Study on Economic, Rapid and Environmental Power Dispatch

Based on Fuzzy Multi-objective Optimization

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Abstract

Environmental awareness and the recent environmental protecting policies have extremely spurred many electric utilities to regulate their practices to account for the emission impacts. One way to accomplish this is by reformulating the traditional Economic Load Dispatch (ELD) module merely with a view to minimal coal consumption of fossil fired units. This paper presents a triple-objective ELD model which consists of the minimal coal consumption, the best time for the unit commitment response and the economic emission index. The rapid/economic/environmental dispatch problem is a multi-objective non-linear optimization problem with constraints. The fuzzy theory is adopted to convert the multi-objective problem into the single-objective problem. The problem is been tackled through dynamic programming algorithm and the approach is tested on a four-unit system to illustrate the analysis process in present analysis. Results simulated through MATLAB show that the approach has great potential in handling multi-objective optimization problem.

Keywords: Economic dispatch, Fuzzy method, Dynamic programming

1. Introduction

Recent years, many researchers stress on the economic statistics of the load optimal dispatching. The mathematical decision makings based on the economic index ensures the economical efficiency whereas ignores the rapid response on the varying loads. The committed generators in a power network operating at absolute minimum cost can no longer be the only criterion for dispatching electric power due to the increasing concern about the environmental protection. The generation of electricity from fossil fuel releases several contaminants, such as sulfur dioxide, nitrogen oxide and carbon dioxide into the atmosphere. Nowadays, environment constraints have topped the list of utility management concerns (Xuebin Li, 2009, pp.789-795).

The approach of minimizing the fuel cost and rapid response for the varying loads has been discussed in some dissertations. The disadvantage about this approach is that the introduced method of weighted makes it possible that the complicate computation and multiple subjective factors which causes the ambiguous optimum solutions. Economic/environmental/rapid dispatch is a multi-objective problem with conflicting objectives because pollution minimization is conflicting with minimum cost of generation. Various techniques have been proposed to solve this problem. Nanda et al (Nanda, 1988, pp.26-32).was one of the first approaches to solve the Economic/environmental dispatch problem considering multi-objective optimization using linear and non-linear goal programming techniques . An ε-constrained technique was used by Yokoyama et al (R.Yokoyama, 1988, pp.317-324).

One approach to solve the triple-objective (rapid response, economic, environmental) is presented in this paper. The mathematical optimal model is constructed through fuzzy multi-objective theory which leads to a feasible and objective counter measure. The separate goal concords with the integrate ones. The idea behind the fuzzy optimal model is to find the junction of the satisfaction with the consideration of every individual goal. Finally, the problem is solved with conventional optimal methods and the advantage is shown in this paper.

2. Problem description

Multi-objective programming is used to solve the minimax problem for the multiple numerical objective functions simultaneously with the condition of the engaged constraints. In many realistic problems, several goals must be simultaneously satisfied to obtain an optimal solution .However, sometimes these multiple objectives, which must be

simultaneously satisfied, conflict. The multiple-objective optimization method is the common approach to solve this type of problem. The conventional multi-objective problem (MOP) is formulated as follows:

$$\left.\begin{array}{l} opt\ \mathrm{f(x)}=[f_1(x)=z_1, f(x)=z_2....f_p(x)=z_p]^{\mathrm{T}} \\ \qquad subject\ to\ x \in \Omega \\ \qquad s.t\quad g_i(x) \geq 0 \\ \qquad\qquad h_j(x)=0 \end{array}\right\} \tag{1}$$

Where solution x is a vector of discrete decision variables, Ω is the finite set of feasible solutions. The image of a solution $x \in \Omega$ is the point z=f(x) in the objective space. Where $g_i(x)$ and $h_j(x)$ is the nonlinear and linear constraints. The solutions that are non-dominated within the entire search space are denoted as Pareto-optimal solutions and constitute the Pareto-optimal set or Pareto-optimal frontier.

It is difficult to handle with that the discrete goal is conflict with each other. Accordingly, the multi-objective problem sometimes transformed into single-objective problem. The method of weighted is widely used during the reforming process which depends on the selection of the subjective factors and the settlement of the dimensionless variables besides. The fuzzy theory is introduced in this paper so as to figure out this type of knotty challenges.

2.1 Fuzzy mathematical model

$$\left.\begin{array}{l} x = [x_1, x_2,...x_n]^T \in \Omega \\ \qquad \min\ f(x,\omega) \\ s.t\quad g_u(x,\omega) \subset G_u \qquad u = 1,2,...,m \\ \qquad \omega = [\omega_1, \omega_2,...\omega_k]^T \in \Omega \end{array}\right\} \tag{2}$$

Where x is the designed variable vector, ω is the fuzzy parameter vector, Ω is the fuzzy domain. Every single objective function is converted to a forged objective function which is represented by the membership function denoted by ufi(x)The membership function is one to one correspondence with the goal function, Where $ufi(x) \in [0,1]$ represents the satisfying degree with the individual goal. λ is selected as the minimum value which is served as the auxiliary variable. If the mean value is found, it can be defined as the total satisfying degree among the forged membership functions.

