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Overview of Economic Load Dispatch Problem in Power System

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Abstract: **The optimal power system operation, in general, involves the consideration of economy of operation, system security, emissions at certain fossil –fuel plants, optimal release of water at hydro generation, etc. Over the past several years, concerns have been raised over the possibility that the exposure to 50.60 Hz electromagnetic fields from power lines, substations and other power sources may have detrimental health effects on living organisms. All these considerations may make for conflicting requirements and usually a compromise has to be made for optimal system operation. In this paper Economic load dispatch problems has been discussed. The power industry planners are demanding stronger trends towards supplying electric supply of higher quality by improving the system security and its impact on environment in parallel with pursuit of economy.**

Keywords- Economic load dispatch, Multi objective optimization, , Approximate model and Rigorous model

1. INTRODUCTION

The planning, operation and control of modern integrated power system pose a variety of challenging problems because of unaccommodating requirements which are being imposed on electric utilities. This tendency has brought about the necessity of attaining system planning as well as system operation of higher level and of greater sophistication. The system operators are interested to determine the optimal system state, by satisfying many kinds of operational constraints. As a means of solving this class of problem, extensive studies of power have been taken on economic dispatch [1]. The economic load dispatch problem pertains to the optimum generation scheduling of available generating units in a power system to minimize the cost of generation subject to system constraints. In view of rapid growth in demand and supply of electricity, electric power system is becoming increasingly larger and more complex day by day [2]. Regular electric supply is the utmost necessity for growing industry and other fields of life. With the increasing dependence of industry, agriculture and day-to-day household comfort upon the continuity of electric supply, the reliability of power systems has put on great importance [3]. Every electric utility is normally under obligation to provide to its consumers a certain degree of continuity and quality of service (power flow on transmission lines in a specified range). Therefore, economy, emission etc. objectives of the power system must be properly coordinated in arriving at optimal power dispatch. It is, therefore, required to search for better and realistic strategies to achieve various objectives along with desired quality of power supply and satisfying simultaneously various system constraints [4]. Optimization is the process of maximizing or minimizing a desired objective, function or goal while satisfying the prevailing constraints. In other words, optimization is the act of obtaining the best result under given circumstances. In design, construction, maintenance and planning of any engineering system, engineers have to take much technological and managerial decision at several stages [5]. The ultimate goal of all such decisions is to either minimize the effort required or maximize the desired benefit. Since the effort required or the benefit desired in any practical situation can be expressed as a function of certain decision variables, so optimization problem can be expressed as a function of certain decision variables and optimization can be defined as the process of finding the conditions that gives the maximum or minimum value of a function [4,6]. In order for engineers to apply optimization at their workplace, they must have an understanding of the theory, algorithms and techniques. This is because practical problems invariably require tuning algorithmic parameters, scaling, and even modifying existing techniques to suit the specific application. Moreover, the user may have to try out several optimization methods to find one that can be successfully applied. In practical fields, the optimization problem has many objectives to be satisfied simultaneously. All these objectives may be of the conflicting nature [7]. The optimization technique, which can handle such problems, is known as multiobjective optimization technique. The conventional optimization

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problem is a single objective, multi or single variable problem. In this Section, the algorithms for optimizing functions having multiple decision variables are described. The algorithms are presented for minimization problems; however these can also be used for maximization problems by using the duality principle. The optimization problem for continuous function is stated as:

Minimize $f(x_v) = f(x_{v1}, x_{v2}, x_{v3}, \ldots, x_{Lv})$

where $x_v = [x_{v1}, x_{v2}, \ldots, x_{Lv}]^T$ is a column vector of L_V real-valued design variables.

The necessary condition for any point x_v^* to be a local minimum is

$$\nabla f(x_v^*) = 0 \qquad (1.1)$$

The sufficient conditions for x_v^* to be strict local minimum are

$$\nabla^2 f(x_v^*) \text{ is positive definite} \qquad (1.2)$$

In a single-variable function optimization, there are only two search directions; a point can be modified either in the positive x-direction or the negative x-direction. The extent of increment or decrement in each direction depends on the current point and the objective function. In multivariable function optimization, each variable can be modified either in the positive or in the negative direction, thereby forming 2^{L_V} different ways. Moreover, an algorithm, having searches along each variable one at a time, can only successfully solve linearly separable functions. These algorithms (called one-variable-at-a time methods) cannot usually solve functions having non-linear interactions among design variables. Ideally, it requires algorithms which either completely eliminate the concept of search direction or manipulate a set of points to create a better set of points or use complex search directions to effectively decouple the non-linearity of the function.

