# THE METHOD OF POWER TRACEABILITY: APPLICATION IN MARKET-ORIENTED INDUSTRIAL AND COMMERCIAL USERS IN CHINESE ELECTRICITY MARKET

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*The innovation of traceability concept lies in the ability to track the exact origin of electricity used by market-oriented industrial and commercial users. However, tracing energy in power transactions remains a challenge. This paper introduces an algorithm-based framework for electricity energy traceability in both wholesale and retail markets. The Sichuan green power traceability system is being developed based on this framework and will oversee green power transactions. Future work will involve real data experiments and evaluation of this algorithm.*

**Keywords:** Market-oriented Industrial and Commercial Users; Distributed Energy Resources; Green Power; Traceability Algorithm

**Notation**

| Symbol | Description |
|---|---|
| $s$ | Supply side |
| $d$ | Demand side |
| $w$ | Power company |
| $h$ | Retail user |
| $EWCD$ | Electricity-water consumption demonstration |
| **Wholesale market** | |
| $E_c$ | Contract volume |
| $E_{c.inc}$ | Signed incremental contract volume |
| $E_c^{in}$ | Incoming contract volume |
| $E_c^{out}$ | Outgoing contract volume |
| $E_c^{br}$ | Contract volume with bilateral reduction |
| $E_{c,inc,tbm}$ | To-be-matched contract volume of contract $a$ under incremental transaction |
| $E_{c.tt}$ | Contract volume under transfer transaction |
| $E_{c,tt,tbm}$ | To-be-matched contract volume of contract a under transfer transaction |
| $E_{c.p}$ | Pre-allocated electricity within contract |

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|---|---|
| $E_{c.s}$ | Settlement volume within contract |
| $E_{c.t}$ | Traceable power within contract |
| $E_{oc.t}$ | Traceable power outside contract |
| $E_{oc.t}^{F}$ | Out-of-contract traceable power of all transaction categories |
| $E_{ex}^{S}$ | Over-generated volume of supply side subjects |
| $E_{t}^{F}$ | Total traceability volume of wholesale market |
| **Retail market** | |
| $T_c$ | Contract volume |
| $T_{c.p}$ | Pre-allocated electricity within contract |
| $T_{c.s}$ | Settlement volume within contract |
| $T_{c.t}$ | Traceable power within contract |
| $T_{oc.t}$ | Traceable power outside contract |
| $T_{oc.t}^{F}$ | Out-of-contract traceable power of all transaction categories |
| $T_{t}^{F}$ | Total traceability volume |

## 1. Introduction

Under carbon peaking and carbon neutrality, the development of large-scale Distributed Energy Resources (DERs), advanced smart metering and information communication technologies has made it possible for producers and consumers to share energy directly at the distribution grid side [1]. As it was proved by the latest directions of research [2], this research area, renewable sources of energy-photovoltaic systems, is one of the most interesting nowadays because of the rapid depletion of conventional energy sources while the demand is rapidly increasing [3]. In this context, the concept of Transactive Energy (TE) [4] came into being, in which producers with generation capacity and consumers can directly supply surplus energy to other consumers through market-oriented transaction [5]. This helps to stimulate the producers and consumers to tap into its flexibility and actively participate in the system operation, thus promoting consumption of new energy near the spot as well as matching of local supply and demand [6].

Green power contributes to environmental protection, so it also has a special physical nature. "Traceability is the ability to identify and trace the history, distribution, location, and application of products, parts, materials, and services. A traceability system records and follows the trail as products, parts, materials, and services come from suppliers and are processed and ultimately distributed as final products and services." (Standard ISO/9000 – 2005). In itself, traceability is implemented by integrated operational and corporate functions within and across firms. It is sometimes seen as a tool but, given the importance of managing the flows induced by its implementation, it is increasingly recognized as a strategic management approach [7]. Thus, traceability cannot take place in isolation and global connectivity between functions and firms is a prerequisite for operations. This issue is now well understood by industrial managers. Thus, the benefits of 'good' traceability constitute a major bonus where and when partnership is required and obtained. But traceability can also endanger the health and safety of consumers if it is misused. In short, while traceability and its application are at the heart of numerous debates on its advantages for personal security, following-up goods and controlling forgeries, and that it is subject to scientific studies underlining its strategic role, it appears interesting to take stock of the barriers and the dangers of implementing traceability and non-traceability [7].

Namely, it is difficult to trace the source from the supply side to the demand side. Domestic scholars have done lots of research in relevant directions. Literature [8] analyze the current situation and polices of trading platform at home and aboard, and then discuss the internal connection between internal factors and external environment through dynamic model considering the green certificate market and carbon emission and several scenarios are carried out. Literature [9-11] designed a power market system for renewable energy quota system, which aims at solving the lack of consideration for the user's friendliness to renewable energy power generation. Literature [12] pilots group of vouches that were successfully applied with the dual purpose of coupling innovation stimulation and support for renewable energy and energy efficiency in Armenia, Belarus, Georgia, and Moldova and sort out the features. Literature [13] proposes a multi-agent-based framework for Peer-to-Peer (P2P) power trading in a locality electricity market (LEM) for self-interested smart residential prosumers. In LEM, prosumers may sell (buy) their excess generation (demand) at a profitable market prices compared to utility prices to achieve a win–win outcome.

