Research on unified system framework of flexible resources under market environment

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Abstract. Flexibility resources are the sources of the ability to service the system's flexibility requirements over a given time scale. Under the power market environment, the price plays the role of economic levers, closely linking the multiple links of source-net-charge-storage, and fully tapping the flexibility potential of resources within the system. Flexibility resources are extended from the traditional generator side units to the complex system with multi-dimension and multi-time scale. Therefore, this paper takes the flexibility demand of power system as the starting point, takes the life cycle of physical flexibility resources as the main line, and studies the unified system of flexibility resources from the aspects of flexibility measures and callable resources.

1. Flexibility of power system
All aspects of the power system are connected as a whole by the power flow, and any fluctuation or failure of any link will affect the whole system. The effect can be large or small, and the result depends on the power system's ability to handle this fluctuation. Different systems may have different processing speeds, processing completion degrees, and processing costs, and this different ability is usually expressed in terms of power system flexibility.

As early as the end of the last century, the concept of power system flexibility was put forward and used to evaluate the ability of power transmission system to deal with uncertain problems caused by changes in initial power source programme conditions [1]. So far, the nature of flexibility has not changed. The power system flexibility in the broad sense usually refers to the power system's ability to take reasonable measures from different time scales and different links to solve various uncertain problems at a certain cost. In the narrow sense, power system flexibility refers to the ability to maintain reliable power supply at reasonable economic cost and meet various safety constraints in order to cope with fluctuations and uncertainties in the power generation side, load side and transmission process during system operation.

2. Flexibility requirements under the access of high proportion of renewable energy
Under the access of high proportion of renewable energy, the uncertainty of its output will fundamentally change the characteristics of system power flow distribution, increasing the randomness and unpredictability of system power flow [2]. At the same time, due to the rapid development of distributed generation, electric vehicles and micro-grid, the system load prediction deviation increases, intermittent load uncertainty increases, and the operation stability of the power system is greatly affected. Therefore, combined with the analysis of typical scenarios of modern power system operation, this paper divides
the flexibility demand into four categories: capacity guarantee demand, slope climbing flexibility demand, frequency stability demand and emergency regulation demand, as shown in figure 1.

2.1. Requirements for capacity guarantee

With the rapid development of industrialization and urbanization, the level of social electricity consumption continues to improve, and the increase of electricity load year by year also brings great pressure to the power system. Therefore, the flexibility of the power system requires the capacity guarantee to provide sufficient supply capacity for the increasing power load.

2.2. Requirements for climbing flexibility

After the large-scale random output of renewable energy is connected, some controllable units will be replaced, and the flexibility adjustment of the system will be undertaken by the remaining units. Moreover, due to the inverse peak regulation characteristics of renewable energy generation (including inverse seasonal peak regulation characteristics and inverse intraday peak regulation characteristics), the peak-valley difference of equivalent load (composed of electricity load minus the output of renewable energy which cannot be adjusted) increases, so the system has a higher demand for slope climbing flexibility.

2.3. Requirements for frequency stability

In essence, the frequency of power system reflects the balance between power generation and load, and controlling the frequency fluctuation range is the basic task of safe and stable operation of power system. Renewable energy power generation, such as wind power and solar power generation, usually has strong randomness and volatility, but it does not have the ability to adjust the frequency. After large-scale renewable energy is connected to the grid, the frequency fluctuation of the power system increases, while the power supply that can provide frequency adjustment decreases, and the requirement for system frequency stability increases.

2.4. Requirements for emergency regulation

Due to the fact that electric energy cannot be stored in large quantities, electric power must be supplied in real time. In case of power generation shutdown or transmission interruption due to an emergency, partial load must be cut off to maintain the balance between supply and demand of the system, which will inevitably affect people's lives and even bring about major property losses and security risks. The spatial distribution of renewable energy resources in China is highly inconsistent with electricity load, and the transmission of renewable energy power is usually carried by (uhvdc) high voltage dc. With the continuous increase in the access ratio, the equivalent inertia of the receiving power grid decreases, the frequency regulation ability decreases, and the dc blocking accidents occur frequently, posing a serious threat to the reliability of the power system. In order to ensure the safety and stability of social production and people's life, the system needs more flexibility to respond to emergencies.
3. Flexible resource classification in market environment

In a certain timescale, the source of the ability to provide services for the system flexibility requirements is flexibility resource, which serves the flexibility requirements and is also the decisive factor of whether the flexibility requirements can be responded to and the quality of the response. Under the power market environment, the price exerts the economic leverage function to closely link the multiple links of source-net-charge-storage, thus fully tapping the flexibility potential of resources within the system. Flexible resources are extended from the traditional generator side units to the complex system with multi-dimension and multi-time scale. In the new system, flexible resources are various, with different characteristics and uneven quality. In order to achieve low cost and high quality in response to the demand for flexibility, it is necessary to conduct targeted selection and classification of flexible resources.

In existing studies, the classification of flexibility resources is usually based on the link of the power system, and some scholars have classified flexibility resources into three categories: transmission system, distribution system, transmission and distribution system double-end flexibility, including conventional power supply, large-scale renewable energy with controllable capacity, interconnected power grid, demand-side management, electric vehicle, energy storage and micro-grid. At the same time, some scholars put forward the method of dividing flexibility resources into upward and downward based on the direction of flexibility. This kind of classification mode seems comprehensive, but it mainly limits flexibility resources to short-term dispatchable resources and does not include effective medium and long-term flexibility regulation mode. It ignores the influence of market mechanism design and system operation plan on the flexibility of power system, and it is difficult to implement the promotion effect on the consumption of renewable energy [3].

