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DYNAMIC REAL TIME ELECTRICITY PRICE MECHANISM BASED ON LOW CARBON EMISSION

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ABSTRACT

Power industry is the most important basic energy industry of national economy development, and it is also a big carbon emitter. With the continuous and rapid growth of renewable energy (RE) capacity, the contradiction between the scale development of renewable energy and the lack of market capacity is becoming more and more obvious. To achieve low-carbon development and build a low-carbon society, we must develop low-carbon electricity and construct a feasible low carbon electricity price mechanism. In this paper, based on the efficient RE consumption, we introduce carbon cost to construct dynamic and variable low carbon real time electricity price mechanism, including the spot market pricing, grid fees and RE surcharge. Then the paper gives the electricity price strategy and its realization algorithm and verifies the beneficial effect of the proposed pricing mechanism by the example analysis. The proposed low carbon price mechanism is of great practical significance for the development and consumption of large-scale renewable energy.

Keywords: price mechanism, real time, carbon emission, dynamic

1. INTRODUCTION

According to the International Energy Agency, by 2020, two-thirds of the global increase in energy supply will come from renewable energy (RE), and in 2035 RE will become the world's second-largest source of electricity. The rapid development of global RE will provide momentum and significant opportunities for the development of RE in China. In terms of total power generation, at the end of 2016, China ranks first in the world in terms of hydropower, solar, wind energy capacity etc. At the same time, the grid consumption problems of RE are also increasing seriously, and large-scale abandoned wind and PV has occurred. In 2016, China's annual "abandoned wind" electricity capacity was 49.7 billion kWh, which exceeded half of the annual power generation capacity of the Three Gorges, and the national average abandoned rate reached 17%.

The problem of abandoned phenomenon reflects the fact that China's current power development and operation modes are increasingly unable to adapt to the development of RE. The main reason is the incomplete design of the market mechanism. How to adopt market-based measures and pricing mechanisms, regulate the low-carbon supply of power producers, increase the flexibility of power systems, and achieve a highly coordinated match of low-carbon energy supply and demand, are problems that need to be resolved urgently.

With the large-scale and rapid development of RE in the world, in recent years, foreign power market has also carried out many explorations in promoting the development of RE and coordinating the demands of relevant parties, mainly in two forms, one is the incentive policy based on electricity, the main form is renewable portfolio standard, representative countries include the United Kingdom, the United States (most states) and the Nordic countries [1-2]. The second is adopting the incentive policy based on price mechanism, mainly including fixed electricity price [3], premium mechanism [4], subscription price [5], CFD [6]. As one of the important forms of price signal, real time electricity price is widely used in today's smart grid. With the development of large-scale renewable energy, the

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existing real time electricity price [7-9] is unable to adapt to the trend of smart grid development and still exist many deficiencies. Firstly, the price signal cannot effectively reflect the external benefits of RE, and lack of effective guidance for RE development; Secondly, the volatility of the electricity price signal is not enough, so the incentive effect of power load is not obvious; Thirdly, renewable energy surcharges are more fixed form, and price signals lack of elasticity.

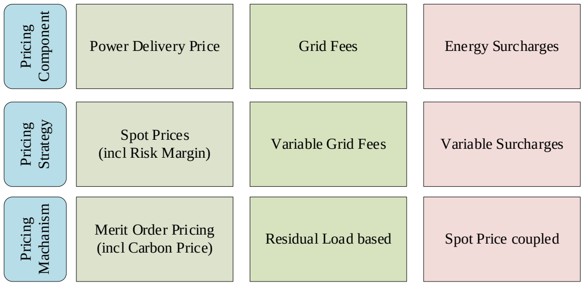
Based on the spot market, considering the supply and demand level of power generation side and demand side, this paper proposes a low carbon real-time pricing (LCEP) mechanism and algorithm based on carbon emission, in order to optimize the regulate of RE resources through electricity price as an important economic lever. Section 2 introduces the LCEP pricing mechanism; Section 3 gives the LCEP strategy and implementation; Section 5 make example analysis in detail and Section 5 summarizes the paper.

