Improved Simplex Method Algorithm used in power Market Clearing

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Abstract. Electric power industry is the foundation of national economy and plays a key role in the development of human society. Traditional power industry is monopolized by industry and lacks market efficiency. In recent years, it is seeking breakthroughs in market-oriented reform. Although China's electricity market reform has achieved some results, but there are still lacking of market players and regional transactions, excessive data management, concentration and other defects. This puts forward higher requirements for the system design of power market trade. It is facing the electricity market security and performance challenges, the goal is to improve the electric power market transaction mode and enhance transaction security, it studied different kinds of markets transaction model to construct a perfect competitive market trade system, which based on block chaining technique. The trade model adopted different levels of multi auction which integrated intra provincial trading and inter provincial trading parts in a system. The intra province trading part adopt the model of contact trading and bidding coexist, each province carried out trading for surplus-deficit electricity on the basement of intra province demand. Here, it constructed a competitive cross-regional power market which can realize the intra-provincial contract, bidding and inter-provincial trading in day power market. The simulation results based on six provinces to shown the different conditions, and operated by the intelligent contracts. It recorded the full trading information distributed through the inter-provincial power trading algorithm in the intelligent contracts, the results has presented the amount of electricity transaction and the corresponding trading volume. It has achieved fair resource scheduling and transaction information security.

1. Introduction

China has carried out electric power market reform since 2000, and have made experiments in several provinces, it realized the separation of plant and network and achieve the competitive bidding construction of sell side market as in refer [1], the electricity market trading volume increased rapidly over the past two years, the total electricity consumption up to 20% through market transactions in 2016 as in refer [2]. However, there are still some problems in the electricity market, for example, the power trading is mainly concentrated of the province market and the management mode unduly centralization [3]. On the one hand, it results in the existing power market difficult to meet the market demand, on the other hand, the centralized data management lead to the low data security and credibility, which also prejudice the development of market integration and resource allocation in refer [4] In order to solve the above shortcomings, it is necessary to seek a decentralization platform
technology to support large-scale regional market transactions and more secure and reliable transaction data storage. Using the new emerging decentralization technology of block chain, the problems in current power market transactions can be better solved. In 2017 September, the State Development and Reform Commission and the Energy Bureau has issued the "Notice on the Pilot Construction of the Electric Power Spot Market " and selected eight electric power spot markets for the first batch plot areas, which is Guangdong, Mengxi, Zhejiang, Shanxi, Shandong, Fujian, Sichuan, and Gansu pilot areas. It is required to organize market entities to carry out daily, daily and real-time electric energy trading, achieve an organic link between scheduling and market trading, and establish a mechanism for spot market clearance and block management units under security constraints. In-day time-sharing tariff mechanism that forms time and location characteristics as in refer [5]. Electric power market is a place or platform where the buyer and seller of the electricity interact with each other, then to determine the clearing price and quantity, it has competitive and open characters, then mainly configure the power resources using market measure. As in [6] it is a new type of power operation mode based on fair competition among electric power enterprises, which can effectively reduce power production cost and raise production efficiency.

The existing electricity trading patterns differences mainly focus on whether Power Grid Corp involved in electricity transactions or responsible for power transmission only. Most of the world countries in early adopted the free market model, which Power Grid Corp is only responsible for power transmission. In American model, the Power Grid Corp is not taken part in the purchase and sale of electricity business, which only in charge of power grid management and wheeling charge [8]. Canada mainly uses the power generation and sale link independent mode, it monopolized of the Power Grid Corp operating in the transmission and distribution sectors, but in the end of power production bidding bringing in competition, then in the customers right bring in market competition and open the clientele choose independently[9]. India and Brazil mainly adopt the transmission and consumption link independent mode, Power Grid Corp does not participate in market transactions only introduce competition on the power generation side[10]. In the Commonwealth model, the national electric power company possess all the power transmission networks, and does not participate in the market of the power generation and the selling side, which fully introduces the market competition. Northern Europe adopts centralized operation and market mode at the same time, where the power generation companies and power users can complete the transaction on the self-supporting power transmission and distribution network, and also can charge net service fees by the Power Grid Corp [12]. In the Argentina electricity market model, it has more realized the independence of all aspects of market links thoroughly such as the generation, transmission, distribution and selling, the Power Grid Corp has completely not participated in the market transactions [10]. Only Japan considering energy security and its specific conditions, it still used integrated system of power supply, transmission and distribution as referred in [10].

