Acta Technica 62 (2017), No. 7A, 1561–1572

Risk analysis of electrical sales company based on the improved particle swarm optimization in the setting of new round of electric power system reform in China

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Abstract. The decision-making and the risk assessment of power purchase and sales business are keys to the adaptation of electrical sales company to the power market. To diverse the power purchase business of the electrical sales company, possible power purchase and sales business of the electrical sales company are classified in the market model of medium and long-term and spot transactions. This paper presents a method based on improved particle swarm optimization for the risk analysis of electrical sales company in the setting of the new round of electric power system reform in China. Random variables of the risk such as spot price and power demand in the model are simulated with the scenario method. Risk profits serve as the risk assessment indicator. The target is the maximization of the aggregate utility of risks and expected revenue of the electrical sales company. A model will be built for the comprehensive decision-making and risk assessment of power purchase and sales business. Explorations are to be made for the effect of different factors on decision-making and risk level of power purchase and sales business under different models of power purchase and sales business. Also, the improved particle swarm optimization is introduced to optimally analyze the proposed, in an effort to provide effective analysis and research on the risks of electrical sales companies.

Key words. particle swarm optimization (PSO), Electric power system reform, Electrical sales company, Risk analysis.

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1. Introduction

In March, 2015, Several Opinions of the CPC Central Committee and the State Council on Further Deepening the Reform of the Electric Power System kicked off a new round of electric power market-oriented reform in China, with one of the top priorities on power sales side reform to "develop participants in market competition on the power sales side in multiple approach and open the power sales business to the social capital in an orderly way". A release of the power sales business will provide consumers with more options. It also improves power sales service quality and enhances consumers' energy consumption level while guaranteeing safety and security and reliable power supply, so as to further promote optimized resource allocation.

Chinese electric power market building is currently more focusing on improving medium and long-term direct electricity transactions. Future steps will move to spot market building to develop the market model of medium and long-term and spot transactions. Electrical sales companies have their core business in power purchase and sales. They purchase electricity from power wholesale market and sell the same to various consumers. In this way, power sources and consumers are effectively linked and integrated. The liquidity of electric power market gets increased. With the development of energy and communication measurement technologies, renewable energy sources, stored energy and other sources have become the resources of power purchase business of electrical sales companies. The power sales business is also diversified based on the load characteristics and power purchase preference of different consumers. For risk identification, electrical sales companies will certainty balance real-time supply and demand of electricity and power consumption in power purchase and sales business through the spot market when operating such business. The result is that they are exposed to risks of consumer demand and of uncertain spot price. On this account, the power purchase and sales business of electrical sales companies primarily focuses on a portfolio of various types of power purchase and sales businesses, so as to appropriately spread the risks among different businesses. Moreover, risk mitigation and revenue increase are achieved through the optimized power purchase strategy and power sales tariff. Given these risk factors and based on modern investment portfolio theories, domestic and international scholars have researched on the risk assessment for power purchase and sales of electrical sales companies. However, these documents allowed for the effect of fluctuations in spot price and targeted at the optimization of purchase portfolios in different markets, without taking the risk of power sales demand into account or analyzing the power sales element in a simply way. For this purpose, literature [12-13] allowed for the risk of uncertainty in consumer demand, took into full account the power sales business including fixed price and minimum-guaranteed and capped real-time price contracts by using price quota curve and consumer utility theory and through scenario simulation, as well as made risk assessment and decision. Literature [14] studied the effects of price and demand gaps on the portfolio strategy of power purchase contracts of electrical sales companies with varying risk preferences. This literature considered the medium and long-term contracts of a single type of power source only when they studied power purchase and sales risk decisions of power suppliers or electrical sales companies. The findings of these researches may not comply with the development of new energy power system. Literature [15-16] allowed for PV, wind power and nitrogen stored energy on the power purchase side. They came up with fixed, time-of-use (TOU), real-time power sales contracts and pricing decision and methodology of interruptible load. However, there was a lack of research on risks. In addition, it was assumed in the literature that there was no cost for the use of energy storage equipment and for purchase of PV and wind power. That was not to the universal rule for receiving return on investment from medium and long-term transactions. Additionally, if power purchase and sales businesses are classified by contract type, most of existing literature only studies the decision-making or risk assessment of a single power purchase and sales business in a specific circumstance. This is far from satisfaction of the actual demands of electrical sales companies to involve in multi-time scale and multiple types of transaction.