2. LCEP PRICING MECHANISM

The current energy system contains already some incentive systems. For example, the price is an incentive system for itself. The higher the energy price, the more efficient energy is used. Also, the feed-in tariff is an incentive system. It motivates to invest in renewable energies and is also an incentive to operate the generation units as long and efficient as possible to produce the maximum amount of energy over a long time

Incentive systems motivate the users to act in a way that offers advantages for the instance that pays the incentive. Regarding energy customers this means that they should be motivated to use existing flexibilities "smart" respective cost efficient from the perspective of the energy system. Incentive systems are important to finance flexibility potentials, but also to give signals when flexibilities should run or stop. These systems are divided in direct control incentives and indirect control incentives. A direct control incentive system is for example the control energy market. The TSO pays a fix capacity price to a power plant operator. When the contracted capacity is needed the TSO sends a (direct) control signal to the plant operator to deliver a certain amount of electrical power.

The main task of this study is to develop an indirect control incentive system for energy customers in form of a variable tariff. So the focus from the market perspective will be on the wholesale market and spot market. Following the indirect control incentive systems of dynamic pricing schemes applied worldwide will be described. Low carbon electricity pricing is a new instrument to motivate customers to run their flexible consumption devices in situations with a high share of renewable energies. So, the pricing mechanism should be a modular system as illustrated in Fig 1.



Pricing Component	Power Delivery Price	Grid Fees	Energy Surcharges
Pricing Strategy	Spot Prices (incl Risk Margin)	Variable Grid Fees	Variable Surcharges
Pricing Machanism	Merit Order Pricing (incl Carbon Price)	Residual Load based	Spot Price coupled

Fig 1 LCEP pricing mechanism

3. LCEP STRATEGY AND IMPLEMENTATION

As shown in Fig1, the LCEP mechanism consists of three components: sport price, grid fees and energy surcharges. So the detailed description of pricing strategy and implementation for each component is given in this section.

3.1 Spot Market Pricing

An energy supplier must predict the consumption profile of his customers and must buy the needed energy in 15 min. granularity for each day. If it has already bought energy at the futures market, the differences between the so far bought volumes and the short-term consumption profile prediction have to be traded at the spot market day-ahead or even intraday. The spot prices have also a steering function for flexible generation units and consumption devices. The volatility of the hourly or even ¼ hourly prices of each day motivates flexibilities to generate/consume energy when the prices are higher/lower. The pricing theory merit order is often used to explain the pricing mechanism of the spot market.

$$\text{Marginal Costs} = \text{Fuel Costs} + \text{Carbon Costs} + \text{Variable Operating Costs} \tag{1}$$

Only the generation units with the lowest marginal costs must be used to meet a given demand. The most expensive generation unit, which is needed to meet the given demand, respectively in this case the consumption determines the price for all other generators. This so-called market clearing price (MCP) is exactly, at least in theory, the marginal costs of the most expensive needed generation unit for a specific period (should be not more than one hour at the spot market).

$$MC_{ESU} = FC_{ESU} + VOC_{ESU} + CA_{ESU} \times CC \tag{2}$$

Where, *MC* denotes marginal costs, *FC* denotes fuel costs, *VOC* denotes variable operating costs, *CA* denotes carbon amounts, *CC* denotes carbon costs, *ESU* denotes energy source unit. Wind, PV and hydro power are generation units, which can deliver energy with very small marginal costs.

3.2 Variable Grid Fees

Variable grid fees (VGF) are an alternative approach, instead of power prices, to motivate the grid customers to adjust their energy consumption to the requirements of the distribution grid. The VGF must be calculated with a transparent algorithm because the DSOs are monopolistic companies and so prices can´t be found in competition. The algorithm should be coupled to the residual load profile (consumption profile less fluctuating generation profiles) with at least three differing price levels: High Price: In times of grid peak load situations; Mid Price: In times of normal situations; Low Price: In times of (nearly) negative residual load situations.

