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A New Model of Economic Dispatch Considering Energy Conservation and Environmental Protection in Electricity Market

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Abstract

The power system economic dispatch model was improved, which only considered the feathers of cost and emission. The conception of energy conservation factor is suggested. Established a new model of economic dispatch considering energy conservation and environmental protection in electricity market, then, used it in a simulation system to verify its effectiveness. The new model gives a preliminary exploration and attempt on the implementation of the energy conservation power generation dispatch.

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Keywords- Electricity Market; Economic Dispatch; Energy Conservation Dispatch; Energy Conservation Factor

1. Introduction

On the field of electric power system and its automation, the electric power system dispatch is a typical problem of optimal allocation of resources theory and engineering. It is one of the branches which leads the mathematics, applied mathematics and numerical calculation, and be compatible with theories of management and economics.

Since the 1990s, the theoretical system of dispatch has been developed to a very mature theory. We can learn the history and progress of the electric power system dispatch theory from the monographs by Erkeng Yu, Wenyuan Li, Wood&Wollenberg, and other professors[1-4].

With the deepening of the electric power industry's market-oriented reform process, the electric power system dispatch theory gradually moving to the electricity market-based economic dispatch problem. In these years, the significant progress is made in the electricity market structure, economic system, trading tools, optimization theory and practice [5-8].

In recent years, the research on electric power system dispatch is focus on many issues, such as demand side response, environmental protection, risk, clean energy, microgrid and so on[9-14].

Energy conservation power generation dispatch method[15] was proposed by the Development and Reform Commission and other Related departments in 2007, it means the electric power system dispatch entered a new phase. There are some discusses on the problems and suggestions through the process of the method's implementation[16,19].

Under the market-oriented environment, the research on electric power system dispatch must take into account the organic links between the supply of exhaustible resources and the utilization of Renewable resources, for the healthy and harmonious operation of electric power system.

2. New model of economic dispatch

2.1 Objective function

The traditional economic dispatch model considers only the cost and emissions factors and energy factors not taken into account. For this reason, a new model of economic dispatch considering energy conservation and environmental protection in electricity market is established.

$$f = [f_c, f_e, f_k]$$ (1)

The parameters f_c, f_e, f_k denote respectively the cost function, the NO_x emissions function, and the energy conservation factor. Details are as follows.

1)   *The cost function*

In the electricity market, the power generation enterprises may use different bidding strategies at different load levels and different times. The bidding curves could be various forms. Therefore, to the power grid, the curve shape of the cost for purchasing electricity should be in various types accordingly. The cost function in the new economic dispatch model is represented as follows.

$$f_c = \sum_{t=1}^{T} \sum_{i=1}^{n} C_i(P_{i,t}) \cdot P_{i,t} I_{i,t}$$ (2)

It is the objective function for the minimum cost based on all power generation enterprises' actual bid price. In the equation (2), i is the number of the generator which bid in the electricity market. If there are n generators in the market, then i could be valued from 1 to n. And t for the time; T for the trading cycle; $P_{i,t}$ for the active power of generator i in time t. $C_i(P_{i,t})$ is the bid curve made by generator i in time t, which is a function of the active power $P_{i,t}$ and the time t, and is different from one another according to the bid curve of different generator. $I_{i,t}$ represents the status of generator i in time t, which equals to 1 if the generator i is running in time t, or equals to 0 if the generator is off at that time.

2)   *The NO_x emissions function*

To minimize the polluting gas emissions, the emissions function is represented as follows.

$$f_e = \sum_{t=1}^{T} \sum_{i=1}^{n} [\alpha_i + \beta_i P_{i,t} + \gamma_i P_{i,t}^2] I_{i,t}$$ (3)

Characteristics of the NO_x emissions is expressed by quadratic curve, and α_i, β_i, γ_i are constant coefficients in quadratic curve of generator i.

3) The energy conservation factor

In the traditional economic dispatch model, only two targets were considered, the purchase cost and the NO_x emissions, without the energy factors.

The principle of energy conservation dispatch is raised in the energy conservation power generation dispatch method[10]. The energy conservation dispatch should strive to per unit of energy production in the least energy consumption and pollutant emissions, by ranking all generators in a province or area at its levels of energy consumption and pollutant emissions.

The implementation of the energy conservation dispatch, should consider the construction of the electricity market and give full play to the role of it, while ensuring energy saving, environmental protection, security and stability of the power system operation and continuous power supply. So the energy conservation factor is proposed to take account of the important optimization goal, energy conservation, which has used the sequence of ranked generators.

