DEPARTMENT OF ELECTRICAL ENGINEERING
DIT UNIVERSITY
POWER SYSTEM OPERATION AND CONTROL

Introduction: The sizes of the electric power systems are increasing rapidly to meet the energy requirements. A number of power plants are connected in parallel to supply the system load by interconnection of power station. With the development of integrated power systems (i.e. grid systems) it becomes necessary to operate the plant units most economically. The economic scheduling of generators aims to guarantee at all times the optimum combination of generators connected to the system to supply the load demand. The economic dispatch problem involves two steps namely unit commitment and on-line economic dispatch.

The main factor which controls the most desirable load allocation between various generating units is the total running cost. The operating cost of a thermal power plant is mainly the cost of the fuel. The fuel supplies for thermal plants can be coal, natural gas, oil or nuclear fuel. The other costs such as costs of labour, supplies, maintenance etc. is difficult to be determined and hence is assumed to vary as a fixed percentage of the fuel cost. Thus the operating cost of a thermal power plant is a nonlinear function of plant generation.

Fuel Cost: The input – output curves of generating units of thermal plant are important to describe the efficiency of the plant. A typical input – output curve is shown in fig.1

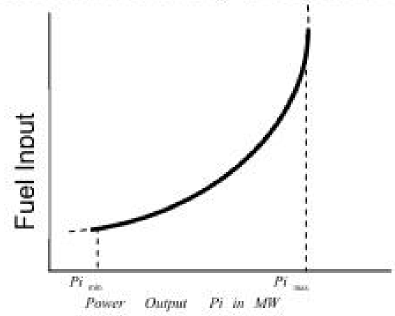


Fig. 1

This is an experimental curve plotted between output power P in MW and fuel input in Joules per hour. The fig.2 shows the fuel – cost curve which is plotted between power output P in MW and cost of fuel in Rs. /hr.

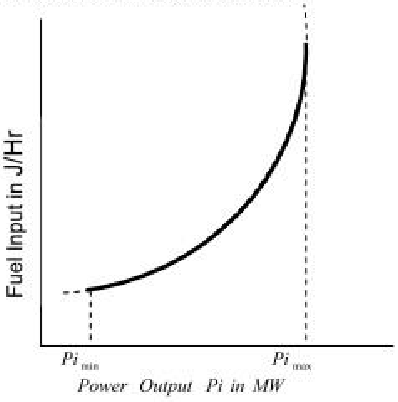


Fig. 2

The majority of generating units have a nonlinear generation cost function C_i. The variation of fuel cost of each generator (C_i) with the active power output (P_i) is given by

$$C_i = \alpha_i + \beta_i P_i + \gamma_i P_i^2 \quad - \quad (1)$$

Where Ci = fuel cost of generator i

Pi = power output of generator i

α_i = constant to account for salary and wages, interest and depreciation. It is independent of generation

β_i = constant which accounts for the fuel cost and is most dominating

γ_i = constant which accounts for the losses of the system

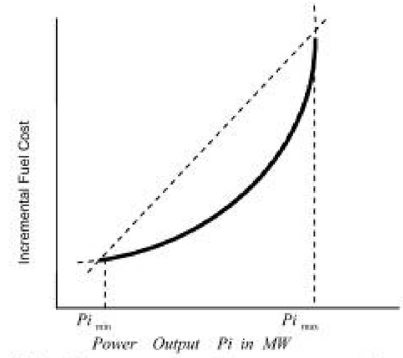
Incremental Fuel Cost: The incremental fuel cost for a generator for any given electrical power output is defined as the limiting value of the ratio of the increase in cost of fuel in Rs./hr to the corresponding increase in electrical power output in MW when the increase in power output tends to zero.

$$(IC)_i = \underset{\delta P \to 0}{Lt} \left. \frac{\partial C_i}{\partial P_i} \right|_{\Delta P_i = 0} = \frac{dC_i}{dP_i}$$

