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FUZZY ECONOMICAL DISPATCH OF ALL THERMAL POWER SYSTEMS

BY

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Abstract:

The basic objective of economic dispatch operation of power systems is “the distribution of total generation of power in the network between various regional zones; various power stations in respective zones and various units in respective power stations such that the cost of power delivered is a minimum.” In the cost of power delivered, the cost of power generation and transmission losses should be considered. This paper presents a novel technique to solve the economic dispatch problem of all thermal power systems, where the system states and control variables are considered fuzzy which is the case in reality. Formulas for the middle and spread of power generation and transmission losses as well as for fuzzy incremental fuel cost are derived. These fuzzy formulas are solved at different degrees of fuzziness and the results are reported in the text of the paper.

Keywords:

Economic dispatch of all power systems, fuzzy systems, loss formula.

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1. Introduction

The objective of the economic dispatch problem is to find the minimum value of the total cost subject to the equality and inequality constraints on the system. The efficient and optimum economic operation and planning of electric power generation systems have occupied an important position in the electric power industry. A saving of a few percent in the operation of the system presents a significant reduction in operating cost as well as in the quantities of fuel consumed. It is no wonder that this area has warranted a great deal of attention from engineers through the years. The purpose of economic dispatch or optimal dispatch is to reduce fuel costs for the power system. Minimum fuel costs are achieved by the economic load scheduling of the different generating units or plants in the power system. Economic load scheduling means the requirement to find the generation of the different generators or plants so that the total fuel cost is a minimum. Electrical utilities face many uncertainties that affect minimizing the cost function in the economical dispatch method and the optimal power flow operation of the network. This uncertainty can propagate through the time horizon; significantly affecting future transaction opportunities, fuel prices, unit availability and system demand. Historically, uncertainty has been modeled based on randomness, as in, stochastic models for random load variation, noise in measurements for state estimation, fluctuations in model parameters, etc... Fuzzy set theory, originally presented by Zadeh is an appropriate instrument to deal with uncertainties, vagueness and/or imprecision. The effectiveness of this approach has been demonstrated in various applications in power systems operation, planning and analysis. The major advantage of the fuzzy set theory is that it can be used to model human judgments and inexactly expressed information. Fuzzy methods do not necessarily need any data from the past. However, some data may be used as a basis for human judgment and subjective estimates. Transforming existing information about loads, voltage sources, power generation and phase angles into fuzzy numbers with triangular or trapezoidal shape membership functions that measure the conformance of a variable to a concept are presented and the arithmetic's operation on them are preformed employing rules derived from Zadeh's algebraic operations and extension principle.
Many papers have been published to deal with economic dispatch problems in different type of categories such as;

1- Based on the Lagrange multiplier approach and principle of incremental fuel cost, a number of methods have been developed for this problem [1, 2, 3, 4, 5, and 18].
2- Constraints related to stability; start up of the generation's units, transmission line limits, security and emission constraint or environmental constraint [6, 7, 8, 9, 16, 17, 20].

In recent years many approaches have been proposed to overcome some of these problems. Using different methods of optimization techniques and applications such

3- as genetic algorithm, neural network approach, dynamic programming, Hopfield modeling and fuzzy optimization [10, 11, 12, 13, 14, 15, and 19].

In fuzzy scheduling many published papers solve the previous categories using fuzzy approach such as, in Reference [21], system demand reserve requirements and prices of future purchase transactions are considered as fuzzy based on the symmetric approach of fuzzy optimization and the LaGrange relaxation technique, a fuzzy optimization-based algorithm is developed. In Reference [23] a fuzzy logic controlled genetic algorithm applied to power system environmental economic dispatch. Reference [23] presents a new implementation of a LP algorithm for security-constrained preventive rescheduling of real power.

All the approaches mentioned are committed to find the reliability, security, minimum emission and minimum optimal cost of the network. On the other hand the classical approaches are not as reliable in dealing with challenging conflicting objectives which had encouraged engineers to develop other methods for more reliable approaches.

