

2.1 Introduction

Generating plants have different characteristics which give different generating costs at any load. Therefore proper scheduling of plants for minimum cost of optimal operation becomes important. and because the cost characteristics of each generating unit are non-linear the problem of achieving the minimum cost becomes non-linear problem [5].

Economic dispatch is generation allocation problem and defined as the process of calculating the generation of the generating units so that the system load is supplied entirely and most economically subject to the satisfaction of the constraints and it is very important and essential daily optimization procedure in the system operation.

The optimal system operation, in general, involves the consideration of economy of operation, system security, emissions at certain fossil-fuel plants, and optimal releases of water at hydro-generation, etc. All these considerations may make conflicting requirements and usually a compromise has to be made for optimal system operation.

Since the basic purpose of economic operation of power system is to reduce the fuel cost for the operation of power system, economic operation achieved when the generation in the system share load to minimize overall generation cost. The main economic factor in the power system operation is the cost of generation real power. In any power system this cost has two components,

- (i) The fixed cost being determined by the capital investment, interest charged on the money borrowed, tax paid, labor charge, salary given to staff and any other expenses that continue irrespective to the load on the power system.
- (ii) The variable cost, a function of loading on generating units, losses daily load requirement and purchase or sale of power [1].

2.2 Generator Incremental Cost Curve

The analysis of the problems associated with the controlled operation of power systems contains many parameters of interest. Fundamental to the economic operating problem is the set of input-output characteristics of a thermal power generation unit as in Figure 2.1 [4].

From the input output curves, the incremental fuel cost (IFC) curve can be obtained. The IFC is defined as the ratio of a small change in the input to the corresponding small change in the output [1].

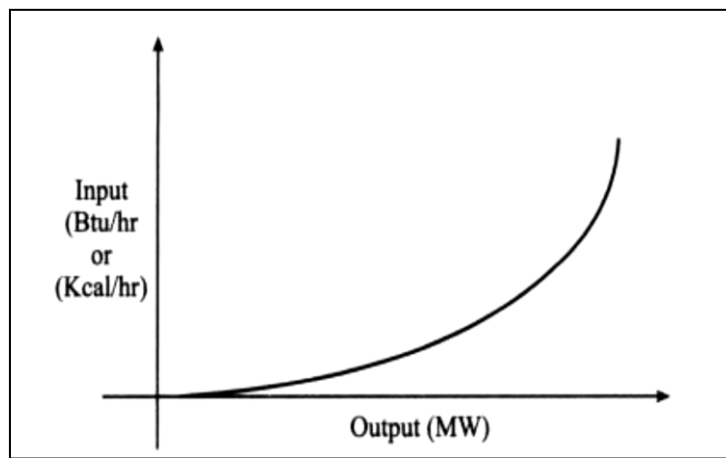


Figure 2.1: Input – Output Characteristic of Steam Turbine

$$IFC = \frac{\Delta Input}{\Delta Output} = \frac{\Delta F}{\Delta P_G} \quad (2.1)$$

Where Δ represents small changes.

As the Δ quantities become progressively smaller, it is seen that IFC is $\frac{d(Input)}{d(Output)}$ and is expressed in cost currency/MWhr. A typical plot of the IFC

versus output power is shown in Figure 2.2.

