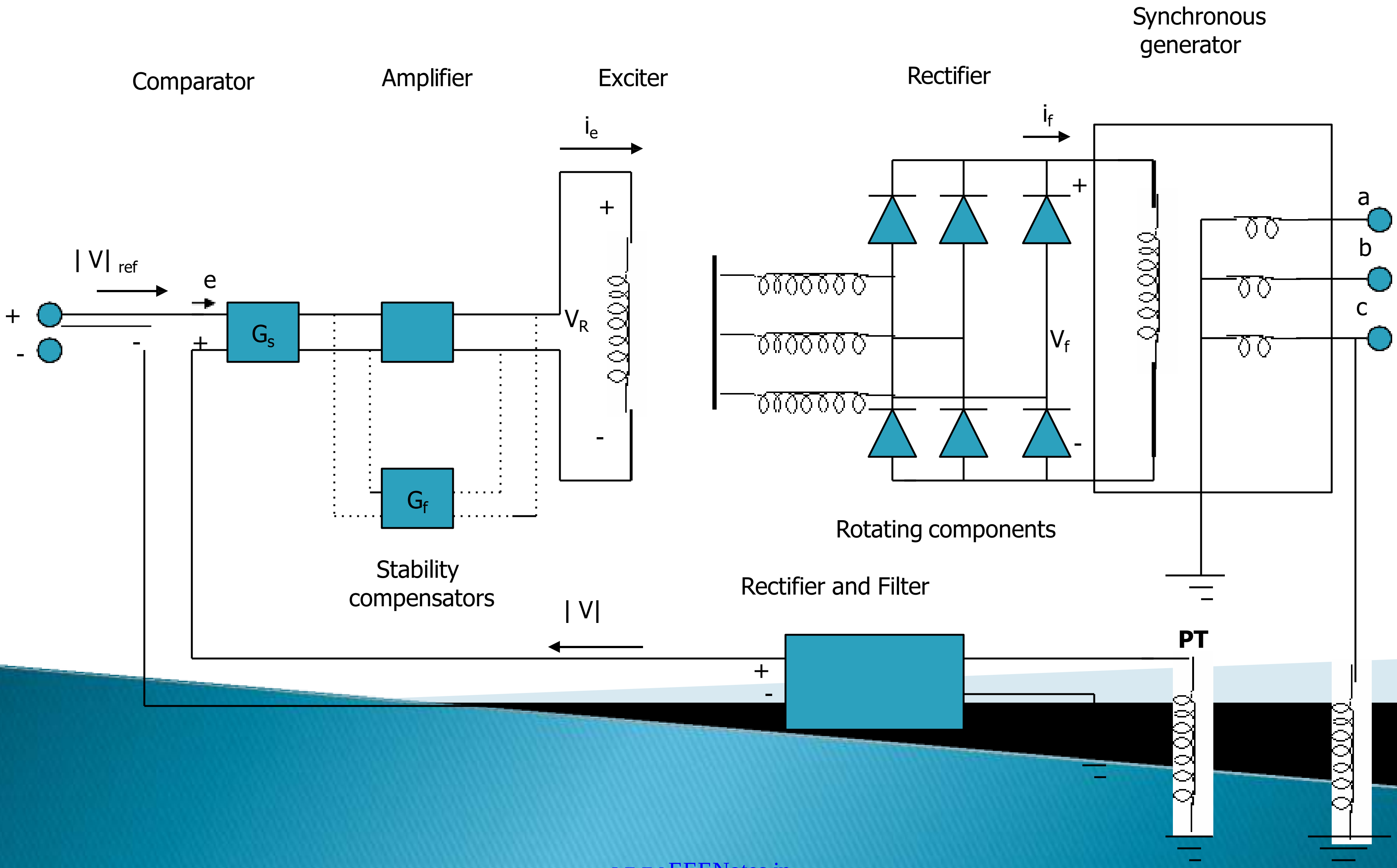
NEED FOR EXCITATION SYSTEMS MODELLING

- Essential for the assessment of desired performance requirements.
- For the design and co-ordination of supplementary control and protective circuits.
- For system stability related to the planning and operation of power systems.

FUNCTIONS OF AVR

- For an isolated generator feeding a load, AVR is used to maintain the bus bar voltage constant.
- To keep the system voltage constant so that the connected equipment operates satisfactorily.
- To obtain a suitable distribution of reactive load between machines working in parallel.
- To improve stability.

FUNCTIONAL BLOCK DIAGRAM OF AVR LOOP



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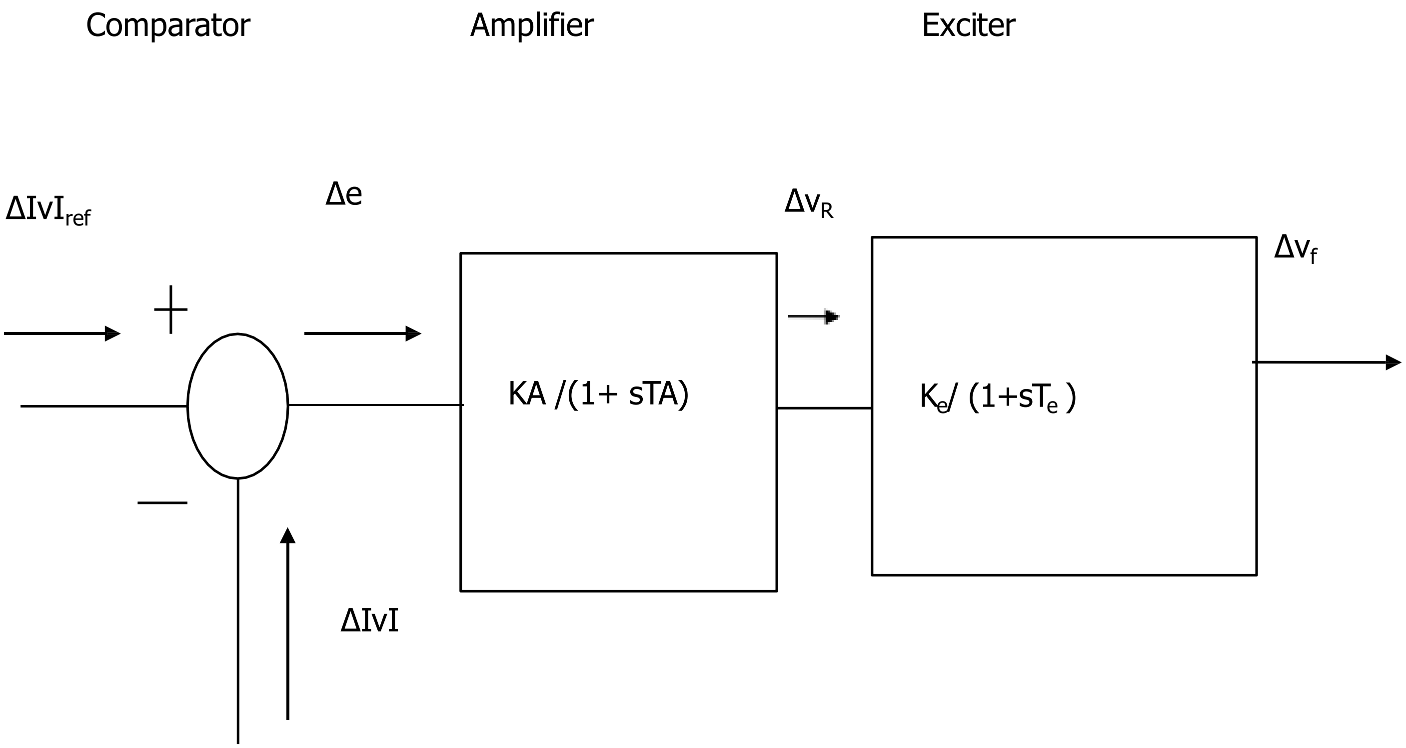
Linear model of the comparator–amplifier–exciter portion of the AVR loop



Comparator

Amplifier

Exciter

ΔIvI_{ref}

Δe

Δv_R

Δv_f

+

−

KA /(1+ sTA)

$K_e/ (1+sT_e)$

ΔIvI

Static Performance of the AVR Loop

$$\Delta e_0 = \Delta\left|V\right|_{ref,0} - \Delta\left|V\right|_{,0} \langle \frac{p}{100} . \Delta\left|V\right|_{ref,0}$$

$$\Delta e_0 = \Delta\left|V\right|_{ref,0} - \Delta\left|V\right|_0 = \Delta\left|V\right|_{ref,0} - \frac{G(0)}{1+G(0)} \Delta\left|V\right|_{ref,0}$$

$$= \frac{1}{1+G(0)} \Delta\left|V\right|_{ref,0} = \frac{1}{1+K} \Delta\left|V\right|_{ref,0}$$

Dynamic Response of the AVR Loop

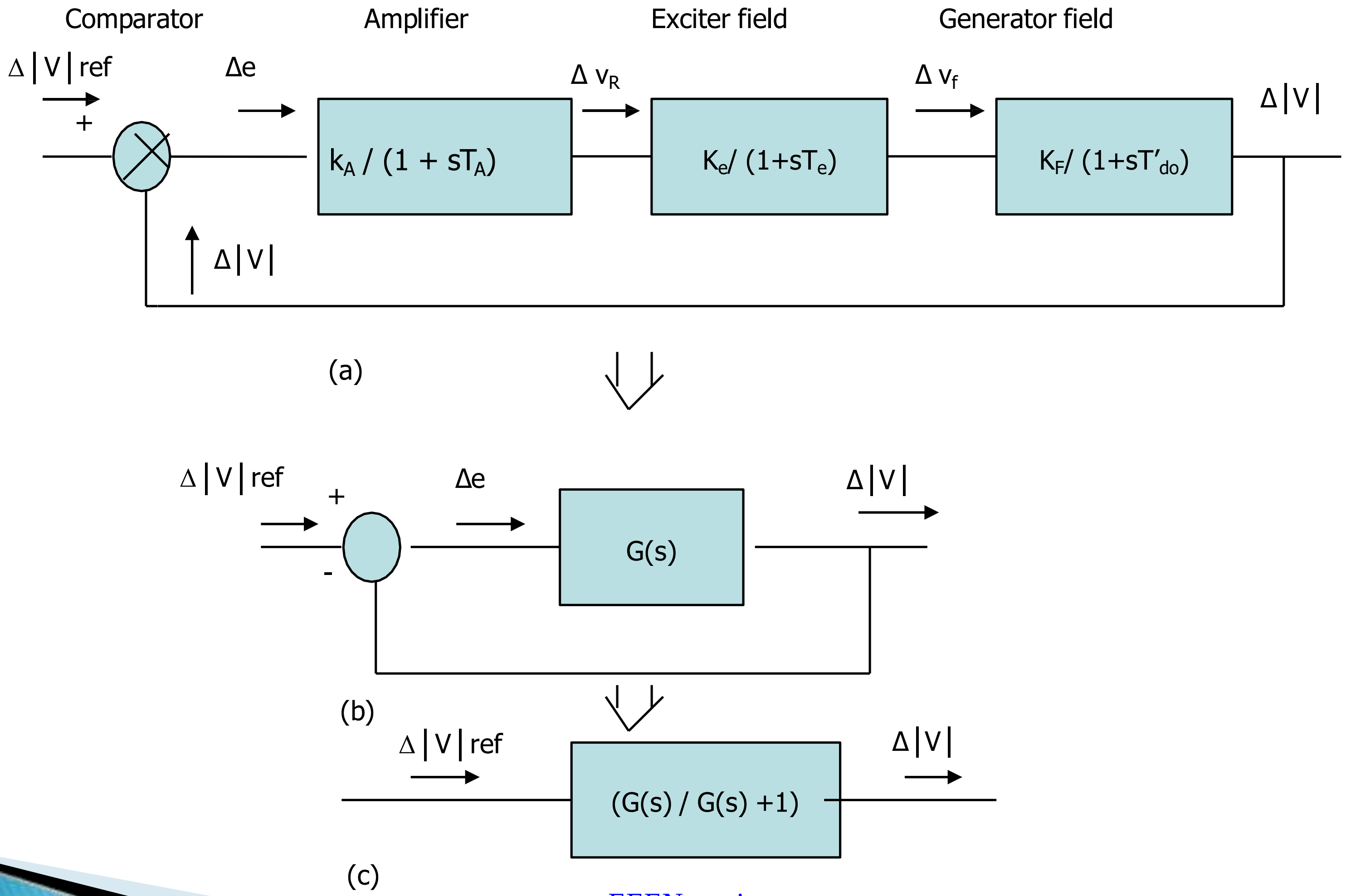
- From the theory of linear control systems it is known that the time response $\Delta|V|$ (t) of the loop equals

  $$\Delta\,|V|\,(t) = £^{-1}\{\Delta V_{ref}(s)\,(G(s) / G(s)+1)\}$$

- Mathematically, the response depends upon the eigen values or closed-loop poles, which are obtained from the characteristic equation

  $$G(s) + 1 = 0$$

Closing the AVR loop; (a) individual block representation; (b) condensed model; (c) closed loop model.



