ECONOMIC OPERATION OF POWER SYSTEMS
(BPSB02)

by

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ECONOMIC LOAD SCHEDULING

CHARACTERISTICS OF STEAM TURBINE:

- Turbine Performance Characteristics of output and efficiency are important parameters.
- At project feasibility stage these parameters are required to fix number and size of units and determine economic feasibility.
- For this purpose output and efficiency at part load of the head range for the turbine is required.
- In tender documents for procurement these characteristics of turbines are specified to be guaranteed under penalty.
- In evaluation of bids, equalization on accounts of differences in efficiencies of turbines of various bidders is made.
- Model tests are required to ensure that the guaranteed parameters offered will be met by the proto type.

VARIATIONS IN STEAM UNIT CHARACTERISTICS

- A number of different steam unit characteristics exist.
- Large steam turbine generators will have a number of steam admission valves that are opened in sequence to obtain ever-increasing output of the unit.
- As the unit loading increases, the input to the unit increases and the incremental heat rate decreases between the opening points for any two valves.
- However, when a valve is first opened, the throttling losses increase rapidly and the incremental heat rate rises suddenly.
- This gives rise to the discontinuous type of incremental heat rate characteristic .

It is possible to use this type of characteristic in order to schedule steam units, although it is usually not done.

- This type of input-output characteristic is non-convex; hence, optimization techniques that require convex characteristics may not be used with impunity.

Mathematically, the economic dispatch problem with piecewise linear incremental cost function and line loss is formed as following equations

$$\lambda = pf_i(m_{i,j}P_i + b_{i,j}) \quad P_{i\min} < P_i < P_{i\max} \qquad (1)$$

$$\sum P_i = Pl_{oad} + P_{loss}$$

$$pf_i = \frac{1}{1 - \frac{\partial P_{loss}}{\partial P_i}}$$

$$P_{loss} = P^T[B]P + B_0^T P + B_{00}$$

Where,

P_i: the power of ith generator;

$m_{i,j}$ and $b_{i,j}$ are the coefficients of jth segment of ith generator's linear incremental function;

pf_i: penalty factor of ith generator;

P : vector of all generator bus;

P_{loss}: the total power loss in transmission line, which is expressed as the function of generator output;

[B], B_0, B_{00}: loss coefficients;

THE ECONOMIC DISPATCH ALGORTHIM

- The method developed here to solve economic dispatch problem is called the modified lambda and penalty factor iteration method (MLPFI).
- Instead of solving nonlinear equations which are introduced by penalty factor, two iteration loops are used in the algorithm.
- In the outer loop, an initial value of Poi is set and based on Poi, penalty factor and power loss are calculated.
- The calculated penalty factor is replaced to form a linear equation for solving Pi.
- The calculated Pi will update the penalty factor until the error of the current Pi and last Pi is within the tolerance.

- At the inner loop, an initial value of lambda is set and generators are scheduled to meet this value.

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- The megawatt output for the units is added together and compared to the desired total.

- Depending on the difference and whether the resulting total is above or below the desired level, a new value of lambda is tried.

- This iteration is repeated until the incremental cost is found that gives the correct desired value.

Concept of Cost Function:

- The relationship between output and costs is expressed in terms of cost function.
- By incorporating prices of inputs into the production function, one obtains the cost function since cost function is derived from production function.
- However, the nature of cost function depends on the time horizon.
- In microeconomic theory, we deal with short run and long run time.

A cost function may be written as:

$C_q = f(Q_f P_f)$

Where C_q is the total production cost, Q_f is the quantities of inputs employed by the firm, and P_f is the prices of relevant inputs.

This cost equation says that cost of production depends on prices of inputs and quantities of inputs used by the firm.

Importance of Cost Function:

- The study of business behavior concentrates on the production process—the conversion of inputs into outputs—and the relationship between output and costs of production.
- We have already studied a firm's production technology and how inputs are combined to produce output.
- The production function is just a starting point for the supply decisions of a firm.
- For any business decision, cost considerations play a great role.

