Source-Network-Load-Storage Coordinated Control System Based on Distribution IOT Cloud Platform and Virtual Power Plant

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Abstract. In view of the distribution network operation problems caused by many distributed generations integration to distribution network, and the increasingly serious peak valley imbalance in grid, this paper proposes a coordinated control system of source-network-load-storage based on virtual power plant technology, which is designed and implemented in the actual project. The system uses cloud platform technology and multi-energy complementary technology to realize coordination and optimization control mechanism between sources, network and loads in regional distribution network. The system is based on the distribution Internet of things cloud master platform. Through the virtual power plant technology, resources such as cogeneration, photovoltaic, wind, distributed energy storage, electric vehicles, flexible loads are aggregated to achieve coordinated and unified control, realize the optimal operation of multi-energy complementary. It can accept the control of the dispatching center, and participate in the power transaction of demand response. Based on the application scenario, this paper explains how to use virtual power plant technology to participate in demand response power transaction, and describes the transaction rules and processes. The system is beneficial to the safety and reliability of the distribution network. It can implement reasonable configuration and consumption of distribution generations. It can control controllable loads such as electric vehicle charging pile to participate in peak regulation of power grid, and provide strong technical support for the realization of demand response.

1. Introduction

Now, the development of information technology represented by big data, cloud computing, Internet of things, 5th generation communications and artificial intelligence is having an impact on the reform of energy system. The Energy Internet takes power system as the core, bases on smart grid, and will access into large amount of renewable energy. With advanced information and communication technology and power electronic technology, we can control and optimize distributed energy by the energy management system based on the Internet of things and cloud platform, so as to realize the multi-energy complementation of cooling, heat, gas, water, electricity and other energies and improve the energy efficiency [1].

The coordinated and optimized control technology of source-network-load-storage is an essential part of energy Internet. Based on existing distribution automation and power consumption automation system, the open interactive coordination control system of active distribution network is built. Through the coordinated control of resources such as cogeneration, photovoltaic, wind, distributed
energy storage, electric vehicle, flexible load, etc., it uses virtual power plant technology to realize load aggregation, accept the control of dispatching center, realize demand response, safety and reliability of distribution network, reasonable configuration and consumption of distributed generations, and electric vehicle charging piles participate in grid peak regulation. It provides strong technical support for the friendly interaction between power supply and load [2-4].

2. The architecture of source-network-load-storage coordinated control system

We built source-network-load-storage coordinated control system based on the distribution Internet of things cloud platform. The system has access to the related operation information within the region (photovoltaic, wind power, gas triple supply, etc.), network (regional distribution network, AC / DC micro grid, cooling / heating pipe network, etc.), load (enterprise users, building users, residential users, electric vehicle charging station, etc.), storage (distributed energy storage, electric vehicle mobile energy storage, home energy storage, etc.), which can be automatic with local dispatching Data interaction is carried out in the automation system of distribution network, power consumption information collection system, operation and maintenance system and power prediction system, which supports the friendly interactive system (load aggregation) of power transaction, demand response, large-scale source-network-load-storage, user interaction, auxiliary analysis and other functions [5,6].

Figure 1. Schematic diagram of source-network-load-storage coordinated control system

As shown in Figure 1, the coordinated control system of source-network-load-storage adopts the method of layered and zoned, can implement coordinated control. In Figure 1, it has power supply includes wind power, photovoltaic power, CHP and other energy systems; power grid includes regional main network, distribution network, AC / DC micro grid, cooling / heating network; energy storage includes household energy storage, grid side energy storage, mobile energy storage; controllable loads include micro energy network management and control terminal, non-intrusive user supervisory terminal and V-to-G charger, etc. The system can coordinate and optimize the source, network, load and storage in the whole area. The system adopts certified safety measures to ensure the safety of the system, and displays coordination control strategy, control object and control effect in a panoramic and visual way, so as to improve the overall safety level and operation efficiency of the regional power grid and maximize the consumption of clean energy [7].
2.1. Software architecture of the system

![Software Architecture of the System](image)

As shown in Figure 2, there are three layers in software platform. They are IaaS, PaaS and SaaS. In Figure 2, IaaS layer is the infrastructure service layer of cloud platform. The PaaS layer is the platform service layer. SaaS layer is a software service layer. The functions in each layer are shown in the figure 2.