For these problems, this paper classifies the power purchase and sales business of electrical sales companies in the market model of medium and long-term and spot transactions. Renewable energy power purchase and energy storage lease business are included. A combination of both results in a set of power purchase and sales business portfolio of electrical sales companies in the electric energy market. Random variables in the model are simulated with the scenario method. The conditional risk profits serve as the risk assessment indicator. The target is the maximization of the aggregate utility of risks and expected revenue of the electrical sales company. A model will be built for the medium and long-term time scale comprehensive decision-making and risk assessment of power purchase and sales business. The risks and profits of each of business portfolio models of electrical sales companies are assessed with example analysis and summary, which provides a reference for its power purchase and sales strategy.

2. Problem description

2.1. Classification of power purchase and sales business and risk analysis

According to the contracted entered into during power purchase and sales activities, possible power purchase and sales businesses of electrical sales companies are classified into two types – business on power purchase side and business on power sales side. The business model is shown in Fig. 1.

For the power purchase element, electrical sales companies may enter into the power purchase contracts for different time scales (annual, quarterly, monthly, weekly, daily contract) in the market model of medium and long-term and spot transactions in order to satisfy the requirements of end users. This will obtain the electric energy of different types of power sources. It achieves substantial balance of unbalanced electric requirements via the spot market. This paper classifies the possible business on power purchase side of electrical sales companies into output fixed-type and output unfixed-type medium and long-term purchase, medium and long-term energy storage lease and sport market power purchase businesses.

For the power sales element, end electricity consumers are grouped into residential, industrial and commercial types. The electrical sales companies will design different types of power sales contracts to be chosen by consumers according to the price quota curves of each consumer group. Typical power sales contracts include: fixed price contract, TOU price contract and minimum-guaranteed and capped real-time price contract. Accordingly, for the business on power sales side, it may be divided into: fixed price sales business, TOU price sales business and real-time price sales business.

In addition to the fluctuation risk in spot price and consumer requirements, major risks existing in these power purchase and sales business may include uncertainty risk in power output. The problem of decision-making and risk assessment of power purchase and sales businesses of the electrical sales companies may be converted to stochastic programming decision-making problem as these risk factors are continuous random variables. Considering that it is hard to solve stochastic programming decision-making problems with continuous random variables, the research may be simplified with the scenario simulation approach. Upon the assessment of these risk factors, the typical synthetic scenario will be obtained by simulating spot price, consumer requirements and related power output conditions. In the initial power purchase and sales strategy, analysis is made on the relationship between these factors and the revenue. The size of revenue under each typical scenario is calculated. Future profit or loss distribution of electrical sales companies is further obtained by using the probability of each scenario. Proper risk assessment indicators are selected for the calculation of risk level. Repeating of these processes, improvement of the strategy for power purchase and sales and reasonable distribution of risks and revenues should be made till an optimal power purchase and sales strategy is obtained.