- Cost function is a derived function.
- It is derived from the production function which captures the technology of a firm.
- The theory of cost is a concern of managerial economics.
- Cost analysis helps allocation of resources among various alternatives.
- In fact, knowledge of cost theory is essential for making decisions relating to price and output.
- Whether production of a new product is a wiser one on the part of a firm greatly depends on the evaluation of costs associated with it and the possibility of earning revenue from it.
- Decisions on capital investment (e.g., new machines) are made by comparing the rate of return from such investment with the opportunity cost of the funds used.

UNIT COMMITMENT

UNIT COMMITMENT - INTRODUCTION

- The life style of a modern man follows regular habits and hence the present society also follows regularly repeated cycles or pattern in daily life.

- Therefore, the consumption of electrical energy also follows a predictable daily, weekly and seasonal pattern.

- There are periods of high power consumption as well as low power consumption.

- It is therefore possible to commit the generating units from the available capacity into service to meet the demand.

- The previous discussions all deal with the computational aspects for allocating load to a plant in the most economical manner.
- For a given combination of plants the determination of optimal combination of plants for operation at any one time is also desired for carrying out the aforesaid task.
- The plant commitment and unit ordering schedules extend the period of optimization from a few minutes to several hours.
- From daily schedules weekly patterns can be developed.
- Likewise, monthly, seasonal and annual schedules can be prepared taking into consideration the repetitive nature of the load demand and seasonal variations.
- Unit commitment schedules are thus required for economically committing the units in plants to service with the time at which individual units should be taken out from or returned to service

Constraints In Unit Commitment:

- Many constraints can be placed on the unit commitment problem.

- Each individual power system, power pool, reliability council, and so forth, may impose different rules on the scheduling of units, depending on the generation makeup, load-curve characteristics, and such.

Spinning Reserve:

- **Spinning reserve** is the term used to describe the total amount of generation available from all units synchronized (i.e., spinning) on the system, minus the present load and losses being supplied.

- Spinning reserve must be carried so that the loss of one or more units does not cause too far a drop in system frequency.

- Quite simply, if one unit is lost, there must be ample reserve on the other units to make up for the loss in a specified time period.

- Spinning reserve must be allocated to obey certain rules, usually set by regional reliability councils (in the United States) that specify how the reserve is to be allocated to various units.

- Typical rules specify that reserve must be a given percentage of forecasted peak demand, or that reserve must be capable of making up the loss of the most heavily loaded unit in a given period of time.
- Others calculate reserve requirements as a function of the probability of not having sufficient generation to meet the load.
- Not only must the reserve be sufficient to make up for a generation-unit failure, but the reserves must be allocated among fast-responding units and slow-responding units.
- This allows the automatic generation control system to restore frequency and interchange quickly in the event of a generating-unit.

- Beyond spinning reserve, the unit commitment problem may involve various classes of “scheduled reserves” or “off-line” reserves.
- These include quick-start diesel or gas-turbine units as well as most hydro-units and pumped-storage hydro-units that can be brought on-line, synchronized, and brought up to full capacity quickly.
- As such, these units can be “counted” in the overall reserve assessment, as long as their time to come up to full capacity is taken into account.
- Reserves, finally, must be spread around the power system to avoid transmission system limitations (often called “bottling” of reserves) and to allow various parts of the system to run as “islands,” should they become electrically disconnected.

Thermal Unit Constraints:

- Thermal units usually require a crew to operate them, especially when turned on and turned off.
- A thermal unit can undergo only gradual temperature changes, and this translates into a time period of some hours required to bring the unit on-line.

As a result of such restrictions in the operation of a thermal plant, various constraints arise, such as:

1. Minimum up time: once the unit is running, it should not be turned off immediately
2. Minimum down time: once the unit is decommitted, there is a minimum time before it can be recommitted.

