Multi – objective economic emission load dispatch solution using wolf's method in various generation plants with wind power penetration

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Abstract

Economic load dispatch means that the generator's real and reactive powers are allowed to vary with in certain limit so as to meet a particular load demand with minimum fuel cost. In this paper a Multi –Objective Economic Emission Load Dispatch problem is solved to minimize the emission of nitrogen oxides(NOx) , oxides of other fuels that release during generation of electricity and fuel cost considering both thermal generators and Wind turbines. The effect of Wind power on overall emission is also investigated here using Quadratic programming by wolf's method. This method have better convergence characteristic . Wolf's method is an extended simplex procedure which can be applied to Quadratic programming problems in which all the problem variables are non negative.

Keywords: Emission dispatch, Fuel cost, Wind turbine, Quadratic Programming by Wolf's Method

1. Introduction

Economic load dispatch (ELD) is one of the most important problems to be solved for the economic operation of a power system [1].

Economic load dispatch is to define the production level of each plant so that the cost of fuel is reduced for the prescribed schedule of load. The objective of economic load dispatch (ELD) is to allocate the generation among the committed units such that the cost of fuel is minimized, while satisfying the equality and inequality constraints [2].

The economic load dispatch (ELD) problem seeks the best generation schedule for the generating plants to supply the required demand plus transmission losses with the minimum production cost. Conventionally, the emphasis on performance optimization of fossil–fuel power systems was on economic operation only, using the ELD approach, as better solutions would

result in significant economical benefits. However, due to the pressing public demand for clean air as well as due to the ‘‘global warming’’ concept, new clean air policies and regulations have been forced on the industries, as environmental effect is a direct consequence of industrial advancement. Thermal power units are responsible—in a major way for creating major atmospheric pollution because of high concentrations of pollutants, such as NOX, SOX, and COX, contained in their emissions. Therefore, power sectors have realized the importance of maintaining a cleaner environment. Due to this constraint, generation allocation is not only governed by production costs, but also by the maximum allowable emissions level. As a result, a new approach has come up, known as the economic emission dispatch (EED) method. EED is an optimization problem that pursues the least emission level of operation of a power system. But operating either at the absolute minimum cost of generation or at the absolute minimum emission level may no longer be a desirable criterion. The obvious approach is to figure out the optimal amounts of the generated powers for the thermal units in the system by minimizing the emission level and cost of generation simultaneously, which is known as economic emission load dispatch (EELD).

Literature survey [1-15] shows that the fuel cost function is represented by a simple quadratic equation and problem is optimized by using different methods [2]. To solve ELD problem some conventional methods are used. Lagrangian multiplier method [2] was introduced to solve the ELD problem. Economic load dispatch (ELD) problem using classical method like Newton-Raphson Method, Approximate Newton-Raphson method, Efficient method were introduced [2,3]. In these methods assumption is made that the incremental cost curves of the generators is linear. However, in practical case, the cost curves of the units are highly non linear. Dynamic programming is used but has dimensionality and local optimality problem [4]. Hierarchical structure method, which is a numerical method was proposed to solve ELD problem with piece-wise quadratic cost functions [5]. Then artificial intelligence techniques named Particle swarm optimization (PSO), Modified PSO (MPSO), Artificial neural network (ANN) were applied [2]. ANN technique suffer from stability problem[6,7].

With winds fairly constant all over the year, with availability of large amount of credit and other financial incentives, limited resources of fossil fuels and no emission of pollutants, there is a growing trend for new wind energy installations in the coastal areas of different countries in world. All over the world, quite a few wind farms in the power range of several hundred megawatts are under planning [16]. In wind power generation, the wind speed is an important random variable which affects the output power. The wind speed in a given period may be represented by a probability density function. In recent years the Weibull distribution has been one of the most widely used and recommended tool to determine the potential of wind energy. The high penetrations of renewable energy sources, such as wind power