Sichuan electricity market is unique among the provincial electricity markets in China in terms of its diverse power transaction varieties and complex transaction rules. Based on market data, comparative analysis is conducted around the dimensions of transaction varieties, scale, structure, user and price to witness the development and progress of Sichuan electricity market together with market players. In Sichuan electricity market, commercial and industrial power users who purchase electricity directly from the electricity market are collectively referred to as market-oriented commercial and industrial users. Market-oriented commercial and industrial users are divided into two categories. One category of users who purchase electricity from the market is called wholesale users, and the other category of users who purchase electricity through the agency of power companies is called retail users. How to trace the energy of the electricity market in power transactions is an urgent problem to be solved at present. Sichuan Province has already pointed out in the overall plan of provincial electricity market transaction in 2022 that the current electricity market energy traceability in electricity transaction can no longer meet the development needs of the electricity market, so how to overcome the shortcomings of the existing technology is an urgent problem that needs to be solved in the field of electricity market energy traceability at present.

In this paper, a method is proposed for electricity energy traceability in electricity transaction, including electricity energy traceability in wholesale market and electricity energy traceability in retail market. The method for electricity energy traceability in wholesale market is to firstly conduct in-contract electricity traceability in wholesale market, then conduct out-of-contract electricity traceability in specific transaction category of wholesale market, and finally conduct out-of-contract electricity traceability in all transaction categories of wholesale market. The method for electricity energy traceability in retail market is to firstly conduct in-contract electricity energy traceability in retail market, then conduct out-of-contract electricity energy traceability in specific transaction category of retail market, and finally conduct out-of-contract electricity traceability in all transaction categories of retail market.

## 2. Framework of electricity energy traceability algorithm

Authorized by government departments, Sichuan Power Trading Center issues clean energy consumption vouchers. Based on the contract data and settlement data of electricity market transaction, the voucher can trace the clean energy power used by commercial and industrial enterprises, including hydropower, wind power, solar power, biomass power and gas power. It accurately reflects the scale, proportion and source of clean energy power used by the electricity consuming enterprises, which plays an important role in reducing carbon tariff on foreign trade export and enhancing the competitiveness of electricity consuming enterprises in international market. The business process of electricity energy traceability in Sichuan electricity market is shown in Fig. 1.

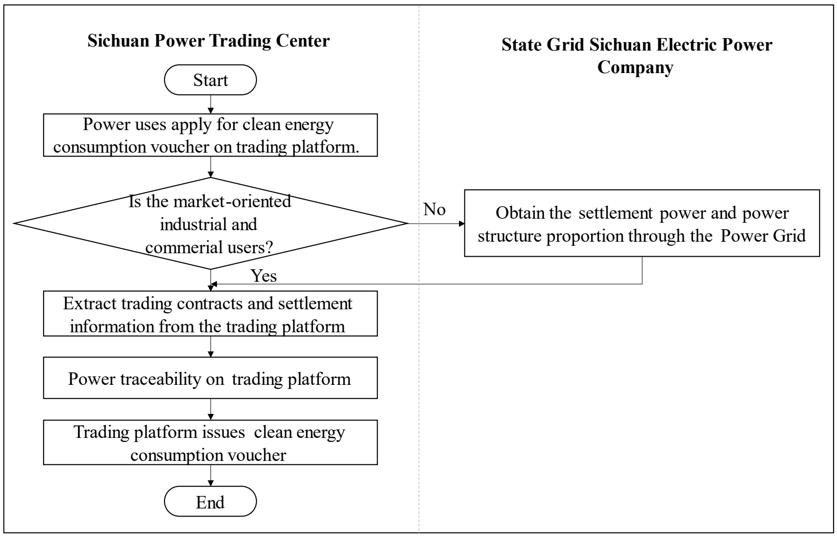


Fig. 1. Flowchart of Electricity Energy Traceability Business in Sichuan Electricity Market

The flowchart of the electricity energy traceability algorithm in Sichuan electricity market is presented in Fig.2, including the following steps.

Step 1, In electricity energy traceability of wholesale market, electricity energy traceability of the wholesale market includes electricity energy traceability between power plants and power companies as well as electricity energy traceability between power plants and wholesale users. Electricity energy traceability in wholesale market is to firstly conduct in-contract electricity traceability in wholesale market, then conduct out-of-contract electricity traceability in specific transaction category of wholesale market, and finally conduct out-of-contract electricity traceability in all transaction categories of wholesale market.