Comparator

Amplifier

Exciter field

Generator field

$\Delta|V|ref$

Δe

Δv_R

Δv_f

$\Delta|V|$

+

$k_A / (1 + sT_A)$

$K_e / (1+sT_e)$

$K_F / (1+sT'_{do})$

$\Delta|V|$

(a)

$\Delta|V|ref$

+

Δe

$\Delta|V|$

-

G(s)

(b)

$\Delta|V|ref$

$\Delta|V|$

(G(s) / G(s) +1)

(c)

Stability compensation

- High loop gain is needed for static accuracy but this causes undesirable dynamic response, possibly instability.
- By adding series and / or feedback stability compensation to the AVR loop, this conflicting situation can be resolved.
- Consider for example the addition of a series phase lead compensator, having the transfer function

$$G_s = 1 + sT_c$$

Stability compensation

- The open-loop transfer function will now contain a zero

  $G (s) = k (1 + sTc) / (1 + sTA) (1 + sTe) (1 + Tdo)$

- The added network will not affect the static loop gain K, and thus the static accuracy.
- The dynamic response characteristics will change to the better.

REACTIVE POWER AND VOLTAGE CONTROL

- Excitation system

- Generation & absorption of reactive power

- Relation b/w V, P,& Q at a node

- Methods of voltage control

Methods of Voltage Control

1. Shunt capacitors
2. Series capacitors
3. Synchronous capacitors
4. SVC
5. Tap changing transformers
6. Booster transformers.

Earlier Day Voltage Control Method

- By adjusting the excitation of the generator at the sending end.
- The larger the reactive power required by the load the more is the excitation to be provided at the sending end.
- Limitation:
  - Worked well in small isolated system where there was no local load at the sending end.
  - Excitation below a certain limit may result in instability and excitation above certain level will result in overheating of the rotor.

Shunt Capacitors and Reactors

- Used across an inductive load so as to supply part of the reactive vars required by the load so that the reactive vars transmitted over the line are reduced, thereby the voltage across the load is maintained within certain desirable limits.
- The shunt reactors are used across capacitive loads or lightly loaded lines to absorb some of the leading vars again to control the voltage across the load to within certain desirable limits.
- Capacitors are connected either directly to a bus bar or through a tertiary winding of the main transformer and are disposed along the route to minimize the voltage drop and the losses.

Series Capacitors

- It reduces the inductive reactance between the load and the supply point, thereby reducing the voltage drop produced by an inductive load.
- It improves the voltage stable state and supplies reactive power to the receiving end such that voltage profile is maintained.
- Improves the steady state stability.
- Increases the power flow transfer in lines.
- For long transmission lines where the total reactance is high, series capacitors are effective for improvement of system stability.

Synchronous Compensator

- It is basically a synchronous motor running at no load.
- Depending on the value of excitation, it can absorb or generate reactive power.
- Its use in high voltage transmission lines helps in either absorption of reactive power or supply of reactive power under light load or heavy load conditions respectively.
- Improves system stability.
- Supply heavy amount of reactive power during short period.

Disadvantages of Compensation Devices

Compensation Type	Drawbacks
Static Switched Shunt Capacitor	On light loads when the corrective vars required are relatively less, the capacitor output is large and vice versa.
Synchronous condensors	Only continuous control is possible. High cost of installment & need high maintenance.
Series Capacitor	Severe over voltage during line fault. Problem of Ferro resonance & Sub synchronous resonance

Static VAR Compensator

- A parallel combination of controlled reactor and fixed static capacitor.
- Working Principle: By varying the thyristor firing angle, the reactor current is varied thereby controlling the reactive power absorption by inductor. Capacitor in parallel supplies reactive power to the system.
- The net reactive power injection to bus becomes $Q = Q_c - Q_l$.
- Q_l is varied and thus Q is controllable. The bus voltage is thus controllable by SVC.
- During light load $Ql > Qc$, while during heavy load $Qc < Ql$.
- Improves system stability, voltage stability and reduces power oscillations.

Tap-Changing Transformer

- Almost the power transformers on transmission lines are provided with taps for ration control i.e. control of secondary voltage. There are two types of tap changing transformers:

  (i) Off-load tap changing transformers.

  (ii) On-load (under-load) tap changing transformers.
- The tap changing transformers do not control the voltage by regulating the flow of reactive vars but by changing the transformation ratio, the voltage in the secondary circuit is varied and voltage control is obtained. This method is the most popular as it can be used for controlling voltages at all levels.

Off-load tap changing transformers

- Requires the disconnection of the transformer when the tap setting is to be changed.

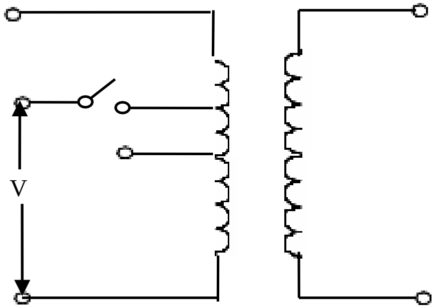
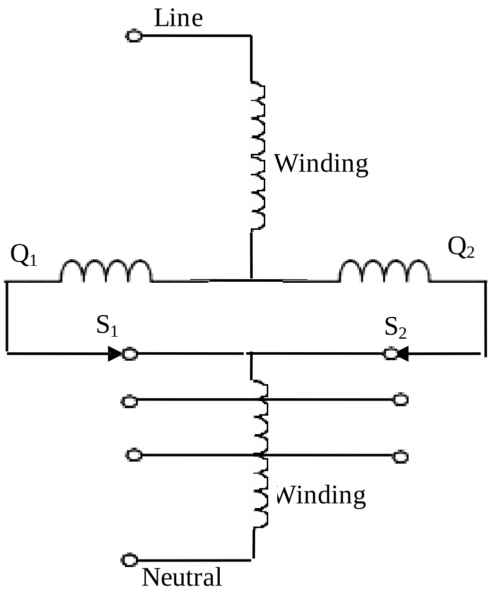


Fig. 4.5.5 Off-load tap changing transformer



ON-load tap changing transformers

- In the position shown the voltage is a maximum and since the currents divide equally and flow in opposition through the coil between Q1 and Q2, the resultant flux is zero and hence minimum impedance.
- To reduce the voltage, the following operations are required in sequence: (i) open Q1; (ii) move selector switch S1 to the next contact; (iii) close Q1; (iv) open Q2; (v) move selector switch S2 to the next contact; and (vi) close Q2.

Radial transmission line with on-load tap changing transformer at both the ends

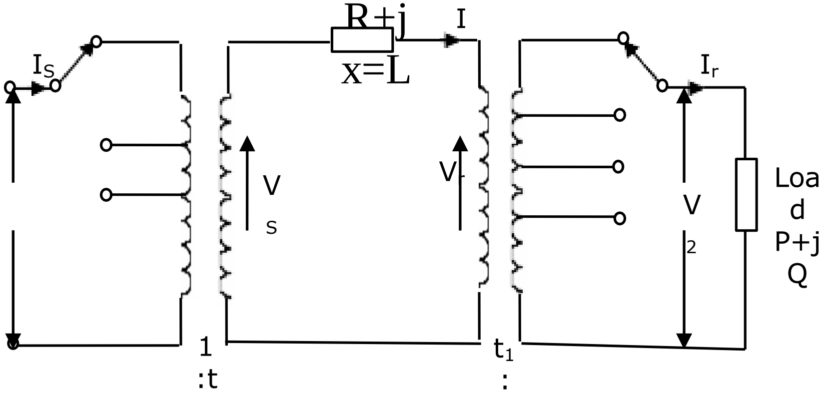


Fig. 4.5.7 Radial transmission line with on-load tap changing transformer at both the ends

$$t_s^2\left[1-\frac{RP+XQ}{V_1V_2}\right]=\frac{V_2}{V_1}$$

For particular values of V_2 and V_1 and the load requirements P and Q, the value of t_s can be obtained.

Tap-setting Adjustment for Reactive Power Injection to Large System

- In large interconnected system, some times with the tap-setting adjustments of the tap-changing transformers indirectly in the system, the reactive power requirement may be altered.

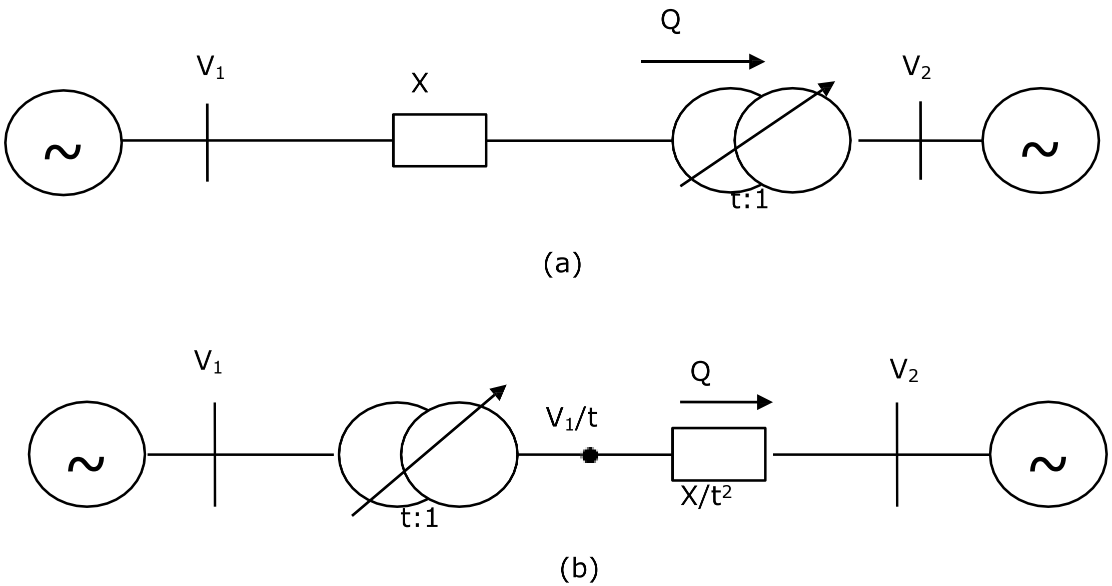


Fig. 4.6.2 (a) Systems interconnected through tap-changing transformer (b) Its equivalent circuit

Continuation

- Reactive power requirement

$$Q = \frac{|V|^2 t(1-t)}{X}$$

  - By changing the off-normal setting t, it is possible to change the var requirement Q of the line due to the reactance X.
  - When t is less than unity, Q is positive and there is thus a flow of lagging VAR to bus 2.
  - When t is greater than unity, Q is negative and there is thus a flow of leading VAR to bus 2.