Reference [24] presents (IGA-MU) approach which integrates an improved genetic algorithm (IGA) with multiplier updating (MU) to solve power economic dispatch (PED) problems of units with valve-point effects and multiple fuels. The IGA equipped with an improved evolutionary direction operator and a migration operation can efficiently search and actively explore solutions, and the MU is employed to handle the equality and inequality constraints of the PED problem. Few PED problem-related studies have seldom addressed both valve-point loadings and change fuels. To show the advantages of the proposed algorithm, which was applied to test PED problems with an example considering valve-point effects, another example considering multiple fuels, and a third example addressing both valve-point effects and multiple fuels. Additionally, the proposed algorithm was compared with previous methods and the conventional genetic algorithm (CGA) with the MU (CGA_MU), revealing that the proposed IGA_MU is more effective than previous approaches, and applies the realistic PED problem more efficiently than does the CGA_MU. Especially, the proposed algorithm is highly promising for the large-scale system of the actual PED operation.

Reference [25] proposes an approach and coding scheme for solving economic dispatch problems in power systems through simulated annealing like particle swarm optimization (SA-PSO). This novel coding scheme could effectively prevent obtaining infeasible solutions through the application of stochastic search methods, thereby dramatically improving search efficiency and solution quality. Many nonlinear characteristics of power generators, and their operational constraints, such as generation limitations, ramp rate limits, prohibited operating zones, transmission loss, and nonlinear cost functions, were all considered for practical operation. The effectiveness and feasibility of the proposed method were demonstrated by four system case studies and compared with previous literature in terms of solution quality and computational efficiency. The experiment showed encouraging results, suggesting that the proposed approach was capable of efficiently determining higher quality solutions addressing economic dispatch problems.

Load conditions change from time to time. The basic objective of economic dispatch operation of power systems is "the distribution of total generation of power in the network between various regional zones; various power stations in respective zones and various units in respective power stations such that the cost of power delivered is a minimum." In the cost of power delivered, the cost of power generation and transmission losses should be considered. It means for every load condition, the load control center should decide the following:

a) How much power is to be generated to meet the prevailing load condition to maintain constant frequency.
b) How much power should each region generate?
c) What should be the exchange of power between the regions (area)?

These aspects can be decided by the regional control center. This paper presents a novel technique to solve the economic dispatch problem of all thermal power systems, where the system states and control variables are considered fuzzy which is the case in reality. Formulas for the middle and spread of power generation and transmission losses as well as for fuzzy incremental fuel cost are derived. These fuzzy formulas are solved at different degrees of fuzziness and the results are reported in the text

2. Problem Formulation

The objective is to find the minimum value of the total cost function subject to the equality and inequality constraints.
Minimize

$$\tilde{C}_{total} = \sum_{i=1}^{NG} \tilde{C}_i = \sum_{i=1}^{NG} \tilde{\alpha}_i + \tilde{\beta}_i \tilde{P}_{Gi} + \tilde{\gamma}_i \tilde{P}_{Gi}^{\,2} \qquad (1)$$

Subject to satisfying

$$\sum_{i=1}^{NG} \tilde{P}_{Gi} \geq \tilde{P}_D + \tilde{P}_L \qquad (2)$$

$$\tilde{P}_{Gi}(\min) \leq \tilde{P}_{Gi} \leq \tilde{P}_{Gi}(\max) \quad i = 1, ...NG \qquad (3)$$

The fuzzy variable added in this case is the power losses $\tilde{P}_L = (\bar{P}_L, L_{\tilde{P}_L}, R_{\tilde{P}_L})$ dnoting the middle, left and right sides of the power losses. The total transmission losses formula is a quadratic function of the generator power output expressed as:

$$\tilde{P}_L = \sum_{i=1}^{NG} \sum_{j=1}^{NG} \tilde{P}_{Gi} B_{ij} \tilde{P}_{Gj} \qquad (4)$$

A more general formula containing linear terms is known as Kron's loss formula is:

$$\tilde{P}_L = \sum_{i=1}^{NG} \sum_{j=1}^{NG} \tilde{P}_{Gi} B_{ij} \tilde{P}_{Gj} + \sum_{i=1}^{NG} B_{0i} \tilde{P}_{Gi} + B_{00} \qquad (5)$$