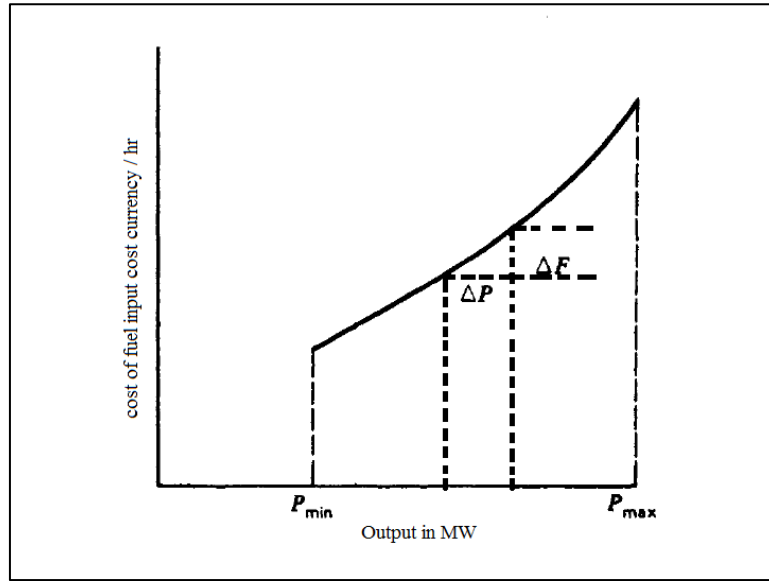


Figure 2.2: Incremental Fuel Cost Curve

Mathematically, the IFC curve can be obtained from the cost curve.

The cost curve,

$$C_i = \frac{1}{2} a_i P_{G_i}^2 + b_i P_{G_i} + d_i \text{ (Second degree polynomial)} \quad (2.2)$$

The IFC,

$$\frac{dC_i}{dP_{G_i}} = (IFC) = a_i P_{G_i} + b_i \text{ (linear approximation) for all } i=1,2,3,\dots,n \quad (2.3)$$

Where $\frac{dC_i}{dP_{G_i}}$ is the ratio of incremental fuel energy input in BTU to the incremental energy output in KWh, which is called 'the incremental heat rate'.

2.3 Optimal Generation Scheduling Considering Of Transmission Losses:

In a practical system, a large amount of power is being transmitted through the transmission network, which causes power losses in the network (P_L) as shown in Figure 2.3.

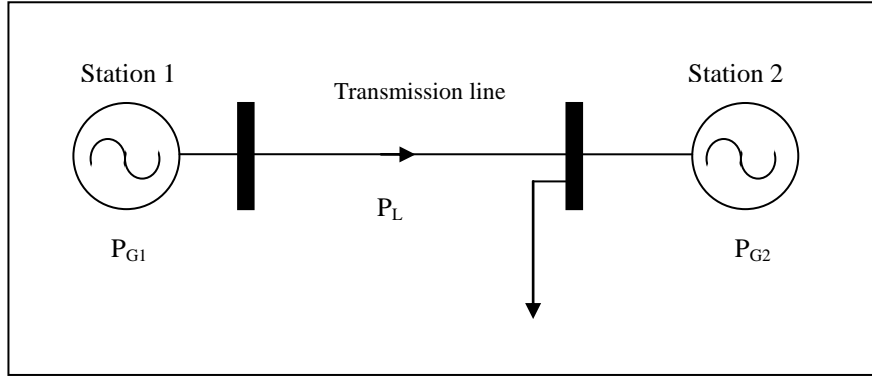


Figure 2.3: Transmission Network

2.3.1 Mathematical Modeling :

Consider the objective function:

$$C = \sum_{i=1}^n C_i(P_{G_i}) \quad (2.4)$$

Minimize equation (2.4) subjected to equality and inequality constrains:

(i) Equality constraint

The real-power balance equation, i.e., total real power generation P_{G_i} minus the total losses P_L should be equal to the real-power demand P_D :

$$\sum_{i=1}^n P_{G_i} - P_L = P_D \quad \text{or} \quad \sum_{i=1}^n P_{G_i} - P_L - P_D = 0 \quad (2.5)$$

(ii) Inequality constrain

Always there will be upper and lower limits for the real and reactive-power generation at each station. The inequality constrain represented:

(a) In term of real –power generation as

$$P_{G_i(\min)} \leq P_{G_i} \leq P_{G_i(\max)} \quad (2.6)$$

(b) in term of reactive-power generation as

$$Q_{G_i(\min)} \leq Q_{G_i} \leq Q_{G_i(\max)} \quad (2.7)$$

(c) in term of voltage at each of the station should be maintain with certain limits

$$V_{i(\min)} \leq V_i \leq V_{i(\max)} \quad (2.8)$$

The optimal solution should be obtained by minimizing the cost function satisfying constrain equations (2.5) to (2.8) [1].