ECONOMIC DISPATCH

INTRODUCTION

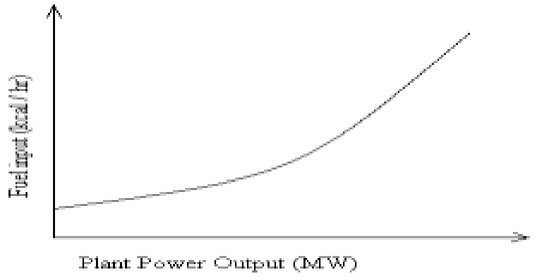
- Refers to the most economic loading of the generators which are connected to the system and running.
- Fuel cost is the principal factor in fossil fuel plants and is given as a function of generation.
- ED problem is to define the production level of each plant so that the total generation and transmission cost is minimum for a prescribed schedule of loads.

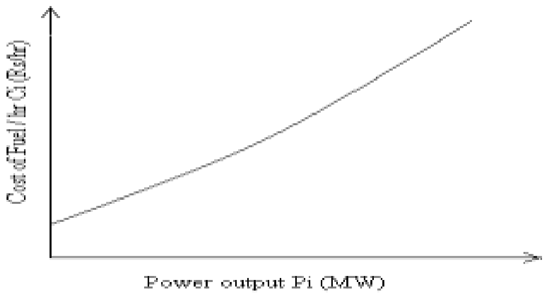
Solution Techniques

- Lagrange Multiplier method
- Lambda Iteration method
- Gradient method
- Dynamic programming
- Evolutionary Computation Techniques

Input-Output Cost Curve

- Used to describe the efficiency of the plants.
- Graphical Representation of input in Rs/hr versus power output in megawatts is called input-output curve.





Incremental Cost curve for thermal Power plants

- A plot of the input in kilocalories per hour versus power output in megawatts is called input-output curve.
- The ordinates of the curve may be converted to Rs/hr by multiplying the fuel in Rs/kilocalories.
- The empirical equation of the this curve is given by

$$C_i = aP_i^2 + bP_i + c$$

- Where a, depending upon a particular plant.

- Incremental fuel cost

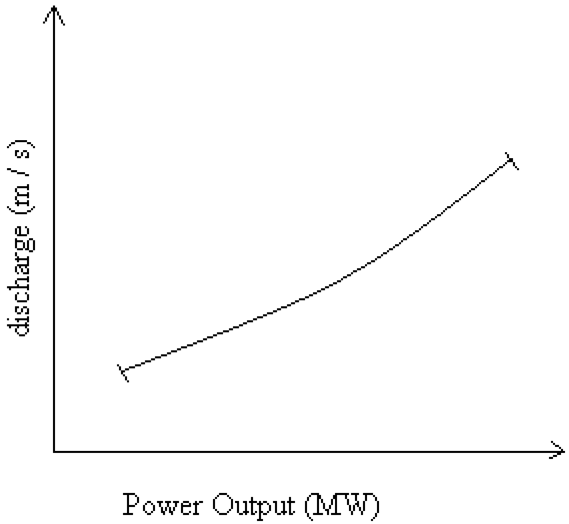
The incremental cost is equal to the slope of the cost curve. A plot of incremental cost versus power output is called the incremental cost curve. It is shown in Fig.3. Equation (2) is of the form =

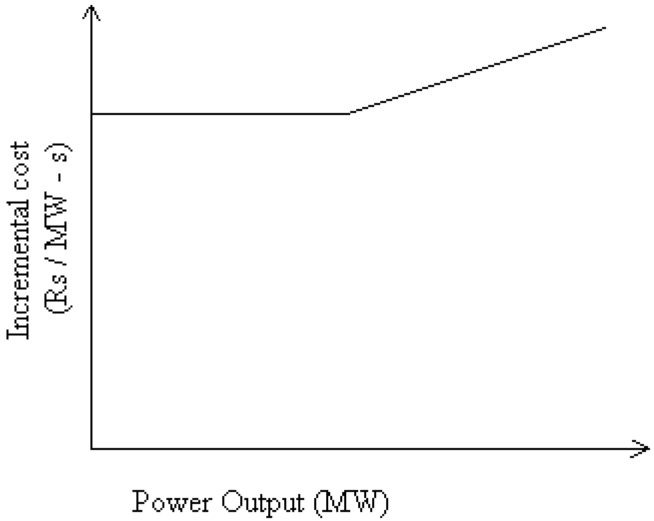
$$(IC)_i = \frac{dC_i}{dP_i} \quad 2aP_i + b \quad \text{Rs/ MWh}$$

The incre equ lope of the cost curve.

Incremental cost curve for Hydro Power Plants

- The input-output curve for a typical hydro unit is shown in Fig. 4. This is obtained by plotting the water input or discharge in cubic meters per second as a function of the power output in megawatts. The incremental cost curve for hydro unit is shown in Fig. 5. This is obtained by plotting the incremental cost in rupees per MW – second (Rs/MW – s)
- as a function of power output in megawatts (MW).


discharge (m / s)
Power Output (MW)


Incremental cost
(Rs / MW - s)
Power Output (MW)

Economic Dispatch Problem

- It consists of N generating units connected to a single bus bar serving a receiving electrical load

Without Loss

- let

[redacted]

[redacted]

subject to (1) energy balance equation and (11) inequality constraints

[redacted]

Lagrange Function

- This is a constrained optimization problem that may be attacked formally using advanced calculus methods that involve the Lagrange function.
- In order to establish the necessary conditions for an extreme value of the objective function, add the constraint function to the objective function after the constraint function has been multiplied by an undetermined multiplier. This is known as the *Lagrange function.*

- Lagrange function with respect to the power output values one at a time give the set of equations shown

$$L = FT + \lambda \Phi$$

Where λ is the Lagrangian multiplier.

- The necessary condition for this optimization problem is taking the first derivative of the Lagrange unction with respect to the each of the independent variables and set the derivatives equal to zero i.e

$$\frac{\partial L}{\partial P_i} = \frac{\partial F_i(P_i)}{\partial P_i} - \lambda = 0$$

$$0 = \frac{\partial F_i}{\partial P_i} - \lambda$$

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- This is the necessary condition for the existence of a minimum cost operating condition for the thermal power system is that the incremental cost rates of all the units be equal to some undetermined value, λ. Of course, to this necessary condition we must add the constraint equation that the sum of the power outputs must be equal to the power demanded by the load. In addition, there are two inequalities that must be satisfied for each of the units. That is, the power output of each unit must be greater than or equal to the minimum power permitted and must also be less than or equal to the maximum power permitted on that particular unit.

- These conditions and inequalities may be summarized as shown in the set of equations N equations

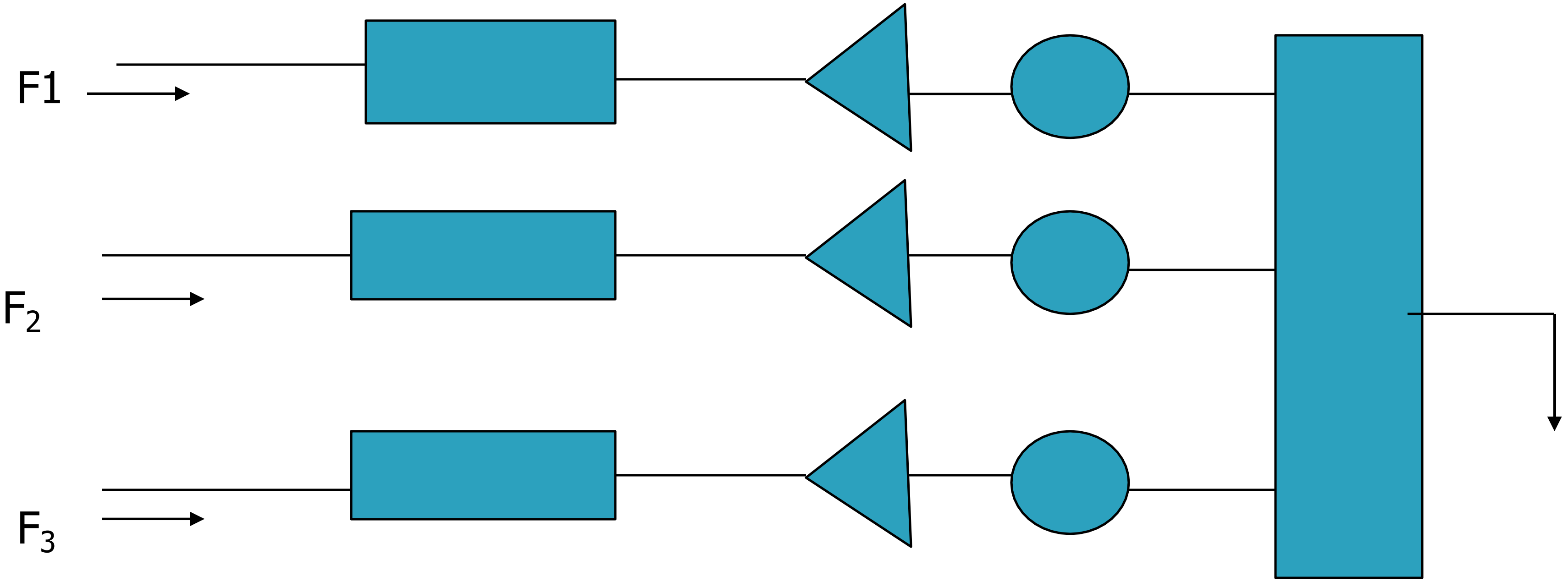
$$\frac{\partial F_i}{\partial P_i} = \lambda$$

$$P_{i,\min} \leq P_i \leq P_{i,\max}$$

$$\sum_{i=1}^{N} P_i = P_{Load}$$

ECONOMIC DISPATCH WITH LOSS

INTRODUCTION



With Loss

- Objective Fn

$$F_T = F_1 + F_2 + \dots\dots\dots + F_N$$

Subjected to

[redacted]

- Using Lagrangian Function

$$L = F_T + \lambda \Phi$$

Where „λ" is the lagrangian multiplier i.e., add the constrained function „ Φ „ to the objective function after the constrained function is multiplied by an undetermined multiplier

- Taking the derivative of lagrangian function with respect to any one of the N values of P_i is shown as:

[redacted]

[redacted]

[redacted]

General approaches to the solution of the problem

- Step1: Development of mathematical model for the losses in the network as the function of the power output of each units (Loss Formula Method).
- Step2: To incorporate the power flow equations

  as essential constraints. (Optimal Power Flow)

λ Iteration method

- One of the method to solve the economic dispatch problem by neglecting the losses.
- Eg.

consider three units system, to find the optimal economic operating point without losses

– assume an incremental cost rate and find the power outputs of these three units.

Procedure

- Is an iterative type of computation and stopping rules are used,

  (1) stopping rules based on finding the proper operating point with in a specified tolerance.

  (2) stopping rules based on maximum number of iteration

Base point and Participation factor

- EDP is solved repeatedly by moving the generators from one economically optimum schedule to another as the load changes by a reasonably small amount.
- Next, the scheduler assumes a load change and investigates how much each generating unit needs to be moved ie, participate in the load change in order that the new load be served at the most economic operating point.
- Assume that both the first and second derivatives in the cost versus power output function are available (ie, both and). As the unit load is changed by an amount , the system incremental cost moves from to . For a small change in power output on this single unit.

