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Multi Objective based Economic Load Dispatch using Game Theory

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Abstract - *Economic operation of power systems or frameworks is met by meeting the load demand through optimal scheduling of force era. Minimization of fuel cost is the primary type of optimal power flow issues. Real power generators of various generators are the control variables in ELD issue. Optimal real power scheduling will ensure economic advantages to the power framework administrators and reduce the release of polluting gasses. Previously, various conventional optimization calculations are misused for taking care of the optimal power flow issues. A major objective of thermal power generation is to reduce fuel consumption by allocating optimum power generation to every unit i.e. economic dispatch and to take care of emissions at intervals the environmental license limits i.e. emission dispatch subject to equality and difference constraints. Owing to conflicting nature of emission and economy objectives downside becomes multi-objective in nature. Power grid stability has been recognized as a very important downside for its secure operation. Owing to increase in power demand, trendy power grid networks area unit being operated below extremely stressed conditions. During this thesis we are going to make out the simplest worth when convergence of minimum iteration. After that, we are going to optimize the economic dispatch and emission dispatch victimization game theory algorithmic rule.*

Keywords—*Economic Load Dispatch (ELD), ELD Formulation, Game Theory, Mat lab Simulator.*

1. INTRODUCTION

Today electrical power plays an exceedingly important role in all walks of life of an individual as well as the community. The development of various sectors such as transportation, industrial, agricultural, entertainment, information and communication sectors etc depend on electrical energy. In fact, the modem economy is totally dependent on the electricity as a basic input. This is turn has led to the increase in the number of power generating stations and their capacities and the consequent increase in power transmission lines which connect the generating stations to the load centres. Interconnections between generating systems are also equally important for reliable and supply quantity of power system which also provide flexibility in system operation. Among different issues in power system operation, economic load dispatch (ELD) and optimal power flow (OPF) problem constitute a major part.

2. ECONOMIC LOAD DISPATCH

Scarcity of energy resources, increasing power generation costs and ever growing demand for energy necessitate optimal economic dispatch in modern power systems. The main objective of economic dispatch is to reduce the total power generation cost while satisfying various equality and inequality constraints. Traditionally, in economic dispatch problems, the cost function for generating units has been approximated as a quadratic function.

A wide variety of optimization techniques have been applied to solving Economic Load Dispatch (ELD). Some of these techniques are based on classical optimization methods, such as linear programming or quadratic programming to solve ELD problems.

By economic load scheduling we mean to determine the generations of different plants such that total operating cost is minimum and at the same time the total demand and the

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losses at any instant is met by the total generation. The operating cost of thermal plants is mainly the cost of fuel. It is given as a function of generation .This cost function is defined as a nonlinear function of plant generation's. Normally graph is given between the heat value of fuel and power generation and knowing the cost of fuel. We can definitely determine the fuel cost as a function of generations for each thermal plant.

3. FORMULATION OF ECONOMIC LOAD DISPATCH

The ELD problem is considered as a general minimization problem with constraints and can be written in the following form:

$$minimize\ f(x) \qquad (i)$$
$$subject\ to\ g(x) = 0 \qquad (ii)$$
$$h(x) \leq 0 \qquad (iii)$$

f(x) is the objective function, g(x) and h(x) are respectively the set of equality and inequality constraints, x is the vector of control and state variables. The control variables are generator active and reactive power outputs, bus voltages, shunt capacitors/rectors and transformers tap setting. The state variables are classic economic load dispatch problem. The objective of the ELD problem is to minimize the total fuel cost at thermal plants

$$OBJ = \sum_{i=1}^{n} F_i\ (P_i\ )$$

Subject to the constraint of equality in real power balance

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

The inequality constraints of real power limits of the generation outputs are

$$P_{imin}\ < P_i\ < P_{imax}$$

where

$F_i\,P_i$ is the individual generation production in terms of its real power generation

P_i is the output generation for unit i

n is the number of generators in the system

P_D is the total current system load demand,

P_L is the total system transmission losses

4. OBJECTIVE FUNCTION

The objective function for the ELD reflects the costs associated with generating power in the system. The quadratic cost model is used. The objective function for the entire power system can then be written as the sum of the quadratic cost model for each generator:

$$f(x) = \sum_{i=1}^{ng} a_i\ + b_i P_{gi}\ + C_i P_{gi}^2$$

where

ng is the number of thermal units,

Pgi is the active power generation at unit I

And ai, bi, ci are the cost coefficients of the i^{th} generator.