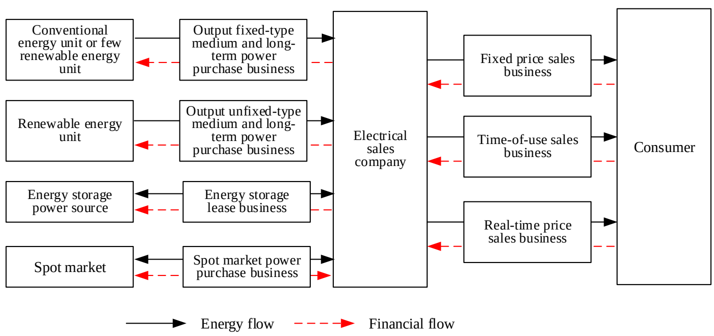

Fig. 1. Power purchase and sales business model

2.2. VaR Purchase portfolio risk VaR

According to Formula (8), during the real-time operation stage of the system, the fluctuation in the profits obtained from purchase and sales of unit quantity of electricity by a transmission company is primarily a result of the fluctuation in the real-time market price. When VaR serves as the risk assessment indicator, the risk from E_{rt} fluctuation will be calculated with RIA. In case that the confidence level of VaR is defined to be, VaR of profit M (expressed in $V_{aR}(M)$) obtained from purchase and sales of unit quantity of electricity by the transmission company on the next day may calculated with Formula (9). It means that the probability at which M is less than $V_{aR}(M)$ does not exceed $1-c$. $V_{aR}(M)$ may also be referred to as the risk-free profit of the unit quantity of electricity purchased and sold on the next day by the transmission company.

$$V_{aR}(M) = E_s - (K_{lt}E_{lt} + K_{da}E_{da} + K_{rt}V_{aR}(E_{rt}) + K_{op}E_{op}) \,. \tag{1}$$

2.3. Optimization model of purchase portfolio

By targeting at maximizing the risk-free profit of unit quantity of electricity purchased and sold, the optimization model of power purchase portfolio of the transmission company is built as follows:

$$\max V_{aR}(M) \,. \tag{2}$$

$$\begin{aligned}
&\text{s.t.}\\
&K_{lt} + K_{da} + K_{rt} + K_{op} = 1\,,\\
&K_{lt,\min} \le K_{lt} \le K_{lt,\max}\,,\\
&K_{da,\min} \le K_{da} \le K_{da,\max}\,,\\
&K_{rt,\min} \le K_{rt} \le K_{rt,\max}\,,\\
&K_{op,\min} \le K_{op} \le K_{op,\max}\,.
\end{aligned}$$

Where, $K_{lt,\min}$ and $K_{lt,\max}$, $K_{da,\min}$ and $K_{da,\max}$, $K_{rt,\min}$ and $K_{rt,\max}$ and $K_{op,\min}$ and $K_{op,\max}$ denote the minimum and the maximum allowable purchase proportion in the long-term contract market, day-ahead market, real-time market and trans-provincial/-regional transaction market by the transmission company.

3. Risk analysis of electrical sales companies based on improved particle swarm optimization

3.1. PSO-based mathematical model

PSO has a conceptual framework deriving from the study on artificial life and predatory behavior of birds. Let's imagine a scene: a flock of birds are searching food randomly. A piece of food lies in this area, and all the birds know where it is, yet they don't know how far for them to get there from their locations. The simplest and most effective way in the optimal strategy to find the food is to search the surroundings with birds that are nearest to the food.

The behavioral characteristic of this species population is an inspiration for POS algorithm that is used to solve the optimization problem. In PSO, the potential solution to each optimization problem can be imagined to be a point in N-dimensional search space, and we call it "particle". All the particles have a fitness value determined by the objective function. Each of the particles also has a speed that determines their flying direction and distance. The particles will then follow current optimal particle to search in the solution space.

In the N-dimensional target search space, M particles make a swarm. Particle i represents a N-dimensional vector $X_i = (x_{i1}, x_{i2}, \dots x_{iN})$, and $i = 1, 2, \dots$ m. It means the position of particle i in the N-dimensional space. X_i is inserted into an objective function to calculate its fitness value. The quality of X_i is measured according to the size of the fitness value. The flying speed of particle i is also a N-dimensional vector expressed in $V_i = (v_{i1}, v_{i2}, \dots v_{iN})$. The algorithm diagram is shown in Fig. 2. The particles are operated with the formulas below:

$$\begin{aligned} V_{id}^{k+1} =& w * V_{id}^{k} + c_1 * rand() * [X_{id}^{k} - X_{id(pbesr)}] \\ &+ c_2 * rand() * [X_{id}^{k} - X_{id(gbest)}], \end{aligned} \tag{3}$$

$$X_{id}^{k+1} = X_{id}^{k} + V_{id}^{k+1}. \tag{4}$$

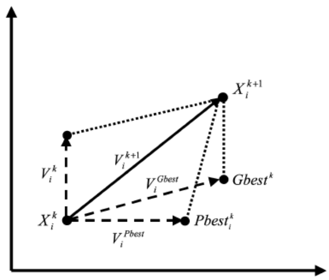

Fig. 2. PSO algorithm schematic

The convergence of particles limits the search range of particles. To broaden the range, it is required to increase the number of particles or weaken the chasing of particles for the global optimal point currently searched by the entire particle swarm. An increase of the number of particles will result in more complexity of algorithm computing. The weakened chasing of particles for the global optimal point is disadvantaged in small algorithm and sensitivity to convergence.

The particle itself has no variation mechanism as the basic PSO algorithm depends on the cooperation and competition among the swarm. It will be very hard for a single particle to get rid of the constraint of a local extremum once subject to the local extremum. In this case, successful findings of other particles will be needed. In fact, the optimization capacity of PSO algorithm results from the interaction among particles. If such interaction among particles is eliminated from the algorithm, the optimization capacity of PSO algorithm may be very limited.

Tests show that in the initial stage of algorithm operation, the convergence speed is higher and the motion trail swings in a sine wave form. However, after operation for a period, the speed begins to decrease and it even stagnates. When the speed of all particles is almost 0, the particle swarm is incapacitated in further evolution, in which case it may be considered that the algorithm execution has been in convergence. In most cases (such as complex multi-modal function optimization), however, the algorithm is not in the convergence to the global extremum, and it even fails to achieve local extremum. This is called premature convergence or stagnation. On occurrence of such phenomenon, the particle swarm is highly concentrated and severely lacking diversity. The particle swarm in a long period will not or will never jump out of the aggregation point. Intensive improvement efforts of PSO are focusing on the diversity of the particle swarm to maintain the capacity of particle swarm for further optimization throughout the iteration process.

3.2. Mathematical model of the improved PSO

The improved PSO is enlightened by BP neural network. BP algorithm is a common method currently used in dealing with multi-layer neural network. It reduces the errors between the actual and predicted output results with the gradient descent approach. However, there is stagnation and oscillation nearby the local optimum. This will lead it to be trapped in local optimum and get away from the globally optimal solution. This problem can be improved in the following way. Such improvement is just the case that the weight is smoothened by the low pass filter [5]. The mathematical expression is:

$$y^t = (1 - \lambda) * x^t + \lambda * y^{t-1}\,. \tag{5}$$

Where, $\lambda \in [0, 1]$, x is the signal sequence to be smoothened. x^t is the signal value at time t. y^t is the output of the filter at time t. A bigger λ value means better smoothness.

On this account, by using PSO speed updating equation, new parameters are imported as follows:

$$\begin{aligned} V_{id}^{k+1} =& (1 - \lambda)\{V_{id}^k + c_1 * rand() * [X_{id}^k - X_{id(pbesr)}] \\ &+ c_2 * rand() * [X_{id}^k - X_{id(gbest)}]\} + \lambda * V_{id}^{k-1}\,. \end{aligned} \tag{6}$$

$$X_{id}^{k+1} = X_{id}^k + V_{id}^{k+1}\,. \tag{7}$$

The improved PSO is additionally provided with $\lambda * V_{id}^{k-1}$ term compared to the original PSO equation. λ is the coefficient of the imported term. Such improvement is greatly different from the existing improvement method with speed updating equation. The reason is that original equation for particle speed updating is a first-order difference equation. However, the equation for particle speed updating in the improved PSO of this paper is a second-order difference equation.