Horizontally, the platform realizes data opening and data sharing with other systems, and realizes big data mining based on this. We can develop new applications innovatively. In order to realize the vision of energy Internet, big data mining and other technologies are used to integrate big data with distribution network business and provide various data services. Open platform can also interact with third-party systems [8].

Vertically, the platform can realize ‘plug and play’ with the intelligent terminal; it can shield the network differences of the perception layer by using the IOT edge agent and IOT management device; implement the collaborative operation for users, services and terminals, and all services run on the cloud platform; the power operational data flow, equipment data flow and security data flow are based on the full service data center which storage, management and analysis. Data is collected only once, which can be used by all businesses. Realize integrated cloud processing.

The software architecture comprehensively considers the external data characteristics of multi-level architecture, multi service components, multi type energy, multi data types, multi access protocols, multi class user access, multi data release methods, multi external interfaces, etc., and provides a unified data collection framework and security system, which can not only achieve standardized data access, but also fully guarantee the energy facilities, energy systems and energy information Integrity, reliability, availability, controllability and confidentiality [9].

The advanced application function is realized by SaaS, including seven main function modules: operation control, comprehensive evaluation, optimized dispatching, micro grid control, virtual power plant, grid support, transaction assistant decision-making. Among them, the operation control module has the functions of autonomous operation, intelligent operation, fault prediction and positioning, energy operation and maintenance. The comprehensive evaluation has the functions of bearing capacity evaluation, adjustable margin evaluation, reactive power characteristics evaluation, external characteristics evaluation. The optimized dispatching has the functions of equipment status prediction, day ahead plan making, day in day plan rolling. The micro grid control has the functions of
multi-functional complementarity, energy efficiency analysis, user interaction, micro The virtual power plant has the functions of multi virtual power plant coordination, operation target setting, active power coordination control, reactive power coordination control, power grid interaction, active grid load storage interaction, emergency response, demand side response, and transaction auxiliary decision-making has the functions of power purchase and sale application, transaction auxiliary quotation and power deviation early warning.

2.2. Hardware architecture of the system
The cloud platform of the Internet of things for distribution is deployed in the management information area. Virtualization and cloud platform software are deployed on the cloud platform hardware to build the resource pool. The IaaS layer resource pool provides the virtual machine service for the PaaS and SaaS layers. The relational database service hardware adopts the database server and array storage device, and the database system is deployed to provide the basic data storage service for the PaaS layer. The listed database service The hardware of PaaS adopts columnar database server, deploys Hadoop and HBase software, and provides columnar data storage service for PAAS layer [10].

The terminal and device will send data to the distribution network IOT cloud platform. This platform provides Internet of things services, access to equipment openly, and supports the connect and management of multi-type, kinds of protocol, multi-level terminals and devices. The IOT service provides connect services for various types of equipment, and equipment type can be expanded. It support the connecting of medium and low-voltage equipment, which improves the access ability of platform equipment and implements the IOT connecting and management of massive devices; the Internet of things service not only provides the access of mqtt IOT protocol terminals, but also has the access ability of IEC standards and other protocol terminals / equipment, and the support protocol can The Internet of things service can not only realize the fast access to the terminal equipment directly connected to the control center, but also support the fast access to the non directly connected equipment.

Equipment management, establish management channel and business channel between control center and terminal, and management channel is responsible for rapid and flexible deployment of terminal business services.

The cloud platform has the ability to access information and to communicate with the software system of production control area and management information area, as shown in Figure 3:

![Figure 3. Hardware Architecture of the System](image-url)
Illustration of Figure 3: ① The intelligent DTU sends operational data and management data to applications of the platform through IOT components, as shown in the blue data flow in the figure; ② The terminal with IEC protocol sends data to the platform through the front-end computer, as shown in the red data flow in the figure; ③ Information interaction service interacts with dispatching center and distribution automation system of zone I through physical isolation equipment; ④ The information interaction service connects information via the business system of enterprise service bus, mainly including PMS/GIS, power consumption information collection system, marketing management system and other business systems.