It is recommended that the multiplicative factor should not affect the annual average price of the grid fees, but only the volatility of the prices. The reason for this is that interdependency issues between input parameters for the pricing can be avoided or at least reduced. The recommended formula for the dynamic processing of the grid fees Mid-Price based on spot prices. The multiplicative factor has been parameterized approximately between the values 0 and 1 (depends on spot prices and the height of the concerned price parameters).

$$Dyn.MGF = SP_j \cdot MF - \frac{\sum_j SP_j \cdot MF}{Q_{MGF_i}} + MGF \qquad (3)$$

Where, *Dyn*. MGF denotes Dynamic Mid-Price Grid Fee, *SP* denotes Spot Price, *MF* denotes multiplicative factor, *MGF* denotes mid-price grid fee, Q_{MGF} denotes quantity of hourly Mid-Price Grid Fees, *i* denotes index for each hour of the year, *j* denotes index for each hour of the year with Mid-Price Grid Fees.

3.3 Variable RES Surcharge

In the spot market, with the RE share increasing, a serious problem is that the prices and the price volatilities decreased over the past few years. The reason for this is the increased share of RE which shift the conventional power plants to the right side of the merit order, and results in decreasing wholesale prices, especially in time periods with high production of renewable energies. The main problem of this development is that the spot market lost its steering function, because it can´t motivate the operators of flexibilities any more to shift consumption when the prices are high. The current RES surcharge is a fix energy price that must be paid by the energy customer and does not provide any incentive to shift consumption to times when the market prices are low or even negative (because RES produce more energy than the customers consume).

So, a “repair mechanism” is necessary to “revitalize” the spot market. The Variable RES Surcharge (VRS) is an approach to revitalize the spot market and give an incentive to improve the system integration of renewable energies. The idea of VRS is to couple the RES surcharge to the day-ahead spot prices with a multiplicative factor that must be calculated based on historical data. This factor should be defined on a yearly basis such as to cover the yearly costs of the RES support scheme.

$$VRS_i = SP_i \cdot MF - SP_i \qquad (4)$$

Where, *VRS* denotes variable RES surcharge, *SP* denotes spot price, MF denotes multiplicative factor, *i* denotes index for each hour of the year.

4. EXAMPLE ANALYSIS

By modeling and quantifying the impact of various tariffs on power planning, we can judge the advantages and disadvantages of low-carbon tariffs and provide useful reference for the selection of tariff types. System Dynamics (SD) is a science that combines the theory of system science with computer simulation technology to study the structure and behavior of system feedback. SD is suitable for the research and analysis of power market. In this paper, the effect of system dynamics model on participants in the implementation of low-carbon electricity price is expressed by causality diagram. Taking economic benefit as the main motivation of each party's strategy selection, this paper examines the impact of electricity price on each participant. The causality of demand response price implementation is constructed as shown in Fig. 2 and Fig. 3 Symbols between elements indicate their interaction relationship, and positive (negative) symbols indicate mutual promotion (restriction) relationship.

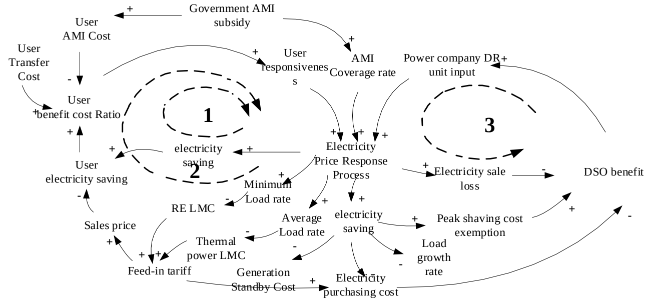


Fig 2 Demand-side causality diagram

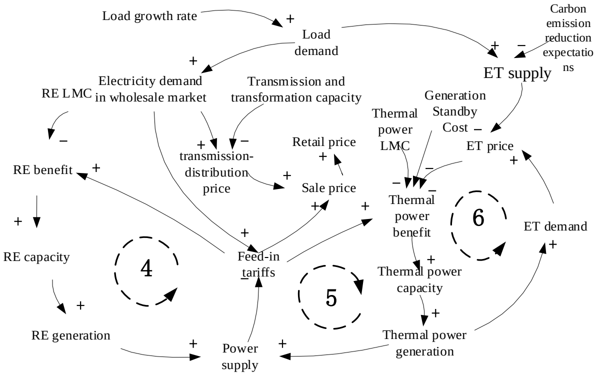


Fig 3 Supply-side causality diagram

The system dynamics software Vensim was used to simulate in time domain for 280 months. Three typical provinces have been selected for case study. Case 1: Jiangxi Province (slow development of renewable energy), Case 2: Jiangsu Province (excessive peak load), Case 3: Xinjiang Uygur Autonomous Region (severe wind abandonment). The growth of installed units and the change of electricity price after the implementation of low carbon price mechanism. Considering that current electricity price is TOU price, in the case, the TOU price and LCEP price are compared.