2.4 **Transmission Loss in Term of Real Power Generation:**

Transmission loss P_L is expressed without loss of accuracy as a function of real-power generation. The power loss is expressed in *B-coefficients* or *loss coefficients*. The final equation is as below

$$ITL = \frac{\partial P_L}{\partial P_{G_i}} = \sum_{j=1}^n 2B_{ij}P_{G_j} \quad (2.9)$$

2.5 **Plant Scheduling Methods:**

At the plant level, several operating procedure were adopted in the past leading efficient operation resulting in economy

(i) **Base loading to capacity**

The turbo generators are successively loaded to their rated capacities in the order of their efficiencies. That is to say, that the most efficient unit will get greater share in load allocation which is a natural solution to the problem.

(ii) **Base loading to most efficient load**

In this case the heat rate characteristics are considered and the turbo-generator units are successively loaded to their most efficient loads in increasing order of their heat rates. In both the above methods thermodynamic considerations assumed importance and the schedules will not differ from each other much.

(iii) **Proportional loading to capacity**

A third method that was considered as a thumb rule in the absence of any technical data is to load the generating units in proportion to their rated capacities as stated on the name plates [6].

2.6 Optimal Power Flow:

In an Optimal Power flow, the values of some or all of the control variables need to be found so as to optimize (minimize or maximize) a predefined objective. It is also important that the proper problem definition with clearly stated objectives be given at the onset. The quality of the solution depends on the accuracy of the model studied. Objectives must be modeled and its practicality with possible solutions.

Objective function takes various forms such as fuel cost, transmission losses and reactive source allocation. Usually the objective function of interest is the minimization of total production cost of scheduled generating units. This is most used as it reflects current economic dispatch practice and importantly cost related aspect is always ranked high among operational requirements in Power Systems.

2.7 Optimal Power Flow Solution Methodologies

The OPF methods are broadly grouped as Conventional and Intelligent. The conventional methodologies include the well known techniques like Gradient method, Newton method, Quadratic Programming method, Linear Programming method and Interior point method. Intelligent methodologies include the recently developed and popular methods like Genetic Algorithm, Particle swarm optimization.

The solution methodologies can be broadly grouped in to two namely:

1. Conventional (classical) methods
2. Intelligent methods.

The further sub classification of each methodology is given below as per the Tree diagram.

