Multi-Objective Optimization using Linear Membership Function

Gurpreet Kaur
Department of Electrical Engg.
Bhai Gurdas Institute of Engg.& Technology
Sangrur, India

Divesh Kumar
Department of Electrical Engg.
Bhai Gurdas Institute of Engg.& Technology
Sangrur, India

Manminder Kaur
Department of Electrical Engg.
Guru Kashi University
Talwandi Sabo, India

ABSTRACT
Economic Dispatch (ED) optimization problem is the most important issue which is to be taken into consideration in power systems. The problem of ED in power systems is to plan the power output for each devoted generator unit in such a way that the operating cost is minimized and simultaneously, matching load demand, power operating limits and maintaining stability. In this paper, the traditional economic dispatch problem has been modified to minimize generation cost and line flow. As the two sub-problems have conflicting objectives, fuzzy decision making multi-objective optimization has been applied to get single optimal solution from conflicting objectives of generation cost and line flow. Practicably, it has been tested on IEEE 30-bus system. The results describe the capability of the proposed approach of reducing line flow while maintaining economy in the load dispatch.

Keywords
Economic Load Dispatch, Fuzzy Decision Making,Multi-Objective Optimization, Line Flow.

1. INTRODUCTION
The aim of power industry is to generate electrical energy at minimum cost while satisfying all the limits and constraints imposed on generating units. Economic Load dispatch (ELD) is the one of the optimization problem in power industry. ELD determines the optimal power solution to have minimum generation cost while meeting the load demand. Due to emerging technology, various techniques have been proposed by several researchers.

The problem of economic load dispatch becomes multi-objective optimization problem with conflicting objectives of generation cost and line flow. Various optimization techniques have been described by many researchers to deal with multi-objective optimization problems having varying degree of success.

In this paper fuzzy decision making technique has been applied to solve the multi-objective optimization problem with conflicting objectives of generation cost and line flow. Fuzzy decision making technique is considered to be more effective than other techniques as far as conflicting objectives are included in the optimization problem. The proposed technique optimizes the said objective functions under a set of system constraints such as real and reactive power balance equations and generating capacity limits. The

performance of proposed technique is tested on IEEE 30-bus system.

2. PROBLEM FORMULATION
The aim of the proposed multi-objective optimization problem is to determine the power generation levels, which will minimize the generation cost and line flow, subject to real and reactive power balance and generation capacity constraints. The problem formulation has been sub-divided into following three parts:

1) Decreasing fuel cost.
2) Minimization of line flow losses.
3) Apply Fuzzy decision making technique using Linear Membership Function.

2.1 Economic Load Dispatch
As the main objective minimize the conflicting objectives of generation cost and line flow, subject to real and reactive power balance and generation capacity constraints. Hence theobjective function is taken equivalent to the total cost for supplying the load demand which is represented by $F_i(P_{gi})$. It can be formulated as follows:

Minimize

$$F_i(P_{gi}) = a_i P_{gi}^2 + b_i P_{gi} + c_i \quad (2.1)$$

Where

a_i, b_i, c_i are the fuel cost coefficient.

P_{gi} is the real power output of the generator.

2.1.1 *Real power dispatch:*

The basic purpose of the real power dispatch problem is to schedule the outputs of thermal generating units so as to meet the system load at minimum cost. Real power dispatch is defined as following by using load flow equations.

$$P_{Gi} - P_{di} - V_i \sum_{m=1}^{n} V_m Y_{im} \cos(\theta_{im} + \delta_m - \delta_i) = 0 \quad (2.2)$$

Where

i=1, 2, 3…..n

P_{di} is load demand of real power at the i^{th} bus

P_{Gi} is generation of real power at the i^{th} bus

V_i is magnitude of votage at i^{th} bus

δ_i is voltage phase angle at i^{th} bus

Y_{im} is admittance matrix of i^{th} and m^{th} busReactive power dispatchReactive power dispatch is treated as an optimization problem that reduces grid congestion by minimizing the active power losses. The Reactive power dispatch requires solving the power flow problem and for this reason is usually known as optimal reactive power dispatch problem or as an optimal power flow problem. The reactive power dispatch is used to solve the power flow equations. Hence as a result an improved voltage profile can be obtained. Reactive power dispatch is defined as following by using load flow equations.

$$Q_{Gi} - Q_{di} + V_i \sum_{m=1}^{n} V_m Y_{im} \sin(\theta_{im} + \delta_m - \delta_i) = 0 \quad (2.3)$$

Where
i=1, 2, 3…..n
Q_{Gi} is total system generation of reactive power bus.