1） Case 1: The initial installation of renewable energy is less, and the initial installation of renewable energy is halved.

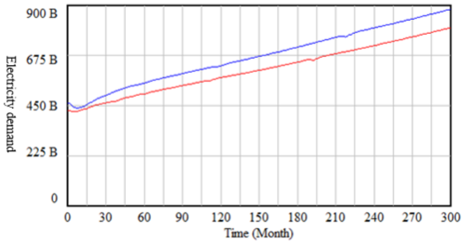


Fig 4 Impact of electricity price on load

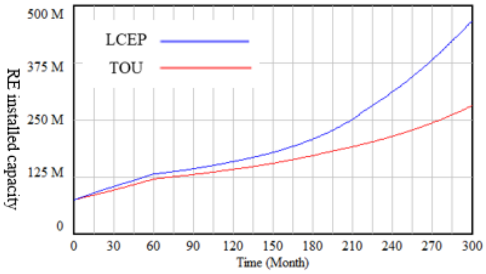


Fig 5 Impact of electricity prices on RE installation

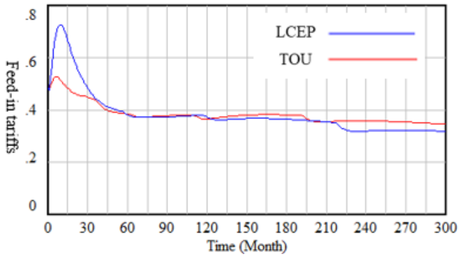


Fig 6 Different electricity prices

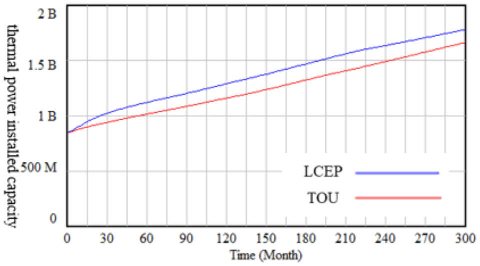


Fig 7 Installed capacity of thermal power under different electricity prices

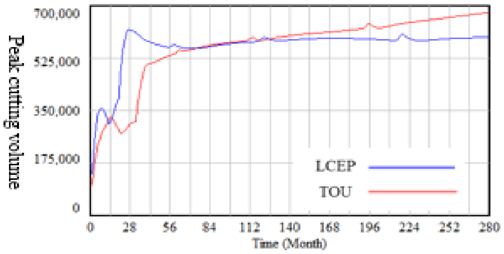


Fig 8 Peak Cutting under different electricity prices

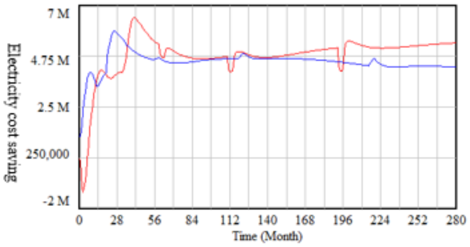


Fig 9 User's electricity cost savings under different prices

For power producers, carbon tax levy has led to a rise in the cost of thermal power production. Through tax burden transfer, electricity prices have also risen. The environmental cost reduces the price advantage of thermal power, stimulates the development of renewable energy installation, and affects the investment of thermal power. Low-carbon tariff can guide users to cut peak and fill valley. As the user response rate is assumed to increase gradually, Fig 9 shows that users benefit from the implementation of low-carbon tariff. By comparing the current hourly tariff in Jiangxi with the low-carbon tariff proposed in this report, we can see that the low-carbon tariff can achieve better peak-cutting effect and more effectively stimulate the development of renewable energy installations.

2）Case 2: The peak-valley difference is too large.