- Cc = cold-start cost (Mbtu)
- F = fuel cost
- Cf= fixed cost (includes crew expense, maintenance expenses) (in R)
- α = thermal time constant for the unit
- t = time (h) the unit was cooled
- Start-up cost when banking = Ct x t x F+Cf

Where

- Ct = cost (MBtu/h) of maintaining unit at operating temperature
- Up to a certain number of hours, the cost of banking will be less than the cost of cooling.
- Finally, the capacity limits of thermal units may change frequently, due to maintenance or unscheduled outages of various equipment in the plant; this must also be taken.

HYDRO THERMAL SCHEDULING

- OPTIMAL SCHEDULING OF HYDROTHERMAL SYSTEM :

- No state or country is endowed with plenty of water sources or abundant coal or nuclear fuel.

- In states, which have adequate hydro as well as thermal power generation capacities, proper co-ordination to obtain a most economical operating state is essential.

- Maximum advantage is to use hydro power so that the coal reserves can be conserved and environmental pollution can be minimized.

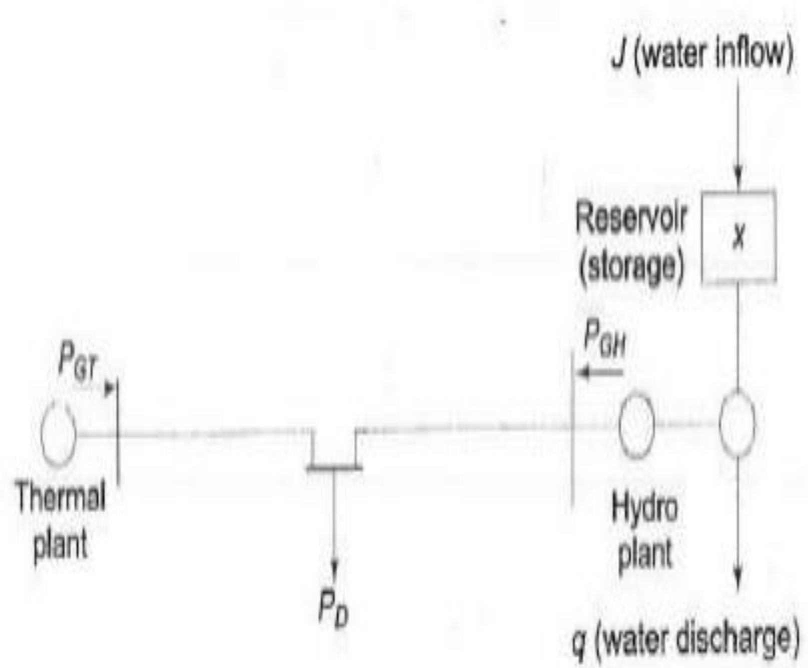
- However in many hydro systems, the generation of power is an adjunct to control of flood water or the regular scheduled release of water for irrigation.
- Recreations centers may have developed along the shores of large reservoir so that only small surface water elevation changes are possible.
- The whole or a part of the base load can be supplied by the run-off river hydro plants, and the peak or the remaining load is then met by a proper mix of reservoir type hydro plants and thermal plants.
- Determination of this by a proper mix is the determination of the most economical operating state of a hydro-thermal system.

- The hydro-thermal coordination is classified into long term co-ordination and short term coordination.
- The previous sections have dealt with the problem of optimal scheduling of a power system with thermal plants only.
- Optimal operating policy in this case can be completely determined at any instant without reference to operation at other times.
- This, indeed, is the static optimization problem.

- Operation of a system having both hydro and thermal plants is, however, far more complex as hydro plants have negligible operating cost, but are required to operate under constraints of water available for hydro generation in a given period of time.

- The problem thus belongs to the realm of dynamic optimization.

- The problem of minimizing the operating cost of a hydrothermal system can be viewed as one of minimizing the fuel cost of thermal plants under the constraint of water availability (storage and inflow) for hydro generation over a given period of operation.


J (water inflow)
Reservoir (storage)
x
P_{GH}
P_{GT}
Thermal plant
Hydro plant
P_D
q (water discharge)

- For the sake of simplicity and understanding, the problem formulation and solution technique are illustrated through a simplified hydrothermal system of Fig.