The incremental cost is equal to the slope of the fuel cost curve. If the cost curve is approximated as a quadratic polynomial (with positive coefficients) as given in eq.1 we have

$$\frac{dC_i}{dP_i} = \frac{d}{dP_i}\left(\alpha_i + \beta_i P_i + \gamma_i P_i^2\right) = \beta_i + 2\gamma_i P_i \ Rs/MWh \qquad (2)$$

Eq. 2 is of the form y = mx + c which represents a straight line. In other words, the incremental cost curves are linear (with positive coefficients). A plot of incremental cost versus power output is called incremental cost curve. It is shown in fig.3



Economic Load Dispatch: It means optimum generation scheduling of available generators in an interconnected power system to minimize the cost of generation subject to relevant system constraints. Economic load dispatch is an important function in power system and operation. The factors which influence the generation of power at minimum cost are operating efficiencies of generators, fuel cost and transmission losses. It may happen that the most efficient generator maybe located so far from the load centre that the transmission losses maybe considerably high thereby making the plant uneconomical. In economic load dispatch, the problem is to determine the generation of different plants such that the operating cost is minimum. Two cases will be considered – in first case the effect of transmission losses will be neglected while in second case the effect of transmission losses will be considered into account.

Constraints in Unit Commitment: In the case of economic load dispatch the following are the types of constraints to be considered:
Equality constraints
Inequality constraints
The equality constraint is

$$\sum_{i=1}^{n} P_i = P_L + P_D \quad or \quad \sum_{i=1}^{n} P_i - P_L + P_D = 0$$

The inequality constraint is

$$P_i^{\min} \le P_i \le P_i^{\max}$$

The inequality constraints are due to physical and operational limitations of the units and components. Each generator in operation has a maximum limit of generation. Similarly each generator in operation also has a minimum limit of generation below which the operation of the boiler becomes unstable and hence a generator cannot be loaded below its minimum rating also.

Economic Load Dispatch Neglecting Transmission Losses: The simplest economic dispatch problem is the case when transmission losses are neglected. The problem model does not consider the system configuration and line impedances. The model assumes that the system is only one bus with all generation and loads connected to as shown in fig.4.

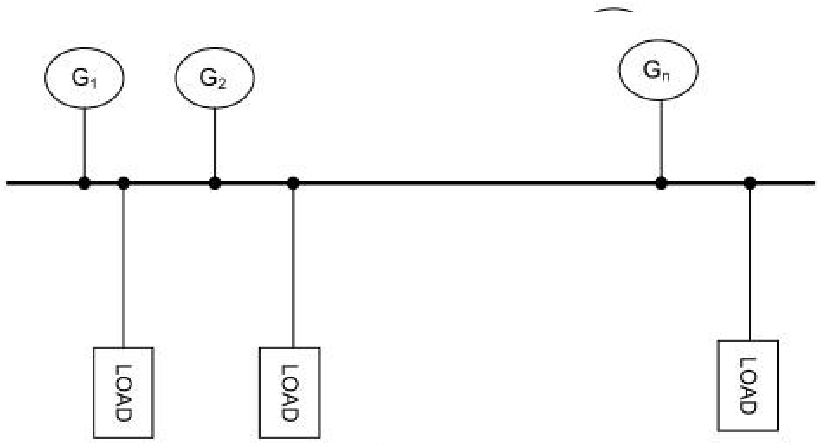


Fig. 4

Since transmission losses are neglected, the total load demand P_D is the sum of all generation. A cost function C_i is assumed to be known for each plant. The problem is to find the real power generation for each plant such that the objective function (i.e. total production cost) as defined by the following equation is minimized subject to the constraints given by eq.3

$$C_t = \sum_{i=1}^{n} C_i = \sum_{i=1}^{n} \left(\alpha_i + \beta_i P_i + \gamma_i P_i^2 \right)$$

$$\sum_{i=1}^{n} P_i = P_D \qquad (3)$$

Let us define a Langrangian function as follows:

$$L = C_t + \lambda \left(P_D - \sum_{i=1}^{n} P_i \right) \quad (4)$$

The minimum cost of generation is given by $\frac{\partial L}{\partial P_i} = 0$

Therefore $\frac{\partial C_t}{\partial P_i} + \lambda \left[\frac{\partial P_D}{\partial P_i} - \frac{\partial}{\partial P_i} \sum_{i=1}^{n} P_i \right] = 0$ (5)