Table 1. Electricity settings for each period

scene	Valley-time （kWh）	Other-time （kWh）	Peak-time （kWh）
Scene1	2.75e+007	3.4022e+007	3.6866e+007
Scene2	2.44e+007	3.003e+007	4.17e+007

Table 2 Electricity proportion in different periods in scene 1

H	1	2	3	4	5	6	7	8
PR	0.9136	0.8919	0.834	0.815	0.846	0.8766	0.9235	0.996
H	9	10	11	12	13	14	15	16
PR	1.143	1.2	1.1646	1.054	0.978	0.9684	0.949	0.95
H	17	18	19	20	21	22	23	24
PR	1.09	1.122	1.229	1.17	1.026	0.983	0.94	0.92

Table 3 Electricity proportion in different periods in scene 2

H	1	2	3	4	5	6	7	8
PR	0. 824	0. 785	0. 686	0. 655	0. 706	0. 758	0. 842	0. 979
H	9	10	11	12	13	14	15	16
PR	1. 289	1. 421	1. 338	1. 096	0. 944	0. 925	0. 889	0. 891
H	17	18	19	20	21	22	23	24
PR	1. 172	1. 242	1. 490	1. 351	1. 039	0. 954	0. 872	0. 835

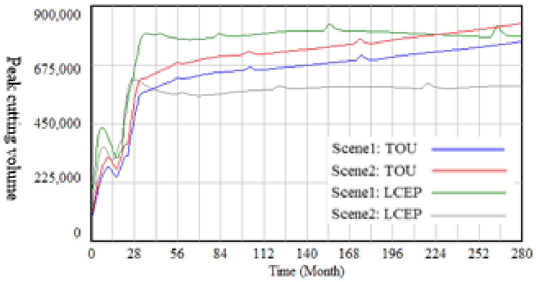


Fig 10 Peak cutting with different electricity prices

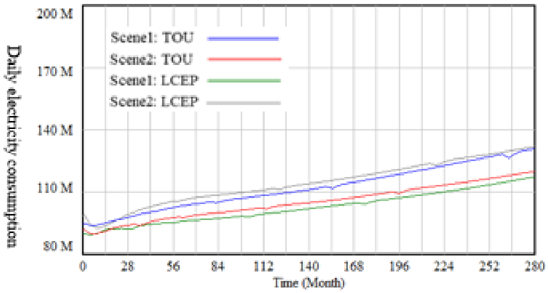


Fig 11 Electricity consumption with different prices

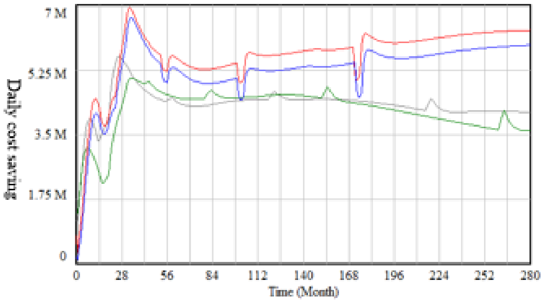


Fig 12 Electricity cost savings with different prices

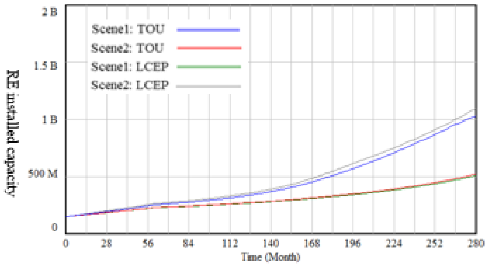


Fig 13 Renewable energy installation dvelopment

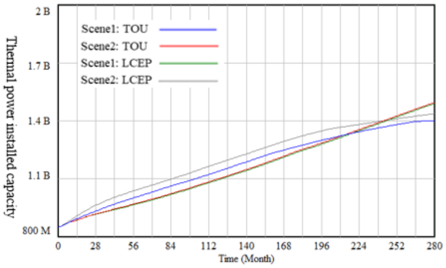


Fig 14 Installed capacity of thermal capacity

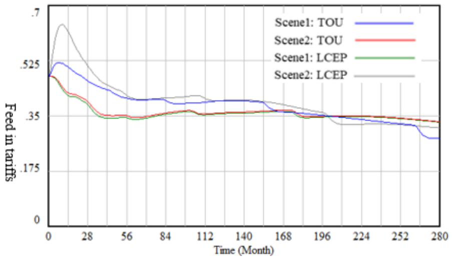


Fig 15 Comparison of feed-in tariffs

From Figure 10, after the implementation of low-carbon tariff in large peak-valley areas, better peak-cutting effect will be achieved in the early stage. Low-carbon electricity price can promote the overall improvement of electricity consumption, as shown in Figure 11, so it has less impact on the loss of electricity sales in the power grid, as shown in Figure 12. Compared with Figure 13 and Figure 14, the implementation of low-carbon tariff in areas with large peak-valley difference can achieve better results than time-of-use tariff; low-carbon tariff in areas with large peak-valley difference is better than that in areas with small peak-valley difference. Although the promotion effect of renewable energy is slightly worse, the difference between the two is smaller, and they are far better than time-of-use tariff. Fig 15 shows that if the peak-valley difference is large in a certain area, the power resources allocated are relatively enough, after the implementation of low-carbon tariff, the competition will be more intense than that in the area where the peak-valley difference is smaller, which will make the tariff less affected by carbon tax (carbon certificate).