- This system consists of one hydro and one thermal plant supplying power to a centralized load and is referred to as a fundamental system.

- Optimization will be carried out with real power generation as control variable, with transmission loss accounted for by the loss formula.

- Classification of Hydrothermal Scheduling Problem
- 1. Long range problem
- 2. Short range problem

- **Long Range Problem :**
- Long range problem includes the yearly cyclic nature of reservoir water inflows and seasonal load demand and correspondingly a scheduling period of one year is used.
- The solution of the long range problem considers the dynamics of head variations through the water flow continuity equation.
- The co-ordination of the operation of hydroelectric plants involves, of course, the scheduling of water releases.
- The long-range hydro-scheduling problem involves the long-range forecasting of water availability and the scheduling of reservoir water releases for an interval of time that depends on the reservoir capacities.
- Typical long-range scheduling goes anywhere from 1 week to 1 year or several years.

- For hydro schemes with a capacity of impounding water over several seasons, the long-range problem involves meteorological and statistical analysis.
- The purpose of the long-term scheduling is to provide a good feasible solution that is close to the long-term cost minimization of the whole system.
- The problem is usually very difficult to solve due to its size, the time span (up to several years) and the randomness of the water inflows over the long term.
- Long-range scheduling involves optimizing a policy in the context of unknowns such as load, hydraulic inflows and unit availabilities (steam and hydro).
- These unknowns are treated statistically and long-range scheduling involves optimization of statistical variables.

- The short term hydrothermal scheduling problem is classified into two groups
- 1. Fixed head hydro thermal scheduling
- 2. Variable head hydro thermal scheduling

- **LOAD FREQUENCY CONTROL**

Load-frequency control (LFC) :

- For large scale electric power systems with interconnected areas, Load Frequency Control (LFC) is important to keep the system frequency and the inter-area tie power as near to the scheduled values as possible.
- The input mechanical power to the generators is used to control the frequency of output electrical power and to maintain the power exchange between the areas as scheduled.
- A well designed and operated power system must cope with changes in the load and with system disturbances, and it should provide acceptable high level of power quality while maintaining both voltage and frequency within tolerable limits.

- Load frequency control is basic control mechanism in the power system operation.
- Whenever there is variation in load demand on a generating unit, there is a momentarily an occurrence of unbalance between real-power input and output.
- This difference is being supplied by the stored energy of the rotating parts of the unit.
- Load Frequency Control (LFC) is being used for several years as part of the Automatic Generation Control (AGC) scheme in electric power systems.
- One of the objectives of AGC is to maintain the system frequency at nominal value (50 Hz).

- **Automatic generation control (AGC) :**

- Automatic generation control (AGC) is defined as, the regulation of power output of controllable generators within a prescribed area in response to change in system frequency, tie-line loading, or a relation of these to each other, so as to maintain the schedules system frequency and / or the established interchange with other areas within predetermined limits.