complicate the EELD problems significantly. In environmental dispatch, the emissions reduction has been represented either as a cost constrained emission dispatch problem, or as a new multi-objective emission load dispatch problem [17–19]. Multi-objective EELD problems use tradeoffs between emission and the cost objective functions. From a typical pair of profiles of emission and fuel cost against power output for an individual generator, it is clear that the fuel cost function is an increasing function of output power, while the emission function is of the U-shape [20]. As the shape of the emission curve is 'U', therefore in the left hand side of the minimum point of the emission curve, amount of emission decreases as the output power increases and move towards minimum point of the emission curve point. Conversely, in the right hand side region of minimum point of the emission curve, emission
increases as the output power increases and moves in the opposite direction. Therefore, participation of wind power (WP) creates complex situation. The participation of WP compensates a portion of power demand, which in turn reduces the power output of thermal generators and increase the emission level. Therefore, depending upon the value of power demand, introduction of WP may increase the emission level. As a result, solution procedure of EELD problem in presence of wind power sources becomes very much complex.

Moreover, wind volatility complicates EELD problems, and raises concerns of system operators with respect to the security of the system. Hatziargyriou et al. [21] presented empirical penetration limits that can be used and proposed online dynamic security techniques. They also presented a methodology where the amount of wind power penetration that can be accepted during the operation of the system is largely determined by the operators' attitude and needs to be included in the problem formulation. One measure of the system's ability to accept wind is the wind uncertainty cost, which incurs the extra cost of operating the system due to the short-term wind uncertainty. Simple statistical analysis cannot calculate this cost, because the dispatch able elements, which balance the wind intermittency, are subject to inter- temporal constraints that limit their responsiveness. The costs of integrating wind are assessed using time-domain simulation in a number of studies, as summarized in [34]. Many studies have modeled the wind output uncertainty by finding the optimal schedule assuming perfect forecast accuracy, and including an explicit reserve requirement to protect the system in case the realized wind power is different from forecast. Xian Liu [35] developed a generic ELD model considering wind penetration that takes account the stochastic property of wind energy. In [32], same author has presented a procedure for modeling of wind power sources and studied its effect on emission dispatch problem.

In this paper, an alternative approach to the Wolfe's method for Quadratic Programming is suggested. Here we proposed a new approach based on the iterative procedure for the solution of a Quadratic Programming Problem by Wolfe's modified simplex method. The method sometimes involves less or at the most an equal

number of iteration as compared to computational procedure for solving EELD. Although, the Wolfe's method is not the first method that has been developed for solving quadratic programming problems (QPP), it is one of the most widely used methods for QPP and was developed by P. wolfe in 1959 Wolfe's algorithm can be directly applied to solve any quadratic programming problems of the form,We observed that there is change in the rule of selecting pivot vector at initial stage and thereby for some EELD it takes more number of iteration to achieve optimality. Here at the initial step we choose the pivot vector on the basis of new rules of method described below. This powerful technique is better understood by resolving a cyclic Existing Economic Dispatch Problem with Emission Control Solution.

l l Problem Formulation

The ED problem may be expressed by minimizing the fuel cost of generator units under constraints. Depending on load variations, the output of generators has to be changed to meet the balance between loads and generation of a power system. The power system model consists of n generating units already connected to the system.

The ED problem can be expressed as:

$$\text{Min} = \sum_{i=1}^{NG} \text{Fi(PGi)}$$

$$F_i P_{Gi} = \left(a_i + b_i P_{Gi} + c_i P_{Gi}^2\right)$$

Where ai, bi and ci are the cost coefficients of the it generator and NG is the number of generators including the slack bus. PGi is the real power output of the i-th generator (MW). Fi(PGi) is the operating cost of unit i ($/h).

Subjects to the following constraints

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad \text{for i} = 1, \ldots \ldots \text{NG}$$

$$\sum_{i=1}^{NG} P_{Gi} - D - P_L = 0$$

Where

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_{Gi} B_{ij} P_{Gi} + \sum_{i=1}^{N} B_{0i} P_{Gi} + B_{00}$$

D : total demand(MW)

P_L : transmission losses(MW)

P_{Gi}^{max} : maximum generation output of i-th generator

P_{Gi}^{min} : minimum generation output of i-th generator

B : coefficients of transmission losses

lll Quadratic Programming By Wolf's Method

If the optimization problem assumes the form

max.z(or min.z) = $\infty + C^T x + x^T G x$

subject to:

$$Ax \begin{pmatrix} \leq \\ \geq \\ = \end{pmatrix} b$$

$x \geq 0$

where A= (a_{ij}) m x n , matrix of coefficents. $\forall i = 1,2,..,m$ and $= 1,2,..,n$.