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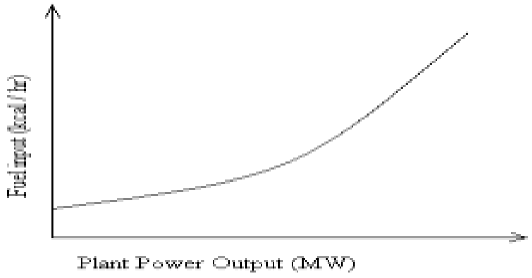

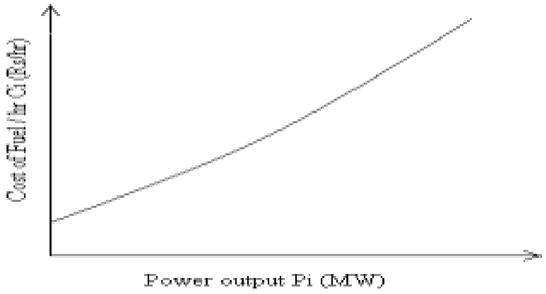

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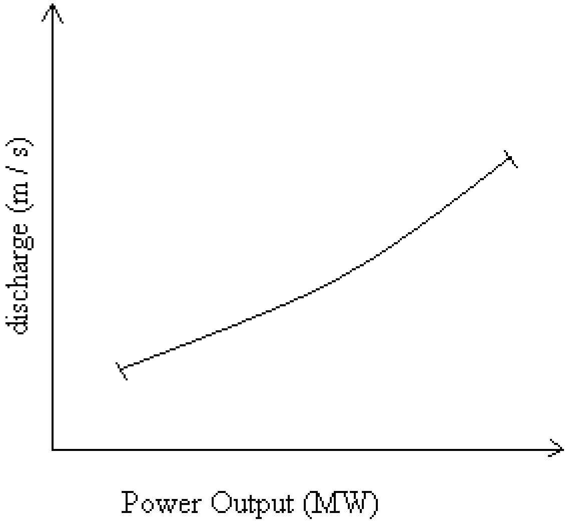
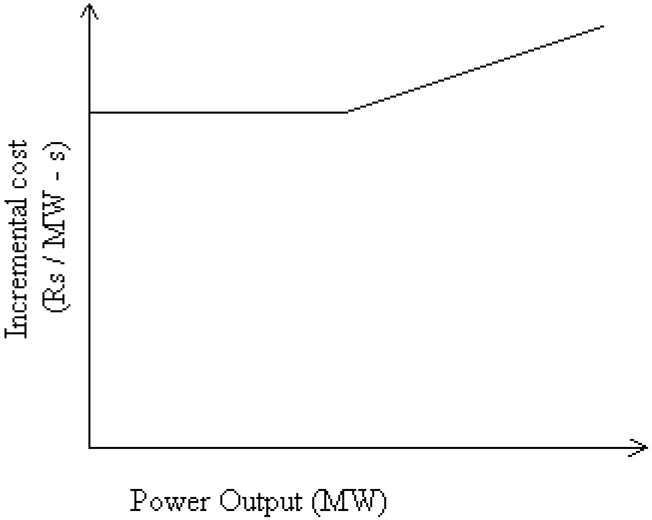

discharge (m / s)
Power Output (MW)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$$P_{i,\min} \leq P_i \leq P_{i,\max}$$

$$\sum_{i=1}^{N} P_i = P_{Load}$$

UNIT COMMITMENT

INTRODUCTION

- The unit commitment economically schedules generating units over a short-term planning horizon subject to the satisfaction of demand and other system operating constraints.
- It involves determining start-up and shut-down schedule of units to be used to meet the forecasted demand , over a future short term period.
- belongs to the class of complex combinatorial optimization problems..

An Example

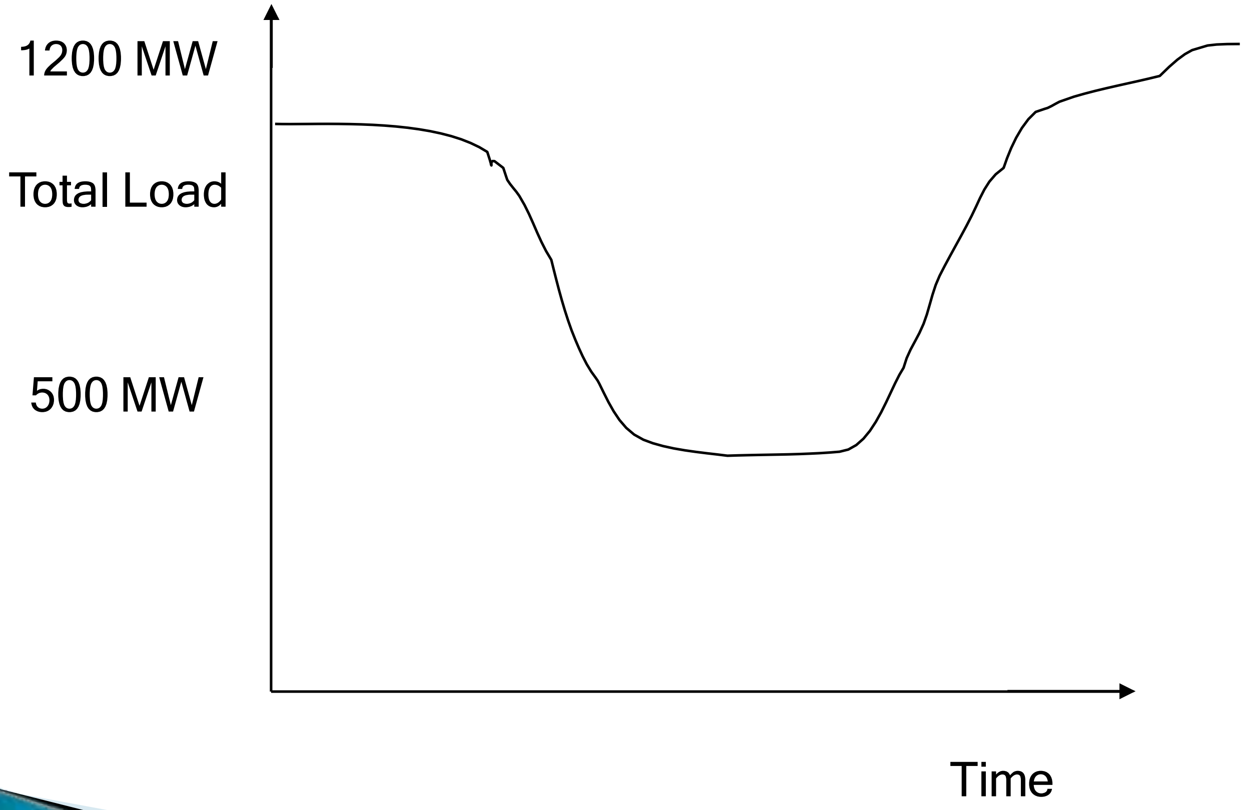
- Consider 3 units shown below:

  Unit 1: Min = 150MW, Max=600MW.
  Unit 2: Min = 100MW, Max=400MW.
  Unit 3: Min= 50 MW, Max = 200 MW.
  Load is 550 MW.

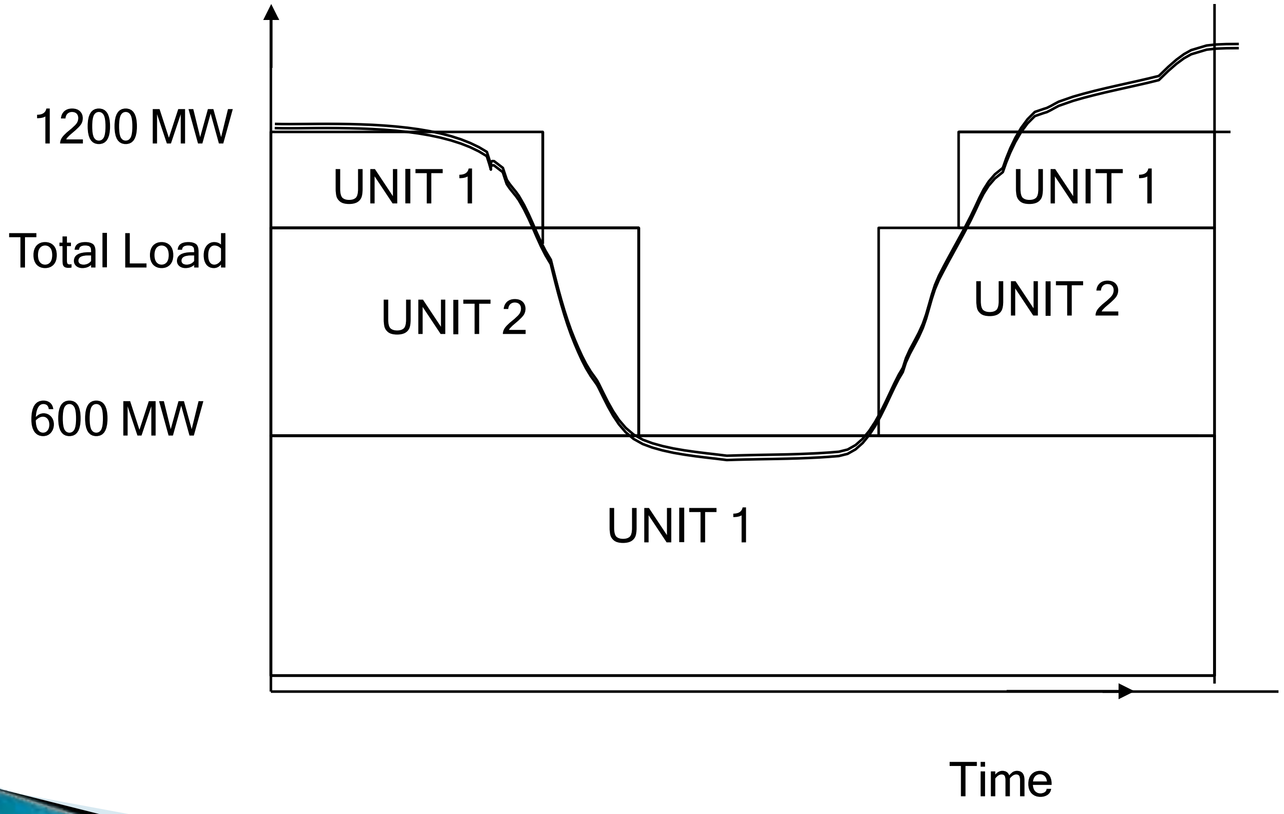
  What is the combination of units to supply the load most economically?

Meeting Variable demand

- An Example of Peak-valley load pattern



Unit commitment schedule



Constraints in Unit Commitment

- Spinning Reserve:
- Describes the total amount of generation schedule available from all units synchronized on the system minus present load and losses being supplied.
- Loss of one or more units should not cause a too far drop in frequency.
- Reserve must be capable of making up the loss of most heavily loaded unit in a given period of time.

Constraints (Continuation)

- Thermal Constraints:

  Thermal units undergo only gradual temperature changes.

- Minimum Up time: Once the unit is running, it should not be turned off immediately
- Minimum Down time: Once the unit is decommited, there is a minimum time before it can be recommitted.
- Crew Constraints: No enough crew members to attend two or more units while starting up.

Start up cost

- Energy expended to bring the unit on-line.
- Cooling:

Allows the units boiler to cool down and then heat back up to operating temperature in time for a scheduled turn-on.