Referring to the CIM model theory of power grid, from the perspective of distribution network data application, distribution network data can be divided into asset domain, power grid domain, security domain, marketing domain and other types. Dispatching system interacts with Internet of things cloud platform in power grid domain, power supply platform interacts with Internet of things cloud platform in power grid domain and security domain, PMS system interacts with Internet of things cloud platform in power grid domain and asset domain. Account and security domain data interaction, marketing system and Internet of things cloud platform for marketing domain data interaction. The terminal unit collects information and interacts with the edge computing node. The edge computing node collects, analyzes and processes data and interacts with the Internet of things cloud platform for source data and operational data. The platform side integrates the information of various business systems, builds the business information model and data storage mechanism, and carries out intelligent analysis and application business of the Internet of things cloud platform.

The source-network-load-storage coordinated control system adopts component-based and modular deployment for system software and cloud platform architecture for hardware architecture, so it can increase or decrease hardware resources according to the scale of access data, complexity of analysis and calculation, flexible deployment of business needs.

2.3. benefits of the system for the distribution network
In terms of security, more and more DGs have entered the distribution network, resulting in the following problems:
- High permeability and strong uncertainty of scenery;
- Disordered charge and discharge of electric vehicles;
- The problem of over-voltage and power blocking is becoming more and more obvious.
After adopting this system, the goal of improving the safety margin of distribution network can be achieved. Specific functions include:
- Realize balanced operation of equipment and lines under normal state and N-1;
- Solve the power blocking problem of new energy town after high penetration of renewable energy;
- Need to improve the safety margin of distribution network and enhance the ability of resist risks.
In terms of efficiency and effectiveness, with the development of electricity market and renewable energy, the following problems arise in the distribution network:
- There are different stakeholders in the distribution network;
- The power utility adopts time-of-use price policy, and customers require operate according to the rules of the electricity market;
- The system operation loss increases;
After the system is adopted, the benefit and efficiency of distribution network operation can be increased. The specific functions include:
- Respond to time-of-use price to reduce the power purchase cost of each customer in the distribution network;
- Intelligent control, optimize power flow, reduce transmission loss and conversion loss of power grid;
- Through the local accommodation of DGs, the power loss on the transmission line is reduced and the energy efficiency is improved.
3. Key technologies

3.1. Virtual Power Plant

Many DGs bring great challenge to grid operators. It is necessary to explore new control mode and business mode to operate and manage distributed power supply. Virtual power plant integrates distributed power and controllable load into an integrated entity to realize the aggregation, coordination and optimization of distributed energy such as distributed power generation, energy storage system, controllable load and electric vehicle. As a special power plant, VPP participates in the power market and grid operation. Virtual power plant does not need to transform the power grid, but can aggregate distributed energy to the stable transmission of public power grid, provide rapid and effective demand side response, and provide rapid response auxiliary services. It has become an effective method for distributed energy and controllable load to participate in power market transactions. The coordination control optimization function of virtual power plant can reduce the impact to the grid caused by distributed energy into the grid, reduce the scheduling difficulty caused by the large number of distributed generations into the grid, make the distribution management more reasonable and orderly, and improves the stability of the system operation [11].

The current demand response technology serves for a single type of load resources, such as air conditioning demand response aggregators, electric vehicle demand response aggregators, etc. It is unable to give full play to the complementary and coordinated advantages between multiple types of demand response resources, load side distributed generation and demand response resources. At present, there are several software platforms for demand side response in the market. By using the coordinated control system of source network load and storage based on virtual power plant technology, the distributed power supply, multiple types of controllable load and storage energy can be integrated and controlled and optimized in a unified way, which can ensure the safe and reliable operation of distribution network and maximize the interests of integrated energy service providers. See Table 1 for detailed comparison [12-14].