The expression of energy conservation factor as follows.

$$f_k = \sum_{t=1}^{T} \sum_{i=1}^{n} \theta_i P_{i,t} \tag{4}$$

θ_i is the energy coefficient of generator i, which be numerically equal to the sort number of generator i in all n generators.

2.2 Constraints

1) Power balance constraints

$$\sum_{i=1}^{n} P_{i,t} I_{i,t} = P_{D,t} + P_{L,t} \tag{5}$$

$P_{D,t}$ is the total load of the power system at time t, $P_{L,t}$ is the loss of active power at time t.

2) Generator output power limit constraints

$$I_{i,t} \cdot P_{i,\min} \leq P_{i,t} \leq I_{i,t} \cdot P_{i,\max} \tag{6}$$

$P_{i,min}$ and $P_{i,max}$ are respectively the minimum and maximum output of generator i.

3) Spinning reserve constraints

$$\sum_{i=1}^{n} S_{i,t} I_{i,t} \geq S_{r,t} \tag{7}$$

$S_{i,t}$ represents the spinning reserve provide by the generator i at time t, and $S_{r,t}$ represents the total amount of spinning reserve requirements.

4) Minimum on and off duration constraints

$$(V_{i,t}^{on} - T_i^{\min-on})(I_{i,t-1} - I_{i,t}) \geq 0$$

$$(V_{i,t}^{off} - T_i^{\min-off})(I_{i,t} - I_{i,t-1}) \geq 0 \tag{8}$$

$V_{i,t}^{on}$ and $V_{i,t}^{off}$ are respectively the on and off duration of generator i in the time t; T_i^{min-on} and $T_i^{min-off}$ are respectively the minimum on and off duration of generator i.

5) Generator's power changing speed constraints
6)

$$r_{di}\Delta t \leq P_{i,t} - P_{i,t-1} \leq r_{ui}\Delta t \tag{9}$$

r_{ui} and r_{di} are the maximum allowable power output rise and fall speed per minute of the generator i; $\triangle t$ is the continuation of a period of time.

7) Generator's spinning reserve changing speed constraints

$$S_{i,t} I_{i,t} \leq S_{i\max}\Delta t \tag{10}$$

S_{imax} is the maximum response speed of the spinning reserve of the generator i.

3. Model Solution

In the multi-objective decision making of considering the energy conservation, environmental protection and economic in general, there is no absolute optimal solution, and the decision-making result is closely associated with the subjective preferences of decision-makers. The interactive decision making method can fully reflect the subjective views of policy makers, which is strong practical for multi-objective decision making[20,21].

Reference[22] proposed a double objective fuzzy optimization strategy. Firstly, the two single-objective deterministic models were solved for their respective objective function value. Secondly, stretching the target values to a certain extent and defining the objective function's membership function, thus the deterministic problem is fuzzified. Finally, using the maximum fuzzy satisfying method to transform the multi-objective problem into single-objective nonlinear problems, and then solve them.

This method is applied to sole the proposed new model of economic dispatch considering energy conservation and environmental protection in electricity market.

3.1 Fuzzyfy the objective functions

The key of Modeling is determining the membership function. The objective of model is to give full consideration to energy conservation, lower purchase costs, and reduce environmental pollution, which meet all the constraints at the same time. So we should lower the cost, NO_x emissions and energy factors as far as possible. The lower semi-linear is selected for the membership function, so the membership function of the three optimization objectives should be respectively equation (11), (12) and (13), and be shown in figure 1.

$$\mu(f_c(x)) = \begin{cases} 1 & f_c(x) \le c_{01} \\ \dfrac{c_{01} + \delta_{01} - f_c(x)}{\delta_{01}} & c_{01} < f_c(x) \le c_{01} + \delta_{01} \\ 0 & f_c(x) > c_{01} + \delta_{01} \end{cases} \quad (11)$$

$$\mu(f_e(x)) = \begin{cases} 1 & f_e(x) \le c_{02} \\ \dfrac{c_{02} + \delta_{02} - f_e(x)}{\delta_{02}} & c_{02} < f_e(x) \le c_{02} + \delta_{02} \\ 0 & f_e(x) > c_{02} + \delta_{02} \end{cases} \quad (12)$$

$$\mu(f_k(x)) = \begin{cases} 1 & f_k(x) \le c_{03} \\ \dfrac{c_{03} + \delta_{03} - f_k(x)}{\delta_{03}} & c_{03} < f_k(x) \le c_{03} + \delta_{03} \\ 0 & f_k(x) > c_{03} + \delta_{03} \end{cases} \quad (13)$$