- Banking:

Requires that sufficient energy be input to the boiler to just maintain operating temperature

Start –up cost when cooling

$$c_c\,(1-\in^{\frac{-t}{\alpha}})\times F + c_f$$

where

c_c = cold-start cost (MBtu)

F = Fuel cost

c_f =Fixed cost

α = Thermal time constant for the Unit

t = time (h) the unit was cooled

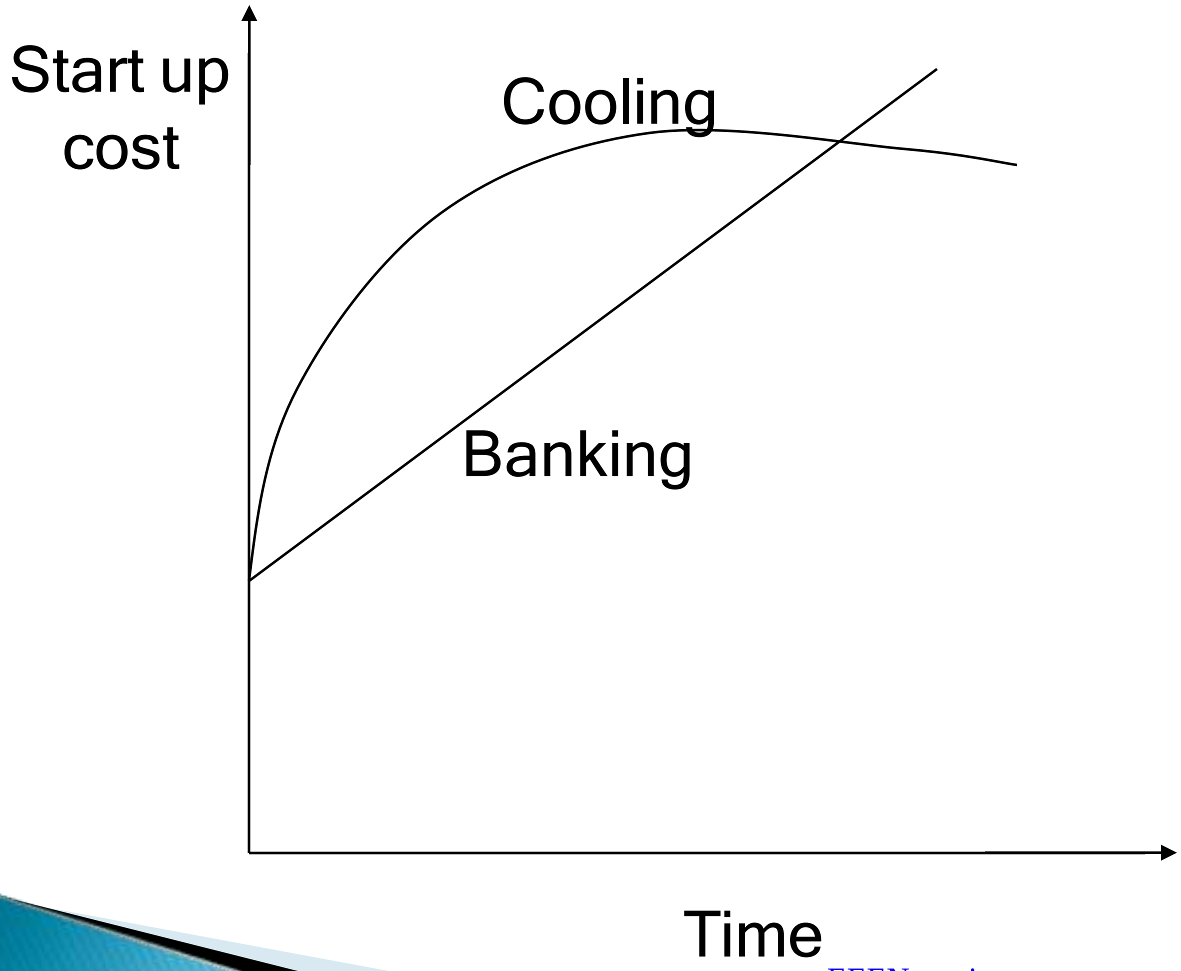
- Start-up cost when banking

$$c_t \times t \times F + c_f$$

where

c_t = cost (MBtu/h) of maintaining unit at operating temperature

Time dependent start-up cost



Other Constraints

- Must run constraint: Some units are given a must run status during all the times.
- Fuel Constraints: Some units have limited fuel or have constraints that require them to burn a specified amount of fuel.

Difficulties in Solving Unit Commitment Problems

- Let there be M periods and N units.
- The total number of combinations at each hour is:

$$C(N,j)=\left[\frac{N!}{(N-j)!\,j!}\right]$$

$$j!=1\times 2\times\ldots\ldots\ldots\times j$$

- The maximum number of possible combinations is $(2^N-1)^M$

Solution Methods

- Priority list schemes
- Dynamic Programming
- Lagrange Relaxation

Priority List Method

- It consists of priority list of units to be committed.
- Full load average production cost of each unit is calculated.
- Then in the order of ascending costs, the units are arranged for commitment.

An Example

- Consider 3 units shown below:

  Unit 1: Min = 150MW, Max=600MW.

  $H_1=510+7.2P_1+0.00142P_1^2$

  Unit 2: Min = 100MW, Max=400MW.

  $H_2= 310+7.85P_2+0.00194P_2^2$.

  Unit 3: Min= 50 MW, Max = 200 MW.

  $H_3 = 78+7.97P_3+0.00482P_3^2$. Load is 550 MW.

  Fuel cost_1=1.1 R/MBtu

  Fuel cost_2=1.0 R/MBtu

  Fuel cost_3=1.2 R/MBtu

  What is the combination of units to supply the load most economically?

Calculation of FLAPC

Unit	Full load average production cost(R/MWh)	Min MW	Max MW
1	9.79	100	400
2	9.48	150	600
3	11.188	50	200

Optimal Combinations

Combination	Min MW	Max MW
2+1+3	300	1200
2+1	250	1000
2	100	400

Limitations of Priority List Scheme

- No load costs are zero.
- Unit input-output characteristics are linear between zero output and full load.
- There are no other restrictions.
- Start up costs are a fixed amount.

Dynamic Programming for UC assumptions

- A state consists of an array of units with specified units operating and the rest off-line.
- The start up cost of a unit is independent of the time it has been off-lined (i.e., it is a fixed amount).
- There are no costs for shutting down a unit.
- There is a strict priority order, and in each interval a specified minimum amount of capacity must be operating.

Recursive Algorithm to compute the minimum cost

$$F_{cost}(K,I) = \min_{L}[P_{cost}(K,I) + S_{cost}(K-1,L:K,I) + F_{cost}(K-1,L)]$$

where

$$F_{cost}(K,I) = least\ total\ \text{cost}\ to\ arriveat\ state(K,I)$$

$$P_{cost}(K,I) = production\ \ \text{cost}\ \ for\ \ state(K,I)$$

$$S_{cost}(K-1,L:K,I) = transition\ \ \text{cost}\ \ from\ \ state\ (K-1,L)\ \ to\ \ (K,I)$$

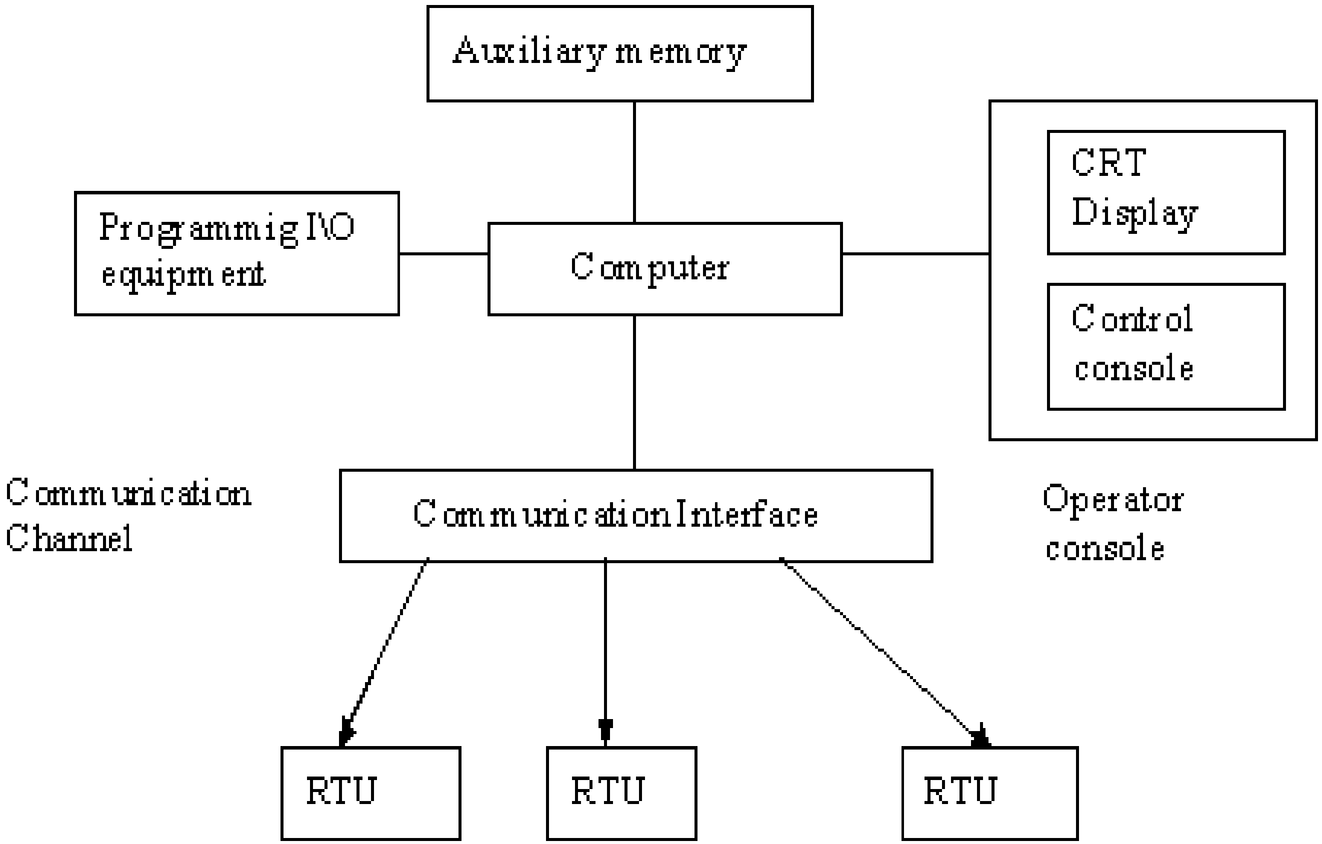
COMPUTER CONTROL OF POWER SYSTEMS

(SCADA)

Introduction

- What is SCADA
  - SCADA – Supervisory Control and Data Acquisition
  - SCADA system includes a computer system with an application program running that acquires the real-time data from the data acquisition units located in the field at a remote location in order the monitor the devices remotely and control them.
- SCADA equipment are located in:
  1. Master control center (national grid control centre)
  2. Zonal (regional) control centers
  3. District control centre (state electricity board)
  4. Control rooms of generating stations and large sub-station.