b = $(b1,b2\ldots bm)^T$, x = $(x1,x2,\ldots\ldots,x_n)^T$, C^T = $(C1,C2,\ldots..C\text{-}n)^T$. and G =$(g_{ij})_{\ n\ x\ n}$ is a positive definite or positive semi-definite symmetric square matrix.Moreover the constraints are linear and the objective

function is quadratic. Such optimization problem is said to be a quadratic programming (QP) problem.

(i) Wolfe's method

The Wolfe's method can be summarized as following.

Max z = f(x) = $\sum_{j=1}^{n} C_j x_j + \frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{n} C_{ij}x_j x_k$. subject to the constraints

$\sum_{j=1}^{n} a_{ij}x_j \leq b_j, x_j \geq 0 (i = 1,2,\ldots.m; j = 1,2,\ldots n)$ where Cjk = Ckj for all j and k . bj ≥ 0 for all i=1,2,….m. wolfe has suggested introducing n non negative artificial variable v_j in to the equation representing $\frac{\partial L}{\partial x_j} = 0$

$\sum_{i=1}^{n} g_{ij}x_i + \sum_{i=1}^{m} \lambda_i a_{ij} + \mu_j + v_j = C_j$

Now, starting with an initial basic solution v=c , s=b and x=0,λ=0.
We maximize

Z_v = - $\sum_{i=1}^{n} v_i$
Subject to
$\mu + C + g_i x + a_j\lambda - \vartheta = 0$
Ax+s=b, and $\lambda, \mu, \vartheta, x, s \geq 0$
And the complementary slack bus conditions are,
$\lambda_i s_i = 0, i = 1,\ldots.m.$
$\mu_i x_i = 0, i = 1,\ldots.n.$

IV. Steps Of Quadratic Programming By Wolfe's Method

Step 1: First convert the inequality constraints into equations by introducing slack variables qi2 in the ith constraint (i=1,2,….m) and the slack variables r12 in the jth non negativity constraint (j=1,2,…n).

Step 2 : Then construct the Lagrangian function

L(x,q,r,λ, μ) = ∇ (x)- $\sum_{i=1}^{m} \lambda_i [\sum_{i=1}^{n} a_{ij} - b_j + q_i^2] - \sum_{j=1}^{n} \mu_j [-x_j + r_j^2]$

Where x = (x1,x2,….x_n), r = (r1,r2,…r_n) , $\lambda = (\lambda 1, \lambda 2, \ldots \lambda n)$.
Differentiating L partially w.r.t. the components of and equating the first order partial derivatives to zero, Kuhn-Tucker conditions are obtained.

Step 3: Introduce the non-negative artificial variable j=1, 2… n in the Kuhn Tucker condition

$C_j + \sum_{k=1}^{n} C_{jk}x_k - \sum_{j=1}^{n} a_{ij}\lambda_i + \mu_j = 0$

for j=1,2,….n and to construct an objective function

$z_v = v_1 + v_2 + \cdots + v_n.$

Step 4: Obtain the initial basic feasible solution to the following linear programming problem min. subject to the constraints,

$\sum_{k=1}^{n} C_{jk}x_k - \sum_{k=1}^{n} C_{jk}x_k - \sum_{k=1}^{n} a_{ij}\lambda_j + \mu_j + \nu_j = -C_j$ for $j = 1,2,\ldots n$