China power industry reform has experienced the stages of complete monopoly, "collecting funds for electricity", simulating electric power market, electricity market pilot, "generation and network separation" reform and regional electricity market pilot operation etc stages refer in [11]. Since the 2015 electricity reform No. 9 release [12], the state grid is implemented the market-oriented reform of the power grid, it aim to achieve a competitive electricity market, which can orderly liberalization the electricity price of competitive aspects and the power plan outside of public welfare adjustment, it can strengthen the electric market platform and voluntary and increase the inter provincial and cross regional market transactions, then enhance market efficiency and promote the power resources configuration optimally in market regulation and in a larger scope, it can improve the network operation efficiency and power supply service level [13].

With the rapid development of clean energy such as wind power, its installed capacity in the total accounts become more and more in various provinces. The trans-regional elimination of renewable energy is also becoming more and more significant, under the power market model, it is necessary to use excellent bidding methods to promote the trans-regional elimination of renewable energy and achieve the optimal use of energy. The competitive trans-regional power market built in this paper can realize the intra-provincial contract electricity, competitive electricity trading and inter-provincial electricity trading in the power market. The optimal power bidding strategy for power plants can be
regarded as a linear programming problem which can be solved by simple method. The improved simplicity rule can avoid the huge economic loss caused by the calculation accuracy error, which is introduce in this paper.

2. Electricity market overview

2.1. Simplex Method

The simplex method is an excellent algorithm for solving linear programming problems, Its basic idea is to find a basically feasible solution, and identified whether if it is the optimal solution or not, then translate into a better basic feasible solution according to a certain law, and identified again; if not, converted again and repeat in the light of this step. Because the basic feasible solution is limited in number, it can obtained a optimal solution through some times conversions. The objective functions and constraint equations of the simplex method are as follows:

\[
\begin{align*}
\max z &= \sum_{j=1}^{n} c_j z_j \\
\sum_{j=1}^{n} d_{ij} x_j &= b_i \quad (i = 1, \ldots, m) \\
x_j &\geq 0 \quad (j = 1, \ldots, n)
\end{align*}
\]

In the constraints equation, the coefficient of \(x_j\) in the objective function is the value coefficient \(c_j\), the control variables \(x_1, x_2, \ldots, x_n\) meet the contraints conditions, the column vector \(X = (x_1 + x_2 + \ldots + x_n)^T\) is the viable solution of the linear programming problem, Maximum feasible solution is the optimal solution which can make the target function value achieve the maximum. When writing program in computer, it is difficult to find the initial base variable, therefore, it is usually use the «two-stage method », it is frist to calculate a base variable then obtain the optimal solution by the above method as in refer [18].

2.2. Improved simplicity method

Based on the above described simple method, it has been improved on its basis, the improved details as are follows:

First, it can be inferred after the above introduction that the shaft calculation is the most important calculation step in the simplex method as in refer[19]. However, all columns of the coefficient Matrix must be calculated in the traditional method, the calculation process is complicated, and the accuracy will be reduced as the depth of shaft calculation increased. In power market, the very small precision errors can cause huge economic losses, therefore, the shaft calculation must be reduced its calculation numbers.

Second, it is considered that the number of power plant units is much smaller than the number of constraint equations, that is, the rows number of the coefficient matrix is much smaller than the columns number, we improved the traditional simplex method algorithm here, it is only made the variable located column as the main element column instead of all columns, which can greatly reduce the calculation number and avoid reducing the shaft calculation accuracy lose at the same time, it can improve the computing accuracy. The above method has verified and achieved the anticipated effect. The specific calculation steps of this algorithm are as follows:

1. It is turned the linear programming problem into a standard form. In order to make all the constraints to equations, it is added the relaxation variable \(x_1, x_2, \ldots, x_n\) to the constraint equation, which can be turned into a standard form.

2. It can select an initial feasible solution. That is using the non-base variable to express the base variables, and let the non-base variable equal to zero. Then we can obtain the basic feasible solution.

3. This step is to determine whether there is still a non-base variable with a positive coefficient in the objective function. If it is ture, that means it is not the optimal solution, and need to continue the following steps. If it is not, it shows that we have obtained the optimal solution and the calculation can be ended, then the optimal solution can be exported.
(4) It is to select the enter base and off-base variables. The selection method of base variable is to take the base variable in the equation which in the equation corresponding is the largest number in the positive coefficient of the non-base variables in the objective function. The method of selecting the off-base variable is to find the ratio of the right end constant to the enter base in the constraint equation of each constraint equation. The off-base variable is base variable who is the minimum non-negative ratio corresponded to the equation.

(5) When operated the shaft calculation it can obtained the initial feasible solution. When let the enter base variable column become the main column, and the off-base variable line as the main element line, the first equation indicates that the main element is the element where the main element line and the main element column intersected there. The n it used Gaussian elimination method to obtain a basically feasible solution, and returned to equation 3 to determine whether the feasible solution is the optimal solution.