**Table 1.** Function comparison between various DR control systems

| Name of control systems | Types of Load resource | Demand response business support platform | Large scale source network friendly interaction system | Source-network-load-storage coordinated control system with virtual power plant function |
|-------------------------|------------------------|-------------------------------------------|-----------------------------------------------------|----------------------------------------------------------------------------------|
| Large scale air conditioning system of orderly peak shaving and virtual peak regulation | Operation control of central air conditioning load in public buildings | Automatic or real-time demand response to the demand side response load of industrial users, non industrial users and residential users | The dispatch direct control load and long time (day-ahead) demand response load are included in the grid operation control | DGs, load resources and storages |
| central | Air | Large users, coal-fired | Industrial and |  |

![Image of the page](image-url)
| Object                      | Air-conditioning, lighting, cold storage and heat storage equipment, power equipment, distributed power supply, etc. for large users, non-industrial users and residents | Power plants, interruptible auxiliary machines, water turning station pumps, large-scale energy storage power plants | Commercial building, air conditioning, user side energy storage, Industrial Park production line load, large user owned power plant, distributed power supply, etc. |
|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Response time scale        | Hour level, minute level                                                                                                                | Hour level, second level, minute level                                                                              | Millisecond level, second level, minute level                                                                                                                     |
| Control mode of loads      | Rigid and flexible control through load integrators                                                                                 | Rigid and flexible control through load integrators                                                                 | Cut off loads from grid directly and accurately                                                                                                                   |
| Control mode of storage    | No                                                                                                                                    | Control centralized and distributed energy storage by load integrators to meet business requirements of multiple scenarios | Rigid control and flexible control through load integrator with virtual power plant                                                                                 |
| Application frequency      | Several times annually                                                                                                                | The fast discharge of large-scale energy storage power station is controlled only on millisecond level so as to ensure the stability of power grid frequency | It can not only directly control the large-scale energy storage power station through minute level, but also control the centralized and distributed energy storage through the load integrator, so as to realize the business requirements of various scenarios |
|                            | Several times annually. During the summer, the peak load is restrained, and valley filling is carried out                           | It is used in the case of sudden loss of power grid, equipment out of limit, cross-section power flow overload, insufficient rotating reserve, etc. | Operating with the power characteristics same as traditional power plants, it can operate normally                                                                  |
The virtual power plant submits the unified quotation curve by aggregating the quotation information of distributed resources in different areas. It can be registered with the power trading center as the market main body. Through making market-oriented incentive mechanism, time-sharing price, peak price and other price mechanisms, the virtual power plant can negotiate with the users independently to reach an energy use agreement, carry out power retail transactions, and obtain adjustable capacity; participate in Wholesale trading of electric power, including medium and long-term electric power market, spot electric power market and auxiliary service market, promotes the optimal allocation of resources and the consumption of clean energy [15,16].

### 3.2. Multi-energy collaborative intelligent optimal scheduling technology based on equipment state prediction

For a long time, the maintenance management mode of power equipment is "planned maintenance based on time", also known as regular maintenance, in order to prevent the occurrence of faults and prevent the trouble before it happens. Although periodic maintenance can play a certain role in preventing equipment failure and accident, and can make the equipment operate safely in a good state, it has a strong planning, and the maintenance cycle is strictly defined as a certain period, regardless of the actual technical state of the equipment, whether there is a fault, in order to avoid the huge economic loss caused by the unexpected failure of important equipment, the maintenance cycle is one Repair as soon as possible. The prediction and prediction of faults is undoubtedly an important part of modern management level. The accuracy and accuracy of fault prediction and prediction will become the key to improve the level of equipment maintenance and safety assurance. Based on the big data analysis technology, starting with the technology of monitoring data analysis and processing, several fault diagnosis methods based on the equipment status monitoring data are sorted out and applied to the software system.

On the premise of monitoring and predicting the operation status of the equipment, fully consider the conversion efficiency of different energy types, different energy production equipment, different energy conversion equipment and energy storage equipment in the whole energy utilization process, realize the multi energy coupling intelligent energy system, and formulate the optimal control scheme based on different objectives. Combined with the links of energy production, energy consumption, energy storage and conversion, the control system is established for the equipment of adjustable resources.