PSO improved in this way is primarily advantageous in: 1. Easy to operate. The improved ISO used in this paper is highly easy to operate, whether in terms of the mathematical expression or of the program execution; 2. The motion trail of smoothed particle eliminates the oscillation in the later stage of iteration; however, it stagnates in the local optimum; and 3. The improved PSO in this paper is almost applicable to all existing improved PSO algorithms with defined particle speed updating equation, such as inertia weight changed PSO, constriction factor changed PSO, hybrid PSO, etc.

3.3. Flow chart of the improved PSO

The flow chart of the improved PSO is shown in Fig. 3:

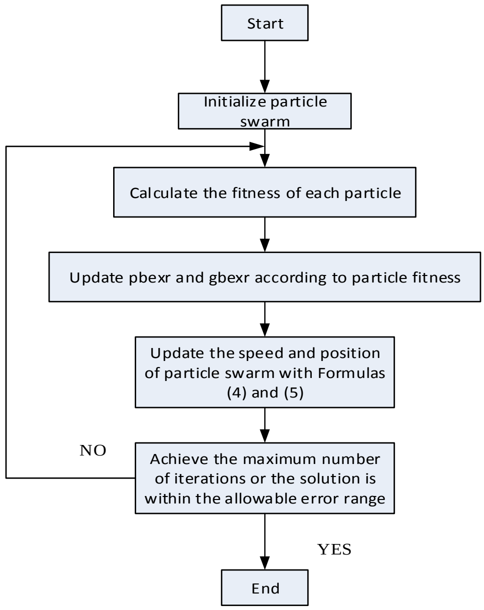

Fig. 3. Flow chart of the improved PSO

4. Experimental analysis

4.1. Standard function test

To verify the performance of the improved PSO, the following test functions are often used by the researchers in the field. Fig. 4 is the images of these functions.

To characterize the performance of the improved PSO, the assessment indicator input is required. Four assessment indicators are used in this paper: convergence precision error ε, algorithm success rate β, convergence speed γ and iteration convergence curve. The convergence precision error ε characterizes the deviation between the theoretical optimal value and the actual result of the objective function. A smaller ε value means higher calculation precision. PSO success rate $\beta = \frac{\mathrm{successfuloperationtime}}{\mathrm{PSOtotaloperationtime}}$. Successful operation time means the time from convergence of the algorithm to the global optimization point with set benchmark to the ending upon satisfaction of algorithm precision. Convergence speed γ characterizes

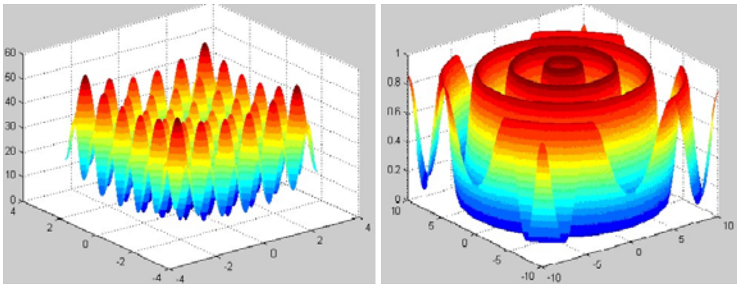

Fig. 4. Test function
(Rastrigrin function and Schaffer function from left to right)