3. The simulation design
Here we adopted the contract added bidding trading mode to build a multi-power market trading platform which composited the regional market and the provincial market. It is combined different levels of trading in the same system, and ensured the supply and demand balance of power resources firstly under the condition of signing the contract trading, we will give priority to the supply and demand balance of intra-province electricity resources, each provinces can share the Surplus-deficit electric quantity and the bidding information, it can conduct bidding trade in the provincial region, then the electricity market transactions efficiency can be realized.

Here it adopted the smart contract based on Ethereum, the transaction is executed automatically according to its established rules, which can reduce the labor cost of system maintenance and increase the reliability of the transaction. The entire transaction data system is de-centralized, that is the transaction information can be queried by the both trading sides at any time, and the data can not be tampered which ensured the trade fair and the trade just and open. In summary, we constructed a safe and efficient power market trading system, it is achieved goal that the electricity trading data can not be tampered off and it can be queried in security, the system can improve the electricity resources distribution more equitable in wide range and enhance the power industry production efficiency.

3.1. System Architecture

![Figure 1. System framework](image-url)
It is built a perfect competitive cross-regional power market system in the section. The system constructed in this paper can realized the intra-province contract electricity disassembled, bidding electricity trading and inter-provincial electricity trading. The actual system solution is shown in fig. 1. The contract of intra-province is the basis of intra-province bidding, the intra-province load forecasting is assigned to designated power units according to the contract, the algorithm used here is the hour rolling allocation algorithm based on the daily load forecast. The intra-provincial bidding is a bidding game between the intra-province power units, it can obtain the optimal price scheme by running the linear programming algorithm according to the unit bidding curve. The inter-provincial trading is the process that it is realized the electricity surplus-deficit rebalance according to the optimal trading strategy, it can generate the best trading strategy in accordance with analysis of electricity surplus-deficit and bidding data of each province used linear programming algorithm. The entire electricity market transaction is shown in Figure 2. The algorithm is based on the following five assumptions:

- in province, the provincial power grid company has the function of single purchase, provincial market operation and system operation.
- the power contract is the power purchase and power grid dispatching agreement which is signed between provincial power company and all the power companies participated in bidding.
- The remaining daily residual electricity in the province refers to the difference between the actual demand and the contract schedule, it is traded according to the spot prices, the trading object is the power plants participated in the province bidding.
- each province, the contract power distribution algorithm is the same, it is difference in actual parameters of the contract electricity hour distribution, the plant parameters, transmission network loss, contract power ratio and bidding curve of each power plant, etc.
- each province will share the surplus electricity and the quotation between provinces which is after the completion of the intra-provincial contract distribution and bidding.

Figure 2. Regional electricity market trade flow chart
3.2. Bidding Algorithm

The contract electricity is generally occupied 70 to 90 percent of the total load forecasting according to the current power market operating conditions. The inter-province contract energy decomposition is adopted the hourly rolling algorithm based on the daily load forecast, and the contract energy is distributed into the corresponding plant based on the hour.

First of all, to adjust the unit load rate according to the actual situation of each power plant, calculate the contracted amount allocated to the plant based on load rate, if the contract power assigned to each power plant meets the actual contract requirements, then end the calculation, if it is not satisfied the above condition, it returned to adjust the unit load rate, the above process repeated until all power plants contract meet the contract requirements.

The specific calculation steps are as follows:

It is to calculate the plant completed contract load rate of the time segment t (which is in hour). The function is shown here.

\[ coe(t) = \frac{load(t) \times coe_{all}}{gen_{max}(t)} \]  

In the function, \( coe(t) \) stand for the contract load rate completed of unit in time \( t \), \( load(t) \) is the system load for all power plants in time \( t \), \( coe_{all} \) is the adjustment factor, \( gen_{max}(t) \) is the maximum output of all power plants in time \( t \).

Then, it determines the daily contract energy at trading day, the function is given as follows.

\[ gen_{quan}(i) = \sum_{t} gen_{unit}(i, t) \times \Delta t \]  

In the formula, \( gen_{quan}(i) \) is the daily contract power of plant \( i \), \( gen_{unit}(i, t) \) is the basic capacity of plant \( i \) in time \( t \), \( \Delta t \) is the time interval. Then to determine whether the contract energy of all power plants meet the contract requirements. If there is a power plant does not meet the trading contract energy requirements, the method is to adjust \( coe_{all} \) and return to function one, make calculation again all the power plant meet the requirements. It is also need to calculate the daily bidding energy \( raval_{day} \), which is the difference between the load forecasting \( load_{day} \) and the contract energy of each power plant.

