The Dispatch Optimization Model for Hydro-thermal Power Units Based on Multi-objective CVaR Method

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Abstract: For achieving the market targets of improving efficiency, reducing costs, optimizing resources allocation and protecting environment, solving cost differences of different power plants and seasonal difference of hydropower because of history and so on, providing fair competitive environment for every power plants, achieving the goals of more hydropower output, improving utilization of large capacity and low emissions units, reducing pollutant and resources consuming, building hydro-thermal power replacement market is a great solving program. This also can balance the interests of all parties, and promote power upgrading of industrial structure. Because hydropower units' generation is constrained by the amount of inflow water, so it makes hydro-thermal scheduling have great uncertainty. Therefore, we need optimize hydro-thermal scheduling through related risk control tools. The paper constructs hydro-thermal power replacement model based on multi-objective CVaR theory. The paper also compares some nature of hydro-thermal power units generation replacement optimization by using VaR and CVaR.

Keywords: HYDRO-THERMAL POWER, REPLACEMENT, CVaR THEORY

1. Introduction

Hydro-thermal power replacement needs to consider various indicators effectiveness of unit output arrangement scheme in the energy saving and low cost targets. In these indicators effectiveness, hydropower units' integrated power performance value have a higher rank, so we need make hydropower on the grid for achieving many goals. However, hydropower units' generation is constrained by the amount of inflow water after guaranteed living water and industrial process water, and arranging waterproof generation [1]. Reservoir' inflow water which is influenced by seasons and periods isn't fixed value, so it makes hydro-thermal scheduling have great uncertainty. Therefore, we need optimize hydro-thermal scheduling through related risk control tools, and the paper builds hydro-thermal generation replacement model by applying multi-objective CVaR theory [2].

Hydropower generation cost is relatively low, thermal power plant annual operating costs approximately is ten or fifteen times of the same capacity hydropower plant; hydropower ramp rate approximately is ten times of thermal power, and hydropower adjustable handle capacity is 0~100%, but thermal power adjustment handle capacity is about 50%~100%. Therefore, thermal power units can achieve load increase and decrease task, and adjust the demand of load change. However, hydropower units have greater influence by seasons, so we can reduce difficulty which electricity load changes for peaking demand through hydro-thermal power generation replacement [3-5].

Value at Risk (VaR) is the product of measurement of financial investment risk. It is risk measurement technology based on statistical analysis, and it can measure the market risk of different trading and different business, conductive to risk size comparison between different business sectors. Multi-objective CVaR theory is another new measure of risk based on VaR theory. it not only absorbs VaR' features like intuitive, objective, and effective, but also overcomes some defects of VaR [4-6].

To analysis the risk that load demand's uncertainty would bring, this paper introduced multi-objective CVaR method and built a hydro-thermal joint scheduling optimization model. In the optimization model, minimize power generation cost, minimize pollutant emission and maximize storage capacity of the hydropower station are optimization objectives. To solve the proposed model, this paper used rough set theory to weight the multi-objective function. Then the model was transferred into a multi-objective CVaR model. Finally, this paper did a simulation based on 6 thermal plants and 3 cascade hydropower stations to verify the effectiveness and feasibility.

2. Multi-objective CVaR theory

2.1. VaR and CVaR method

Assuming $\pi(x,y)$ presents revenue function of portfolio vector x, $x \in R^n$, $y \in R^m$ is random vector, presents uncertainty investment factor of portfolio, assuming probability density function was $p(y)$, for any x, the distribution of $\pi(x,y)$ would be:

$$\psi(x,\xi) = \int_{\pi(x,y)\le\xi} p(y)\,\mathrm{dy} \qquad (1)$$

The formula is no increasing, right continuous function about ξ. For any confidence level $\eta \in [0,1]$, revenue $\eta - VaR$ is:

$$VaR_\eta(\pi(x,y)) = \sup\{\xi \in R : \psi(x,\xi) \le \eta\} \qquad (2)$$

VaR method can descript portfolio program' revenue risk simply, but non additive and convexity of the method restrict application space of the VaR method. CVaR method is introduced for overcoming VaR method' disadvantages, that is:

$$CVaR_\eta(\pi(x,y)) = E\left[\pi(x,y) \middle| \pi(x,y) \le VaR_\eta(x)\right] \qquad (3)$$

For simplified method of solving, according to research at home and abroad, formula (3) equivalent to formula as below:

$$CVaR_\eta(\pi(x,y)) = \max_{v\in R}\left\{v + \frac{1}{\eta}E\left[\pi(x,y) - v\right]^-\right\} \qquad (4)$$

In the formula, $\left[\pi(x,y)-v\right]^- = \min\{\pi(x,y)-v, 0\}$, when formula (4) obtains the maximum, v values is VaR values.