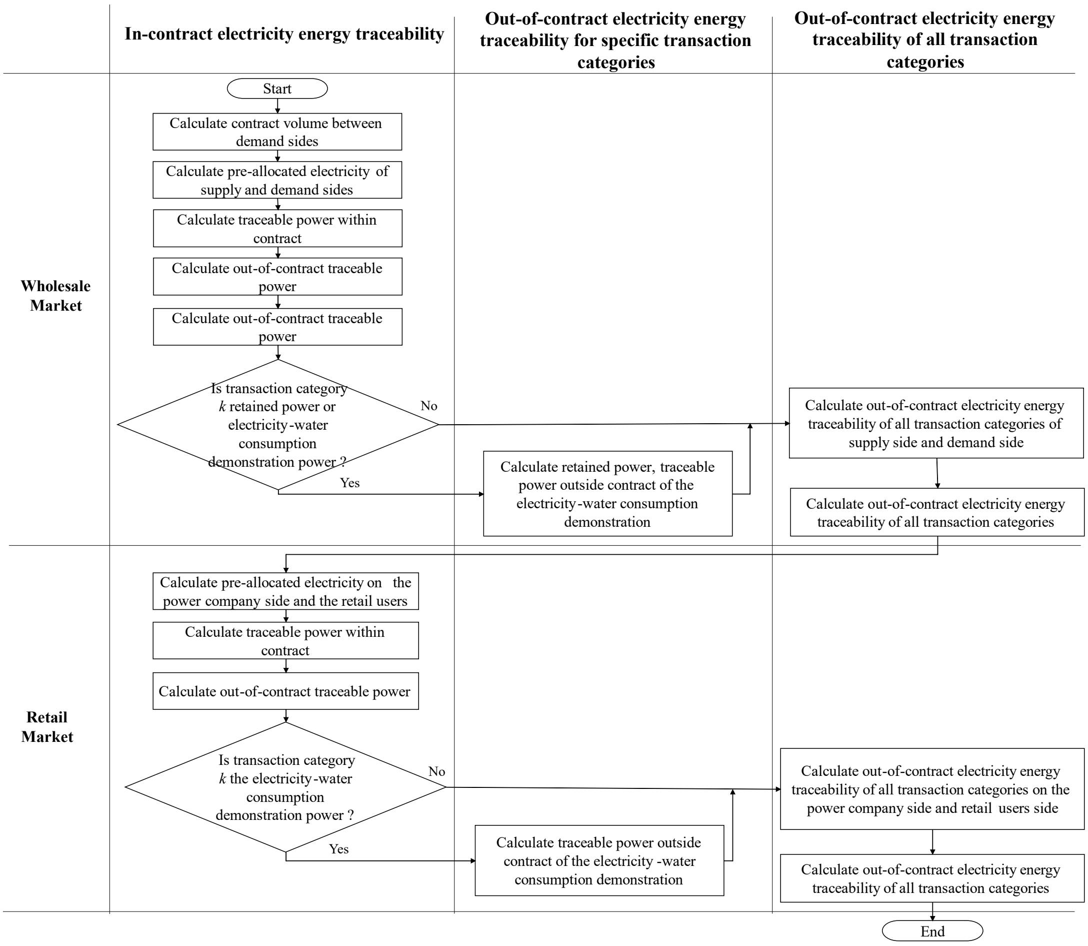


Fig.2. Energy traceability calculation flowchart of Sichuan electricity market

Step 2, In electricity energy traceability of retail market, electricity energy traceability of the retail market includes electricity energy traceability between power companies and retail users. The method for electricity energy traceability in retail market is to firstly conduct in-contract electricity energy traceability of power company and retail user in retail market based on electricity energy traceability between the power plant and power company in the wholesale market, then conduct out-of-contract electricity energy traceability in specific transaction category of power company and retail user in retail market, and finally conduct out-of-contract electricity energy traceability in all transaction categories of power company and retail user in retail market.

Step 3, the electricity energy traceability of the electricity market is completed via the electricity energy traceability of the wholesale market and the electricity energy traceability of the retail market.

## 3. Electricity energy traceability in the wholesale market

### 3.1 In-contract electricity energy traceability in the wholesale market

Contract volume:

The market players on the supply and demand sides carry out energy increment transaction, contract volume transfer transaction and contract bilateral reduction transaction to establish the contract volume correlation between the market players on the supply and demand sides.

(1) Incremental transaction of contract volume between supply and demand sides.

The electricity energy increment contract a is signed between the supply side subject s and demand side subject d. After the supply side and the demand side complete the contract volume transfer and contract bilateral reduction transaction respectively, the contract volume of contract a held by the supply side and the demand side is as follows:

$$E_c^s = E_{c,inc}^s + E_c^{s,in} - E_c^{s,out} - E_c^{s,br} \tag{1}$$

$$E_c^d = E_{c,inc}^d + E_c^{d,in} - E_c^{d,out} - E_c^{d,br} \tag{2}$$

where: $E_c$ is its contract volume; $E_{c,inc}$ is the signed incremental contracted volume; $E_c^{in}$ is the incoming contracted power; $E_c^{out}$ is the outgoing contract volume; $E_c^{br}$ is the contract volume with bilateral reduction.

The supply side subjects include the direct-transfer hydropower enterprises from the Southwest Branch of the National Power Dispatching Center (hereinafter referred to as "Southwest Network Dispatching") and the direct-transfer radial hydropower enterprises, non-radial hydropower, wind power and photovoltaic (except grid-parity wind and solar turbine units and photovoltaic poverty alleviation projects) power generation enterprises directly transferred by the Southwest Network Dispatching and the provincial dispatching of Sichuan Electric Power Dispatching and Control Center (hereinafter referred to as "Provincial

Dispatching") that participated in the 2022 provincial electricity market transactions, the same below.

The demand side subjects include the power companies, market-oriented commercial and industrial users who purchase electricity directly from the wholesale market, the same below.