3) Case 3: In the model, wind power access is limited, and load increase during the valley period is guided by electricity price. The model assumes that all the increased electricity comes from wind power.

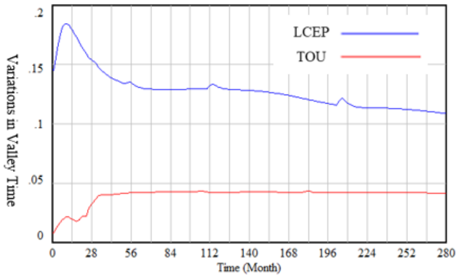


Fig 16 Variations in valley time with different prices

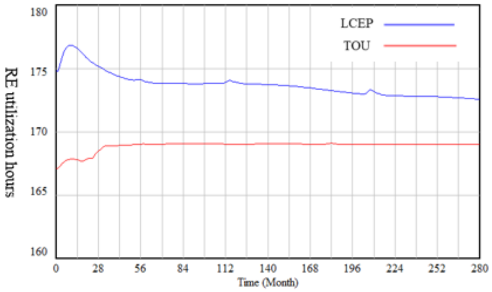


Fig 17 RES utilization hours with different Prices

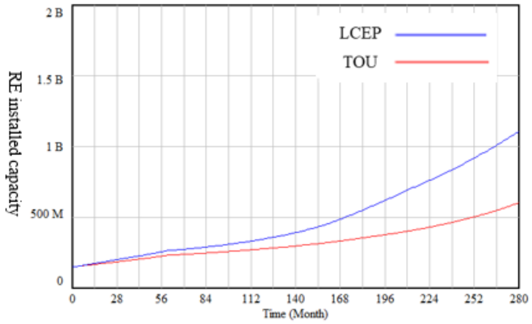


Fig 18 RE installed changes with different electricity prices

In the wind abandonment scenario, the adjustment effect of low-carbon electricity price on the valley period is more obvious, so it can significantly improve the utilization hours of wind power and improve the phenomenon of wind abandonment. Although the time-sharing tariff in the example also considers carbon emissions, it is still less effective than the low-carbon tariff in improving the load curve. In a word, even if the emission penalties for thermal power units are not considered, the low-carbon electricity price is more advantageous than the time-of-use price. If the penalties for carbon emissions are considered, the competitive advantage of renewable energy is more obvious, and the application prospects are broader.

5. CONCLUSION

The transition of Low-carbon development mode characterized by low energy consumption, low pollution and low emission is the intrinsic requirement of sustainable development. Under the condition of modern electricity market, demand response becomes one of the important tools to relieve the contradiction between supply and demand in power market, reduce peak load and realize energy saving and emission reduction. As a kind of demand response of price type, real time electricity price plays a very important role in power grid. Starting from the power supply side and demand side, considering the operation characteristics and requirements of the power system of the large-scale fluctuation power supply, this paper puts forward the dynamic variable real time pricing mechanism based on the carbon cost, provide useful reference to China's electric power system reform. It is of great significance to solve the problem of new energy dissipation in China, such as abandoning wind and PV generation.

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