2.2. Multi-objective CVaR method

The above chapter is shown that traditional single objective CVaR model just consider single loss function scenario and the method need to extend when considering multi-loss function (the paper will objective function as loss function)[7]. Assuming there was n-loss function $\pi_i(x,y)$ related to decision variables $x \in \mathbf{X} \subset R^n$ and they are continuous function, which would be:

$$\psi_i(x,\xi) = \int_{\pi_i(x,y)\le\xi} p(y)\,dy \qquad (5)$$

For in favor of discussion, the paper will set weight of every loss functions $\lambda_i\ (i = 1,2,\dots,n)$. When discussing multi-objective CVaR method, defining decision variables x, $\alpha - VaR$ loss value under confidence level α based on weight λ firstly:

$$\xi^*(x,\lambda) = \min\left\{\xi \middle| \sum_{i=1}^{n}\lambda_i(1-\alpha_i)^{-1}\psi_i(x,\xi) \ge \sum_{i=1}^{n}\lambda_i\alpha_i(1-\alpha_i)^{-1}\right\} \qquad (6)$$

Then, defining decision variables x, $\alpha - CVaR$ loss value under confidence level α based on weight λ:

$$\phi\left(x,\left(\xi^*(x,\lambda)\right)\right) = \sum_{i=1}^{n}\lambda_i\phi_{i,\alpha_i}\left(x,\xi^*(x,\lambda)\right) \qquad (7)$$

For finding out minimum loss value in $\alpha - CVaR$ the feasible region, that is finding out minimum x in $\phi\left(x,\left(\xi^*(x,\lambda)\right)\right)$, we need solve optimization problem as below:

$$\min \phi\left(x,\left(\xi^*(x,\lambda)\right)\right) = \sum_{i=1}^{n}\lambda_i\phi_{i,\alpha_i}\left(x,\xi^*(x,\lambda)\right) \qquad (8)$$

s.t. $x \in X$

The paper re-defines loss function and optimization problem for simplifying solving process due to model (8) is very complex during solving process, specific as shown in (9):

$$F_{i,\alpha_i}(x,\xi_i) = \xi_i + (1-\alpha_i)^{-1}\int_{z\in R^m}\left(\pi_i(x,z)-\xi_i\right)^+ p(z)\,dz, \qquad (9)$$

$i = 1,2,\dots,n$

$$\min \sum_{i=1}^{I}\lambda_i F_{i,\alpha_i}(x,\xi)$$

s.t. $\xi \in R$, $x \in X$

If there was ξ, making $\min \sum_{i=1}^{I}\lambda_i F_{i,\alpha_i}(x,\xi)$ achieving optimal and meet constraint $P\left(\pi_i(x,y)=\xi\right) = \int_{\pi_i(x,z)=\xi} p(z)\,dz = 0\ (i = 1,2,\dots,n)$ in regard to any x, that would be:

$$\sum_{i=1}^{n}\lambda_i\phi_{i,a_i}(x,\xi) = \min_{\xi\in R}\sum_{i=1}^{I}\lambda_i F_{i,\alpha_i}(x,\xi) \qquad (10)$$

$$\xi = \xi^*(x,\lambda)$$

If (x,ξ) made (9) achieve optimal in regard to λ, and formula (10) founded, could make model (9) achieve optimal.

If there wasn't specific function of loss function, we would define it by simulations, assuming analog data was $z_j^i \left(j=1,2,\ldots,J \right)$, specific loss function defining as below:

$$\begin{gathered}(1-\alpha_i)^{-1} \int\limits_{z\in R^m} \left(\pi_i(x,z)-\xi_i\right)^+ p(z)\,dz = \\ (1-\alpha_i)^{-1} J^{-1} \sum_{j=1}^{J} \left(\pi_i\left(x,z_j^i\right)-\xi_i\right)^+\end{gathered} \quad (11)$$