2. MULTIOBJECTIVE OPTIMIZATION

Optimization problems very seldom require optimization of a single objective function. Instead, there are often competing objectives, which should be optimized simultaneously. In contrast to single objective optimization problems, the solution for a MOP is not a single solution but a set of non-dominated solutions. The task of finding this set of solution is not always an easy one. The purpose of multiobjective problem in the mathematical programming framework is to optimize '*L*' different objective functions subject to a set of system constraints.

Maximize $f(x) = [f_1(x), \ldots, f_i(x), \ldots, f_L(x)]^T$ (2.1a)

Subject to $x \in X$ (2.1b)

where x is an n dimensional vector of decision variables.
X is the decision space.
$f(x)$ is a vector of L real valued functions.

In order to make the problem non-trivial, it is assumed that the objectives are in conflict and incommensurable. Owing to the conflicting nature of objectives, an optimal solution that simultaneously maximizes/minimizes all the criteria is usually not attainable. Instead there are several solutions, called efficient solutions that have the property, that no improvement in any objective is possible without sacrificing one or more of the other objectives. Many approaches and methods have been proposed in recent years to solve MOP. These methods can be broadly grouped under two major titles: non-interactive and interactive methods. In the non-interactive methods a global preference function of the objective is identified and optimized with respect to the constraints. On the other hand, in the interactive method, a local preference function or trade-off among objectives is identified by interacting with DM and solution process proceeds gradually towards the globally satisfactory solution. In power system, the solution of economic dispatch problem is obtained through the optimization techniques. The procedure involves the allocation of total generation requirements among the available generating units in system in such a manner that the constraints imposed on different system variable are adequately satisfied and the overall cost associated with it is a minimum. The non-linear nature of the problem makes the process an iterative one and careful tuning of algorithm is frequently required to avoid divergence or oscillatory slow progress.

3. ECONOMIC DISPATCH PROBLEM

Economic dispatch problem has been divided into two general categories, viz:

1. Approximate model and
2. Rigorous model

Each of the two categories is differentiated by the types of variables manipulated.

1. Approximate model

Approximate model utilizes reduced set of variable in which only the control variables appear in the mathematical model. Classical economic dispatch problem is formulated using reduced set of variables. When the electric energy losses are small as in small networks, then the dispatching problems is to minimize fuel cost while serving the total load and with all units operating between their minimum and maximum output limits.

Minimize

$$F(P_{gi}) = \sum_{i=1}^{N} \left(a_i P_{gi}^2 + b_i P_{gi} + c_i \right) \quad \text{Rs/h} \quad (3.1a)$$

Subject to

(i) The energy balance equation

$$\sum_{i=1}^{N} P_{gi} = P_D \qquad (3.1b)$$

(ii) and the inequality constraint

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max}; (i = 1, 2, \ldots\ldots, N) \qquad (3.1c)$$

$$P_{gj} = 0; (j \ne i) \qquad (3.1d)$$

The fuel cost for each power generating unit is a function of the power output. Prior to 1930 various methods were in use such as:

a) *The Base Load Method*: Where the most efficient unit was loaded to its maximum capability, then the second most efficient unit was loaded.
b) *Best Point loading:* Where units were successively loaded to their lowest heat rate point beginning with the most efficient unit and working down to the lowest efficient unit etc.

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It was recognized as early as 1933, the incremental method, later known as the equal incremental method, yielded the most economical results. The electric utilities industries refer to this incremental cost as the system 'Lambda' acknowledging its origin in the proof using Lagrange Multipliers. A digital computer determines the dispatch by iterating on Lambda using the incremental cost equation. Once the output of the generators adds to the total load, the iterations stop. Equal incremental dispatching was discussed in detail by L.K.Kirch-mayer and is also available in several other books written by W.D.Stevensen, M.E1.Hawary and G.S.Christensent and D.P.Kothari and I.J.Nagrath. With the development of interconnected power system and interconnections between electric utilities for the purpose of economic interchange of power, it becomes necessary to consider the transmission line losses in system for achieving better economy. When the generating units and loads are dispersed, the unit with a higher incremental cost closer to the load and incurring lower losses is preferred than to generate at the same incremental cost at a distant location. The transmission losses enter into the constraints as follows;

Minimize

$$F\left(P_{gi}\right)=\sum_{i=1}^{N}\left(a_i P_{gi}^2+b_i P_{gi}+c_i\right) \qquad \text{Rs/h} \qquad (3.1e)$$