5. EQUALITY CONSTRAINTS

The equality constraints g(x) of the ELD problem is represented by the power balance constraint, where the total power generation must cover the total power demand and the power loss. This implies solving the load flow problem which has equality constraints on active and reactive power at each bus as follows:

$$P_1\ = P_{gi}\ - P_{di}\ = \textstyle\sum_{j=1}^{n} Vi\ V_j\,(G_{ij}\ \cos\theta ij\ + B_{ij}\ \sin\theta ij)$$

$$Q_1\ = Q_{gi} - Q_{di} = \sum_{j=1}^{n} Vi\ V_j\,(G_{ij}\ \sin\theta ij\ - B_{ij}\ \cos\theta ij)$$

where

i = 1, 2, 3… N and θ_ij=θ_i-θ_j

P_1, Q_1 injected active and reactive power at bus I.

$Q_{gi} - Q_{di}$ active and reactive power demand at the bus I.

Vi, θ bus voltage magnitude and angle at bus I.

Gij, Bij conductance and suspectance of the (I,j) element in the admittance matrix..

6. INEQUALITY CONSTRAINTS

The inequality constraints h(x) reflect the limits on physical devices in power system as well as the limits created to ensure security. Upper and lower bounds on the active and reactive generations:

$$P_{gimin} \leq P_{gi} \leq P_{gimax}$$
$$Q_{gimin} \leq Q_{gi} \leq Q_{gimax}$$

Upper and lower bounds on the tap ratio (t) and phase (α) of variable transformers:

$$t_{ijmin} \leq t_{ij} \leq t_{ijmax}$$
$$\alpha_{ijmin} \leq \alpha_{ij} \leq \alpha_{ijmax}$$

Upper limit on the active power flow (Pij) of line ij:

$$|P_{ij}| \leq P_{ijmax}$$

where

$$P_{ij} = |-G_{ij}V_i^2 + G_{ij}V_iV_j\cos(\theta i - \theta j) + B_{ij}V_iV_j\sin(\theta i - \theta j)|$$

Upper and lower bounds on bus voltage magnitude

$$V_{imin} \leq V_i \leq V_{imax}$$

It can be seen that the generalized objective function F is a non linear, the number of the equality and inequality constraints increase with the size of power distribution systems. Applications of a conventional optimization technique such as the gradient based algorithms to a large power distribution system with a very non linear objective functions and great number of constraints are not good enough to solve this problem. Because it depend on the well computing of these derivatives in large search space.

7. LITERATURE REVIEW

Economic operation of power systems is met by meeting the load demand through optimal scheduling of power generation. Minimization of fuel cost is the main form of optimal power flow (OPF) problems [1]-[2]. Real power generations of different generators are the control variables in economic load dispatch problem. Optimal real power scheduling will ensure economic benefits to the power system operators and reduce the release of polluting gases. Economic Load Dispatch primarily aims at optimal scheduling of real power generation from committed units in such a way that it meets the total demand and losses while satisfying the constraints [3]. Achieving minimum cost while satisfying the constraints makes the Economic Load Dispatch problem a large-scale highly non-linear constrained optimization problem. The non linearity of the problem is due to non linearity and valve point effects of input–output characteristics of generating units. The objective of cost minimization may have multiple local optima. There is always a demand for an efficient optimization technique for these kinds of highly non linear objective function [4]. Further, the algorithm is expected to produce accurate results for the Economic Load Dispatch problem. In the past, numerous conventional optimization algorithms are exploited for solving the optimal power flow problems [5].

Major drawback of those methods is that they require Smooth and convex functions for better results and more likely to trap into local optima. Later, evolutionary algorithms are exploited for economic load dispatch problems and improved results were obtained [6]-[8]. In the last decade, several bio inspired algorithms are introduced and attempted for many engineering optimization problems. Some of the notable bio inspired algorithms are particle swarm optimization algorithm (PSO), a well received algorithm and utilized in almost all engineering applications successfully [9]-[10]. Firefly algorithm is another recently introduced algorithm for engineering optimization [11] that has been successfully used to solve the dynamic economic load dispatch problem. Theses algorithms are highly efficient and cannot easily trap in to local optima. In addition, they are comfortable with all types of objective functions. Researchers across the world are constantly working to develop still efficient algorithms by copying the behaviour of nature/species. Flower pollination algorithm or pollinator based algorithm is one such nature inspired algorithm developed by Xin Yang for engineering tasks. The efficiency of nature/bio inspired algorithms is proved to be outperforming even the evolutionary based algorithms. It introduced pollinator based algorithm [12] for achieving improved results in the ELD problem. This algorithm is with less number of operators and hence can be easily coded in any programming language. To prove the strength of this algorithm its performance is compared with other algorithms.