Model (9) would convert approximately:

$$\min \sum_{i=1}^{I} \lambda_i \left(\xi_i + (1-\alpha_i)^{-1} J^{-1} \sum_{j=1}^{J} \left(\pi_i\left(x,z_j^i\right)-\xi_i\right)^+ \right) \quad (12)$$

s.t. $\xi \in R$, $x \in X$

3. Model constructions

3.1. Objective function

Due to the amount of inflow water of reservoir is random variables, for minimum generation risk and maximum hydro-thermal power replacement in the hydro-thermal scheduling, we need to simulate the amount of inflow water[8]. The paper assumes the amount of inflow water W obey normal distribution $W \sim \left(u,\sigma^2\right)$, u is the mean amount of reservoir' inflow water, σ^2 is the variance of reservoir' inflow water, the two parameters are obtained from the reservoir' inflow water of past year data. The paper assumes hydropower' output power meets binomial function, as below:

$$g_{ht}\left(U_{ht}\right) = \varpi_h + \theta_h U_{ht} + \vartheta_h U_{ht}^2 \quad (13)$$

In the formula, ϖ_h, θ_h, ϑ_h present hydropower units output coefficient which are obtained from generation historical data.

Generation energy consumption amount minimum objective function

$$\min \pi_c = \sum_{t=1}^{T} \sum_{i=1}^{I} \left(u_{i,t} f_c\left(g_{i,t}\right) + u_{i,t}\left(1-u_{i,t-1}\right) D_{i,t} \right) \cdot p_{it} \quad (14)$$

$$f_c\left(g_{i,t}\right) = a_i + b_i g_{i,t} + c_i g_{i,t}^2 \quad (15)$$

In the formula: a_i, b_i, c_i is generation unit i ' fuel cost coefficient which are determined from generation units generation historical data.

$$D_{i,t} = \begin{cases} D_i^h, T_{d,i}^{\min} < X_i^{off}(t) \le H_i^{off} \\ D_i^c, X_i^{off}(t) > H_i^{off} \end{cases} \quad (16)$$

$$H_i^{off} = T_{d,i}^{\min} + T_{s,i}^c \quad (17)$$

In the formula, D_i^c is generation unit i ' cold start cost; D_i^h is generation unit i ' hot start cost; $T_{d,i}^{\min}$ is generation unit i ' minimum allow downtime; $X_i^{off}(t)$ is generation unit i ' continuous downtime at j moment; $T_{s,i}^c$ is generation unit i ' cold start time; H_i^{off} is the sum of the shortest downtime and cold start time of generation units. For considering the uncertainty of inflow water, the chapter wills hydropower units' output replace thermal power units generation output, as below:

$$\sum_{i=1}^{n} g_{i,t} = L(t) - \sum_{h=1}^{m} g_{ht} \quad (18)$$

In the formula, n, m presents the total number of thermal power units and hydropower units respectively.

generation pollutant emissions amount minimum objective function

Recently, the main pollutant emissions of generation are CO_2, SO_2, NO_x which our country focuses on, making $k=1,2,3$ separately presents CO_2, SO_2, NO_x, obtaining objective function as below:

$$\min F_e = \sum_{t=1}^{T} \sum_{i=1}^{I} \sum_{k=1}^{K} \left\{ u_{i,t} \left[\alpha_i^k + \beta_i^k g_{i,t} + \gamma_i^k g_{i,t}^2 \right] p_{i,k} \right\} \quad (19)$$

In the formula, K presents the kind number of pollutant, making $K=3$;

α_i^k, β_i^k, γ_i^k presents generation unit i 'pollutant emissions coefficient which apply the least squares method according to the unit harmful emissions monitoring data.

Abandoned water cost minimum objective function

$$\min F_m = \sum_{t=1}^{T} \sum_{i=1}^{n} \sum_{h=1}^{m} \left\{ \left(g_{ht} - g_{ht}^* \right) p_{ht} \right\} \quad (20)$$

In the formula, g_{ht}^* presents hydropower units' available power output; g_{ht} presents hydropower units' actual power output.

3.2. Solving process

3.2.1. Weight calculating

We need to make multi-objective problem convert to single objective problem when solve multi-objective optimization problem, so we need reasonably established every objective function' weight value, the paper establishes every objective function' weight value applying rough set theory. There are more literatures about rough set theory at home and abroad, and the weight calculating steps based on rough set theory as below:

Constructing evaluation function, making generation multi-objective function convert single objective function:

$$\min F = \min \sum_{i=1}^{n} w_i f_i \tag{21}$$

$$\sum_{i=1}^{n} w_i = 1 \tag{22}$$

Establish relational data model.