Subject to

(i) The energy balance equation

$$\sum_{i=1}^{N} P_{gi}=P_D+P_L \qquad (3.1f)$$

(ii) and the inequality constraint

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max};\left(i=1,2,\ldots..,N\right) \qquad (3.1g)$$

$$P_{gj}=0;\left(j \ne i\right) \qquad (3.1h)$$

The inclusion of transmission losses for the optimal operation leads to the incremental transmission loss formula which when incorporated with incremental fuel cost lead to the classical coordination equation method for optimal dispatch. The loss formula approach has gained wide popularity and is still being widely used, but does require some important judgments and approximations. A set of procedures and algorithms are developed by Dale et al for dynamic economic dispatch of generation units. When coupled with short term load predictor, 'load ahead' capability is provided by the dynamic economic dispatch that co-ordinates predicted load changes with the rate of response capability of generation units. Dynamic economic dispatch enables valve point loading of generation units. T.H.Lee et al presented a new economic dispatching method, based on two transportation techniques. The minimum cost flow method is used to find and initial optimum cost based on linear model. The resultant consistent set of power flow is used as the starting point for the Minty algorithms. The Minty algorithm used a stepwise approximation of the generators and transmission line incremental costs to find the optimum, based on the non linear model. This method presents topology of the power system since it does not involve a calculation of the penalty factor into usual sense. Aoki et al [3] proposed many new algorithms using parametric quadratic programming and recursive quadratic programming for the solution of classic economic power dispatch problem. An analytical method to optimize generation schedule has been developed by Srikrishna et al [5] .This method does not take into account the transmission losses. It has been claimed that results obtained by this method coincide accurately with those by other standard methods already in use. For large system having more than three plants, the above approach becomes slightly laborious, since the overall cost equation becomes a function of more than one variable. New graphical method for optimum power generation has been presented by the same author in which the transmission losses are taken into account by neglecting the mutual B-coefficients. No doubt this approach is simple and elegant but restriction on plant capacities is not placed. A straightforward method was developed by N-Ramaraj [4] named as 'No Lambda' method. This method expressed all the optimum plant generation as a cubic function of the load demands which readily gives the optimum plant generation. It seems suitable for the system with any number of plants.

A simple non-iterative quick method to optimal generation schedule had been presented by Palanichamy et al [5], which reviews the criteria for the constrained optimization of real power generation with transmission losses. This method is suitable for real time economic dispatch in power system operation where computation time is a crucial factor. In another method named fast economic power dispatch by the same author presented a simple analytical approach based on the solution of quadratic function of Lambda. The procedure eliminated the conventional iterative method without loss of accuracy. A modified power balance equation has been presented by Kannan and Nityanandan for economic load dispatch and optimum scheduling in terms of incremental cost of received power and total load demand of an n-plant system .This modified equation includes transmission losses. For the known total power demand, the optimum valued for lambda is obtained within few iterations even when Lambda starts with zero. Therefore the economic load for each plant can be directly obtained from co-ordination equations among the plants. The optimum generation schedule for each unit in a plant is determined by the modified co-ordination equation by substituting the economic load determined from the previous step. Chanana et al. had suggested an analytical direct method for optimum thermal scheduling with exponential cost characteristics and including transmission losses. As no iterative process is employed the algorithm is fast and suitable for real time monitoring.

2. Rigorous model

Rigorous economic dispatch uses full set of variables consisting of all voltage magnitude, phase angle, bus loads and PQ generation (to over come the loss formula approximations). This procedure is also known as optimal power flow dispatch and is formulated as:

Minimize

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$$F(P_{gi}) = \sum_{i=1}^{N} \left(a_i P_{gi}^2 + b_i P_{gi} + c_i \right) \quad \text{Rs/h} \tag{3.2a}$$

Subject to

$$\sum_{i=1}^{M} P_{di} - \sum_{i=1}^{N} P_{gi} + P_L = 0 \tag{3.2b}$$

$$\sum_{i=1}^{M} Q_{di} - \sum_{i=1}^{N} Q_{gi} + Q_L = 0 \tag{3.2c}$$

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \quad ; i = 1,2,\ldots,N \tag{3.2d}$$

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} ; i = 1,2,\ldots,N \tag{3.2e}$$

where

P_{di} and Q_{di} are real power and reactive power demands, respectively at the ith bus.

P_{gi} and Q_{gi} are real power and reactive power generation, respectively at the ith bus.

P_L and Q_L are real and reactive transmission losses, respectively.

M is total number of buses in the power system networks.

P_{gi}^{min} and P_{gi}^{max} are lower and upper limits of active power generation by ith generator, respectively.

Q_{gi}^{min} and Q_{gi}^{max} are lower and upper limits of reactive power generation by ith generator, respectively.