8. ECONOMIC DISPATCH PROBLEM USING GAME THEORY

Game theory is a discipline which helps to find out optimum choice. It is used firstly in economics to analyze different strategies. Today, game theory is applied to other branches of science. The fundamental insight of game theory was to apply the logic of games to events in real life. A game-theoretic model is an environment where actions of each decision maker interact with other decision makers. Game theory uses economic and mathematical tools to solve decision making problems. A game is a description of strategic interaction that includes the constraints on the actions that the players can take and the players' interests, but does not specify the actions that the players take. A solution is a systematic description of the outcomes that may emerge in a family of games. Game theory suggests reasonable solutions for classes of games and examines their properties. Nash equilibrium is one of the most basic concepts in the game theory and the widespread method of predicting the outcome of strategic decisions. Equilibrium is defined as a stable outcome based on the payoffs received by players at the end of the game. Also, all players choose strategies which are best for them according to given their opponents choices at this equilibrium point [8]. In Nash equilibrium, each player responds to the others with best decision. A game includes three key ingredients: players, actions, and payoffs. The description of these three elements and their functions will be explained in the following example:

1) A set of players N=({1,2,...,n})is a finite set of n, indexed by i.

2) A set of actions (pure strategies) available to each player $(a = (a_1, a_2, \dots, a_n) \in A)$ determines their possible moves or strategies.

3) A payoff functions $(u = (u_1, u_2, \dots, u_n))$ represent each player's preferences and shows what players receive at the end of the game.

Best response in a game is defined as $a_i^* \in BR(a_{-i})$ if $\forall a_i \in A_i, u_i(a_i^*, a_{-i}) \geq u_i(a_i, a_{-i})$.

$a = (a_1, a_2, \dots, a_n)$ is a pure strategy Nash equilibrium if $\forall a_i \in BR(a_{-i})$

Before the system analyze, game theory elements of the system should be clarified. In this paper, game theory elements with their power generation system equivalents are defined at Table 1 and flow chart of the proposed algorithm is given at Figure 1.

Table 1: An Example of Two Player Game

Game Theory Elements	Power System Equivalent
Players	Generation Plants
Strategies	Produced Power
Payoffs	1/0 According to Demand

To explain the algorithm, an example two generator simplified game can be defined and generator payoff matrix is given in Table 2. According to the Table 2, two players, generation plant 1 and generation plant 2 has been defined with two different production amounts; 100 MW or 200 MW options.

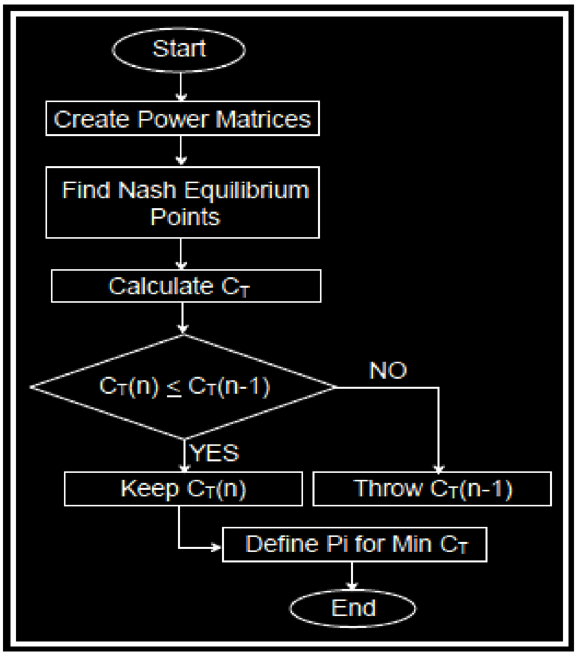

Figure 1: Flow Chart of Proposed Algorithm.

Table 2: NASH Equilibrium Points of Two Generation Plant.

GP1\GP2	100MW	200MW
100MW	(0,0)	(1,1)
200MW	(1,1)	(0,0)

If the system total demand is equal to 300 MW, Nash equilibrium points, which supply the total demand, are 100 MW, 200 MW and 200 MW, 100 MW. Nash equilibrium points are signed in Table 3.

Table 3: An Example of Two Generation Plant.

GP1\GP2	100MW	200MW
100MW	(0,0)	(1,1)
200MW	(1,1)	(0,0)

After the loop of the presented algorithm, detected Nash equilibrium points are used to calculate total cost of the system. Minimum of calculated costs gives the system minimum total cost, in other words this point shows optimum operating strategy.

9. SIMULATED RESULTS

The main objective is to solve this system using game theory Nash equilibrium. To solve economic dispatch problem using game theory Nash equilibrium has been presented.

Table 4: Comparison of Power and Cost using various Optimization Techniques w.r.t 6 Generator.