The paper makes every objective function as condition attributes, and given initial weights $w_i = 1/n$, obtaining comprehensive objective function F which as decision attributes. Assuming decision attributes set was $D = \{F\}$, and comprehensive objective function u_k under different optimization objective was a message of study F, all comprehensive objective function value construct set $u_k = (f_{1k}, f_{2k}, \ldots, f_{mk}; F_k)$ under single objective function. $U = \{u_1, u_2, \ldots, u_k\}$ is domain, object u_k, attribute is $f_i(u_k) = c_{ik}$, $F_i(u_k) = F_k$, $i = 1, 2, \ldots, m$; $k = 1, 2, \ldots, n$.

Calculating knowledge base R_{C}, dependence to knowledge base R_{D} is:

$$r_{R_C}(R_{\text{D}}) = \frac{\sum \rho[R_C([F]_{R_{\text{D}}})]}{\rho(U)} \tag{23}$$

In the formula, $\rho(\ )$ presents set cardinality;

$p_c(D)$ and $p_{c-|c_i|}(D)$ separately is the objective set which expressed knowledge of all applying classification U/C of universe U before and after removing indicator C_i.

Calculating knowledge base R_D, dependence to knowledge base $R_{C-|c_i|}$ for every single objective optimization function f_i, that is:

$$r_{R_{C-|c_i|}}(R_{\text{D}}) = \frac{\sum \rho[R_{C-|c_i|}([F]_{R_{\text{D}}})]}{\rho(U)} \tag{24}$$

Calculating the importance of i-th optimal objective, that is:

$$\sigma_{\text{D}}(D) = r_{R_C}(D) - r_{R_{C-|c_i|}}(D) \tag{25}$$

Weight coefficient of i-th optimal objective is:

$$\lambda_i = \sigma_{\text{D}}(c_i) / \sum_{i=1}^{m} \sigma_{\text{D}}(c_i), \quad i = 1, 2, \ldots, m \tag{26}$$

In the formula, λ_i presents weight coefficient of i-th optimal objective function.

3.2.2. Multi-objective CVaR optimization problem construction

Constructing hydro-thermal units' generation replacement optimization model based on multi-objective CVaR theory. The goal is minimum $\alpha - CVaR$ loss value, specific solving process as below:

(1)We solve weight coefficient λ_i of every objective function respectively, according to weight calculation model;

(2)We define loss function according to multi-objective CVaR theory, specific as below:

$$F_{j,\alpha_j}(G, \xi_j) =$$

$$\xi_j + (1-\alpha_j)^{-1} \int_{z \in R^m} \left(F_j\left(G, g_{ht}\left(U_{ht}\right)\right) - \xi_j\right)^+ p(U)\, dU, \tag{27}$$

$$j = 1, 2, 3$$

In the formula, G presents thermal power units and hydropower units' output arrangement program, obtaining thermal power units and hydropower units' optimization model based on $\alpha - CVaR$ minimum loss value, specific model as below:

$$\min \sum_{j=1}^{3} \lambda_j F_{j,\alpha_j}(x, \xi) =$$

$$\min \sum_{j=1}^{3} \left(\begin{array}{l} \xi_j + (1-\alpha_j)^{-1} \\ \displaystyle\int_{z \in R^m} \left(F_j\left(G, g_{ht}\left(U_{ht}\right)\right) - \xi_j\right)^+ p(U)\, dU \end{array} \right) \tag{28}$$

$$\begin{cases} s.t. \sum_{i=1}^{n} g_{it} + \sum_{h=1}^{m} g_{ht} = L(t) \\ (5-38) - (5-52) \\ G = \{g_{it}, g_{ht}\} \\ i = 1, 2, \ldots, n; h = 1, 2, \ldots, m \end{cases} \tag{29}$$

4. Cases analysis

In order for the proposed model numerical example, paper selects six thermal power plants (T1 to T6) and three cascade hydropower stations (H1 to H3) as a hydro-thermal scheduling system, the basic parameters of thermal power and integrated emission factors see [9] , the operating parameters of cascade hydropower stations, see [10] below. Load forecasting deviation assumed normal distribution, the typical daily load load conditions, see [11] below. With the GAMs software to solve the proposed model, the specific results see 4.1 and 4.2.