$\sum_{k=1}^{n} C_{jk}x_k + q_i^2 = b_j$

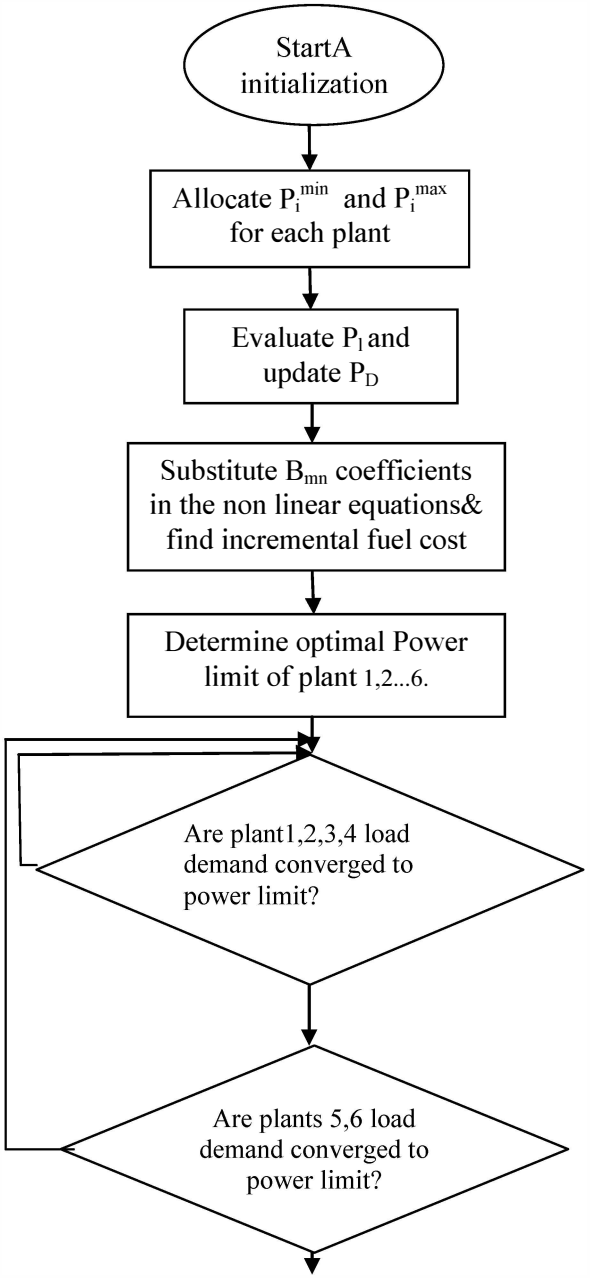
Where i=(1,2,….m),$\lambda_i, \nu_j, \mu_j, x_j \geq 0$ (i=1,2,…m: j=1,2,..n) and satisfying the complementary slackness condition:

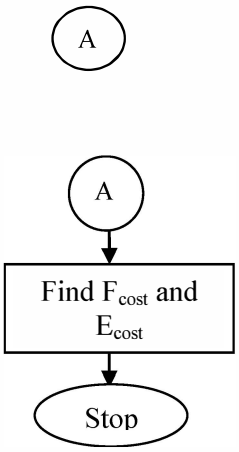
$\sum_{k=1}^{n} \mu_j x_j - \sum_{i=1}^{m} \lambda_i s_i = 0$ where ($s_i = q_i^2$) $\lambda_i s_i$=0 and $\mu_j x_j$=0 , (i=1,2,…m: j=1,2,..n).

Step 5: Now apply 2- phase simplex method to find and optimum solution of Linear Programming problem in

step 4 .The solution must satisfy the above complementary slackness condition.

Step 6: Thus the optimum solution obtained in step 5 is the optimal solution of the given Quadratic programming problem (QPP).





V Solution For Quadratic Programming Problem By Modified Simplex Method

This section deals with the solution of the quadratic programming problem by the method exactly similar to Simplex Technique in linear programming. This method can be successfully adapted to high speed computational. We can apply this method if the constraints of the problem are linear function. i.e. our problem is of the form

Max. z (or Min.z) = $(C^T x + \alpha)(d^T x + \beta)$

Subject to :

(i) A is m x n matrix:

(ii) x,C,d are n x 1 column vectors;

(iii) b is m x 1 column vectors;

(iv) α, β are scalars and prime (T) denoted the transpose of the vector.