Applying fuzzy interval arithmetic operations implemented by their α-Cut operation to obtain the power losses formula that include the middle, left and right sides of the triangular membership function, it becomes:

$$\tilde{P}_L(\bar{P}_L, L_{\tilde{L}}, R_{\tilde{L}}) = \sum_{i=1}^{NG} \sum_{j=1}^{NG} (\bar{P}_{Gi}, L_{\tilde{P}_{Gi}}, R_{\tilde{P}_{Gi}}) B_{ij} (\bar{P}_{Gj}, L_{\tilde{P}_{Gj}}, R_{\tilde{P}_{Gj}}) + \sum_{i=1}^{NG} B_{0i} (\bar{P}_{Gi}, L_{\tilde{P}_{Gi}}, R_{\tilde{P}_{Gi}}) + B_{00} \qquad (6)$$

Using the simplest quadratic form we get:

$$\tilde{P}_L = \sum_{i=1}^{NG} B_{ii} \tilde{P}_{Gi}^{\,2} \qquad \textbf{(7)}$$

Substituting the middle, left and right sides of the generation triangular membership function into the equation we get:

$$(\bar{P}_L, L_{\tilde{L}}, R_{\tilde{L}}) = \sum_{i=1}^{NG} (B_{ii} \bar{P}_i^{\,2}, B_{ii} L_{\tilde{P}_i}^{\,2}, B_{ii} R_{\tilde{P}_i}^{\,2}) \qquad \textbf{(8)}$$

The middle, left and right side of the equation are given as:

$$\bar{P}_L = \sum_{i=1}^{NG} B_{ii} \bar{P}_{Gi}^{\,2} \qquad \textbf{(9)}$$

$$L_{\tilde{L}} = \sum_{i=1}^{NG} B_{ii} L_{\tilde{P}_{Gi}}^{\,2} \qquad \textbf{(10)}$$

$$R_{\tilde{L}} = \sum_{i=1}^{NG} B_{ii} R_{\tilde{P}_{Gi}}^{\,2} \qquad \textbf{(11)}$$

The power generation of each unit can be calculated as:

$$(\bar{P}_{Gi}, L_{\tilde{P}_{Gi}}, R_{\tilde{P}_{Gi}})^{[k]} = \frac{(\bar{\lambda}, L_{\tilde{\lambda}}, R_{\tilde{\lambda}})^{[k]} - (\bar{\beta}_i, L_{\tilde{\beta}_i}, R_{\tilde{\beta}_i})}{2((\bar{\gamma}_i, L_{\tilde{\gamma}_i}, R_{\tilde{\gamma}_i}) + (\bar{\lambda}, L_{\tilde{\lambda}}, R_{\tilde{\lambda}})^{[k]} B_{ii})} \qquad \textbf{(12)}$$

To perform the fuzzy set arithmetic calculation then, the middle crisp, left and right value of the equation becomes:

$$\bar{P}_{Gi}^{[k]} = \frac{\bar{\lambda}_i^{[k]} - \bar{\beta}_i}{2(\bar{\gamma}_i + \bar{\lambda}_i^{[k]} B_{ii})} \tag{13}$$

$$L_{\tilde{P}_{Gi}}^{[k]} = \frac{L_{\tilde{\lambda}}^{[k]} - R_{\tilde{\beta}_i}}{2(R_{\tilde{\gamma}_i} + r_{\tilde{\lambda}}^{[k]} B_{ii})} \tag{14}$$

$$R_{\tilde{P}_{Gi}}^{[k]} = \frac{R_{\tilde{\lambda}}^{[k]} - L_{\tilde{\beta}_i}}{2(L_{\tilde{\gamma}_i} + L_{\tilde{\lambda}}^{[k]} B_{ii})} \tag{15}$$