4.1. Multi-objective same confidence level scenario

The scenario separately chooses α=0.85, 0.9 and α=0.95, 0.99, and obtains units' output program of different confidence level for analyzing different confidence level' influence for hydro-thermal power generation replacement, specific as shown in Table 1, and separately obtaining VaR values and CVaR values of different confidence level, specific as shown in Table 2.

The Table 1 can be found that with hydro-thermal power generation replacement acquiring confidence level α ' increase, thermal power units' output in-

Table 1. The unit output arrangement under the same α in scenario 1

α	1#	2#	3#	4#	5#	6#	7#	8#	9#	10#	Hydro-1	Hydro-2
0.85	14250	11320	7650	5042	3983	900	1100	20	40	80	2450	2092.2
0.9	14400	11405	7756	5077	4013	850	1025	0	0	60	2636	2140
0.95	14400	11515	7838	5131	4058	886	1047	55	21	70	2372.4	1968.8
0.99	14400	11515	7918	5201	4113	928	1081	97	53	110	2372.4	1968.8

Table 2. The VaR and CVaR values under the same α in scenario 1.

α	VaR values			CVaR values
	f_1	f_2	f_3	
0.85	0.272	0.284	0.242	0.314
0.9	0.278	0.288	0.245	0.321
0.95	0.285	0.293	0.247	0.327
0.99	0.272	0.284	0.242	0.334

crease gradually and hydropower units' output decrease gradually. This is generated for overcoming the risk which hydropower units' output uncertainty bring about. The higher confidence level, the lower risk tolerances of generators, the generators intend to increase thermal power units' output and decrease hydropower units' output. For analyzing units' generation output arrangement under different confidence level, the paper calculates VaR and CVaR values of generation scheduling objective function, as shown in Table 2.

The Table 2 can be found that with confidence level increase, VaR and CVaR values increase at the same time. Combined the Table 1, we can find that units' output arrangement approach gradually, more and more intend to generate from thermal power units. CVaR values increasing gradually present that the higher confidence level, the lower risk tolerances. This situation presents multi-objective CVaR model applicable hydro-thermal power generation replacement transactions optimization problem.

4.2. Multi-objective different confidence level scenario

The Table 3 can be found that CVaR values under different confidence level are higher than CVaR values under the same confidence level, and VaR values under high confidence level are higher than VaR values under low confidence level as shown in Table 2 and Table 3. Though weighting objective function, we can counterpoise hydro-thermal power generation replacement transaction risks.

Table 3. The VaR and CvaR values under the same α in scenario 2

Program	VaR values			CVaR values
	f_1	f_2	f_3	
1	0.330	0.308	0.292	0.330
2	0.347	0.322	0.304	0.337
3	0.364	0.336	0.316	0.344
4	0.382	0.351	0.328	0.351

4.3. Results contrast

For further contrasting different confidence level influencing on system integrated generation replacement revenue, the chapter comparison analyses generation energy consumption, pollutant emissions and abandoned water opportunity cost of both scenario, specific results as shown Table 4.

As shown in TABLE 4, we firstly contrast scenario1 and scenario2. Due to the requirement of every objective confidence level are different, scenario2

Table 4. Generation replacement benefits comparative analysis in different scenarios

	Program	Generation Coal Consumption/Tce		Generation Pollutant Emissions Amount/t			Abandoned Water Opportunity Cost/Ten Thousand Yuan
		Generation Coal Consumption	Start/Stop Coal Consumption	CO_2	SO_2	NO_x	
Scenario1	1	13418	146	33014	105	101	1002
	2	13999	153	33847	111	102	1015
	3	14139	155	34185	112	103	1026
	4	14280	156	34527	113	105	1036
Scenario2	1	14713	159	35221	115	107	1046
	2	14860	158	35573	116	108	1057
	3	14423	163	35929	117	109	1067
	4	14568	161	34872	114	106	1078