Since P_D is independent of P_i therefore we have $\frac{\partial P_D}{\partial P_i} = 0$

Since power generation of i^{th} plant is independent of power generation of other plants therefore we have $\frac{\partial P_1}{\partial P_i} = \frac{\partial P_2}{\partial P_i} = --------- \frac{\partial P_n}{\partial P_i} = 0$ except $\frac{\partial P_i}{\partial P_i} = 1$

Hence $\frac{\partial}{\partial P_i} \left(\sum_{i=1}^{n} P_i \right) = 1$

Thus equation (5) becomes $\frac{\partial C_t}{\partial P_i} + \lambda \left(0 \; -1\right) = 0$

$$or \; \frac{\partial C_t}{\partial P_i} - \lambda = 0 \quad or \; \frac{\partial C_t}{\partial P_i} = \lambda \quad (6)$$

The cost of generation of i^{th} plant is independent of the power generated by other plants hence we have $\frac{\partial C_i}{\partial P_i} = \frac{dC_i}{dP_i}$ Finally we have from equation (6) $\frac{\partial C_i}{\partial P_i} = \lambda$ for i = 1, 2 ….n

Thus for economic load dispatch all units must operate at the same incremental fuel cost.

Incremental Transmission Loss: The incremental transmission loss for a generator 'i' for any given electrical power output is defined as the partial derivative of the total power transmission loss with respect to the power generated by i^{th} plant i.e. $\left(\partial P_L / \partial P_i\right)$. It gives the extra system loss incurred by increment of active power injection by generator 'i'.

Penalty Factor: The penalty factor of a plant is defined as follows:

$L_i \triangleq \frac{1}{1 - \partial P_L / \partial P_i}$ where L_i is penalty factor of plant 'i' and $\left(\partial P_L / \partial P_i\right)$ is incremental transmission loss. The penalty factor of a plant depends upon the location of the plant. The larger is the incremental transmission loss, the larger is the penalty factor.

General Loss Formula: Ideally exact power flow equations should be used to account for the transmission loss in the system. However it is a common practice to express the transmission loss in terms of active power generations only. This approach is generally known as the loss formula or B – coefficient method. The general loss formula is given by

$$P_L = \sum_{m=1}^{k} \sum_{n=1}^{k} \left(P_m B_{mn} P_n \right)$$

Where P_L = transmission loss

P_m = active power generation at m^{th} plant

P_n = active power generation at n^{th} plant

B_{mn} = loss coefficient or B coefficient

The above formula for transmission losses is also known as George's formula.

Economic Load Dispatch Including Transmission Losses: When the distances of generating plants form the load are different, the cost of different transmission losses will affect the economic distribution. Let us consider n generating plants where $C_1, C_2, - - - -, C_n$ be the fuel costs of individual plants for the corresponding electrical outputs $P_1, P_2, - - -, P_n$ respectively. Let P_D be the total power received by the loads i.e. load demand and P_L be the total transmission losses.

For n plants, the total fuel cost is given as $C_T = C_1 + C_2 + - - - - - - - - - - - + C_n = \sum_{i=1}^{n} C_i$

The total input to the network (from all the plants) is $P = P_1 + P_2 + - - - + P_n = \sum_{i=1}^{n} P_i$

Since the total demand and the transmission loss must be met by the total power generation at that instant therefore we have

$$P_D + P_L = P_1 + P_2 + - - - - - - + P_n = \sum_{i=1}^{n} P_i$$