The associated contract volume $E_{c,inc}^{sd}$ of the incremental contract between the supply side subject and the demand side subject is:

$$E_c^d = E_{c,inc}^d + E_c^{d,in} - E_c^{d,out} - E_c^{d,br} \tag{3}$$

For the supply and demand sides of the incremental contract, contract volume of to-be-matched contract a of the supply side subject and the demand side subject is:

$$E_{c,inc,tbm}^s \tag{4}$$

$$E_{c,inc,tbm}^d = E_c^d - E_{c,inc}^{sd} \tag{5}$$

where, $E_c^s$ and$E_c^d$ are the contract volume of contract a held by the supply side/demand side, respectively, which is calculated by Equation (1) and (2). $E_{c,inc,tbm}^s$ and $E_{c,inc,tbm}^d$ are the contract volume of to-be-matched contract a of the supply side/ demand side under incremental transaction.

(2) Transfer transaction of associated contract volume of supply side/demand side.

For the supply and demand sides holding contract a through contract volume transfer, the contract volume of to-be-matched contract a of the supply side subject, demand side subject is:

$$E_{c,tt,tbm}^d = E_c^{d,in} - E_c^{d,out} - E_c^{d,br} \tag{6}$$

$$E_{c,tt,tbm}^s = E_c^{s,in} - E_c^{s,out} - E_c^{s,br} \tag{7}$$

where $E_{c,tt,tbm}^d$ is the to-be-matched contract volume of the demand side under the transfer transaction, $E_c^{d,in}$ is the incoming contract volume on the demand side; $E_c^{d,out}$ is the outgoing contract volume; $E_c^{d,br}$ is the contract volume with bilateral reduction; $E_{c,tt,tbm}^s$, $E_c^{s,in}$, $E_c^{s,out}$ and $E_c^{s,br}$ are the corresponding variables on the supply side.

For the associated matching of to-be-matched contract volume on the supply, demand sides, the associated contract volume $E_{c,tt}^{sd}$ for the transfer contract between the supply side subject and the demand side subject is:

$$E_{c,tt}^{sd} = \begin{cases} \frac{E_{c,tt,tbm}^s \times E_{c,tt,tbm}^d}{\sum_d E_{c,tt,tbm}^d}, if \ \sum_S E_{c,tt,tbm}^s \le \sum_D E_{c,tt,tbm}^d \\ \frac{E_{c,tt,tbm}^s \times E_{c,tt,tbm}^d}{\sum_s E_{c,tt,tbm}^s}, if \ \sum_S E_{c,tt,tbm}^s > \sum_D E_{c,tt,tbm}^d \end{cases} \tag{8}$$

where S and D are respectively the number of supply side subjects and demand side subjects in the to-be-matched contract a.

(3) For the associated contract volume between the supply side and the demand side under a certain transaction category *k*.

The associated contract volume $E_c^{sd}(k)$ for transaction category k between the supply side subject and demand side subject is:

$$E_c^{sd}(k) = E_{c,inc}^{sd}(k) + E_{c,tt}^{sd}(k) \tag{9}$$

where transaction category k contains 11 categories of retained power of Ganzi, Aba, Liangshan, Electricity-Water Consumption Demonstration (EWCD) in Ganzi, Aba, Liangshan, Panzhihua, Ya'an and Leshan, wind and solar high energy consumption, and other transaction varieties (including conventional direct purchase, strategic long-term agreement, surplus power during wet period, electric energy substitution). Other parameters are the same as in the previous section.

Pre-allocated electricity:

Pre-allocated electricity is the electricity allocated according to the proportion of the associated contract volume between the supply and demand side market players in the contract volume held by the supply and demand side market players respectively. The pre-allocated electricity on the supply side is:

$$E_{c,p}^{s}(k) = \frac{E_s^s(k) \times E_c^{sd}(k)}{\sum_N E_c^s(k)} \tag{10}$$

where $E_{c,p}^{s}(k)$ is the supply side pre-allocated electricity of transaction category k between the supply side subject and the demand side subject, $E_{c,s}^{s}(k)$ is the settlement electricity of transaction category k for the supply side subject, $E_c^{sd}(k)$ is the associated contract volume of transaction category k between the supply side subject and the demand side subject, $E_c^s(k)$ is the contract volume of transaction category k held by supply side subject, and N is the contract volume of transaction category k held by supply side subject.

The pre-allocated electricity on the demand side is as follows, and the meanings of its parameters are the same as that on the supply side.

$$E_{c,p}^{d}(k) = \frac{E_{c,s}^d(k) \times E_c^{sd}(k)}{\sum_N E_c^d(k)} \tag{11}$$

Traceable power within contract:

Traceable power within contract is the traceable power between the supply and demand sides within the scope of associated contract volume. The traceable power within contract of transaction category k between the supply side and the demand side is:

$$E_{c,t}^{sd}(k) = \min\left(E_c^{sd}(k), E_{c,p}^{s}(k), E_{c,p}^{d}(k)\right) \tag{12}$$