2.2 MOP fulfilling Steps

Hence the basic ideology and detail resolving steps for the MOP is shown as follows:

(1) Resolving the constraint maximum and minimum value (M and m)of the sub-objective function.

(2) Fuzzy processing every sub-objective function

$$u_{f_i}(x) = \left(\frac{M - f_i(x)}{M - m}\right)^q \tag{3}$$

(3) Construct the fuzzy decision-making

$$D(X) = \bigcap_{i=1}^{n} f(x) \tag{4}$$

$$u_D(X) = \min\{u_{f_i}(x),...,u_{f_n}(x)\} \tag{5}$$

(4) Resolving the optimum solution and get the maximum value for the membership function.

$$u_D(X^*) = \max \min\left[u_{f_i}(x),...u_{f_n}(x)\right] \tag{6}$$

(5) So by making use of the mathematical manipulation, the MOP problem is transferred into the SOP(single objective problem), it can be mathematically stated as follows:

$$\left.\begin{array}{l} \qquad \max\ \lambda \\ s.t.\ u_{f_i}(x) \geq \lambda,\ i=1,2,...n \\ \qquad\quad 0 \leq \lambda \leq 1 \\ \quad g_i(x) \leq 0,\ j=1,2,...n \\ \quad X = \left[x_1, x_2,...x_n, \lambda\right]^T \end{array}\right\} \tag{7}$$

3. Mathematical model for the MOP

3.1 Economic dispatch

The proposed approach can accommodate non-quadratic (high order) fuel cost and multiple emission of differentiable nature objective function. The classical economic dispatch problem of finding the optimal combination of power generation which minimizes the total fuel cost while satisfying the total demand, it can be shown as follows(C.Palanichamy, 2008, pp.1129-1137):

$$F_T = \sum_{i=1}^{n} (a_i p_{Gi}^2 + b_i p_{Gi} + c_i) \quad \$/h$$

(8)

Where: F_T total fuel cost (\$/h); P_{Gi}: generation of unit i (MW),a_i, b_i, c_i: fuel cost coefficient of unit i; and n: number of generation units. The economic dispatch problem is optimized subject to:

(i) Power balance constraint: the total power generated must supply total load demand and transmission loss.

$$\sum_{i=1}^{n} p_{Gi} = P_D + P_L \quad MW$$

(9)

Where P_D: total load demand (MW) and P_L: total transmission loss (MW)

(ii) Unit capacity constraint: the power generated P_{Gi} by each generator is constrained between its minimum and maximum limits, i.e

$$P_{Gi\,min} \leq p_{Gi} \leq p_{Gi\,max}$$

Where P_{Gimin}: minimum generation limit, and P_{Gimax}: maximum generation limit

3.2 Emission dispatch

The emission dispatch problem is defined as the following optimization problem, subject to the power balance and unit capacity constraints. Sulfur dioxide and nitrogen oxide emissions have taken into account, but carbon dioxide is ignored in this paper.

$$E_T = \sum_{i=1}^{n} (d_i p_{Gi}^2 + e_i p_{Gi} + f_i) \quad kg/h$$

(10)

Where E_T: total emission (kg/h); P_{Gi}: generation of unit i(MW); di,ei,fi: emission coefficient of unit i: and n number of generating units.

3.3 Time dispatch

Considering the quick variable-load for the unit generation, the concept of the temporal summation of the quick variable-load for multiple units is introduced in this paper. If the load increment of the unit generation is given, the load should be changed as fast as possible so as to accomplish the mission of peak regulation, subject to the rate of variable-load for unit generation constraints, can be mathematically stated as follows (Peiyan Feng, 2007, pp.11-15):

$$Q_T = \min \Delta T = \min \sum_{i=1}^{n} (\Delta p_i / V_i) \quad 0 \leq V_i \leq V_{i\,max}$$

(11)

3.4 Fuzzy processing of the sub-objective function

It is troublesome to determine the membership function of the fuzzy parameter during the working process. Thus, dualistic contrast composition and fuzzy statistical method is adopted generally (Panos Y. Papalambros, 2000, pp.20-25). If the data is efficiency, a approximate membership function which represent the transformation process from the may be used. Considering the Energy Saving & Emission Reduction, the lower semi-trapezoid curve represents the membership function. While the upper semi-trapezoid curve represents the membership function because the variable-load time is in inverse proportion to the load rate. The membership function is shown as follows separately.

$$u_{f1} = \begin{cases} 1 & F \leq F_{min} \\ \dfrac{F_{max} - F}{F_{max} - F_{min}} & F_{min} < F < F_{max} \\ 0 & F \geq F_{max} \end{cases}$$