δ_i is voltage phase angle at i^{th} bus.
V_i is magnitude of votage at bus i^{th} bus.
Y_{im} is admittance matrix of i^{th} and m^{th} bus.

2.1.3 Power balance constraints

The total power generation must be equal to total demand and real power loss in transmission line.

$$\sum_{i=1}^{NG} P_{Gi} = P_D + P_{Loss} \quad (2.4)$$

2.1.4 Generation capacity constraints

To stabilize the operation, the generator output, bus voltage magnitudes and voltage angles are restricted by upper and lower limits. These upper and lower bounds are defined as following:

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \quad (2.5)$$

Where
i=1,2,3…..n
P_{gi}^{min} is minimum output power of thegith unit
P_{gi}^{max} is maximum output power of thegith unit
Voltage magnitude must satisfy the inequality

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

Where
i = 1, 2, 3…..n
V_i^{min} = minimum voltage of theith unit
V_i^{max} = maximum voltage of the i^{th} unit
The power system equipment is designed to operate at fixed voltages with allowable variation of $\pm$(5-10) % of the rated value.

Voltage angle also satisfy the inequality
$\delta_i^{min} \le \delta_i \le \delta_i^{max}$ (2.6)
Where
i = 1, 2, 3…..n
δ_i^{min} = minimum voltage angle of theith unit
δ_i^{max} = maximum voltage angle of the i^{th} unit

2.2 Line Flow

Whenever the network component is overloaded then line flow losses occurs in the network. In a competitive market, line flow has its own importance because of the complexity involved. This line flow may be due to overloading of transmission line. Line flow is managed at the dispatch stage In this paper to reduce the line flow we minimized the line flow in branch 2 from bus 1 to bus 3.

2.2.1 Computation of Line Flow:

Consider that line is connecting the buses I and M. The Real power is injected from bus I to M and is given as following.

$$P_{im} + jQ_{im} = V_i[(V_i - V_m)Y_{im} + V_i Y_{im0}] \quad (2.7)$$

Reactive power is injected from bus M to bus I as following

$$P_{mi} + jQ_{mi} = V_m[(V_m - V_i)Y_{mi} + V_i Y_{mi0}] \quad (2.8)$$

Where
Y_{im} is the series admittance
Y_{im0} is the shunt admittance

V_i is the voltage at the i^{th} bus

$$S_{im} = P_{im} + jQ_{im} \quad (2.9)$$
$$S_{mi} = P_{mi} + jQ_{mi} \quad (2.10)$$

Power losses in the (I-M)th line is the sum of the power flows in the (I-M)th line from the i^{th} bus and the m^{th} bus.

$$P_{Lim} = S_{im} + S_{mi} \quad (2.11)$$

2.2 Fuzzy Decision Making Technique Using Linear Membership Function

Fuzzy multiple objective linear programming formulates the objectives and the constraints as fuzzy sets, characterized by their individual linear membership functions. The decision set is defined as the intersection of all fuzzy sets and the set defined by relevant hard constraints.

2.2.1 Linear Membership Function

Logical decision making can be defined by fuzzy sets using the operating conditions. The fuzzy sets are defined by equations called the membership functions. These functions represent the degree of membership in some fuzzy sets using the values from 0 to 1. The membership value 0 indicates incompatibility with the sets, while 1 means full compatibility. When neither is true, a value between 0 and 1 is taken. To find out the membership function of cost and line flow first step is to find the minimum and maximum values of cost and line flow.

$$\mu f_i(\mathbf{x}) = \begin{cases} 1 & f_i(x) \le f_i^{\,min} \\ \dfrac{(f_i^{max} - f_i(x))}{(f_i^{\,max} - f_i^{\,min})} & f_i^{\,min} < f_i(x) < f_i^{\,max} \\ 0 & f_i(x) \ge f_i^{\,max} \end{cases} \quad (2.12)$$

Where
$f_i(x)$ = value of an original fuel cost which is varying
$f_i^{\,min}$ = value of an original fuel cost that is completely satisfactory
$\mathbf{f_i^{max}}$= value of an original fuel cost that is completely unsatisfactory

2.3 Methodology

Step1. Input parameters of system, fuel cost co- efficient and specify lower and upper boundaries and define minimum fuel cost function.

Step2. Get the power generation for six generating units and total fuel cost and total losses.

Step3. For minimizing line flow we have to check whether any line is overloaded or not.
Step4. If overload exists, find the minimum value of line flow by using equations
Step5.As the fuel cost and line flow are the conflicting objectives so an optimal solution cannot be obtained, hence to obtain the optimal solution linear membership function is applied.

Step 6.The Value of membership function is obtained using equation (2.12) for fuel cost and line flow which lies on one optimal point.