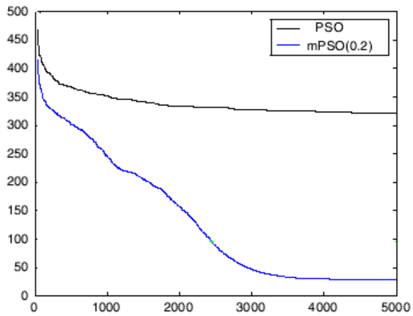

Fig. 5. Rastrigrin function calculations

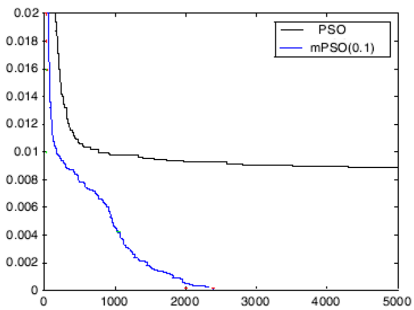

Fig. 6. Schaffer function calculations

the time for convergence of the algorithm to the global optimum. The iteration convergence curve characterizes the trajectory of change of the objective function value over the change in number of iterations. A comparison between the iteration convergence curves leads to a direct and clear conclusion. The experimental results are shown in Fig. 5-6.

4.2. Example analysis

An example is the hourly real-time price data for the period from June 1, 2007 to December 31, 2011 in the relatively mature US PFM electric power market. The proposed method is used to calculate VaR as a result of price fluctuation. It is compared for analysis with the traditional VaR results. Here analyzes the mean value of the daily real-time prices. There are a total of 1,675 daily average prices. The distribution curve of the sequence of daily average price expressed in $E_p\,(t)$ is shown in Fig. 7.

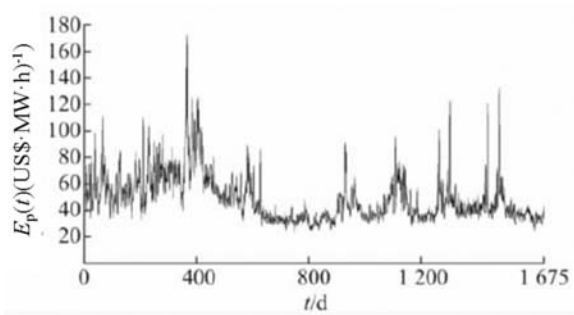

Fig. 7. Distribution curve of the sequence of daily average price

An example is the power purchase plans for January 1, May 3 and July 22, 2011 prepared by the transmission company. The power purchase structure of the transmission company is optimized by using the risk optimization model for short-term power purchase plan described in Formula (10). In case that the confidence levels of the set VaR are 95% and 99%, respectively. The short-term power purchase portfolio of the transmission company is optimized based on VaR calculations of the real-time price. The results are included in Table 1.

Table 1. Results of risk optimization for short-term power purchase portfolio of the transmission company

VaR confidence level / %	Date	$[K_{lt}, K_{da}, K_{rt}, K_{op}]$ Purchase portfolio $[K_{lt}, K_{da}, K_{rt}, K_{op}]$	$V_{aR}\,(M)$
95	January 1	$[0.6, 0.3, 0.1, 0]$	13.083
	May 3	$[0.5, 0.4, 0, 0.1]$	10.714
	July 22	$[0.6, 0, 0.2, 0.2]$	9.609
99	January 1	$[0.6, 0.3, 0.1, 0]$	11.908
	May 3	$[0.6, 0.3, 0.1, 0]$	8.945
	July 22	$[0.6, 0.1, 0.1, 0.2]$	9.104

The results above show that the calculations of multifractal VaR is relatively sensitive to the price fluctuation in different periods. It offers high adaptability and is of practical value. The transmission company may select appropriate purchase portfolio optimization strategies with its preference for risks to reasonably analyze and effectively control the risks in power purchase transactions.

5. Conclusion

This paper presents a method based on improved particle swarm optimization for the risk analysis of electrical sales company in the setting of the new round of electric power system reform in China. Random variables of the risk such as spot price and power demand in the model are simulated with the scenario method. Risk profits serve as the risk assessment indicator. The target is the maximization of the aggregate utility of risks and expected revenue of the electrical sales company. A model will be built for the comprehensive decision-making and risk assessment of power purchase and sales business. Also, the improved particle swarm optimization is introduced to optimally analyze the proposed, in an effort to provide effective analysis and research on the risks of electrical sales companies. The experimental results validate the effectiveness of the proposed.

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Received May 7, 2017