In the equation (11) ~ (13), $x= [P_{1,t} \ P_{2,t} \ … \ P_{n,t}]^T$. In Figure 1, $c+\delta$ represent the maximum acceptable purchasing cost, NO_x emissions or energy conservation factor. The parameters c_{01}, c_{02} and c_{03} are the target values of the cost single-objective optimization model, the total NO_x emissions single-objective optimization model and the energy conservation factor single-objective optimization model. On this basis, the domains of three objective functions are determined.
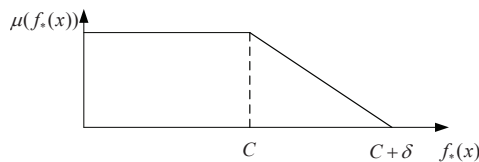
Figure 1. Membership functions

3.2 Multi-objective fuzzy optimization model

Being fuzzified, the solution of Equation (1) is transformed into the problem of maximizing the degree of membership (i.e. satisfaction λ), which can meet the three objectives and all constraints, that is the problem M of minimizing the $-\lambda$. It can be expressed as follows.

$$\min - \lambda \qquad (14)$$

$$s.t. \qquad f_c(x) + \delta_{01}\lambda \le c_{01} + \delta_{01} \qquad (15)$$

$$f_e(x) + \delta_{02}\lambda \le c_{02} + \delta_{02} \qquad (16)$$

$$f_k(x) + \delta_{03}\lambda \le c_{03} + \delta_{03} \qquad (17)$$

$$0 \le \lambda \le 1 \qquad (18)$$

Equation (5) ~ (10)

3.3 The process of solving

Step 1: Enter the raw data to solve the single-objective deterministic model for the minimum cost. Calculate the purchasing cost c_{01} at each time period, the total NO_x emissions $c_{02}[1]$, the energy conservation factor $c_{03}[1]$, the result of unit commitment, and the active power of every generator.

Step 2: Enter the raw data to solve the single-objective deterministic model for the minimum emissions. Calculate the NO_x emissions c_{02} at each time period, the total purchasing cost $c_{01}[2]$, the energy conservation factor $c_{03}[2]$, the result of unit commitment, and the active power of every generator.

Step 3: Enter the raw data to solve the single-objective deterministic model for the minimum energy conservation factor. Calculate the energy conservation factor c_{03} at each time period, the total purchasing cost $c_{01}[3]$, the NO_x emissions $c_{02}[3]$, the result of unit commitment, and the active power of every generator.

Step 4: On the basis of step 1~3, stretch the single targets, namely to determine δ_{01}, δ_{02}, δ_{03}, thus fuzzify the deterministic problem.

The method to determine δ_{01} is to keep the value of $c_{01}+\delta_{01}$ larger than c_{01} but smaller than $c_{01}[2]$ and $c_{01}[3]$. The methods for δ_{02} and δ_{03} are similar.

$$c_{01} < c_{01}+\delta_{01} < c_{01}[2], \quad c_{01} < c_{01}+\delta_{01} < c_{01}[3]$$
$$c_{02} < c_{02}+\delta_{02} < c_{02}[1], \quad c_{02} < c_{02}+\delta_{02} < c_{02}[3]$$
$$c_{03} < c_{03}+\delta_{03} < c_{03}[1], \quad c_{03} < c_{03}+\delta_{03} < c_{03}[2]$$

If the requirements to the energy-saving factors, environmental factors or economic factors are different, the stretching target could be selected at different levels. Theoretically, the smaller δ_{01}, δ_{02} and δ_{03} are, the better those factors are, but the difficulty to solve them will increase accordingly.

Step 5: Put the parameters c_{01}, δ_{01}, c_{02}, δ_{02}, c_{03} and δ_{03} into equation (15) ~ (17) respectively, the membership function expression can be drawn.

Step 6: Transform the multi-objective problem into the single objective nonlinear problem M by maximizing satisfaction.

Step 7: Solve the problem *M*, and then get the greatest satisfaction at each time period, the unit commitment, and the power output of every generators.

3.4 Simulation and result analysis

There are six generators in the simulation system, and the calculation cycle is divided into 24 periods, some parameters of which are taken from [23]. To simplify the calculation of simulation, that the active power losses have been credited to the load, and the bidding curve was selected as the function $c_i(P_{i,t})=a_iP_{i,t}+b_i$. The bidding curves are same at various periods. The parameters and the required load are shown in table I to III.