Here it is assumed that $(C^T x + \alpha)(d^T x + \beta)$ are positive all feasible solutions ,the set of all feasible bounded, and closed convex polyhedron. Also,at least two distinct feasible solution exist. To apply

simplex process, first $\Delta_{j1}$and Δ_{j2} need to be found from the coefficients of the linear vector and second linear vector of objective function respectively, by using the following formula:

$\Delta_{ji} = C_{ij} - C_{Bi}x_{ij}$, i= 1,2,….m+n

$Z_1 = C_{B1}\nu_B + \alpha$

$Z_2 = C_{ij}\nu_B + \beta$

And compute $\mu_j = \min\left[\frac{\nu_B}{x_j}\right]$ for non-basis vector, in this approach the formula is defined to find Δ_j from $\Delta_{j1}\Delta_{j2}Z_1Z_2$ and μ_j following:

$\Delta_j = Z_1\Delta_{j2} + Z_2\Delta_{j1} + \mu_j\Delta_{j1}\Delta_{j2}$

(i)Algorithm For Modified Simplex Method

An algorithm for solve QPP by modified simplex method can be summarized as following:

Step 1: Write the standard from of the problem, by introduction slack and artificial variables to constraints, and write starting simplex table.

Step 2: Calculate the by the following formula, then write it in the starting simplex table

Step 3: Find the solution by using simplex process.

Step 4: Check the solution for feasibility in slep3, if it is feasible then go to step5, otherwise use dual simplex method to remove infeasibility.

Step 5: Check solution for optimality if all, then the solution is optimal, otherwise go to step 3.

(ii) Mathematical Form Of QFPP

The mathematical form of this type of problems is given as follows:

$$\text{Max.z} = \frac{C^T x + \frac{1}{2}x^T G_1 x}{d^T x + \frac{1}{2}x^T G_2 x}$$

Subject to:

$$\text{Ax}\begin{pmatrix}\leq\\ \geq\\ =\end{pmatrix}\text{b}$$

$x \geq 0$

Where G1 and G2 is matrix of coefficients with are symmetric matrixes. All vectors are assumed to be column vectors unless transposed where an -dimensional vector of decision variables is, b is the dimensional vector of constants, C is -dimensional vector of constants. In this work the problem that has objective function is tried to be solved as the form.

$$\text{Max.z} = \frac{(C1^T x + \frac{1}{2}x^T G_1^1 x)}{(d1^T x + \frac{1}{2}x^T G_2^1 x)} \frac{(C1^T x + \frac{1}{2}x^T G_1^2 x)}{(d2^T x + \frac{1}{2}x^T G_2^2 x)}$$

VI Result and Discussion

The solution of economic emission load dispatch using QPWM has been tested on the six unit system and the numerical result are obtained through the MATLAB simulation.

The six generating units considered are having different characteristic. Their cost function characteristics are given by following equations.

Economic load dispatch data:

$F1=0.15247P_1^2+38.53975P_1+756.79886$Rs/Hr
$F2=0.10587P_2^2+46.15916P_2+451.32513$Rs/Hr
$F3=0.02803P_3^2+40.3965P_3+1049.9977$Rs/Hr
$F4=0.03546P_4^2+38.30553P_4+1243.5311$Rs/Hr
$F5=0.02111P_5^2+36.32782P_5+1658.5596$Rs/Hr
$F6=0.01799P_6^2+38.27041P_6+1356.6592$Rs/Hr

Their maximum and minimum power is also different. The unit operating ranges are given by,

10MW=P1=125MW
10MW=P2=150MW
35MW=P3=225MW
35MW=P4=210MW
130MW=P5=325MW
125MW=P6=315MW

The B_{min} loss coefficient matrix is given by

$$B_{min} = \begin{bmatrix} 1.4 & .17 & .15 & .19 & .26 & .22 \\ .17 & .6 & .13 & .16 & .15 & .2 \\ .15 & .13 & .65 & .17 & .24 & .19 \\ .19 & .16 & .17 & .71 & .3 & .25 \\ .26 & .15 & .24 & .3 & .69 & .32 \\ .22 & .2 & .19 & .25 & .32 & .85 \end{bmatrix}$$

Emission data:

$E_1 = 0.00419\ P_1^2 + 0.32767\ P_1 + 13.8593$ kg / hr.
$E_2 = 0.00419\ P_2^2 + 0.32767\ P_2 + 13.8593$ kg / hr.
$E_3 = 0.00683P_3^2 + -0.54551P_3 + 40.2669$ kg / hr.
$E_4 = 0.00683P_4^2 + -0.54551P_4 + 40.2669$ kg / hr.
$E_5 = 0.00461\ P_5^2 + -0.51116\ P_5 + 42.8955$ kg / hr.
$E_6 = 0.00461\ P_6^2 + -0.51116\ P_6 + 42.8955$ kg / hr.