### 3.2 Out-of-contract electricity energy traceability for specific transaction categories in the wholesale market

The traceable power out-of-contract transaction category k between the supply side subject (s) and the demand side subject (d) is:

$$E_{oc,t}^{s}(k) = E_{c,p}^{s}(k) - E_{c,t}^{sd}(k) \tag{13}$$

$$E_{oc,t}^{d}(k) = E_{c,p}^{d}(k) - E_{c,t}^{sd}(k) \tag{14}$$

(1) When the transaction category k is retained power, the retained power either on the supply side or demand side that is not traced within the contract is given priority for matching the traceability within the prefecture, and its traceable power outside contract is calculated as

$$E_{oc,t}^{sd}(r,z) = \begin{cases} \frac{E_{oc,t}^{d}(r,z)\times E_{oc,t}^{s}(r,z)}{\sum_S E_{oc,r}^{s}(z)}, \text{if } \sum_D E_{oc,t}^{d}(r,z) \le \sum_S E_{oc,t}^{s}(r,z) \\ \frac{E_{oc,t}^{d}(r,z)\times E_{oc,t}^{s}(r,z)}{\sum_D E_{oc,t}^{d}(z)}, \text{if } \sum_D E_{oc,t}^{d}(r,z) > \sum_S E_{oc,t}^{s}(r,z) \end{cases} \tag{15}$$

where $E_{oc,t}^{sd}(r,z)$ is the retained out-of-contract traceable power of the supply side subject and the demand side subject in z prefecture, $E_{oc,r}^{d}(r,z)$ and$E_{oc,r}^{s}(r,z)$ are the retained power of z prefecture not traced in the contract between the demand side and supply side respectively, S and D are the amount of not traced retained power of the supply side and demand side in z prefecture in the contract, respectively. Prefecture z is the one where the retained power is located, i.e. Ganzi, Aba or Liangshan.

(2) When the transaction category k is EWCD, the supply and demand side EWCD power that is not traced within the contract is given priority for matching traceability within this demonstration area, and traceable power outside contract is calculated as follows:

$$E_{oc,t}^{sd}(ew,q) = \begin{cases} \frac{E_{oc,t}^{d}(ew,q)\times E_{oc,t}^{s}(ew,q)}{\sum_S E_{oc,t}^{s}(ew,q)}, \text{ if } \sum_D E_{oc,t}^{d}(ew,q) \le \sum_S E_{oc,t}^{s}(ew,q) \\ \frac{E_{oc,t}^{d}(ew,q)\times E_{oc,t}^{s}(ew,q)}{\sum_D E_{oc,t}^{d}(ew,q)}, \text{ if } \sum_D E_{oc,t}^{d}(ew,q) \le \sum_S E_{oc,t}^{s}(ew,q) \end{cases} \tag{16}$$

where $E_{oc,t}^{sd}(ew,q)$ is the traceable power outside contract of the EWCD between the supply side subject and the demand side subject in the q demonstration area, $E_{oc,t}^{d}(ew,q)$ is the amount of EWCD power in the q demonstration area not traced by demand side subject in the contract, $E_{oc,t}^{s}(ew,q)$ is the EWCD power in the q demonstration area not traced by supply side subject in the contract. S and D are the number of supply side subject and the demand side subject in the q demonstration area of electricity-water consumption not traced in the contract. q demonstration area is for EWCD exchange, i.e. Ganzi, Aba, Liangshan, Panzhihua, Yaan or Leshan.

### 3.3 Out-of-contract electricity energy traceability of all transaction categories in the wholesale market

After out-of-contract electricity energy traceability of specific transaction category in the wholesale market, there are still not traced retained power of the supply, demand sides, EWCD power, which are subjected to out-of-contract electricity energy traceability of all transaction categories in the wholesale market together with wind and solar high energy consumption of the supply, demand sides not traced in the contract, other transaction varieties of electricity, as well as over-generated volume of the supply side.

To-be-traced electricity energy outside the contract of all transaction categories of demand side subject d:

$$E_{oc,t}^{F,d} = \sum_K E_{c,s}^{d}(k) - \sum_S \sum_K E_{c,t}^{sd}(k) - \sum_S E_{oc,t}^{sd}(r) - \sum_S E_{oc,t}^{sd}(ew) \quad (17)$$

To-be-traced electricity energy outside the contract of all transaction categories of supply side subject s:

$$E_{oc,t}^{F,s} = \sum_K E_{c,s}^{s}(k) + E_{ex}^{s} - \sum_D \sum_K E_{c,t}^{sd}(k) - \sum_D E_{oc,t}^{sd}(r) - \sum_D E_{oc,t}^{sd}(ew) \quad (18)$$

where $E_{ex}^{s}$ is the over-generated volume of the supply side subject and the rest of parameters are the same as above.

The out-of-contract traceable power of all transaction categories between the supply side subject s and the demand side subject d is as follows:

$$E_{oc,t}^{F,sd} = \frac{E_{oc,t}^{F,d} \times E_{oc,t}^{F,s}}{\sum_S E_{oc,t}^{F,s}} \quad (19)$$

### 3.4 Total traceable power in the wholesale market

The total traceable power between supply side and demand side is as follows.

$$E_{t}^{F,sd} = \sum_K E_{c,t}^{sd}(k) + E_{oc,t}^{sd}(r) + E_{oc,t}^{sd}(ew) + E_{oc,t}^{F,sd} \quad (20)$$

where K is all transaction types and the remaining parameters are consistent in the full text.