Substituting the values of generation into the loss formula then the power losses can be calculated. The equality constraints are checked to see if they have been satisfied. If the constraints are not satisfied, then the iterative method shown in flow chart (1) is being used. Where $\sum_{i=1}^{NG} \left(\frac{\partial \tilde{P}_{Gi}}{\partial \tilde{\lambda}} \right)$ is given as:

$$\sum_{i=1}^{NG} \left(\frac{\partial \tilde{P}_{Gi}}{\partial \tilde{\lambda}} \right) = \sum_{i=1}^{NG} \left[\frac{\tilde{\gamma}_i + B_{ii} B_i}{2\left(\tilde{\gamma}_i + \tilde{\lambda}^{[k]} B_{ii} \right)^2} \right] \tag{16}$$

Replacing the fuzzy parameters with their middle, left and right sides into the equation we get:

$$\sum_{i=1}^{NG} \left(\frac{\partial(\bar{P}_{Gi}, L_{\tilde{P}_{Gi}}, R_{\tilde{P}_{Gi}})}{\partial(\bar{\lambda}, L_{\tilde{\lambda}}, R_{\tilde{\lambda}})} \right) = \sum_{i=1}^{NG} \left[\frac{(\bar{\gamma}_i, L_{\tilde{\gamma}_i}, R_{\tilde{\gamma}_i}) + B_{ii}(\bar{\beta}_i, L_{\tilde{\beta}_i}, R_{\tilde{\beta}_i})}{2\left((\bar{\gamma}_i, L_{\tilde{\gamma}_i}, R_{\tilde{\gamma}_i}) + (\bar{\lambda}, L_{\tilde{\lambda}}, R_{\tilde{\lambda}})^{[k]} B_{ii} \right)^2} \right] \tag{17}$$

The middle crisp value becomes.

$$\sum_{i=1}^{NG}\left(\frac{\partial \bar{P}_{Gi}}{\partial \bar{\lambda}_i}\right)=\sum_{i=1}^{NG}\left[\frac{\bar{\gamma}_i + B_{ii}\bar{\beta}_i}{2\left(\bar{\gamma}_i+\bar{\lambda}_i^{[k]}B_{ii}\right)^2}\right] \tag{18}$$

The left side of the power generation becomes:

$$\sum_{i=1}^{NG}\left(\frac{\partial L_{\tilde{P}_{Gi}}}{\partial L_{\lambda i}}\right)=\sum_{i=1}^{NG}\left[\frac{L_{\tilde{\gamma}_i}+B_{ii}L_{\tilde{\beta}_i}}{2\left(R_{\tilde{\gamma}_i}+R_{\tilde{\lambda}}^{[k]}B_{ii}\right)^2}\right] \tag{19}$$

The right side of the power generation becomes:

$$\sum_{i=1}^{NG}\left(\frac{\partial R_{\tilde{P}_{Gi}}}{\partial R_{\tilde{\lambda}}}\right)=\sum_{i=1}^{NG}\left[\frac{R_{\tilde{\gamma}_i}+B_{ii}R_{\tilde{\beta}_i}}{2\left(L_{\tilde{\gamma}_i}+L_{\tilde{\lambda}}^{[k]}B_{ii}\right)^2}\right] \tag{20}$$

Sine $\Delta\lambda^{(k)}$ denotes the increment of change in the incremental cost is equal to:

$$\Delta\lambda^{(k)}=\frac{\Delta\tilde{P}^{[k]}}{\sum\left(\frac{dP_{Gi}}{d\lambda}\right)^{[k]}} \tag{21}$$

Replacing the fuzzy parameters with their middle, left and right value into equation (21)

$$\Delta(\bar{\lambda},L_{\tilde{\lambda}}R_{\tilde{\lambda}})^{(k)}=\frac{\Delta(\bar{P}_{Gi},L_{\tilde{P}_{Gi}},R_{\tilde{P}_{Gi}})^{[k]}}{\sum\left(\frac{d(\bar{P}_{Gi},L_{\tilde{P}_{Gi}},R_{\tilde{P}_{Gi}})_i}{d(\bar{\lambda},L_{\tilde{\lambda}}R_{\tilde{\lambda}})}\right)^{[k]}} \tag{22}$$