Multi energy collaborative intelligent optimal scheduling technology based on equipment state prediction has the following two optimal objectives:

In order to maximize the consumption of clean energy in the day, the typical date power and load power data are selected, combined with the adjustable resource operation model, under the condition of system operation safety constraints, particle swarm optimization algorithm is used to simulate the operation, and compared with the conventional control scheme, the hourly level optimal control scheme is obtained;

Aiming at the lowest operating cost in a day, a mathematical model is established according to the
equipment investment cost, operation and maintenance cost, and taking into account the income of
power generation and grid access. The typical data power generation, load power data and power
generation, load power data are selected. The intelligent optimization algorithm such as particle swarm
optimization is used to simulate the operation, and compared with the conventional control scheme,
the hourly level optimization control scheme is obtained.

3.3. Regional distributed generation forecasting and multi energy load forecasting technology
The regional integrated energy system includes a variety of distributed power generation equipment,
such as photovoltaic power generation. Photovoltaic power generation has great volatility, and most of
the photovoltaic power in the region is distributed, so it is necessary to predict the short-term output of
photovoltaic considering the aggregation effect. The output of photovoltaic power generation system
has a strong seasonal and daily variation cycle, which is discontinuous and uncertain. Its fluctuation
may affect the stability of power grid. The platform is based on the output power prediction model of
artificial neural network, based on the learning of historical photovoltaic output power, temperature,
light intensity and other historical data, training to get the prediction model, and predict the change
trend of photovoltaic output in the next period of time according to the weather prediction data. As the
photovoltaic power generation system in the region is mainly roof type photovoltaic and decentralized
photovoltaic, so the distributed cluster prediction technology is also used. Firstly, cluster and principal
component analysis are carried out for small areas with similar meteorological conditions, and
comprehensive meteorological indicators affecting the output of all photovoltaic power generation
systems in this region are obtained. Then a unified unit output model is obtained based on BP neural
network Historical data and comprehensive meteorological indicators are used for prediction.

Accurate multi energy load forecasting is not only the basis of project planning and design, but also
the basis of project optimization operation strategy. Multi energy load includes cooling load, heating
load and electrical load, in which the cooling and heating load mainly includes air conditioning
cooling load, air conditioning heating load and domestic hot water load, and the electrical load mainly
consists of various electrical equipment in the building. The cooling and heating loads are mainly
related to the environmental requirements of the personnel or equipment in the building. The
characteristics of the power load are directly related to the rated power of various electrical equipment
in the building, the power consumption performance and scheduling of the equipment. The calculation
of cooling and heating power load includes the calculation of load scale, the calculation of seasonal
load difference and the prediction of daily hourly load. The characteristics of cooling, heating and
electric loads of different types of buildings or users are quite different, while the time difference of
the distribution of cooling and heating loads of the same type of buildings or users in different areas is
also quite different. According to these characteristics of distributed energy cooling and heating load,
the platform has the following multi energy load forecasting scheme:

(1) Investigate the cooling index, heating index and electricity index of various typical buildings in
different regions, analyze and summarize the data obtained from the investigation, and realize the
budget estimation of user side cooling, heating and electricity load in combination with the building
area; determine the electrical load, cooling load and heat load index of the building by selecting the
building type; determine the demand index of domestic hot water; input the building area; according to
the The calculation formula is given in the system, and the estimation and prediction results of cold,
heat and electric loads are given.

(2) The historical data of cooling, heating and power loads of various typical buildings and users
are analyzed and summarized by hourly load clustering method, and the data are obtained to calculate
hourly cooling, heating and power loads on the user side. According to the historical operation data of
the system, combined with the annual maintenance plan and grid connection constraints, this paper
analyzes the error characteristics (uncertainty analysis) of short-term generation, cooling and heating
power load prediction, and establishes the artificial intelligence prediction algorithm model of
short-term generation, cooling and heating power load prediction by using expert system or artificial
neural network. Based on the short-term generation / cooling and heating power load forecasting
model, the day ahead generation and regional comprehensive energy optimization scheduling plan are formulated to provide support for the rolling plan revision of regional comprehensive energy optimization scheduling in the day. There are a large number of user terminals on the platform with complex types. The energy consumption curves of industrial users, data centers, public institutions and other users are different, and the demand for cooling and heating loads is quite different. First, principal component analysis is carried out to convert multiple linear related random variables into a few linear independent random variables, so as to simplify the prediction model. Then, many terminals in a certain region are analyzed. Users cluster analysis to classify users, use fuzzy clustering technology to cluster loads, and then use BP neural network model to predict the total load of each category. The daily load prediction results of each category add up to get the total load prediction value of the region, reduce the scale of BP prediction network, and improve the prediction accuracy.