## 4. Electricity energy traceability in the retail market

For wholesale users and retail users, the retained power is directly traced according to the electricity energy traceability principle of wholesale market, and traceable power of small hydropower station is the electricity user's electricity guaranteed by the local small hydropower stations. For retail users' power, electricity energy traceability is carried out other than the retained power, secured power of small hydropower station in the retail market.

### 4.1 In-contract energy traceability in the retail market

For in-contract energy traceability by power companies in the retail market, pre-allocation and electricity traceability within contract will be carried out in the retail market for transaction category (EWCD transaction category includes out-of-contract electricity energy traceability of EWCD).

Pre-allocated electricity：

(1) Pre-allocated electricity within contract of power company.

a. When the transaction category k is non-EWCD, the pre-allocated electricity within the contract of the power company is:

$$T_{c,p}^{w}(k)=\frac{\sum_{S}T_{c,t}^{sw}(k)\times\min\left(T_{c}^{wh}(k),T_{c,s}^{wh}(k)\right)}{\sum_{H}\min\left(T_{c}^{wh}(k),T_{c,s}^{wh}(k)\right)} \tag{21}$$

b. When the transaction category k is EWCD, the pre-allocated electricity within contract of the power company is:

$$T_{c,p}^{w}(k)=\frac{\sum_{S}\left(T_{c,t}^{sw}(k)+T_{oc,t}^{sw}(k)\right)\times\min\left(T_{c}^{wh}(k),T_{c,s}^{wh}(k)\right)}{\sum_{H}\min\left(T_{c}^{wh}(k),T_{c,s}^{wh}(k)\right)} \tag{22}$$

where $T_{c,t}^{sw}(k)$ is the traceable power within contract of transaction category k between the supply side subject s and power company w, $T_{c}^{wh}(k)$ is the contract volume of transaction category k between the power company w and retail user h, $T_{c,s}^{wh}(k)$ is the settlement volume of transaction category k between the power company s and retail user h, $T_{oc,t}^{sw}(k)$ is traceable power outside contract of transaction category k between the supply side subject s and power company w. S and H are the number of supply side subjects and retail users, respectively.

(2) Pre-allocated electricity on the retail user side

$$T_{c,p}^{h}(k)=T_{c,s}^{wh}(k) \tag{23}$$

where $T_{c,s}^{h}(k)$ is the settlement electricity of transaction category k between power company w and retail user h.

Traceable power within contract：

Traceable power within contract of transaction category k between power company w and retail user h is calculated as follows.

$$T_{c,t}^{wh}(k)=\min\left(T_{c,t}^{wh}(k),T_{c,p}^{w}(k),T_{c,p}^{h}(k)\right) \tag{24}$$

(1) When the transaction category k is non-EWCD:

$$T_{c,t}^{swh}(k)=\frac{T_{c,t}^{wh}(k)\times T_{c,t}^{sw}(k)}{\sum_{S}T_{c,t}^{sw}(k)} \tag{25}$$

(2) When the transaction category k is EWCD:

$$T_{c,t}^{swh}(k)=\frac{T_{c,t}^{wh}(k)\times\left(T_{c,t}^{sw}(k)+T_{oc,t}^{sw}(k)\right)}{\sum_{S}\left(T_{c,t}^{sw}(k)+T_{oc,t}^{sw}(k)\right)} \tag{26}$$

The meanings of the parameters are consistent in the full text.

### 4.2 Out-of-contract electricity energy traceability of EWCD in the retail market

When the transaction category k is EWCD, for the EWCD power on the side of power company and the retail user side within the same power company that is not traced within the contract, priority is given for matching traceability within the same demonstration area.

When EWCD power is not traced in the contract：

The EWCD power not traced in the contract of supply side s in power company w is calculated as:

$$T_{oc,t}^{s}(ew) = T_{c,t}^{sw}(ew) + T_{oc,t}^{sw}(ew) - \sum_{H} T_{c,t}^{swh}(ew) \quad (27)$$

Power not traced in the contract between the power company w and retail user h on the side of retail user of EWCD is calculated as Equation (28).

$$T_{oc,t}^{h}(ew) = T_{c,p}^{h}(ew) - T_{c,t}^{wh}(ew) \quad (28)$$

Out-of-contract electricity energy traceability of EWCD：

Traceable power outside contract of EWCD between the supply side subject s and power company w, retail user h is as follow.

$$T_{oc,t}^{swh}(ew) = \frac{T_{oc,t}^{s}(ew) \times T_{oc,t}^{h}(ew)}{\sum_{H} T_{oc,t}^{h}(ew)} \quad (29)$$

where H is the number of retail users and the rest of the parameters are consistent in the full text.

### 4.3 Out-of-contract electricity energy traceability of all transaction categories in retail market

Within the scope of the same power company, if there are still untraced EWCD power of power company and retail users after out-of-contract EWCD power traceability in the retail market, the untraced EWCD power will be conducted out-of-contract electricity energy traceability of all transaction categories together with power company, retail user side and other transaction category power not traced within the contract.