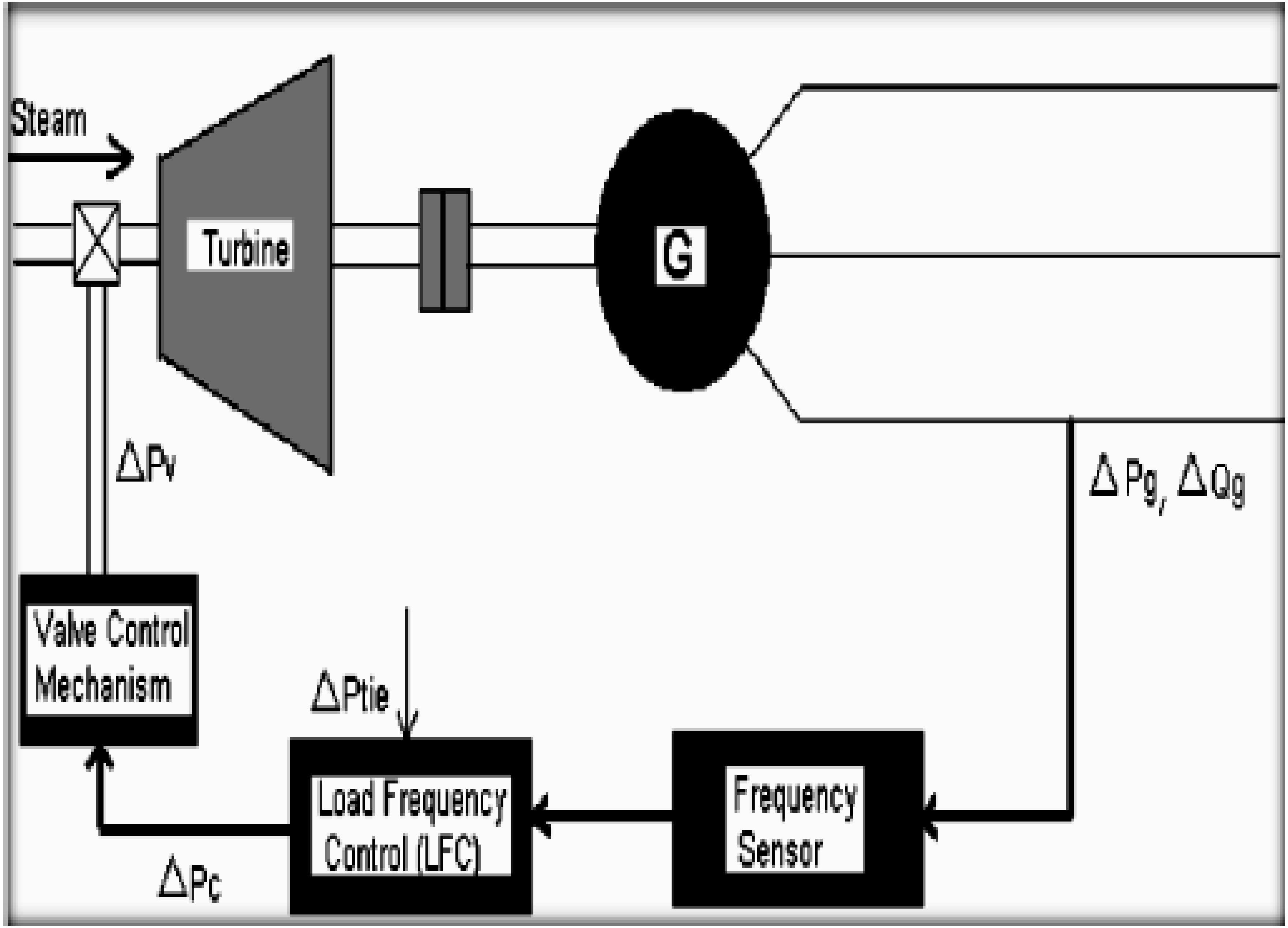
- The two basic inter-area regulating responsibilities are as follows:-

- (i) When system frequency is on schedule, each area is expected automatically to adjust its generation to maintain its net transfer with other areas on schedule, thereby absorbing its own load variations. As long, all areas do so; scheduled system frequencies as well as net interchange schedules for all area are maintained.

- (ii) When system frequency is off-schedule, because one or more areas are not fulfilling their regulating responsibilities, other areas are expected automatically to shift their respective net transfer schedules proportionally to the system frequency deviation and in direction to assist the deficient areas and hence restore system frequency.
- The extent of each area’s shift of net interchange schedule is programmed by its frequency bias setting. Therefore, a control strategy is needed that not only maintains constancy of frequency and desired tie-power flow but also achieves zero steady state error and inadvertent interchange.
- Numbers of control strategies have been employed in the design of load frequency controllers in order to achieve better dynamic performance.