Optimal power flow has been the subject of continuous intensive research and algorithmic improvements since its introduction in the early sixties. Carpentier applied the Kuhn-Tucker Theorem to obtain the necessary conditions of optimality. This gives a system of nonlinear simultaneous equations, which are solved by gauss-seidal iterative procedure. The convergence is found to be very difficult and erratic. The method developed by Dommel and Tinney [6] uses Lagrange multipliers to associates the load flow equations to the objective functions which includes penalties for functional inequality constraint violations. Newton's method is used to solve the load flow equations. The resulting reduced gradient is multiplied by an acceleration factor to update the control vector. The procedure of Dommel and Tinney is basically a first order method and its convergence is very sensitive to the accelerating factor used. The sequential unconstrained minimization technique used by Sasson [7] develops convergence difficulties as the system size increases and is therefore not suitable for practical power system .The reduced Hessian method is inherently a second order method, has been applied to the optimal load flow problem, by Bala et al in conjunction with a procedure for handling the constraints on the control variables, resulting in highly reliable convergence and excellent accuracy. The computation time per iteration was more because of the effort necessary to reduce the size of the original matrix. Ms.G.Agnihotri et al had presented a decomposition technique for the load flow solution of very large power system. This method is distinctly superior to the existing decomposition methods from the point of view of speed and storage. The large power network was decomposed into number of blocks by identifying boundary buses and branches. The blocks were analyzed sequentially from lower to higher accuracy. Palanichamy et al presented a real time economic dispatch method by calculating the penalty factor from decoupled load flow solution. The algorithm utilized a closed form expression for the calculation of Lambda without loss of accuracy. This method accounted for the change in transmission loss due to change in generation. In another attempt Palanichamy et al developed a new technique for real time economic load dispatch with inequality constraints. The optimal conditions derived relate the incremental production cost of any generator to that of the swing bus. The method by passed the Lagrangian approach and offered the load dispatch solution directly. This new approach circumvented the convergence problem as it used a direct expression for economic generation. Nanda et al [8] made the comparison of first order and second order load flow methods and proved that the second order load flow methods in rectangular coordinates are more accurate and computationally superior to first order load flow versions. Nidul Sinha, R.Chakrabarti and P.K.Chattopodhyay have presented Evolutionary programming as an optimization tool for handling nonlinear programming problems. Various modifications to the basic method have been proposed with a view to enhance speed and robustness and these have been applied successfully on some benchmarked mathematical problems. Absolute as well as relative, performance of the algorithms is investigated on ELD problems of different size and complexity having nonconvex cost curves where conventional gradient-based methods are inapplicable. R.Naresh, J.Dubey and J.Sharma [1] had presented a two-phase optimization neural network based modelling framework and a solution for solving ELD problem in large scale systems. The method is based on the solution of a set of differential equations obtained from transformation of an augmented lagrangian energy function. K.P.Wong and C.C.Fung [2] had developed an economic dispatch algorithm based on the simulated annealing technique. In the development of algorithm, transmission losses are first discounted and they are subsequently incorporated in the algorithms through the use of B-matrix loss formula. The results are compared to those found by dynamic programming. Sheble et al presents the application of genetic algorithm to the unit commitment scheduling problem and to the economic dispatch of generating units. Several approaches to implementing a refined genetic algorithm to unit commitment and OELD are explored and results are verified for a sample problem using a classical Lagrangian search technique. P.Aravindhababu,K.R.Nayar had presented a new efficient method for on-line economic dispatch which is based on the radial basis function network that directly gives method to compute the economic generations iteratively.

4. APPROXIMATE VS RIGOROUS MODEL

Frequent recalculation of a new dispatch (2 minutes to 2 seconds) and limited computer size require that the applied method be simple in structure and fast in calculation. The classical economic load dispatch method has provided a simple and fast solution procedure. Since the load flow equations must be solved iteratively in rigorous methods.

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The disadvantage of these methods lies in the requirements of large computer memory and the amount of computation per iteration to reach a solution. Happ [9,10] has conducted a comparative study to determine the dispatch procedures. There is no significant difference in his revised paper that has reported the direction of industry concerning economic load dispatch, in which it is stated that the reason for employing more advanced techniques cannot be justified for executing different functions associated with the security of operations. However since the capacity of transmission lines is designed with sufficient margin, limits on transmission lines are not needed for the normal operating state. In the case of emergency lines capacity limit will be treated in the energy control to maintain the safety of the system.

CONCLUSION

Multiobjective problems (MOP) are those where the no. of objectives is more than one. In the multiobjective framework it is realized that cost, NO_X emission, SO_2 emission and CO_2 emission are conflicting objectives and are subject to mutual interface. In engineering applications, it is often a problem to formulate a design in which there are several criteria. If the objectives are interactive, then the problem is to find the best possible design which still satisfies the interactive objectives. Generally the engineer's goal is to maximize or minimize not a single objective but several objective functions simultaneously. In such a case, it is assumed that the entire objectives are in conflict and non-commensurable. Owing to the conflicting nature of objectives, an optimal solution that simultaneously maximizes/ minimizes all the criteria is usually not attainable. Instead, there are several solutions called non-inferior or efficient solution set that has the property that no improvement in any objective is possible without sacrificing one or more of the other objectives. So it is concluded that the multiobjective optimization problems are solved and non-inferior solutions are generated by exploiting weighting method.

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