Structure of SCADA System



FUNCTIONS OF SCADA SYSTEMS

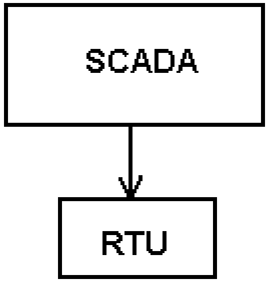
1. Monitoring
2. Alarm
3. Control and indication of production automatic generation control (AGC)
4. Data logging
5. Data acquisition
6. Control ON/OFF, RAISE/LOWER
7. Display

Additional functions are provided with SCADA systems for national load control centres:

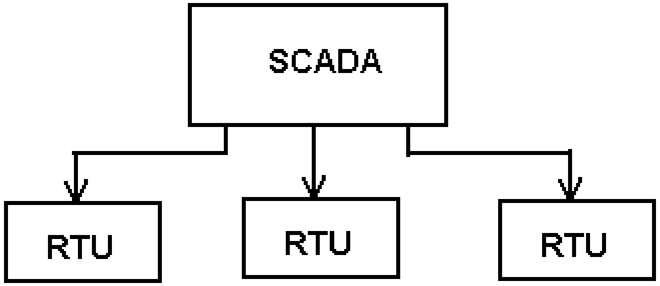
1. Interactive studies
2. Security assessment calculations contingency
3. Training simulator
4. Network modeling and Energy management systems(EMS)

SCADA Architecture

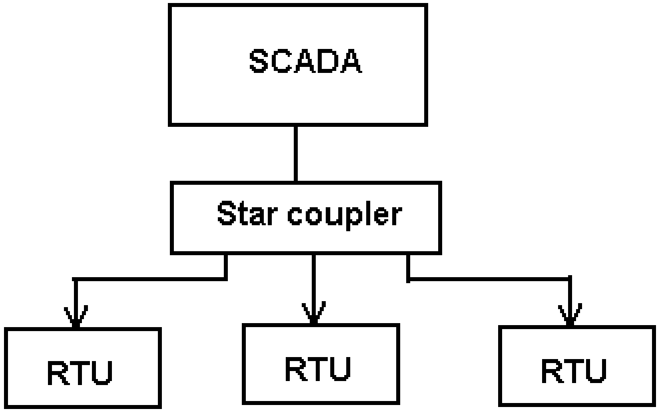
- Point to Point Connection


SCADA
RTU

Multiple point to point connection


SCADA
RTU
RTU
RTU

Star connection


SCADA
Star coupler
RTU
RTU
RTU

Application areas:

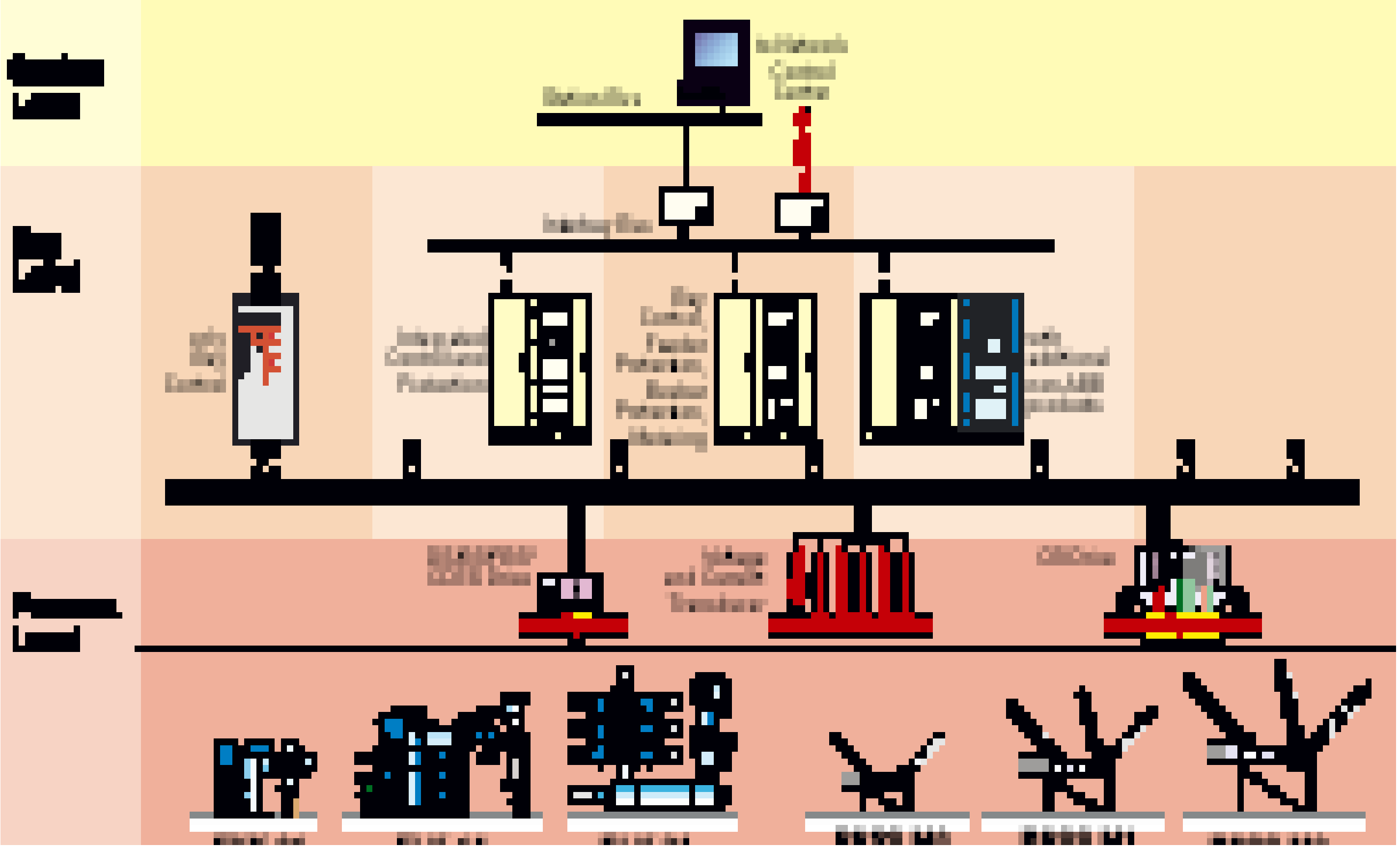
- SCADA system is for local and remote control applications suitable for electrical and non-electrical distribution areas.
- SCADA-based electrical application areas are:
  - Power transmission and distribution
- The SCADA-based non- electrical application areas are:
  - District heating
  - Water purification and distribution
  - Waste water treatment
  - Oil and gas distribution etc.

Substation Automation system

Substation Automation means that the substation has equipment, which enables communication with the primary equipment and use of process data for supervision, control and communication.

- The functions may include:
  - viewing status of breakers and disconnectors
  - controlling the breakers and disconnectors
  - dynamic coloring of the busbars
  - viewing and setting of protection parameters
  - viewing condition of auxiliary equipment e.g. batteries
  - collection of metering data
  - transferring data to network control center

Classical Substation Automation System



Substation functions through SCADA

The integration of control, protection and monitoring in one common system is achieved using SCADA system in a substation.

Control functions

- Control and monitoring of switching devices, tapped transformers, auxiliary devices, etc.
- Bay- and a station-wide interlocking
- Dynamic Busbar coloring according to their actual operational status.
- Automatic switching sequences
- Automatic functions such as load shedding, power restoration, and high speed bus bar transfer (HBT)
- Time synchronization by radio and satellite clock signal

Monitoring functions:

- Measurement and displaying of current, voltage, frequency, active and reactive power, energy, temperature, etc.
- Alarm functions. Storage and evaluation of time stamped events
- Trends and archiving of measurements
- Collection and evaluation of maintenance data
- Disturbance recording and evaluation
- **Protection functions:**
- Substation protection functions includes the monitoring of events like start, trip indication and relay operating time and setting and reading of relay parameters.
- Protection of bus bars. Line feeders, transformers, generators
- Protection monitoring (status, events, measurements, parameters, recorders)
- Adaptive protection by switch-over of the active parameter set
- Optional: all information regarding protection on a separate workplace.

Benefits of Substation Automation

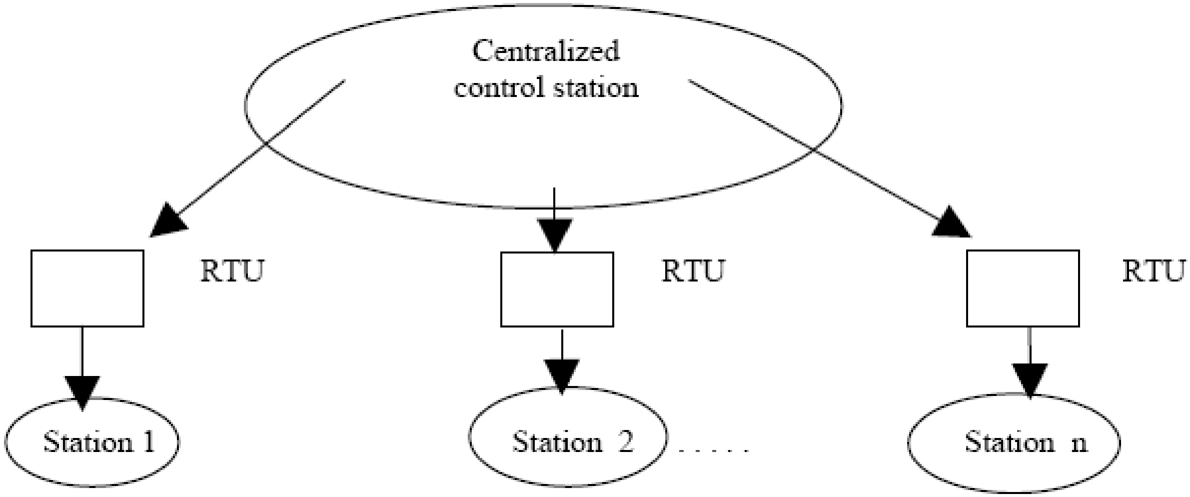
Strategic Benefits:

- Improved quality of service
- Improvedreliability
- Maintenance/expansion of customer base
- High value service provider
- Added value services
- Improved customer access to information
- Enterprise information accessibility
- Flexible billing options

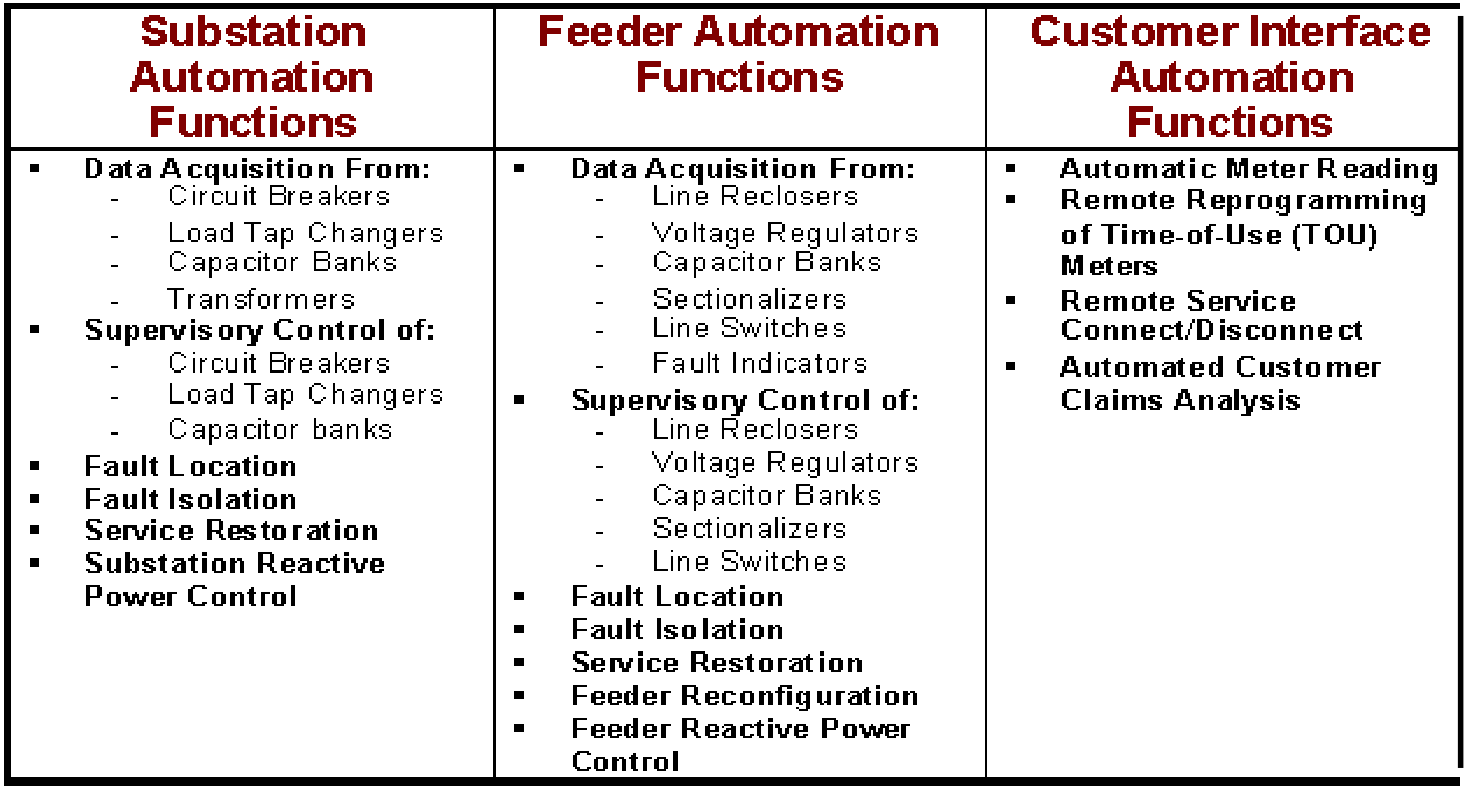
Tangible Benefits:

- Reduced manpower requirements
- Reduced system implementation costs
- Reduced operating costs
- Reduced maintenance costs
- Ability to defer capacity addition projects
- Improved information for engineering decisions
- Improved information for planning decisions
- Reduced customer outage minutes

Distribution Automation



Functions of distribution automation



Substation Automation Functions	Feeder Automation Functions	Customer Interface Automation Functions
▪ **Data Acquisition From:** - Circuit Breakers - Load Tap Changers - Capacitor Banks - Transformers ▪ **Supervisory Control of:** - Circuit Breakers - Load Tap Changers - Capacitor banks ▪ **Fault Location** ▪ **Fault Isolation** ▪ **Service Restoration** ▪ **Substation Reactive Power Control**	▪ **Data Acquisition From:** - Line Reclosers - Voltage Regulators - Capacitor Banks - Sectionalizers - Line Switches - Fault Indicators ▪ **Supervisory Control of:** - Line Reclosers - Voltage Regulators - Capacitor Banks - Sectionalizers - Line Switches ▪ **Fault Location** ▪ **Fault Isolation** ▪ **Service Restoration** ▪ **Feeder Reconfiguration** ▪ **Feeder Reactive Power Control**	▪ **Automatic Meter Reading** ▪ **Remote Reprogramming of Time-of-Use (TOU) Meters** ▪ **Remote Service Connect/Disconnect** ▪ **Automated Customer Claims Analysis**

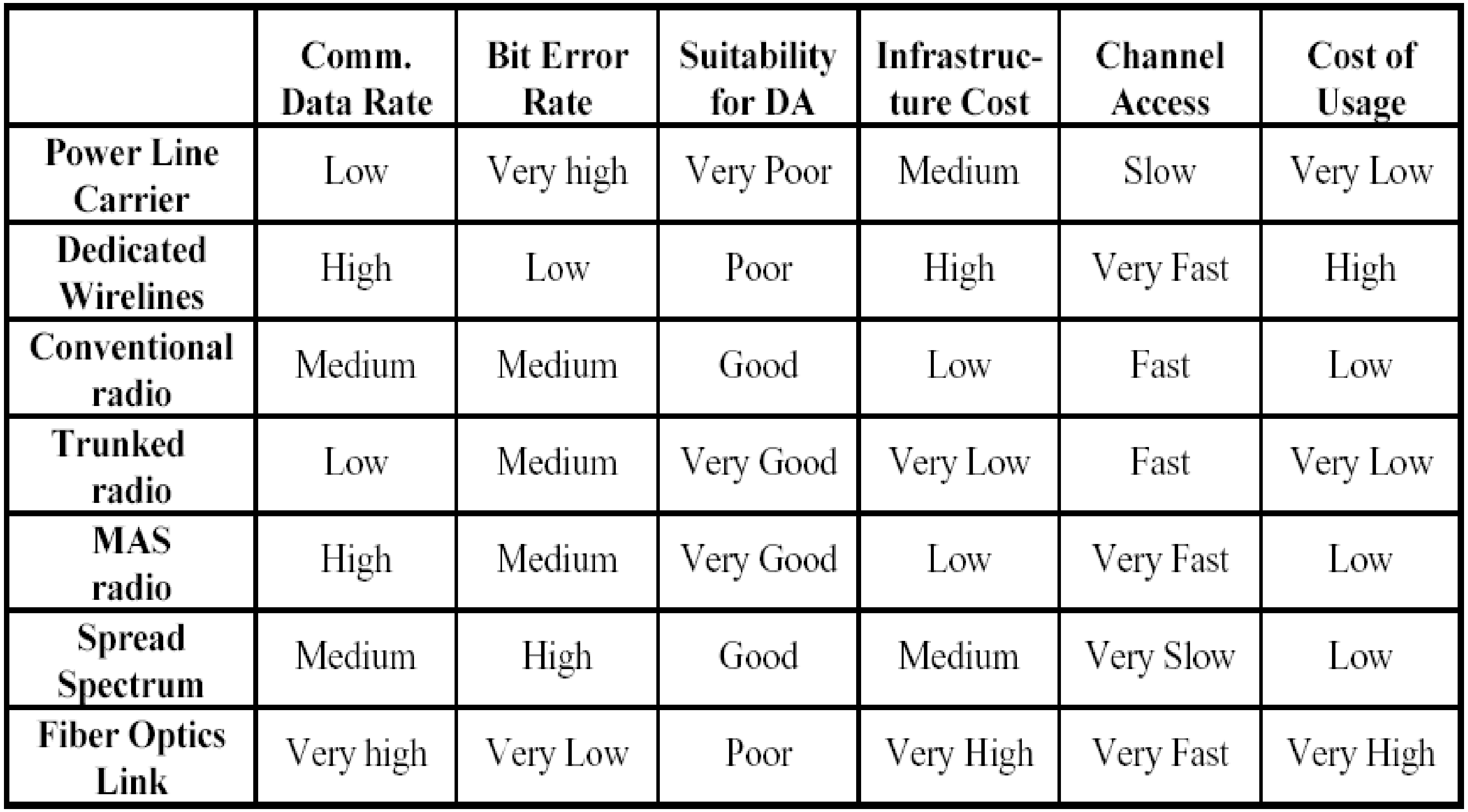
Protective functions:

- Under frequency protection
- Earth fault protection
- Condition Fail protection
- feeder protection & auto reelecting
- Breather failure protection
- Busbar protection
- Back up protection

Benefits of distribution automation:

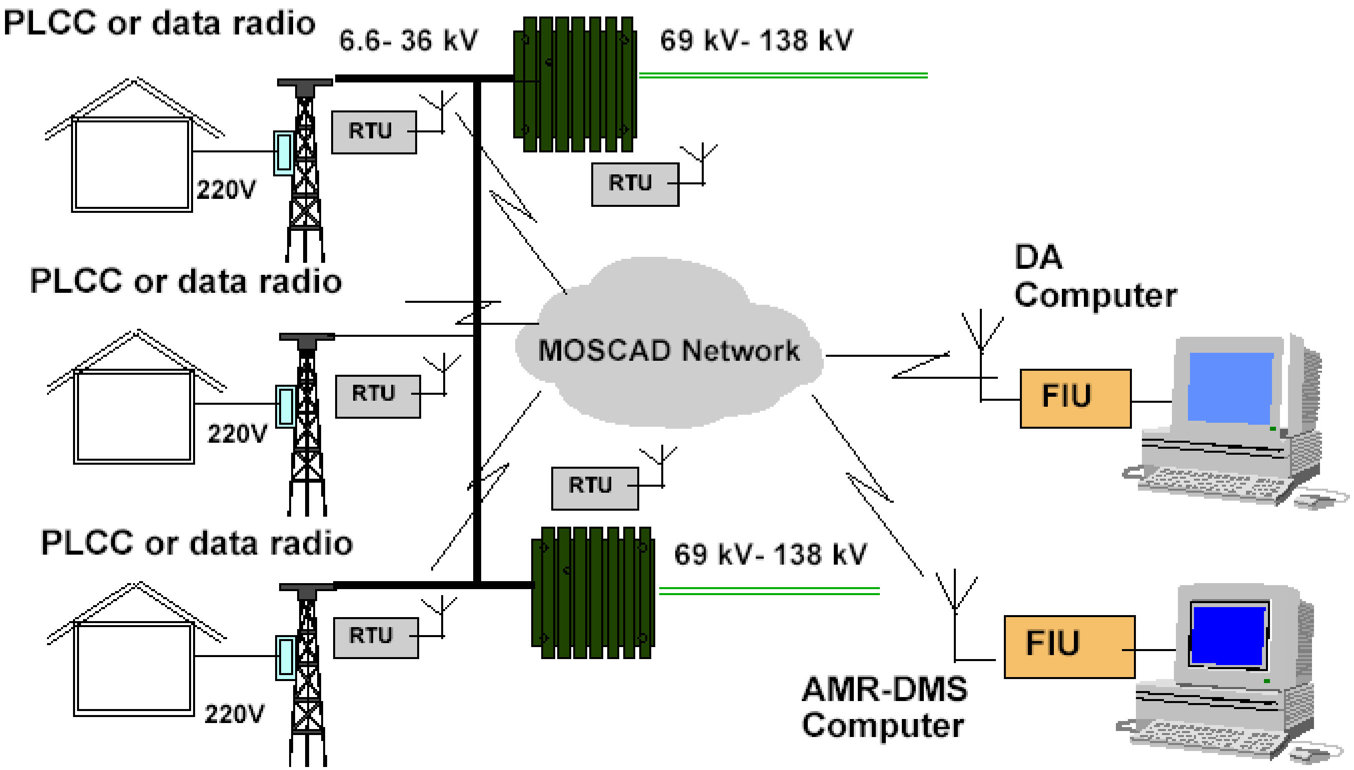
- Improved reliability
- Economic benefits
- Early warning feature

communication media for DA

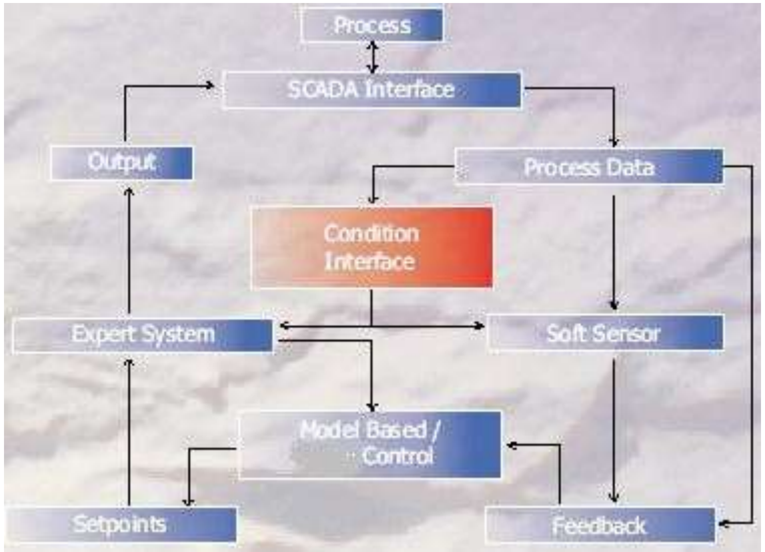


	Comm. Data Rate	Bit Error Rate	Suitability for DA	Infrastructure Cost	Channel Access	Cost of Usage
Power Line Carrier	Low	Very high	Very Poor	Medium	Slow	Very Low
Dedicated Wirelines	High	Low	Poor	High	Very Fast	High
Conventional radio	Medium	Medium	Good	Low	Fast	Low
Trunked radio	Low	Medium	Very Good	Very Low	Fast	Very Low
MAS radio	High	Medium	Very Good	Low	Very Fast	Low
Spread Spectrum	Medium	High	Good	Medium	Very Slow	Low
Fiber Optics Link	Very high	Very Low	Poor	Very High	Very Fast	Very High