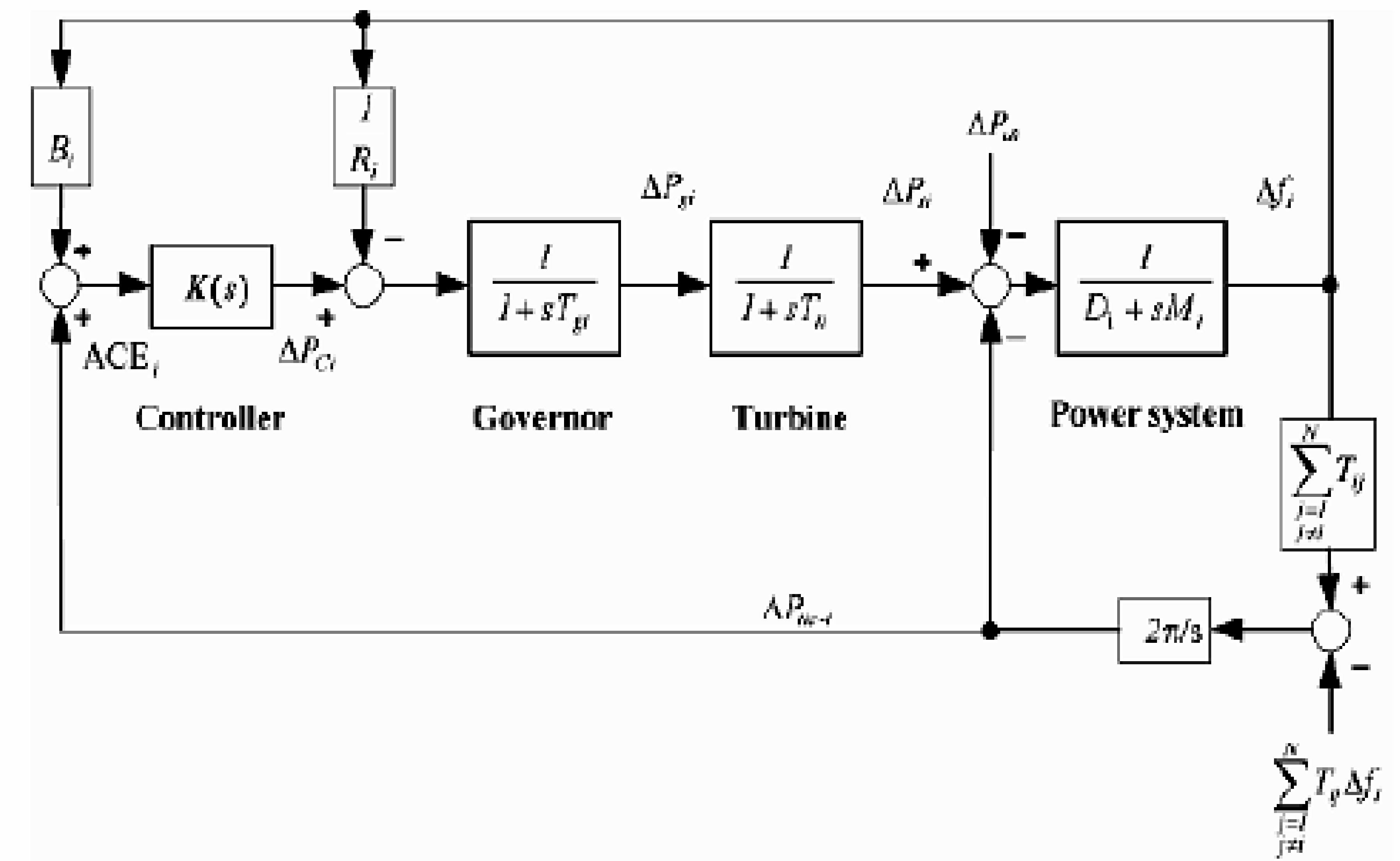
LFC problem in Single Area Power System :

- Basically, single area power system consists of a governor, a turbine, and a generator with feedback of regulation constant. System also includes step load change input to the generator.
- This work mainly, related with the controller unit of a single area power system.
- The load frequency control strategies have been suggested based on the conventional linear Control theory.
- These controllers may be unsuitable in some operating conditions due to the complexity of the power systems such as nonlinear load characteristics and variable operating points.
- To some authors, variable structure control maintains stability of system frequency.