need integrated generation replacement risk minimum as a target when optimize generation results. For meet the requirement of confidence level, scenario2 need increase thermal power units' generation output, and decrease hydropower units' generation output, reducing the uncertainty of inflow water which influence on generation replacement revenue, finally, resulting in generation energy consumption, generation pollutant emissions and generation abandoned water opportunity cost of generation replacement are higher than scenario1. Then, with confidence level increase, system integrated generation replacement energy consumption cost, pollutant emissions cost increase at the same time because every objective function confidence level same. In the scenario2, due to the requirement of hydropower abandoned water cost minimum objective function confidence level is higher another two kinds objective function, the system gives priority to the objective function when conducts generation replacement, and increase thermal power units' generation and high-capacity generation units' generation. Finally, the generation will increase, but generation energy consumption will decrease [5]. Due to thermal power units' grid capacity increase, units' start and stop times will increase, units' start and stop coal consumption will increase. Similarly, generation pollutant emissions' analysis and generation energy analysis are the same. The above analysis can be verified from program4 of scenario2. Program2, program3 and confidence changes in the same direction because the generation energy consumption cost objective function and generation pollutant emissions cost objective function confidence requirement for generators corresponding increase.

5. Conclusions

The system considers related optimization model based on CVaR theory when it conducts generation replacement. This can advance generation replacement effectively and improving large capacity units' generating capacity and making generation total efficiency increase. Finally, the generating capacity has a certain addition, but generation energy consumption decreases. Similarly, though grid capacity of thermal units and start and stop times increase, resulting in start and stop coal consumption correspondingly increases. We need conduct generation replacement considering various factors.

Through the above results suggest that hydro-thermal units generation replacement optimization model' CVaR value are different in different context confidence level. It makes hydro-thermal power generation replacement trading risk get certain balance through weighting objective function [6]. Power generation system in order to achieve the lowest of generation risk, in the hydro-thermal power replacement, thermal power units output will increase generation with the increase of confidence level requirements, hydropower units output will decrease generation with the increase of confidence level requirements. Therefore, in the hydro-thermal power generation replacement, in order to overcome uncertainty impact of hydropower output, relevant departments are supposed to exit interconnection discount policies for increase system integral generation performance.

In the actual operation, hydro-thermal power units' generation replacement can achieve optimization maximize based on multi-objective CVaR methods. In the same time, it can try to meet the needs of power peaking, and guarantees hydro-thermal power output jointly contributes to meet the load demand. This is important to grid safe and stable operation, environmental protection and resource optimization.

References

1. Francesca Bonenti, Giorgia Oggioni,Elisabetta Allevi, et al. Evaluating the EU ETS impacts on profits,investments and prices of the Italian electricity market. [J] Energy Policy,2009,37(10): 3967-3977.
2. Djamel Kirat, Ibrahim Ahamada. The impact of the European Union emissions trading scheme on the electricity generation sector[J]. Energy Economics, 2011,33 (5):995-1003.
3. Druckman, P. Bradley, E. Papathanasopoulou, T. Jackson. Measuring progresstowards carbon reduction in the UK[J]. Ecological Economics. 2008,32 (4): 346-367.
4. Gudrun Benecke. Varieties of carbon governance: taking stock of the local carbon market in India[J]. Journal of Environment Development, 2009,18: 346-375.
5. Shigemi Kagawa. How does Japanese compliance with the Kyoto Protocol affect environmental productivity in China and Japan[J] Structural Change and Economic Dynamics, 2008,19: 173-188.
6. Guri Bang, Camilla Bretteville Froyn, Jon Hovia, et al. The United States and international climate cooperation: international 'puir versus domestic fpushf[J], EnergyPolicy,2007, 35 (11): 1282-1291.
7. Short-term Hydrothermal Scheduling Using Mixed-integer Linear Programming [J]. Proceedings of the CSEE, 2009, 29(28): 82-88
8. WU Jiekang, TANG Li. Stochastic Optimization Scheduling Method for Hydrothermal

Power Systems With Stochastic Loads[J]. Proceedings of the CSEE, 2012, 32 (28): 36-44

9. QI Minfang, FU Zhongguang, JING Yuan, etal. A Comprehensive Evaluation Method of Power Plant Units Based on Information Entropy and Principal Component Analysis[J]. Proceedings of the CSEE, 2013, 33(2): 58-60
10. Jiang Min, Jiang Baozhen, Meng Zhiqing,etal. RISK MEASURE AND STRATEGY OF PORTFOLIO INVESTMENT BASED ON THE MULTIOBJECTIVE CVaR MODEL[J]. MATHEMATICS IN ECONOMICS, 2007, 24(4): 385-391
11. Xu Man, Qiao Ying Lu Zongxiang.A Comprehensive Error Evaluation Method for Short-term Wind Power Prediction[J]. Automation of Electric Power System, 2011, 35(12): 20-26.