The middle or crisp value will be:

$$\Delta(\bar{\lambda}_i)=\frac{\Delta(\bar{P}_{Gi})}{\sum_{i=1}^{NG}\left[\frac{\bar{\gamma}_i+B_{ii}\bar{\beta}_i}{2\left(\bar{\gamma}_i+\bar{\lambda}_i^{[k]}B_{ii}\right)^2}\right]} \tag{23}$$

The left side becomes:

$$\Delta(L_{\lambda_i}) = \frac{\Delta(L_{P_{Gi}})}{\sum_{i=1}^{NG}\left[\dfrac{R_{P_i} + B_{ii} R_{P_i}}{2\left(L_{P_i} + L_{\lambda_i}^{[k]} B_{ii}\right)^2}\right]} \qquad (24)$$

The right side becomes:

$$\Delta(R_{\lambda_i}) = \frac{\Delta(R_{P_{Gi}})}{\sum_{i=1}^{NG}\left[\dfrac{L_{P_i} + B_{ii} L_{P_i}}{2\left(R_{P_i} + R_{\lambda_i}^{[k]} B_{ii}\right)^2}\right]} \qquad (25)$$

Then calculate the new value of the incremental cost

$$\lambda^{(k+1)} = \lambda^{(k)} + \Delta\lambda^{(k)} \qquad (26)$$

Substituting the middle, left and right sides into equation (26) we get:

$$(\bar{\lambda}, L_{\lambda}, R_{\lambda})^{(k+1)} = (\bar{\lambda}, L_{\lambda}, R_{\lambda})^{(k)} + \Delta(\bar{\lambda}, L_{\lambda}, R_{\lambda})^{(k)} \qquad \textbf{(27)}$$

If the value of $\Delta\lambda^{(k)}$ is very small then the iteration is stopped and the power generation, the power losses and the total cost of all units are calculated. If it's not small then the iteration is continuing until a convergence is achieved.

3. Case Study

The iterative technique is used with a complete (ED) problem when the power losses are included into the system to find the optimal solution. In this method the initial guess of the incremental cost can be calculated for the middle, left and right side from equations (16), (17) and (18) assuming that the power losses are small and can be ignored then the iterative method will find the best equal incremental cost value. If this value does not give the optimal solution then the iterative program repeats the process until a solution is found. The power generation equation has to be modified to take into account the power losses in the network when power losses is no longer neglected and contribute to the system performance. A simulated example is used to calculate the optimal minimum cost values of the three units committed to the network. The B_{ii} loss coefficients for this example are

$$B_{ii}(pu) = \begin{bmatrix} 0.0218 & 0 & 0 \\ 0 & 0.0228 & 0 \\ 0 & 0 & 0.0179 \end{bmatrix}$$

Evaluating the results obtained using the program based on the flow chart given in chart 1, the following observations are noted:

1. In the example presented the optimal solution was found after 8 to 10 iterations for each fuzzy load for 24 hours.
2. The results shown in all the tables and graphs satisfy the constraints set to obtain a minimum solution to the objective function.
3. Different values of α, β and γ are tested to examine their effects on the total cost value. Those values are tabulated and plotted in different figures. The maximum, minimum range of the total cost increases when the value of α, β and γ increases and decreases when those value decreases, which is the nature of the quadratic equation of the cost function.
4. Comparing the minimum total cost results obtained with 3% deviation for α, β and γ with the result obtained in Table (1) the crisp value is higher in the transmission power losses procedure, which proves that when considering power losses the overall economy of the system will be affected including the upper and lower limits of the minimum cost value. The extra cost value is a result of increased power generation to balance the equality constraint set in equation (2) to compensate the power losses in the transmission line.
5. The power losses were kept as low as possible and the variations of the power losses hour by hours were tabulated and plotted. This in fact is a great asset to the command and control center to know all this information variation on line and hour by hour.