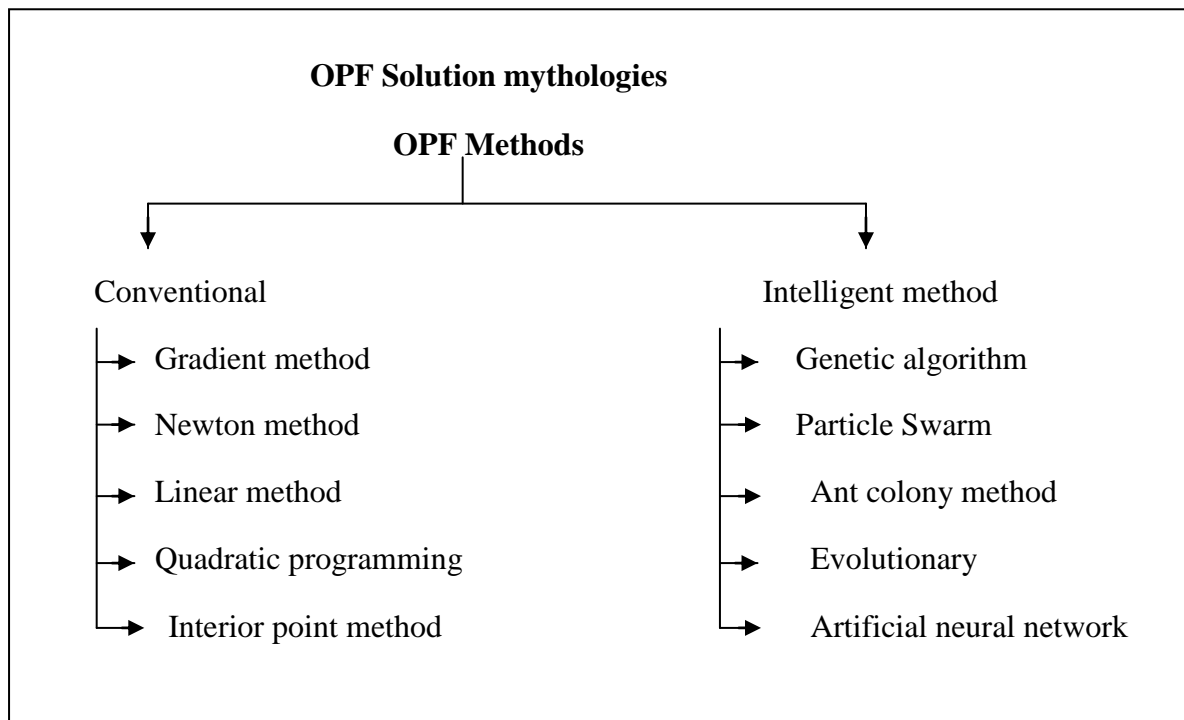


Figure 2.4 Tree Diagram Indicating Optimal Power Flow Methodologies

2.7.1 Conventional Methodologies

The list of OPF Methodologies is presented in the Tree diagram Figure 2.4. It starts with Gradient Method.

2.7.1.1 Gradient Method:

The Generalized Reduced Gradient is applied to the OPF problem with the main motivation being the existence of the concept of the state and control variables, with load flow equations providing a nodal basis for the elimination of state variables. With the availability of good load flow packages, the sensitivity information needed is provided. This in turn helps in obtaining a reduced problem in the space of the control variables with the load flow equations and the associated state variables eliminated.

2.7.1.2 Newton Method:

In the area of Power systems, Newton's method is well known for solution of Power Flow. It has been the standard solution algorithm for the power flow problem for a long time the Newton approach is a flexible formulation that can be adopted to develop different OPF algorithms suited to the requirements of

different applications. Although the Newton approach exists as a concept entirely apart from any specific method of implementation, it would not be possible to develop practical OPF programs without employing special sparsity techniques. The concept and the techniques together comprise the given approach. Other Newton-based approaches are possible.

Newton's method is a very powerful solution algorithm because of its rapid convergence near the solution. This property is especially useful for power system applications because an initial guess near the solution is easily attained. System voltages will be near rated system values, generator outputs can be estimated from historical data, and transformer tap ratios will be near 1.0 p.u.

2.7.1.3 Linear Programming Method

Linear Programming (L.P) method treats problems having constraints and objective functions formulated in linear form with non negative variables. Basically the simple method is well known to be very effective for solving LP problems.

The Linear Programming approach has been advocated on the grounds that

- (a) The L.P solution process is completely reliable.
- (b) The L.P solutions can be very fast.
- (c) The accuracy and scope of linearised model is adequate for most engineering purposes.

It may be noted that point (a) is certainly true while point (b) depends on the specific algorithms and problem formulations. The observation (c) is frequently valid since the transmission network is quasi linear, but it needs to be checked out for any given system and application.

2.7.1.4 Quadratic Programming Method

Quadratic Programming (QP) is a special form of NLP. The objective function of QP optimization model is quadratic and the constraints are in linear form. Quadratic Programming has higher accuracy than LP – based approaches. Especially the most often used objective function is a quadratic.

The NLP having the objective function and constraints described in Quadratic form is having lot of practical importance and is referred to as quadratic optimization. The special case of NLP where the objective function is quadratic (i.e. is involving the square, cross product of one or more variables) and constraints described in linear form is known as quadratic programming. Derivation of the sensitivity method is aimed at solving the NLP on the computer. Apart from being a common form for many important problems, Quadratic Programming is also very important because many of the problems are often solved as a series of QP or Sequential Quadratic Programming (SQP) problems.