4. Application scenario of virtual power plant in demand response

Build demand response resources to realize the controllable load with multiple types, large proportion, flexible and controllable, so that the adjustable power of controllable load can become an alternative resource of power supply side. This has changed the past development mode that only rely on the development of power supply side to meet the growing power demand, and improved the efficiency of energy utilization. This can not only alleviate the dilemma of power supply and demand balance, but also promote environmental protection and energy conservation. Demand side response resources include distributed power supply, energy storage device and controllable load. The traditional method of demand response resource call is simple and extensive, poor timeliness and low automation, which can not meet the requirements of smart grid real-time power balance. The load storage coordination control system of the source network can use the virtual power plant technology to aggregate the resources of demand side response, and can receive the instructions from the dispatching center online and respond reliably like the generator set, which is beneficial to the power grid and promotes the construction of demand side response.

4.1. Market establishment and market subjects

Taking a project as an example, a demand response market is established. First of all, according to the rules of demand response issued by the government, in order to solve the demand of peak load regulation of the local power grid, the mechanism of demand side response resources participating in the power market transaction is established, which mainly provides two services: power demand increase and power demand decrease. In the form of virtual power plant, load aggregator provides demand increase service and demand decrease service. Virtual power plant, as the main implementation body of demand side response, can receive the instructions from the dispatching center online and respond reliably like the generator set, which is beneficial to the power grid and promotes the construction of demand side response.

Demand addition service and demand reduction service is to consider the transaction behavior among market operators, service providers and service purchasers to maintain the balance of power grid supply and demand, and is supervised by market regulators. At present, the market mechanism introduces five market participants: government, clean energy power plant, peak load regulating power plant, rotating standby / hot standby unit, virtual power plant, among which government, clean energy power plant, peak load regulating power plant, rotating standby / hot standby unit are service purchasers, virtual power plant are service providers; there are two kinds of market operators, namely dispatching organization and trading organization. The market regulator is the local government's regulatory authority. This demand side responds to the establishment of electric power trading market, enriches the trading mechanism of electric power market, and strengthens the dominant position of the market in the optimization of resource allocation.

There are four main bodies of the demand side response market: Service buyer, market operator, service provider and market supervisor. Service buyers and service providers are the main participants in the market. The architecture is shown in Figure 4:
4.2. Transaction rules and types

Based on the existing local policy environment, combined with the construction of regional power transaction, the designed market transaction rules are as follows:

(1) The government provides the necessary demand response fund pool for the market through the peak price policy. Many virtual power plants bid in the trading market, and obtain the corresponding income according to the actual implementation.

(2) Clean energy power plants can purchase the increased demand services provided by virtual power plants at a reasonable market price through the trading market. The virtual power plants absorb the energy that can not be sent to the public grid by the clean energy power plants, so as to make up for the loss of daily power generation revenue caused by the complete abandonment of wind and light, and improve the proportion of clean energy consumption. In the later stage, after the establishment of the day trading market of virtual power plants, clean energy power generation enterprises can consider purchasing the services of demand increase / demand decrease to avoid the possible generation plan curve deviation assessment costs.

(3) Peak shaving power plants can purchase the additional services provided by virtual power plants at a reasonable market price through the trading market, so as to make up for the apportionment loss caused by their failure to participate in the deep peak shaving, start and stop peak shaving, and avoid the possible assessment cost of auxiliary services.

(4) Rotating standby / hot standby can purchase the reduced service provided by virtual power plant at a reasonable market price through the trading market, so as to avoid the possible assessment cost of standby auxiliary service.

The market transaction flow chart is shown in Figure 5.
4.3. Transaction process
Transaction types include day-ahead transaction and intraday transaction.