The bidding constraint equations are obtained according to the parameters of the power plant

\[
\begin{align*}
\sum_{j=1}^{n} P_{ij} & \leq gen_{unit \_max}(i) \\
\sum_{j=1}^{n} P_{ij} & \leq \sum_{j=1}^{n} P_{ij} \leq down_{i} \Delta t \\
\sum_{i=1}^{m} \sum_{j=1}^{n} P_{ij} & = raval_{day}
\end{align*}
\]  

In the formula, \( P_{ij} \) is the unit \( i \) bidding price corresponding to the bidding power \( j \) in time \( t \), \( gen_{unit \_max}(i) \) is the maximum generating power in time \( t \), \( down_{i} \) is the unit \( i \) falling output velocity, \( \Delta t \) is their time interval, \( raval_{day} \) is the daily total bidding quantity.

The calculate objective function is as follows:

\[ \min_{i} = \sum_{i=1}^{n} gen_{unit \_raval}(i) \times per(i) \]  

In the formula, \( gen_{unit \_raval}(i) \) is the intra-province bidding electricity quantity of power plant, \( per(i) \) is the average price of each power plant, \( z \) is the inter-province total bidding price, according to the above conditions, we can obtain the best strategy of the inter-province competitive electricity trading.

4. Analysis of simulation result

Here we constructed six provinces in the simulation model, the daily electricity demand with much difference of each province, the province in the mode is divided into seller and purchaser according to the electric quantity surplus-deficit, the trading information can be shared in the regional electricity market. The arrangement is to reflect the difference in the provinces with in the study area. The power
generation parameters and the contract electricity distributed by the power plant with each province is shown in table 1 and figure 3.

**Table 1. Plant main power generation parameters**

| province | Daily load forecasting/MWh | Percentage of contracted electricity | plants Number of Contract electricity distribution | Plant number of bidding distribution |
|----------|-----------------------------|-------------------------------------|--------------------------------------------------|-------------------------------------|
| 1        | 25000                       | 80%                                 | 5                                                | 3                                   |
| 2        | 50000                       | 75%                                 | 5                                                | 3                                   |
| 3        | 100000                      | 84%                                 | 5                                                | 3                                   |
| 4        | 130000                      | 82%                                 | 5                                                | 3                                   |
| 5        | 180000                      | 81%                                 | 5                                                | 3                                   |
| 6        | 200000                      | 83%                                 | 5                                                | 3                                   |

Table 1 lists the generation parameters which had entered into the test model, it is including the ratio of daily load forecasting to contract electricity of each province. For example, the second line of table 1 indicates that the daily load forecasting entered by province 1 at the time of testing is 25,000 MWh, in which, the contract energy take up to 80%, and in the test model, it is set that five power plant of each province to participate in the contract power distribution, in addition, three power plants participated in bidding power distribution.

In figure 3, it showed the bidding curve of the six provinces. The power demand with each province abided by the basical principle of power balance in real-time, and the average network loss coefficient of power transmission channel in provincial one is set to 0.15% in the model, the block coefficient of area transmission is 1.26%.

**Table 2. Electricity Trade results of inter-provincial**

| province | Report electricity/MWh | Buy(sell)electricity/MWh | Buy(sell)sum/ten thousand yuan |
|----------|-------------------------|--------------------------|-------------------------------|
| 1        | 2470(surplus)           | 322(sell)                | 644(sell)                     |
| 2        | 1634(surplus)           | 328(sell)                | 1640(sell)                    |
| 3        | 1252(surplus)           | 338(sell)                | 2028(sell)                    |
| 4        | 467(surplus)            | 352(sell)                | 2816(sell)                    |
| 5        | 668(lack)               | 698(buy)                 | 3711(buy)                     |
| 6        | 613(lack)               | 642(buy)                 | 3417(buy)                     |

The smart contract is deployed through the Solid language, and used Web3 interface to interact with the web page, the test data in table 1 is entered into the web page, then we can obtain the following results.
Figure 3. Six province reported bidding curve
Taking Figure 4-1 as an example, it can be seen that province 1 has obtained different daily contract power from each contract power distribution plant. Looking through the six column diagrams, it is clear that the contribution of the contract power distributed power plant of each province to the required daily contract power of each province is different, and it is meeting the actual requirements. The contract distribution energy is shown in Figure 4-2 in the form of histogram, the electricity distribution data of province five and six are shown in Figure 4-3.