Quadratic Programming based optimization is involved in power systems for maintaining a desired voltage profile, maximizing power flow and minimizing generation cost. These quantities are generally controlled by complex power generation which is usually having two limits. Here minimization is considered as maximization can be determined by changing the sign of the objective function. Further, the quadratic functions are characterized by the matrices and vectors.

2.7.1.5 Interior Point Method

It has been found that, the projective scaling algorithm for linear programming proposed by N. Karmarkar is characterized by significant speed advantages for large problems reported to be as much as 12:1 when compared to the simplex method. Further, this method has a polynomial bound on worst-case running time that is better than the ellipsoid algorithms. Karmarkar's algorithm is significantly different from Dantzig's simplex method. Karmarkar's interior point rarely visits too many extreme points before an optimal point is found. In addition, the IP method stays in the interior of the polytope and tries to position a current solution as the "center of the universe" in finding a better direction for the next move. By properly choosing the step lengths, an optimal solution is achieved after a number of iterations. Although this IP approach requires more

computational time in finding a moving direction than the traditional simplex method, better moving direction is achieved resulting in less iteration. In this way, the IP approach has become a major rival of the simplex method and has attracted attention in the optimization community. Several variants of interior points have been proposed and successfully applied to optimal power flow.

The Interior Point Method is one of the most efficient algorithms. The IP method classification is a relatively new optimization approach that was applied to solve power system optimization problems; it solves a large scale linear programming problem by moving through the interior, rather than the boundary as in the simple method, of the feasible region to find an optimal solution. The IP method was originally proposed to solve linear programming problems; however later it was implemented to efficiently handle quadratic programming problems.

2.7.2 Intelligent Methodologies:

Intelligent methods include Genetic Algorithm and Particle Swarm Optimization methods.

2.7.2.1 Binary Coded Genetic Algorithm Method:

The drawbacks of conventional methods were presented in Section 2.7.1. All of them can be summarized as three major problems:

- Firstly, they may not be able to provide optimal solution and usually getting stuck at a local optimal.
- Secondly, all these methods are based on assumption of continuity and differentiability of objective function which is not actually allowed in a practical system.
- Finally, all these methods cannot be applied with discrete variables, which are transformer taps. It is observed that Genetic Algorithm (GA) is an appropriate method to solve this problem, which eliminates the above drawbacks. GAs differs from other optimization and search procedures in four ways [8]:

- GAs work with a coding of the parameter set, not the parameters themselves. Therefore GAs can easily handle the integer or discrete variables.
- GAs search within a population of points, not a single point. Therefore GAs can provide a globally optimal solution.
- GAs use only objective function information, not derivatives or other auxiliary knowledge. Therefore GAs can deal with non-smooth, non-continuous and non-differentiable functions which actually exist in a practical optimization problem.
- GAs use probabilistic transition rules, not deterministic rules[4].

The Main GA features over other search techniques are:

1. GA algorithm is a multipath that searches many peaks in parallel and hence reducing the possibility of local minimum trapping.
2. GA works with a coding of parameters instead of the parameters themselves. The coding of parameter will help the genetic operator to evolve the current state into the next state with minimum computations.
3. GA evaluates the fitness of each string to guide its search instead of the optimization function.

2.7.2.2 Particle Swarm Optimization Method

Particle swarm optimization (PSO) is a population based stochastic optimization technique inspired by social behavior of bird flocking or fish schooling.

In PSO, the search for an optimal solution is conducted using a population of particles, each of which represents a candidate solution to the optimization problem. Particles change their position by flying round a multidimensional space by following current optimal particles until a relatively unchanged position has been achieved or until computational limitations are exceeded. Each particle adjusts its trajectory towards its own previous best position and

towards the global best position attained till then. PSO is easy to implement and provides fast convergence for many optimization problems and has gained lot of attention in power system applications recently.

The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. In PSO, each particle makes its decision using its own experience together with its neighbor's experience.

In this thesis, PSO was used as an intelligent method in MATLAB, for comparison with the conventional method (Newton Raphson).