Day-ahead trading process:
1) Trading institutions shall issue trading information announcement of the next day, including but not limited to the following:
   1) Total scale of market increase / decrease in response to execution cycle
   2) Response execution period and load baseline
   3) Conditions for members of transaction access, transaction declaration time, deadline, result release time, etc.
2) Trading institutions shall organize market members to declare, and the trading time shall be within working days:
   1) Market entities declare the response price and response period of trading varieties on the trading center platform;
   2) The trading institution preliminarily determines the market clearing price;
   3) The trading institution shall draw up the list of regional power transaction and transfer;
   4) The dispatching organization shall check the clearing result and call list for safety.

Intraday trading process:
According to the actual situation of power grid operation and safety constraints, the dispatching organization arranges the market main body to respond to the invitation in combination with the results of clearing up in advance:
1) The dispatching organization will send the verified call list to the regional power transaction management platform;
2) According to the call list, the virtual power plant management platform sends the instructions to the subordinate virtual power plants participating in the market;
3) Each transaction user responds to the invitation according to the transaction results and
instructions.

(4) Trading center issues results according to actual implementation

At present, only day ahead transactions are carried out. When the market and technology are mature, intraday trading will be carried out.

4.4. Transaction settlement

The dispatching organization and trading organization are responsible for the measurement and settlement of virtual power plant participating in the demand side response market. The dispatching organization is based on the power data of the virtual power plant electric energy collection system (Gateway table), combined with the rationalized baseline design: (1) to increase the service, the similar daily baseline of the previous year shall prevail; (2) to reduce the service, the baseline average value of the first five working days of the implementation date shall prevail, measure the electric load and transfer of the virtual power plant participating in the market transaction, and calibrate the data Check to ensure accurate support of power consumption unit settlement. According to the transaction rules of the demand side response service market, the trading institution cooperates to complete the relevant work of market settlement, and issues the settlement results to each market entity for result confirmation or dispute settlement.

The compensation standards for additional and reduced auxiliary services shall be settled by the actual declared price of regional power transaction. The specific settlement amount is the sum of the actual power load of each file multiplied by its corresponding price.

5. Examples and field data

The coordinated control system of the source-network-load-storage is applied to the field distribution network, and good results are obtained. According to the data collected from the field experiments, the system has achieved good results in improving the renewable energy consumption rate, reducing the line load rate and line loss.

![Figure 6. Comparison of Accommodation capacity of PV by the system used and not used](image)

After the system is used in a distribution network, it has a good effect on improving the consumption rate of distributed PV. As shown in Figure 6, after the system is applied, the accommodation capacity of PV in this distribution network is increased from 2471.3kw to 2543.9kw.
Figure 7. Comparison of line load ratio by the system used and not used

After the system is used in a distribution network, it has a good effect on reducing the line load ratio of the distribution network. As shown in Figure 7, after the system is applied, the load ratio of one line in this area is reduced from 1.14 to 0.42.

Figure 8. Comparison of line active power loss by the system used and not used

After the system is used in a distribution network, it has a good effect on reducing the line active power loss of distribution network. As shown in Figure 8, after the system is applied, the active power loss of one line in this area is reduced from 12.49 kw to 2.12 kw.

6. Conclusion and prospect

Through the source-network-load-storage coordinated control system and virtual power plant technology, DG with energy storage device, flexible loads, or load with energy storage device can be aggregated, which can bundle or independently participate in the power market transaction of demand response as a load aggregator. Each virtual power plant control center (achieved by the source network load storage coordination control system) can obtain accurate information to get the optimal goal of the system, so that the interests of the load aggregator can be maximized. The realization elements of virtual power plant include schedulable power supply, interruptible power supply, controllable load and energy storage device.

In the future, for the promotion of demand side response and the implementation of virtual power plant, the following technologies need to be further studied:

- Research on the characteristics of the combined factors of cogeneration, distributed photovoltaic, distributed wind power, controllable load, energy storage, electric vehicle charging pile, etc;
- Research on mathematical model of virtual power plant;
- Development of various software components of virtual power plant;
- Research on bidding strategy of virtual power plant participating in various forms of power transaction, such as demand side response;
- Research on the benefit distribution mechanism of virtual power plant after the aggregation of multi stakeholders.
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