3. RESULT AND DISCUSSION

The fuzzy decision making technique is tested on four different test cases for six unit system of economic load dispatch and line flow problem. The test case 1 considers only operating cost without line flow and losses, test case 2 considers operating cost with losses, test case 3 considers losses with line flow and operating cost and test case 4 considers operating cost with line flow and losses. The cost coefficient and operating ranges data and load data for 1 hour is taken with power demand 290 MW.

3.1 TestCase 1

Here generation limit of six unit system and the generation cost coefficients are taken. For this test case line flow and losses are not considered. In this test case operating cost and real power generation of six unit system is calculated. For this test case condition used as

$$\sum P_{Gi} = \sum P_d$$

Where
$i = 1, 2, 3.....6$
P_{Gi} = Real power generation of i^{th} generator
P_d = Real power demand
.

Table1. Result of Test case 1

Test Case	Total Fuel Cost ($/hr)	Total Fuel Cost (Rs/hr)
Without losses	882.4157	55591.83

3.2 Test Case 2

Here generation cost coefficients and generation limit of six unit system are taken. In this test case operating cost with losses of six unit system is calculated. Here we use line flow equations when losses are considered.

$$\sum P_{Gi} = \sum P_d + P_L$$

Where
$i = 1, 2, 3.....6$
P_{Gi} = Real power generation of i^{th} generator
P_d = Real power demand
P_L = Power losses

Table 2. Result of Test case 2

Test Case	Power Losses (MW)	Line Flow(MW)	Fuel cost($/h)	Fuel cost (Rs./hr)
With losses and line flow	6.13	51.88	907.27025	57158

3.3 Test Case 3

Here generation cost coefficients and generation limit of six unit system are taken from appendix. In this test case operating cost with losses of six unit systems is calculated. For minimizing the Line Flow equation of branch 2 from bus 1 to bus 3, load flow equations are applied.

Table 3. Result of Test case 3

Test Case	Power Losses (MW)	Line Flow(MW)	Fuel cost($/h)	Fuel cost Rs./hr
With Minimization of Line Flow in Branch 2(1-3)	4.3	27.72	999.64	62977.32

3.4 Test Case 4

In this test case operating cost including line flows with power losses of six unit system is calculated using fuzzy decision making technique with linear membership function.

Table 4. Result of Test case 4

Test Case	Power Losses (MW)	Line Flow(MW)	Fuel cost ($/h)	Fuel cost (Rs./hr)
When Fuzzy Decision Making is Applied	4.83	35.79	938.12538	59101.56
Membership Function		0.666	0.666	

3.5 Comparison between different voltages

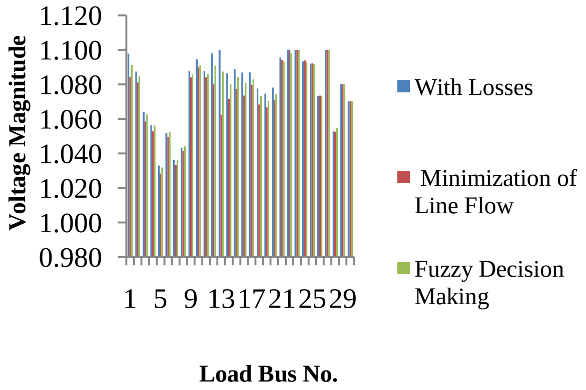

Fig 1. Comparison of voltages for different test cases

Table 5. Power generation of six units for different cases

S N	Test Case	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)
1	Case 1	130.2	62.96	23.6	35	19.0	19.0
2	Case 2	127.7	64.63	25.0	35	21.4	22.2
3	Case 3	59.3	80	50	35	30	40
4	Case 4	86.28	68.91	34.6	35	30	40

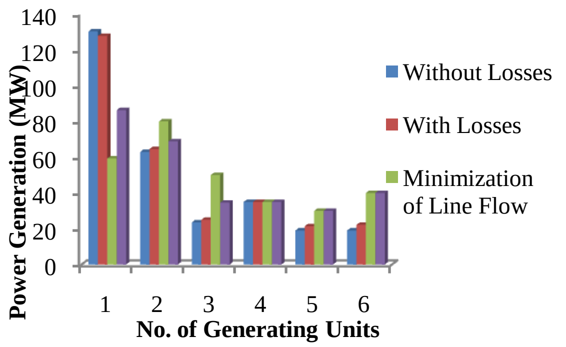

Fig 2. Graph for power generation of six units for different cases

Table 6. Performance parameters of IEEE 30 Bus System

Test Cases	Power Losses (MW)	Line Flow(MW)	Fuel cost ($/h)	Fuel cost Rs./hr
With Losses	6.13	51.88	907.27	57158
With Minimization of Line Flow in Branch 2(1-3)	4.3	27.72	999.64	62977.3
When Fuzzy Decision Making is Applied	4.83	35.79	938.12	59101.5
Linear Membership Function		0.666	0.666	