Steam
Turbine
G
ΔPv
ΔPg, ΔQg
Valve Control Mechanism
ΔPtie
Load Frequency Control (LFC)
Frequency Sensor
ΔPc

- The frequency is sensed by frequency sensor. The change in frequency and tie line real power can be measured by change in rotor angle δ.
- The load frequency controller amplify and transform error signal, i.e., (Δfi and ΔPtie) in to real power command signal ΔPci which is sent to the prime mover via governor (that control the valve mechanism).
- To call for an increment or decrement in torque the prime mover balances the output of governor which will compensate the value of error signal that is Δfi and ΔPtie.
- The process continues till deviation in form of Δfi and ΔPtie as well as the specified tolerance.

- The LFC problem in power systems has a long history. In a power system, LFC as an ancillary service acquires an important and fundamental role to maintain the electrical system reliability at an adequate level.
- It has gained the importance with the change of power system structure and the growth of size and complexity of interconnected systems.
- The well-known conventional LFC structure for a given control area and a multi area power system (includes N area) is


Controller
Governor
Turbine
Power system
K(s)
ACE
2π/s

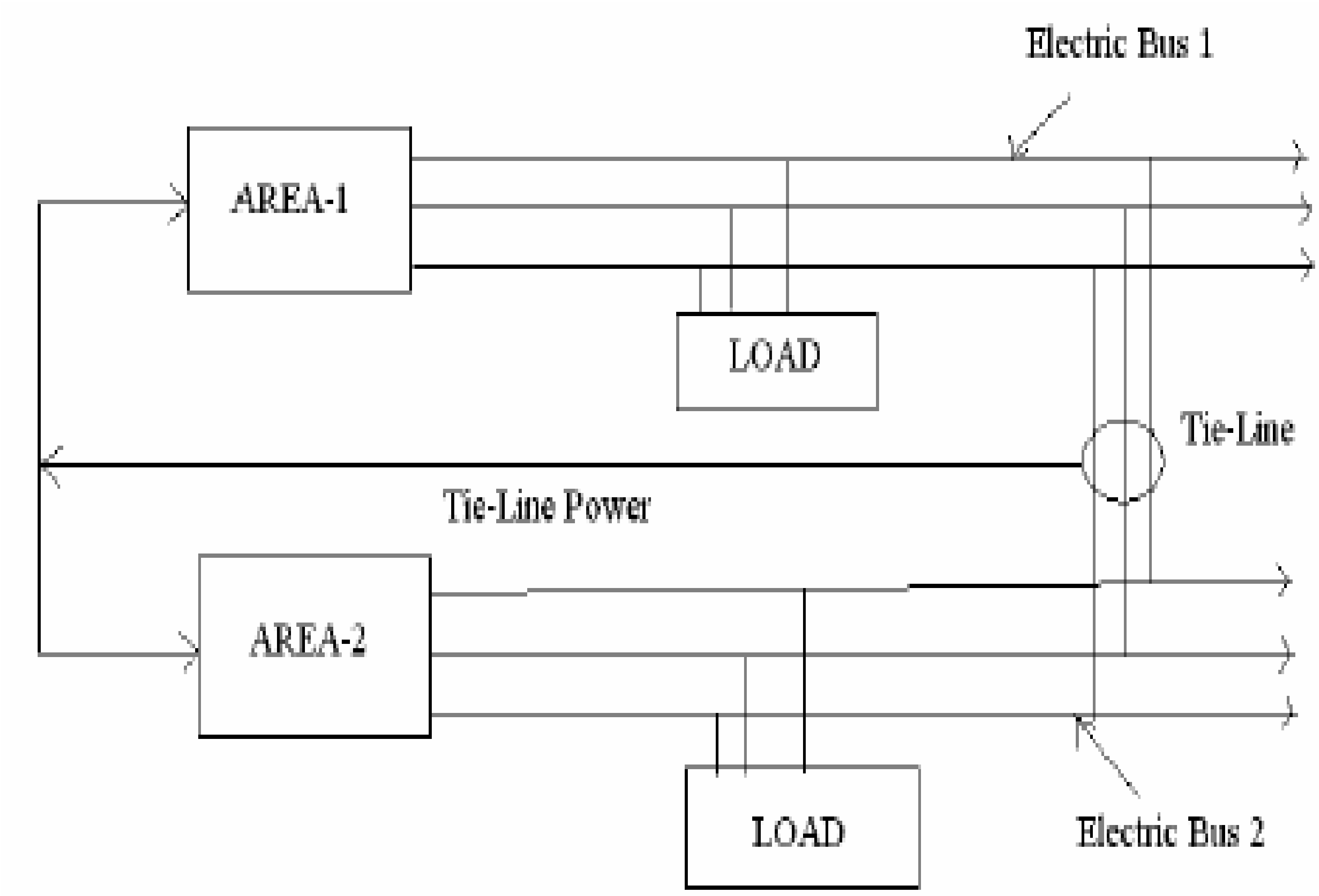
Concept of Two Area Control :