4. Conclusion

This paper provides a new algorithm for solving the economic dispatch problem of all thermal power system, where, the variations of load are assumed as fuzzy, that make the output generation of each unit, the system power losses and the total network cost become fuzzy. This fuzziness provides the load control center with valuable information, which is listed below:

- The 10% fuzzy load deviation presented gives a range of security knowledge assessment to the load control center. Knowing the minimum and maximum generation needed to compensate the load variation which occurs at each hour in question can be a great asset to the command and control engineer. If this variation cannot be supplied by the unit committed to the network, then more units can be brought in to overcome the sudden variation.
- The maximum, minimum and middle cost variation at each hour is calculated. This give the company supplying the load an optimal minimum cost generation of each unit and the total cost of all units for that particular load variation at the hour in question. This information is very helpful in decision making for the company

supplying the load to the consumer. The company can decide weather to supply it if it is not costly or buy it from another company interconnected with the network.

- The variation of the cost function parameters can effect the over all performance of the network including the total cost. This mean the companies have to be very careful in choosing the right unit that has the best cost function parameters to commit into the network to reduce the maximum and minimum cost value.
- The power loss information is very helpful to the sub-station control room where the reactive power flow is minimized through transmission lines by compensation to minimize line losses and to maintain a stable voltage level.

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Table (1) ***Membership Function of Total Cost*** **for (0, 0.5, 0.75, 1)** α **-Cut Representation for Model "A" Weekdays With 10% Deviation for** (P_D) **and 3% for** (α, β, γ)

Membership Function	$\mu_C = 0$			$\mu_C = 0.5$			$\mu_C = 0.75$			$\mu_C = 1$		
Daily Hours	Left Cost $/h	Mid Cost $/h	Right Cost $/h	Left Cost $/h	Mid Cost $/h	Right Cost $/h	Left Cost $/h	Mid Cost $/h	Right Cost $/h	Left Cost $/h	Mid Cost $/h	Right Cost $/h
1	10605	12635	14904	11592	12635	13738	12106	12635	13179	12635	12635	12635
2	9232.6	10943	12843	10142	10943	11781	10558	10943	11336	10943	10943	10943
3	8496	10041	11750	9355	10041	10754	9709	10041	10380	10041	10041	10041
4	7685.5	9051	10555	8463	9051	9659	8762	9051	9345	9051	9051	9051
5	7061	8292	9643	7771	8292	8828	8033	8292	8554	8292	8292	8292
6	7669.4	9032	10532	8457	9032	9624	8744	9032	9324	9032	9032	9032
7	8169.3	9642	11267	9021	9642	10283	9330	9642	9959	9642	9642	9642
8	8905.2	10541	12356	9848	10541	11258	10192	10541	10896	10541	10541	10541
9	11119	13271	15682	12349	13271	14230	12806	13271	13745	13271	13271	13271
10	12007	14375	17038	13356	14375	15436	13860	14375	14900	14375	14375	14375
11	11912	14256	16892	13248	14256	15306	13747	14256	14776	14256	14256	14256
12	12850	15425	18331	14313	15425	16586	14863	15425	15999	15425	15425	15425
13	12486	14972	17774	13901	14972	16090	14431	14972	15525	14972	14972	14972
14	11790	14105	16705	13110	14105	15140	13602	14105	14617	14105	14105	14105
15	11094	13240	15644	12321	13240	14195	12776	13240	13713	13240	13240	13240
16	10516	12525	14769	11667	12525	13415	12092	12525	12966	12525	12525	12525
17	10307	12267	14454	11431	12267	13134	11845	12267	12696	12267	12267	12267
18	10550	12567	14821	11706	12567	13461	12133	12567	13010	12567	12567	12567
19	11503	13748	16267	12785	13748	14750	13261	13748	14244	13748	13748	13748
20	10880	12976	15321	12080	12976	13907	12523	12976	13437	12976	12976	12976
21	11053	13190	15583	12275	13190	14140	12728	13190	13660	13190	13190	13190
22	12044	14421	17094	13398	14421	15486	13904	14421	14948	14421	14421	14421
23	11663	13947	16512	12967	13947	14968	13452	13947	14452	13947	13947	13947
24	10531	12543	14792	11685	12543	13435	12110	12543	12985	12543	12543	12543