Fuel cost and emission rate of six unit with different power demand value is shown here,

O/P variables	Pd= 700	Pd= 900	Pd= 1100	Pd= 1300	Pd= 1500	O/P variables	h 2	Pd= 700	Pd= 900	Pd= 1100	Pd= 1300	Pd= 1500
Pg1	68.214	101.13	125.00	126.63	163.30	**Pg1**	1	68.214	101.13	125.00	126.63	163.30
Pg2	69.359	107.63	148.69	151.63	188.30	**Pg2**	20	69.359	107.63	151.63	151.63	188.30
Pg3	117.96	147.04	178.17	226.63	263.30	**Pg3**	40	117.96	147.04	226.63	226.63	263.30
Pg4	117.47	145.04	175.87	211.6	248.30	**Pg4**	80	117.47	145.04	211.6	211.6	248.30
Pg5(W1)	172.75	213.96	257.80	326.63	368.30	**Pg5**	80.5	172.75	213.96	326.63	326.63	368.30
Pg6(W2)	171.08	212.28	225.99	316.63	353.30	**Pg6**	100	171.08	212.28	316.63	316.63	353.30
Fuel cost (Rs.)	3.769e +004	4.872e +004	6.0587e +004	7.1607e +004	8.0535e +004	**Emission (Ton/hr)**		436.39	687.7	1.002e +003	1.049e +003	2.022e +003

Table:1 Output For Six Unit System(Four Thermal Generator And Two Wind Generator)