Figure 4-1. Histogram of daily contract electricity distributed by plant of province 1 and 2

Figure 4-2. Histogram of daily contract electricity distributed by plant of province 3 and 4
The inter-provincial electricity trading results is recorded in table 2. The second line in table 2 is the surplus electricity 2470 MWh reported by province 1, and the selling power is 322 MWh, the amount of sold electricity was 6.44 million yuan. It can be seen from table 2, each province has a surplus in power generation by running smart contract, each province published its surplus power generation, used the inter-provincial electricity trading algorithm among the smart contract, then the provinces can buy and sell electricity, it can purchase and sale of electricity and obtain the corresponding business transactions sum.

5. Conclusion
The power grid reform is carried out in our national power grid, it hope to establish a competitive electricity trading market, but the reality is trading mainly focus on the market inside inter-province, and the district has weaker connections with each other, the trade between provinces is restricted.

The electricity market trading model proposed here can support multiple trades of intra-provinces and inter-provinces between the side of generator and consumers. In order to maintain the stability of the power supply system, the transaction can be divided into two parts of contract power and bid power, the province and plant can make a two-tier unit, the intra-province electricity trading of each province electricity market must be completed with priority, according to the basic parameters of the power plant, it has established the power market simulation model with six provinces, it can obtained the simulation results of 6 provinces through optimized clearing on plant trading results. The intra-province and regional electricity trading market integrated with each other, which coordinated the distribution justice of electricity resources across regions, it can play the role of market regulation, and promote the healthy development of the power industry and the rational consumption of cross-regional energy sources.

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6. References
[1] China coal network. New electricity reform over the past two years, the challenges are still many, [EB/OL]., http://www.cctd.com.cn/show-19-166296-1.html, 2017-05-26
[2] SHI Lian jun, HAN Fang. China electric power market status and prospects[J]. automation of electric power, 2000,2 p 1-4.
[3] Chen Zheng. Reflections on the construction of regional electricity market [N]. China Energy News, 2017-p 03-20
[4] Tai Xue, Sun Hongbin, Guo Qinglai. Power chain trading and congestion management method based on block chain in power Internet [J]. power system technology, 2016,40 (12)p 3630-3631
[5] The national development and reform commission and the energy administration issued "Notice for the Pilot Construction of the Power Spot Market" [J]. Energy Research & Utilization, 2017(5) p 500

[6] ZENG Ming, CHENG Jun, WANG Yuqing, LI Yuanfei, YANG Yongqi, DOU Jinyue. Primarily Research for Multi Module Cooperative Autonomous Mode of Energy Internet Under Blockchain Framework [J]. Proceedings of the CSEE. Vol. 37 No.13. p 3672-3681

[7] Zhu Jizhong. Analysis of the development and implementation of American power market [J]. South China power grid technology, 2016, (05) p 22-28.

[8] Liu Gang. The inspiration of the electricity market reform in Ontario, Canada. [J]. China prices, 2006, (07) p 47-50

[9] Yuan Jian. Comparison and reference of foreign power market structure [D]. Shandong University, 2014

[10] LENG Yuan, Chen Zheng, OU Peng, Wang Qinghong. MENG Wen chuan. The latest UK electricity market reform act and Its Enlightenment to China [J]. China energy, 2014, (04)p 12-15

[11] BAO Minglei, Ding Yi, Shao Changzheng, Song Yonghua. Review of the Nordic electricity market and its Suggestions for China [J]. proceedings of the CESS. Vol.37 No.17 p 4881-4892

[12] LUAN Feng kui, JIA Junguo, HAN Yinghao, ZHOU Wenyu, ZENG Ming. Japan's power industry reform and its reference to China's power market construction [J]. East China power, 2006, (09) p 6-9.

[13] KANG Jia-ning, SUN Wei chan, Electric power industry reform, the market mechanism and international comparison [J]. Chinese energy, 2016, 25. (05)p 21-25

[14] CHANG Dong-ling, TU Jin, CHENG Xiaolei. Lessons from the American electricity market in California and its implications for the reform of China's electricity market [J]. power technology and economics, 2006, (04)p 25-27.

[15] CPC Central Committee and the State Council. Some opinions on further deep the reform of power system [J]. wind energy industry, 2015, (4)p 7-11.

[16] GUO Xiu ying, Studying the linear programing simplex method [J]. Science-Technology and Management 2010, Vol.12 No.3, p 26-28

[17] XIE Zhen Improvement on the basis of the efficient simplex method [J]. Journal of taiyuan Normal University 2012 Vol.11 No.1 p 104-107

[18] LAN Yan LI Xue yong, A Developed simplex method [J]. Journal of chagnsha university Vol.12 No.4 p 29-32.