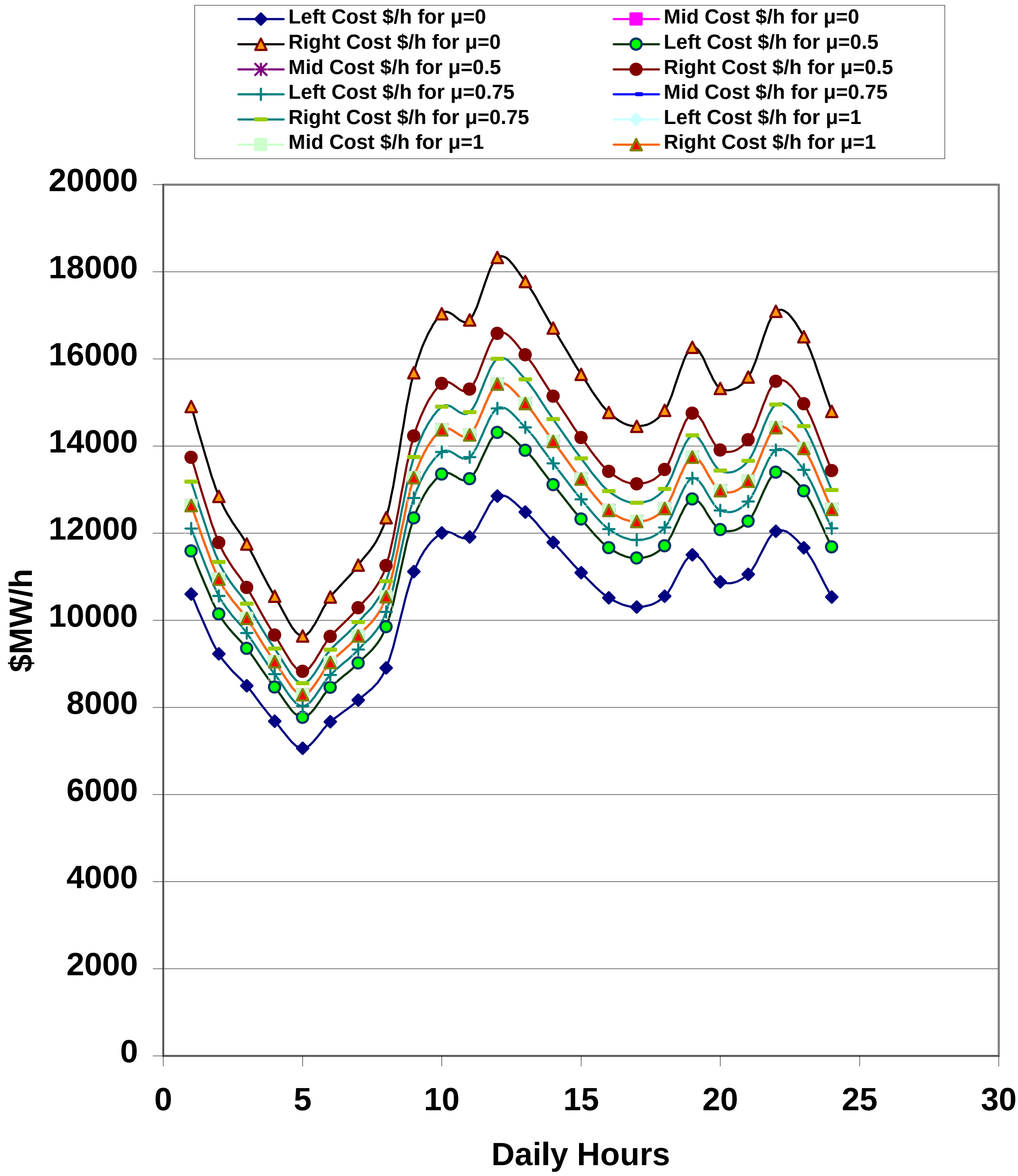

Figure (1) Fuzzy Min Total Cost for All α -Cut Representation