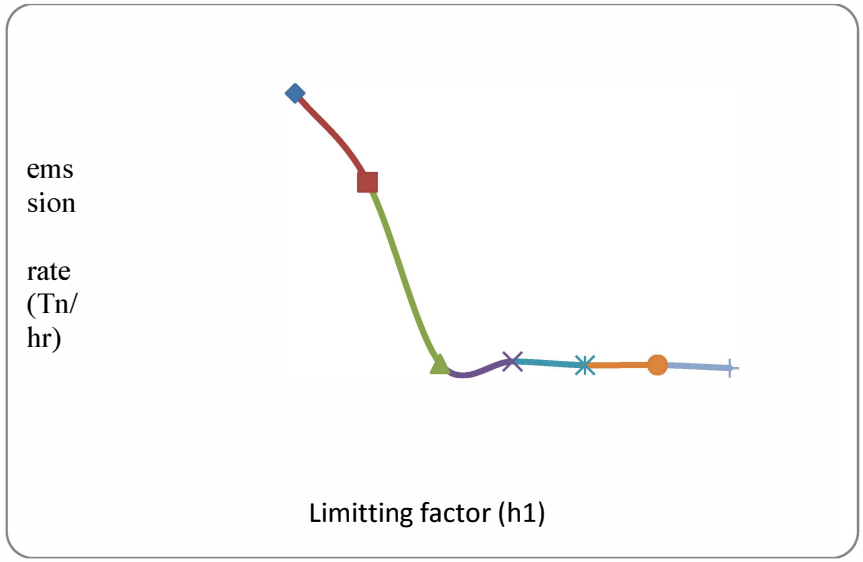


Figure1: Emission Of Nox And Limiting Factor Characteristic

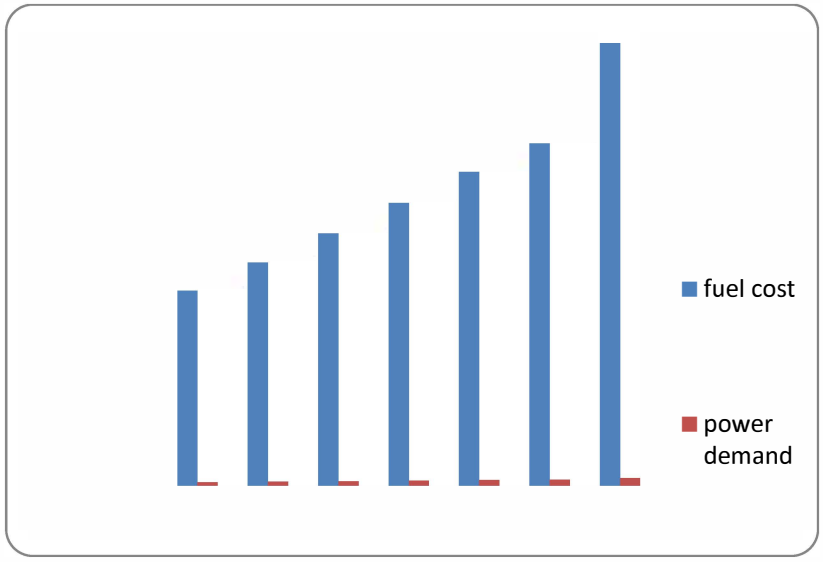


Figure2: Fuel Cost And Power Demand Characteristic

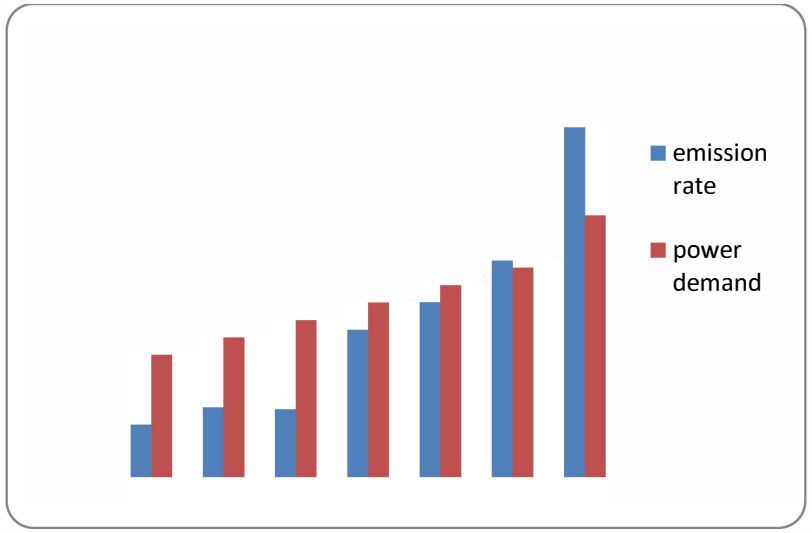


Figure3: Emission of NOx And Power Demand Characteristic

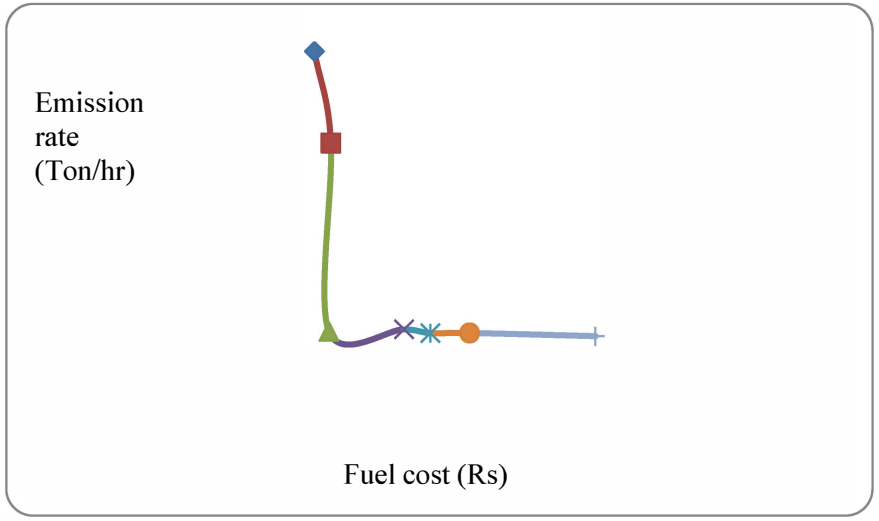


Figure4: Emission Rate Of Nox And Fuel Cost Characteristic

VII Conclusion

The QPM has been successfully implemented to solve both the multi-objective EELD problems. A basic EELD model is used to coordinate the power generated from thermal and wind generators. The model used in this case is very simple where fuel cost characteristics of thermal generators are assumed as quadratic in nature; effect of valve point loading is not included in the problem formulation. Similarly operating limit and power balance constraints are considered at the time of problem formulation only.