S/N	1	2	3	4
METHOD	**GAME**	**PBO**	**MODE**	**PDE**
POWER DEMAND (MW)	1200	1200	1200	1200
P_1(MW)	**120.121**	114.8951	108.6284	107.3965
P_2(MW)	**109.2140**	110.0341	115.9456	122.1418
P_3(MW)	**234.3018**	218.9038	206.7969	206.7536
P_4(MW)	**224.5618**	213.5678	210.0000	203.7047
P_5(MW)	**390.120**	310.987	301.8884	308.1045
P_6(MW)	**360.912**	306.9100	308.4127	303.3797
Fuel Cost (Rs)	**60121**	63499	64843	64920

Table 5: Determination of Power Dispatch and Fuel Cost w.r.t 6 Generator.

GENERATOR	GENERATOR OUTPUT
P_1(MW)	**120.121**
P_2(MW)	**109.2140**
P_3(MW)	**234.3018**
P_4(MW)	**224.5618**
P_5(MW)	**390.120**
P_6(MW)	**360.912**
Total Power Generation	**109.2140**
Fuel Cost (Rs)	**60121**

In the case study, the proposed method has been applied to 14 bus, 6 thermal generators of power system. The presented algorithm results show that the proposed game theory method gives the minimum total cost of the system with minimum error instead of Lagrange functions results and different algorithm results. Furthermore, if the computation is revised to find minimum total cost without error, total cost decrease. Finally, the results of this study show that game theory helps to find better results for solving economic dispatch problem.

Table 6: Comparison of Power and Cost using various Optimization Techniques w.r.t 10 Generator.

S/N	1	2	3	4
METHOD	**GAME**	**PBO**	**MODE**	**PDE**
POWER DEMAND (MW)	2000	2000	2000	2000
P_1(MW)	**56.9181**	54.9982	54.9487	54.9853
P_2(MW)	**70.3120**	78.321	74.5821	79.3803
P_3(MW)	**93.1201**	82.2134	74.4294	83.9842
P_4(MW)	**101.1010**	92.8923	80.6875	86.5942
P_5(MW)	**160.9001**	145.9021	136.8551	144.4386
P_6(MW)	**210.990**	174.99	172.6393	165.7756
P_7(MW)	**300.0192**	290	283.8233	283.2122
P_8(MW)	**350.5892**	325.5898	316.3407	312.7709
P_9(MW)	**450.6120**	459.9898	448.5923	440.1135
P_{10}(MW)	**455.0192**	438.9091	436.4287	432.6783
Fuel Cost (Rs)	**10189**	11313	11348	11351

Table 7: Determination of Power Dispatch and Fuel Cost w.r.t 10 Generator.

GENERATOR	GENERATOR OUTPUT
P_1(MW)	**56.9181**
P_2(MW)	**70.3120**
P_3(MW)	**93.1201**
P_4(MW)	**101.1010**
P_5(MW)	**160.9001**
P_6(MW)	**210.990**
P_7(MW)	**300.0192**
P_8(MW)	**350.5892**
P_9(MW)	**450.6120**
P_{10}(MW)	**455.0192**
Total Power Generation	**56.9181**
Fuel Cost (Rs)	**10189**

To solve economic dispatch problem using game theory Nash equilibrium has been presented. In the case study, the proposed method has been applied to 39 bus, 10 thermal generators of power system. The presented algorithm results show that the proposed game theory method gives the minimum total cost of the system with minimum error instead of Lagrange functions results and different algorithm results. Furthermore, if the computation is revised to find minimum total cost without error, total cost decrease. Finally, the results of this study show that game theory helps to find better results for solving economic dispatch problem. The table above shows the comparison of power dispatch and fuel cost of 14 and 39 bus systems using various optimization techniques. The results show that the value of power output and fuel cost obtained by game theory based optimization technique is better than other optimization techniques. Furthermore, if the computation is revised to find minimum total cost without error, total cost decrease. Finally, the results of this study show that game theory helps to find better results for solving economic dispatch problem.

10. CONCLUSION

According to previous approaches another nature propelled calculation is actualized for various economic load dispatch issues. The numerical comes about plainly demonstrate that the proposed calculation gives better results. The game theory based algorithm based advancement beats the other as of late created calculations. The calculation is simple to actualize and can be coded in any computer language. Power framework operation optimizing issues can be attacked with the assistance of this calculation. Power framework administrators can likewise utilize this calculation for different enhancement issues. The proposed algorithm is to find minimum total cost without error, total cost decrease. Finally, the results of this study show that game theory helps to find better results for solving economic dispatch problem. For further extent game theory algorithm can be combined with other simple optimization techniques to improve their performance when applied to ELD problems and obtain better results.

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