Distribution system communication



SCADA System in Cement Industries

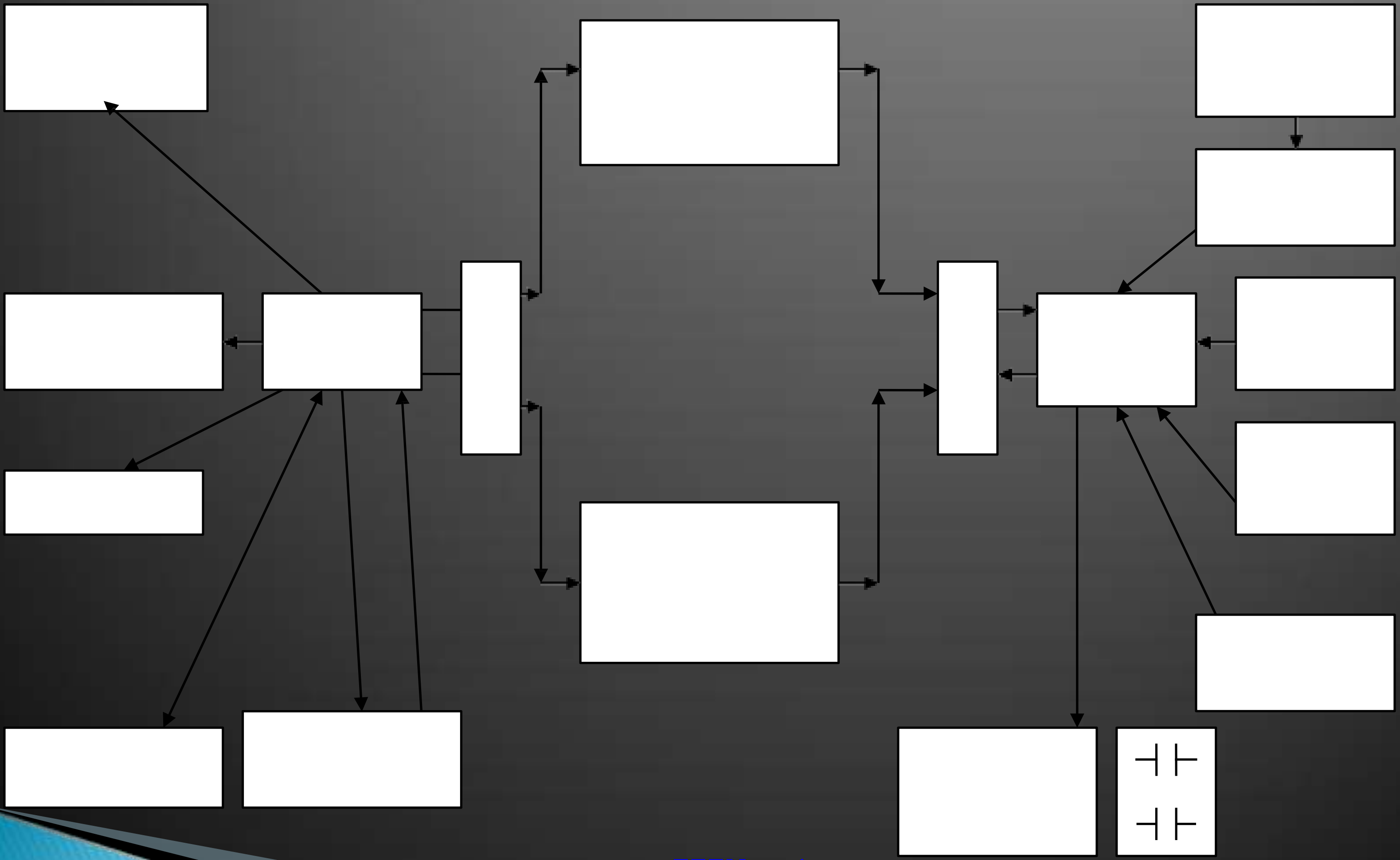


Soft sensor:

It allows for proper closure of the control loop on product quality, leading to superior performance in quality control, while also meeting production targets on throughput and energy consumption.

SCADA system allows optimal use of the plant and generates sustainable improvements in product quality and consistency.

Figure: SCADA requires communication between Master control station and Remote control station



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COMMUNICATIONS TECHNOLOGIES

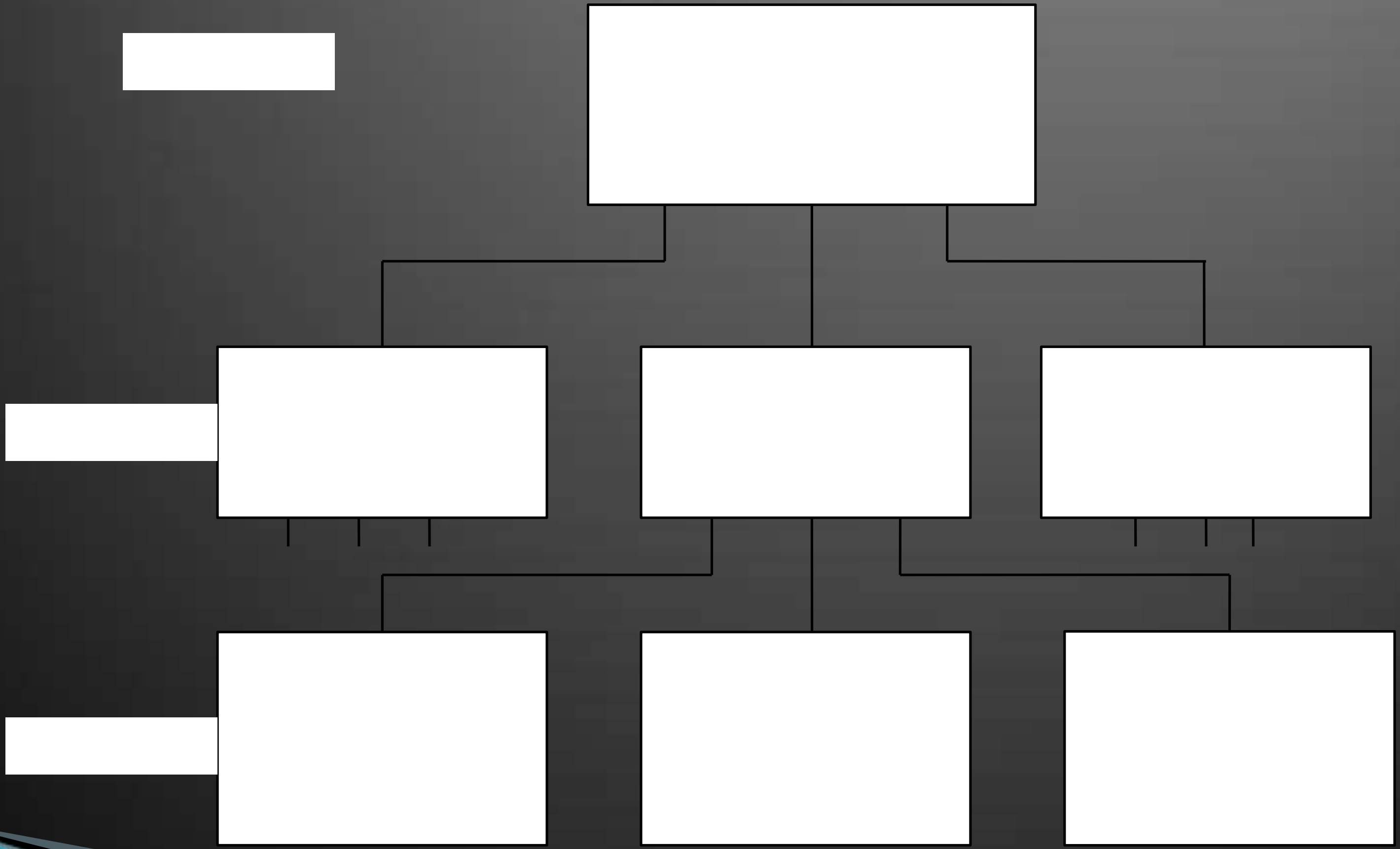
Power Line Carrier:

- Power line carrier communication **(PLCC)** was quite popular in the past, mainly for signaling.
- Power line carrier systems use electric transmission and distribution lines to carry digital data and voice.

Wire lines:

- Many SCADA systems employ wireline links (private networks) to communicate between the SCADA Master Control Center **(MCC)** and substation RTUs.
- The commonly used wireline and telephone networks allow very reliable point-to-point or point-to-multi-point (multi-drop) communication.

Three levels of control of SCADA system and control system



Regional load control centre:

It decides generation allocation to various generating stations within the region on the basics of equal incremental operating cost considering line losses are equal and Frequency control in the region.

Plant load control room

It decides the allocation of generation of various units in the plant on the basis of:

1. Equal incremented operating cost of various units
2. Minimize the reactive power flow through line so as to minimize line loss and maintain voltage levels and Frequency control in the plant.

Sub-station control room:

It minimizes
1. Reactive power flow through the transmission lines by compensation.
2. Maintain voltage levels by minimize the line
3. The Synchronizing and system restoration are also done by the Sub-station control room.

The primary objectives of the various levels are:

- load frequency control
- voltage control
- economic load dispatch

Data:

1. Electrical and mechanical variables on/off states
2. Analogue quantities
3. Digital quantities
4. Change of state sequence of event
5. Time of occurrence and several other data which the control room operator would like to know.

Data transmission:

Data is transmitted from the process location to the control room and the control room to the control center.

Data processing and data logging:

- The large number of electrical/ mechanical/other data are scanned at required interval, recorded and displayed as per the requirements. Some of the data is converted from analogue to digital form by A/D converters. The data loggers perform the following function:
  - Input scanning
  - A/D conversion
  - Display
  - Signal amplification
  - Recording
  - Programming

Data collections (acquisition):

1. The data is acquired by means of a CTs VTs, transducers and other forms of collecting informations.
2. The transducers convert very large number of electrical, mechanical and other datas (informations) into electrical form to enable easy measurement and transmission.
3. Data may be collected at low level (5 mA) or high level (5 v). The data amplified in signal amplifier and conditioned in data signal conditioner.

REMOTE TERMINAL UNIT:

- Remote Terminal Units are special purpose computers which contain analog to digital converters (ADC), digital to analog converters (DAC), digital inputs (status) and outputs (control).
- The inputs and outputs are fully protected against spurious electrical transients.
- RTUs may be either AC powered (120/230V) or battery powered (12, 24, 48, 125 or 250V).

RTU functions

- Acquisition of information (measured values, signals, alarms, meter readings), including features such as plausibility checks and filtering.
- Output of commands / instructions (binary pulse type or continuous commands, set points, control variables) . Including their monitoring (as a function of time, lout of n)
- Recognition of changes in signal input states, pulse time data allocation for sequential recording of events by the master control stations.
- Processing of information transmitted to and from the telecommunication equipment (Data compression, Coding and protection)
- Communication with master control stations.

Transmission Substation RTUs:

- Main substation RTU can connect to many other RTUs in the substation, each with a specific function or functions, including closed loop control and computation.

- Many RTUs have the ability to interface with other substation devices generally referred to as IEDs (Intelligent Electronic Devices)

Distribution Automation RTUs:

- "DA" RTUs are having all inputs, outputs and the RTU microprocessor on just one printed circuit board.
- If the RTU is expandable, additional input and output cards are connected by flat ribbon cables rather than plug-in cards, making the system more rugged and compact.
- These RTUs usually contain an integral lead acid gel cell battery backup system and integral communications module (radio, telephone modem or fiber optic transceiver).