Table 1. Parameters of generators (1)

No.	Constant coefficient in the bidding function ($/MWh)		NO$_X$ emissions (10^{-6}t/h)			Output limit (MW)	
	a_i	b_i	γ_i	β_i	α_i	$P_{i,min}$	$P_{i,max}$
1	2.12	1801.5	6.490	-5.5540	4.091	50	150
2	2.61	1535.4	5.638	-6.0470	2.543	75	280
3	2.89	1264.3	4.586	-5.0940	4.257	120	320
4	1.48	1213.0	3.380	-3.5500	5.326	125	445
5	1.27	1195.4	4.586	-5.0940	4.258	250	520
6	1.35	1128.5	5.155	-5.5555	6.130	250	550

Table 2.Parameters of generators (2)

No.	T_i^{min-on} (h)	$T_i^{min-off}$ (h)	r_{ui} (MW/min)	r_{di} (MW/min)	S_{imax} (MW/min)	θ_i
1	3	3	0.750	0.750	0.750	6
2	5	5	1.400	1.400	1.400	5
3	5	5	1.600	1.600	1.600	3
4	8	8	2.225	2.225	2.225	4
5	8	8	2.600	2.600	2.600	1
6	8	8	2.750	2.750	2.750	2

Table3.Loads and reserves during operation

Period	Load (MW)	Reserve (MW)	Period	Load (MW)	Reserve (MW)
1	2000	140	13	1300	84
2	1980	139	14	1260	81
3	1940	136	15	1240	80
4	1900	133	16	1260	81
5	1840	129	17	1260	88
6	1870	131	18	1380	97
7	1820	127	19	1560	109
8	1700	119	20	1700	119
9	1510	106	21	1820	127
10	1410	99	22	1900	133
11	1380	92	23	1950	138
12	1300	88	24	1990	139

　　　Simulated by Matlab, the target values of the tri-objective fuzzy optimization, the dual-objective optimizations, the single-objective optimizations and their comparison listed in Table IV. Figure 2 shows the load distribution of every generator in the various optimizations.

Table 4.The target values comparison

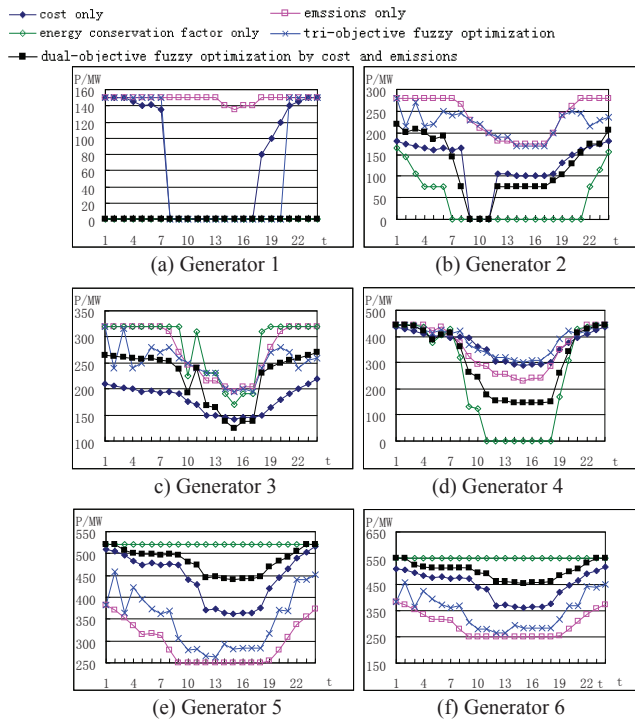| Target	Cost ($)	Emissions (t)	Energy conservation factor
Cost only	70603	65.7634	106913
Emissions only	71126	51.6469	125439
Energy conservation factor only	74609	84.7161	87500
Dual-objective fuzzy optimization	70696	56.4024	106117
Tri-objective fuzzy optimization	71083	57.6402	91792

Figure2. The output power curves by each optimization objective

　　　Compared with the target values by the single-objective optimizations and the dual-objective optimizations, the tri-objective fuzzy optimization's result has obvious advantages. Its cost for power purchase has 5.47% increase, and the NO_x emissions only increase 2.19%, but the energy conservation factor has 13.50% lower, which fully reflects the balance between energy conservation, environmental protection, and economic.

5. Conclusion

　　　After simulation, the results comparison between the new model with the single objective optimization model and the traditional model of economic dispatch and its analysis proved that the dispatch model is

improved. The new model of economic dispatch considering energy conservation and environmental protection in electricity market is comprehensive well in energy conservation, environmental protection, and economic. It provides technical support to the implementation of energy conservation dispatch and the efficient use of energy.

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