It is also clear from the results of different trials that the implementation of this new QPM approach can eliminate the shortcoming of premature convergence, exhibited by other optimization techniques. The new exploration ability of gravitational attraction model of QPM handles the problem of premature convergence in an effective manner compared to other existing algorithm. Due to these features, in the future, the QPM seems to become an important tool for solving complex power system optimization problems in search of better quality results.

REFERENCES

1. Abido M. (2003) "Environmental/ economic power dispatch using multiobjective evolutionary algorithms" , IEEE Trans Power System 1529–37.
2. Azamathulla H.Md, Fu-Chun Wu, Aminuddin Ab Ghani, Sandeep M Narulkar, N or Azazi Zakaria, Chun Kiat Chang (2008) "Comparison between genetic algorithm and linear programming approach for real time operation", Journal of Hydro-environment Research 2 p.172-181
3. C. T. Su, C. T. Lin, "New approach with a Hopfield modelling framework to economic dispatch ", IEEE Trans. Power Systems, 15
4. D.P. Kothari, and J.S. Dhillion(2011),"Power system optimization''PHI, 2nd edition.
5. Hatziargyriou ND, Karapidakis ES,(2002) "Online preventive dynamic security of isolated power systems using decision trees". IEEE Trans Power System,17(2):297–304.
6. He Da-Kuo, Wang Fu-Li, Mao Zhi-zhong(2008)," Hybrid genetic algorithm for economic dispatch with valve-point" , Electric Power Systems Research 78,626-633.
7. J. R. Wona, Y. M. Park(2003)," Economic dispatch solution with piecewise quadratic cost function using improved genetic", Electr.Power Energy Syst. 25 (5), 355-361
8. Lin CE, VivianiGL (2000) , " Hierarchical economic dispatch for piece-wise quadratic cost function", IEEE Trans PAS 1984, PAS-103(6)
9. Liu Xian, Xu Wilsun(2010) "Minimum emission dispatch constrained by stochastic wind power availability and cost", IEEE Trans Power Syst 2010;25(3):1705–13.
10. Maria Dicorato, Giuseppe Forte, Mariagiovanna Pisani, and Michele Trovato, (2012)"Planning and Operating Combined Wind-Storage System in Electricity Market",IEEE Transactions On Sustainable Energy, Vol. 3, No. 2, April
11. M. Vanitha, K. Thanushkodi, "An efficient Technique for solving the Economic Dispatch problem using Biogeography Algorithm", European

Journal of Scientific Reaearch.vol.50 No.2(2011),pp.165-172 optimization , IEEE Region 10 conference TENCON 2008, pp.1-6, 2008.

12. Naveen Kumar, K.P.Singh Parmar and Surender Dahiya(2012) “A Genetic Algorithm Approach for the Solution of Economic Load Dispatch Problem”,International Journal on Computer Science and Engineering (IJCSE) vol.4 No. 06 June 2012
13. N. Sinha, R. chakrabarti, P. K. Chhattopadhyay, Evolutionary programming techniques for economic load dispatch, IEEE Trans. Evol. Comput. 7 (1) (2003), 83-94
14. Naoto Yorino, Habibuddin M. Hafiz, Yutaka Sasaki and Yoshifumi Zoka (2012)“High-Speed Real-Time Dynamic Economic Load Dispatch” ,IEEE Transactions On Power Systems, Vol. 27, No. 2, May
15. Saoussen Brini, Hsan Hadj Abdallah, and Abderrazak Ouali (2009) “Economic Dispatch for Power System included Wind and Solar Thermal energy”, Leonardo Journal of Sciences Issue 14, January-June p. 204-220
16. Xian Liu and Wilsun Xu,(2010) “Minimum Emission Dispatch Constrained by Stochastic Wind Power Availability and Cost”, IEEE Transactions On Power Systems, Vol. 25, No. 3, August