To-be-traced power outside contract of all transaction categories of supply side subject s in power company w:

$$T_{oc,t}^{F,s} = T_{t}^{sw} - \sum_{H}\sum_{K} T_{c,t}^{swh}(k) - \sum_{S} T_{oc,t}^{swh}(ew) \quad (30)$$

To-be-traced power outside contract of all transaction categories of power company w and retail user h is:

$$T_{oc,t}^{F,h} = \sum_{K} T_{c,s}^{wh}(k) - \sum_{K} T_{c,t}^{wh}(k) - \sum_{S} T_{oc,t}^{swh}(ew) \quad (31)$$

Traceable power outside contract between the supply side subject s and retail user h of power company w,

$$T_{oc,t}^{F,swh} = \frac{T_{oc,t}^{F,h} \times T_{oc,t}^{F,s}}{\sum_{S} T_{oc,t}^{F,s}} \quad (32)$$

### 4.4 Total traceable power in the retail market

Total traceable power between the supply side subject s and power company w, retail user h is:

$$T_{t}^{F,swh} = \sum_{K} T_{c,t}^{swh}(k) + T_{oc,t}^{swh}(ew) + T_{oc,t}^{F,swh} \quad (33)$$

where K is the number of transaction categories. The rest of the parameters are consistent in the full text.

Additionally, in terms of the traceability of bundled purchased electricity energy, for the power users' bundled purchased electricity (including the bundled purchased provincial coal-fired thermal power, inter-provincial purchased power, priority power of new energy and gas turbine units, as well as the replaced wind power and photovoltaic power), the power transaction platform will automatically match the power for them as traceable power.

## 5.Calculation examples

### 5.1 Calculation example 1: contract volume correlation between the suppliers and demanders

The hydropower plant $s_1$ signed an incremental contract of other trading varieties with the power company w1, and the electricity quantity contracted by the hydropower plant $s_2$ was 1 MWh; the electricity quantity contracted by the hydropower plant $s_2$ was 0.5 MWh; the electricity quantity contracted by the hydropower plant $s_1$ was 0.2 MWh with the power company $s_2$. Contract a for the transfer of electricity from hydropower plant s1 to hydropower plant $s_3$ for 0.1 MWh; Contract b for the transfer of power company $w_2$ to power company $w_3$ for 0.2 MWh; Contract b for hydropower plant $s_2$ and contract a for electricity company w1 for bilateral reduction contract electricity reduction for 0.1 MWh. Thus, for contract *a*, the contract volume of contract a held by hydropower plant and power company is as follow:

$E_{c,inc}^{s_1} = 1 - 0.2 - 0.1 = 0.7$ MWh , $E_{c,inc}^{w_1} = 1 - 0.1 = 0.9$ MWh

Therefore, the associated contract volume $E_{c,inc}^{s_1 w_1}$ of the incremental contract between hydropower plant and power company is:

$E_{c,inc}^{s_1 w_1}$ =min (0.7, 0.9) = 0.7 MWh

For contract *b*,

$E_{c,inc}^{s_2} = 0.5 - 0.1 = 0.4$ MWh , $E_{c,inc}^{w_2} = 0.5 - 0.2 = 0.3$ MWh

Therefore, the associated contract volume $E_{c,inc}^{s_2 w_2}$ of the incremental contract between hydropower plant and power company is:

$E_{c,inc}^{s_1 w_1} = \min(0.4, 0.3) = 0.3$ MWh

The contract volume of to-be-matched contract *a* of hydropower plant and power company under incremental transaction is :

$E_{c,inc,tbm}^{s_1}$== $0.7 - 0.7 = 0$, $E_{c,tt,tbm}^{s_2} = 0.2$ MWh , $E_{c,tt,tbm}^{s_3}$=0.1 MWh

$E_{c,inc,tbm}^{w_1}$=$0.9 - 0.7 = 0.2$ MWh

The contract volume of to-be-matched contract *b* of hydropower plant $s_1$ and power company under incremental transaction is :

$E_{c,inc,tbm}^{s_2} = 0.4 - 0.3 = 0.1$ MWh , $E_{c,inc,tbm}^{w_2} 0.3 - 0.3 = 0$

$E_{c,tt,tbm}^{w_3} = 0.2$ MWh

Thus, the contract volumes of to-be-matched contract *a* of hydropower plants, power companies are:

$E_{c,tt,tbm}^{s} = 0 + 10 + 20 = 0.3$ MWh, $E_{c,tt,tbm}^{w} = 0.2$ MWh

As it can be seen that $E_{c,tt,tbm}^{s} > E_{c,tt,tbm}^{w}$, and thus ,

$E_{c,tt}^{s_3 w_1} = \frac{20\times10}{10+20} = 0.067$ MWh , $E_{c,tt}^{s_2 w_1} = \frac{20\times20}{10+20} = 0.133$ MWh

The contract volumes of to-be-matched contract *a* of hydropower plants, power companies are:

$E_{c,tt,tbm}^{s} = 0.1$ MWh , $E_{c,tt,tbm}^{w} = 0 + 0.2 = 0.2$ MWh

As it can be seen that $E_{c,tt,tbm}^{s} < E_{c,tt,tbm}^{w}$, and thus , $E_{c,tt}^{s_2 w_3} = \frac{20\times10}{0+20} =$ 0.1 MWh

### 5.2 Calculation example 2: In-contract electricity energy traceability

The known information among hydropower plants, wind power plants, wholesaler and power company are listed in Table 1,2 and 3.