(12)

$$u_{f2} = \begin{cases} 1 & E \leq E_{min} \\ \dfrac{E_{max} - E}{E_{max} - E_{min}} & E_{min} < E < E_{max} \\ 0 & E \geq E_{max} \end{cases}$$

(13)

$$u_{f3} = \begin{cases} 0 & V \le V_{min} \\ \dfrac{V - V_{max}}{V_{max} - V_{min}} & V_{min} < V < V_{max} \\ 1 & V > V_{max} \end{cases}$$

(14)

3.5 Model of fuzzy multi-objective problem

According the fuzzy theory, the corresponding solution of the maximum λ value is the optimal solution for the MOP.

$$\lambda = \min\left\{u_{f1}(x), u_{f2}(x), u_{f3}(x)\right\}$$

(15)

$$\max \lambda = \max \min\left\{u_{f1}(x), u_{f2}(x), u_{f3}(x)\right\}$$

(16)

The model can be mathematically stated as follows:

$$\left.\begin{array}{l} \max \lambda \\ \lambda \le u_{f1}(x) \\ \lambda \le u_{f2}(x) \\ \lambda \le u_{f3}(x) \\ s.t. \quad p = \sum_{i=1}^{n} p_i \\ p_{min} \le p_i \le p_{max} \\ 0 \le V_i \le V_{i\,max} \\ 0 \le \lambda \le 1 \end{array}\right\}$$

(17)

4. Introduction of the dynamic programming algorithm

Dynamic programming algorithm used in the optimal solution of a certain nature (Liang tong, Li, 2003, pp.9-11). In such matters, there may be many feasible solutions. Each solution corresponds to a point; we hope to find a solution with the optimal value. Dynamic programming algorithm with sub-rule method is similar to the basic idea is to solve the problem to be broken down into several sub-questions, the first sub-problem solving, and then from the sub-problem of the solution in the solution of the original problem. With different sub-rule method is suitable to use dynamic programming to solve the problem, the decomposition of sub-questions have been often mutually independent. If sub-rule method is used to solve such problem, the problem is decomposed to be a subset of number, some sub-questions were double-counting of a lot of times. If we can save a sub-problem resolved the answer, and again when necessary to identify the answer has been obtained, so many double-counting could have been avoided. We can use a table to record all of the sub-solution answers to these questions. Regardless of the sub-problem used, as long as it was calculated that the results will populate the table. This is the basic idea of dynamic programming method. Specific dynamic programming algorithm shows a diversity of practice, but they have the same format to fill in a form

5. Case study

The four-generating unit system is used in this paper to demonstrate the dynamic programming approach. The fuel cost and emission coefficient of four generating is shown in table 1.

Simulation results:

The initial load of the four-units is 200MW, 220MW, 380MW and 360MW respectively. According to the different type of compound modes, 1 unit, 2 units, 3 units and 4 units complete the mission peak separately from the four units. Due to the space limitation, only two types of compound modes is discussed in this paper. The analytical results can be illustrated through bar graphics as Figurer1-6.

6. Conclusion

(1)   The fuzzy decision making method is as easy as linear weighted method on constructing a single objective function. Hence, the programming approach of single objective problem may be naturally adopted on the MOP.

(2)   The multi-objective design method is simple and practical. It is a recommend way to resolve the MOP which the coal consumption, emission and variable-load time is mutually conflict. Therefore, a utopia solution is easy to obtain amongst the tradeoff ones.

(3)   According to the analysis of simulation result, the coal consumption of MOP is higher than the SOP. Whereas the variable-load time gets a sharp decrease. Meanwhile, exhausted pollutants get a gratifying decrease. Generally speaking,

the fuzzy multi-objective method is more satisfactory the single-objective method accounting for the coal consumption.

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Table 1. Fuel cost coefficients and emission coefficient (SO_2,NO_X)

$Generator_i$	a_i	b_i	c_i	d_i	e_i	f_i	p_{min}	p_{max}	v_i
G_1	0.003689	-2.26605	655.3730	0.00607	-2.28070	539.9171	180	350	5
G_2	0.00048	-0.40192	397.0223	-0.0508	28.59314	-3107.297	180	300	8
G_3	-0.00008	0.01882	338.7645	0.0058	-5.08329	1585.924	300	625	10
G_4	0.000126	-0.131228	357.1300	-0.0121	14.89956	-3363.239	305	600	15

Figure 1. Variable-load Time Contrast Simulation Results of One from Four Modes

Figure 2. Coal Consumption Rate Contrast Simulation Results of One from Four Modes

Figure 3. Emission Contrast Simulation Results of One from Four Modes

Figure 4. Coal Consumption Rate Contrast Simulation Results of Two from Four Modes

Figure 5. Variable-load Time Contrast Simulation Results of Two from Four Modes

Figure 6. Emission Contrast Simulation Results of Two from Four Modes