- An extended power system can be divided into a number of load frequency control areas interconnected by means of tie lines. Without loss of generality two- area case connected by tie-line is considered.
- The control objectives are as follows:
- (1) Each control area as for as possible should supply its own load demand and power transfer through tie line should be on mutual agreement.
- (2) Both control areas should controllable to the frequency control.

- A two area system consists of two single area systems connected through a power line called tie-line.
- Each area feeds its user pool, and the tie line allows electric power to flow between the areas, because both areas as well as the power flow on the tie-line.
- For the same reason, the control system of each area needs information about the transient situation in both areas to bring the local frequency back to its steady state value.
- Information about the local area is found in the tie line power fluctuations.
- Therefore, the tie-line power is sensed, and the resulting tie-line power signal is fed back into both areas.
- It is conveniently assumed that each control area can be represented by an equivalent turbine, generator and governor system.

- In an isolated control area case the incremental power (ΔP_G-ΔP_D)was accounted for by the rate of increase of stored kinetic energy and increase in area load caused by increase in frequency.

- Since a tie line transports power in or out of an area, this fact must be accounted for in the incremental power balance equation of each area.


Electric Bus 1
AREA-1
LOAD
Tie-Line
Tie-Line Power
AREA-2
LOAD
Electric Bus 2

OPTIMAL POWER FLOW

- **The optimal power flow :**

- The Optimal Power Flow (OPF) problem is the most difficult and complicated problem in power system analysis and design, it is a non linear optimization problem.
- The objective of the OPF is to minimize the total operating cost and total losses, subjected to many constraints such as total generation must equal to total load plus total losses and the voltage profile must be within their limits.
- The OPF problem is a combination between the economic dispatch and the power flow. In order to solve the OPF problem, they must be solved simultaneously.

- LOAD DISPATCH :
- In power engineering, the power-flow study, or load-flow study, is a numerical analysis of the flow of electric power in an interconnected system.
- A power system uses simplified notation such as a one-line diagram and per-unit system, and focuses on various aspects of AC power parameters, such as voltages, voltage angles, reactive power and real power. It describes the power systems in normal steady-state operation.
- Power-flow or load-flow studies are depicted for planning future expansion of power systems as well as in discoursing the best operation of existing systems.
- The principal information obtained from the power-flow study is the phase angle and magnitude of the voltage at each bus, and the real and reactive power flowing in each line.

Economic Load Dispatch Problem :

- The economic dispatch problem (EDP) is one of the important problems in operation and control of modern power systems.

- The objective of the EDP of electric power generation is to schedule the committed generating unit outputs so as to meet the required load demand at minimum operating cost while satisfying all unit and system equality and inequality constraints.


Thank you