4. CONCLUSION AND FUTURE SCOPE

In this paper,Fuzzy Decision Making technique is applied to economic power generation for six generating units. Fuzzy Decision Making Technique was employed to solve the ELD problem for four cases of six generating unit system without losses, with losses, with minimization of line flow and fuzzy decision making technique with linear membership function. The conclusion describes the capability of the proposed fuzzy decision multi-objective technique to solve the problem of economic load dispatch and line flow.Fuzzy Neural Network can be used for solving Multi-objective optimization problem.

5. REFERENCES

[1] Wood, A.J. and Wollenberg, B. F.1984,"Power Generation Operation and Control", John Wiley and Sons.

[2] Farag, A.,Baiyat, S.A.and Cheng, T.C.1995,**"**Economic load dispatch multi-objective optimization procedure using linear programming techniques," IEEE Transactions on Power Systems, vol. 10, no 2, pp 0885-8950.

[3] Behera, R., Panigrahi, P. B. and Pati, B. B 2001, "Economic Load Dispatch Using Modified Genetic Algorithm."

[4] Niimura, T. and Nakashima, T.2003, "Multi-objective trade-off analysis of deregulated electricity transactions," sciences direct Electrical Power and Energy Systems, vol.25, pp. 179–185.

[5] Abido, M.A 2003, **"**A novel multi-objective evolutionary algorithm for environmental/Economic power dispatch," Science Direct Electric Power Systems Research, vol.65, pp.71- 81.

[6] Bae, J., Song, K., Rin, J., and Lee, K.Y.2005,"A particle swarm optimization for economic dispatch with non-smooth cost functions", IEEE Transactions on Power Systems, vol.20, no.1,pp.34-42.

[7] Bae, J., Won, Y., Kim, H. and Shin, J.2006, "An Improved Particle Swarm Optimization for Economic Dispatch with Valve-Point Effect", International Journal of Innovations in Energy Systems and Power, Vol. 1, no. 1.

[8] Abedinia, O., Garmarodi, D., Rahbar, R., and Javidzadeh, F.2012, "Multi-objective Environmental/Economic Dispatch Using Interactive Artificial Bee Colony Algorithm," J. Basic. Appl. Sci. Res., vol.2, no.11, pp.11272-11281.

[9] Surekha, P. and Sumathi, S.2012, "Solving Economic Load Dispatch problems using Differential Evolution with Opposition Based Learning", Wseas Transactions on Information Science and Applications, volume 9, issue 1.

[10] Soni, S.K and Bhuria, V.2012, "Multi-objective Emission constrained Economic Power Dispatch Using Differential Evolution Algorithm", International Journal of Engineering and Innovative Technology (IJEIT) volume 2, issue 1, pp 120-125.

[11] Agrawal, S., Bakshi, T. and Majumdar, D. 2012, "Economic Load Dispatch of Generating Units with Multiple Fuel Options Using PSO", International Journal of Control and Automation vol. 5, no. 4, pp 79-92.

[12] Mathur, D. 2013, "A New Methodology for Solving Different Economic Dispatch Problems," International

Journal of Engineering Science and Innovative Technology, vol.2, pp. 494-499.

[13] Bijay Baran Pal, Kumar, M. 2013, "A linear Fuzzy Goal Programming Method for Solving Optimal Power Generation and Dispatch Problem", International Journal of Advanced Computer Research, volume 3, number 1, issue 8, pp 56-64.

[14] Ramyasri, N.and Reddy, G.S. 2013, "Fuzzified PSO for Multiobjective Economic Load Dispatch Problem," International Journal of Research in Engineering and Technology, volume 2 issue 8, pp. 157-162.

[15] Palaniyappan, S., and Ilayaranimangammal, I.2013, "An Optimistic Solution Technique For Economic Load Dispatch Problem Using Immune Inspired Algorithm" , International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering volume 2, issue 12, pp. 6191-6195.

[16] Rajangam, K., Arunachalam, V.P, Subramanian, R. 2013, "Fuzzy Logic Controlled Genetic Algorithm to Solve The Economic Load Dispatch For Thermal Power Station", European Scientific Journal , edition vol. 8, No.7, pp 172-184.

[17] Kothari, D.P. and Dhillon, J.S. 2013 "Power System Optimization", PHI.

[18] Appendix 19, "Data Sheets for IEEE 30 Bus System" pp. 129-134.