*Table 1*

**The monthly related contracts volumes among market subjects (MWh)**

| Suppliers | Demanders | Trade category | Contract volume |
|---|---|---|---|
| Hydropower Plant $s_1$ | Wholesaler $w_2$ | others | 3 |
| Hydropower Plant $s_1$ | Power company $w_1$ | others | 4 |
| Wind Power Plant $s_2$ | Wholesaler $w_2$ | others | 4.3 |
| Wind Power Plant $s_2$ | power company $w_1$ | others | 3.5 |

*Table 2*

**Market subjects hold other types of contract electricity(MWh)**

| Market subjects | Trade category | Holding contract volume |
|---|---|---|
| Hydropower Plant $s_1$ | others | 20 |
| Wind Power Plant $s_2$ | others | 10 |
| Wholesaler $w_2$ | others | 12 |
| Power company $w_1$ | others | 8 |

*Table 3*

**Settlement contract volume among market subjects (MWh)**

| Market subjects | Trade category | Settlement contract volume |
|---|---|---|
| Hydropower Plant $s_1$ | others | 22 |
| Wind Power Plant $s_2$ | others | 9 |
| Wholesaler $w_2$ | others | 10 |
| Power company $w_1$ | others | 8.8 |

The pre-allocated electricity on the supply side is calculated as follows:

$E_{c,p}^{s_1,w_2}(other) = \frac{20\times4}{20} = 4.4$ MWh , $E_{c,p}^{s_2,w_2}(other) = \frac{9\times4.3}{10} = 3.87$ MWh

$E_{c,p}^{s_2,w_1}(other) = \frac{9\times3.5}{10} = 3.15$ MWh

The pre-allocated electricity on the demand side is calculated as follow:

$E_{c,p}^{s_1,w_2}(other) = \frac{10\times3}{12} = 2.5$ MWh, $E_{c,p}^{s_1,w_1}(other) = \frac{8.8\times4}{8} = 4.4$ MWh

$E_{c,p}^{s_2,w_2}(other) = \frac{10\times4.3}{12} = 3.58$ MWH, $E_{c,p}^{s_2,w_1}(other) = \frac{8.8\times3.5}{8} =$ 3.85 MWh

And thus, the traceable power within contract is presented as follow:

$E_{c,t}^{s_1,w_2} = \min(3, 3.3, 2.5) = 2.5$ MWh, $E_{c,t}^{s_1,w_1} = \min(4, 4.4, 4.4) = 4$ MWh

$E_{c,t}^{s_2,w_2} = \min(4.3, 3.87, 3.58) = 3.58$ MWh

$E_{c,t}^{s_2,w_1} = \min(3.5, 3.15, 3.85) = 3.15$ MWh

Additionally, the out-of-contract traceable power on the supply side is presented as follow:

$E_{oc,t}^{s_1,w_2}(other) = 3.3 - 2.5 = 0.8$ MWh, $E_{oc,t}^{s_1,w_1}(other) = 4.4 - 4 = 0.4$ MWh

$E_{oc,t}^{s_2,w_2}(other) = 3.87 - 3.58 = 0.29$ MWh, $E_{oc,t}^{s_2,w_1}(other) = 3.15 - 3.15 = 0$

The out-of-contract traceable power on the demand side is presented as follow:

$E_{oc,t}^{s_2,w_2}(other) = 2.5 - 2.5 = 0$, $E_{oc,t}^{s_1,w_1}(other) = 4.4 - 4 = 0.4$ MWh

$E_{oc,t}^{s_1,w_2}(other) = 3.58 - 3.58 = 0$, $E_{oc,t}^{s_1,w_1}(other) = 3.85 - 3.15 = 0.7$ MWh

For the remaining transaction categories, the calculation method of the traceable electricity in the contract and the untraceable electricity in the contract on the power generation and power consumption side is the same as that of other transaction varieties.

## 6. Conclusion

The paper mainly analyzes and sorts out the current transaction status of Sichuan electricity market, studies the process and core data of green power traceability, designs the electricity traceability algorithm based on market-oriented industrial and commercial users. By developing the software of Sichuan green power traceability system based on the algorithm, chain storage and multi-point query of key data are possible, including power generation, transmission, distribution, transaction and consumption. Through the trial run of the algorithm on the platform of Sichuan Power Trading Center, this algorithm-based framework helps the government to supervise the use of green power transaction and provides the theoretical and principal basis for the practice of carbon neutrality. Besides, green power traceability technology can also provide support for power market construction and energy management. Through the monitoring and analysis of the power market, we can understand the supply and demand of the market and provide the basis for decision-making. On the other hand, the formation of electricity prices can be regulated to ensure a fair and transparent electricity market. Meanwhile, Green power traceability technology can supervise and manage the consumption of electricity. Through the monitoring of power use equipment, the use of power can be understood in real time, 3/4/2024including power consumption, power consumption time, etc. Future work will focus on improving the judicial-level validity of the green power transaction data based on the Blockchain, so that to improve the data credibility, ensures the authenticity and credibility of the key green power information throughout the whole process of green power transaction.

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