![Figure 2 Flexibility resource unified system framework in market environment](image_url)

This paper argues that under the power market environment, market mechanisms such as green certificate, renewable energy bundle outsourcing transaction, power generation right transfer, and auxiliary service market can provide a return on investment for flexibility resources in the physical sense, and the expected income provided by the market can provide decision-making basis for optimal scheduling of physical resources with the lowest cost, and guide the most effective allocation of resources. As the basis of physical resource scheduling, planned measures such as maintenance plan and power generation plan can also become effective sources to improve the flexibility potential of the system. Therefore, this paper proposes a unified system of flexibility resources with the life cycle of physical flexibility resources as the main line, and classifies flexibility resources from two aspects: flexibility measures and callable resources. Flexibility measures include market incentives and planning measures, and callable resources include four links: source-net-load-storage. The unified framework includes green certificate, time-of-use electricity price, wind & solar & hydro-(electric) & thermal power bundling, power generation right transfer of self-owned power plant, reserve auxiliary service market[4], peak regulation auxiliary service market, frequency modulation auxiliary service market, maintenance plan, power generation plan, traditional energy units, large-scale renewable energy base, micro grid, tie-line channel, flexibility load, electric vehicle, energy storage, etc. The framework of a unified system of flexibility resources in the market environment is shown in figure 2.
3.1. Flexibility measures

3.1.1. Market incentive measures. Market incentive measures include green certificate\(^5\), time-of-use electricity price, wind & solar & hydro-(electric) & thermal power bundling, power generation right transfer of self-owned power plant, reserve auxiliary service market (including emergency demand response and interruptible load participation reserve), peak regulation auxiliary service market (including emergency demand response and interruptible load participation peak regulation), frequency modulation auxiliary service market (including direct control load participation frequency modulation), etc.

3.1.2. Planning measures. Planning measures include maintenance plan and power generation plan. The maintenance plan affects the overall operation of the unit in the next annual cycle, which is closely related to the system operation safety and operation plan, and determines the average level of flexibility service provided by the unit in each month of the following year. Power generation plan is mainly used for the arrangement of power generation quantity and power plan in short and medium term, which has the ability to provide the power system with flexibility adjustment in short cycle.

3.2. Callable resources

3.2.1. Source side. (1) Traditional power supply with regulating capacity: Traditional power supply with regulating capacity includes thermal power, adjustable hydropower, pumped storage power station. If it does not distinguish the flexibility quality such as its regulation capacity, regulation rate, response time, this kind of power supply occupies a large proportion in the whole power supply structure, which can provide a strong guarantee for the stability and reliability of the system. However, all kinds of power supply have their own characteristics of regulation, the advantages and limitations of each resource are not the same; (2) Large-scale renewable energy base: The output of a single renewable energy unit has strong randomness and intermittence, but the output of large-scale renewable energy base often has certain correlation and complementarity. Taking wind power as an example, when the wind farm group is studied as a whole, the uncertainty of the output of each wind power unit will be largely offset. Therefore, the controllability of large-scale renewable energy base will be an important research direction to solve the flexibility problem fundamentally in the future.

3.2.2. Net side. (1) Micro grid: Micro grid is a self-balancing body which integrates distributed power generation, energy storage, load and integrated dispatching system under large power grid. The power supply network of micro grid has the characteristics of modularization and decentralization, with flexibility energy storage and flexibility load resources. Through the highly informationized and automated comprehensive energy system, the operation of micro grid can be effectively regulated, and it has a high capacity of renewable energy production and consumption. Micro grid not only has a high internal flexibility, but also can become a flexibility power supply of power system and a flexibility load of power grid through grid-connected operation; (2) Tie-line channel: The tie-line connects the two regional power systems and enables power exchange between regions. Through regional interconnection, flexibility resources can also achieve a wider range of planning and utilization, reducing the cost of flexibility resources scheduling. From a specific point of view, the two regions are interconnected and can be mutually used for power supply and load. The flexibility of tie-lines is related to the flexibility of power generation in the sending end area and the flexibility of load in the receiving end area.

3.2.3. Load side. (1) Flexibility load: In this paper, flexibility load is defined as the load that is willing to obtain price difference income or flexibility service subsidy income by changing the using electric power with the help of user-side control equipment in a certain time scale. Divided by participation in the market, common flexibility loads can be divided into four categories, namely time-of-use response load, emergency demand response load, interruptible load and direct control load\(^6\); (2) Electric vehicle:
After adopting the scheme of orderly charging management, electric vehicles will also become a flexibility power source that makes a positive contribution to the regulation of the power system. At the same time, electric vehicle is also a mobile energy storage device, combined with micro grid and other technologies, which can actively provide flexibility services for the power grid.

3.2.4. Storage side. Energy storage is the resource with the highest flexibility among the callable resources [7]. It is not only a flexibility power generation resource, but also a flexibility power load. It can provide multi-time scale adjustment of day, hour, minute and second, with fast response rate and accurate adjustment.

4. Summary
This paper introduces the definition of power system flexibility and the requirements for power system flexibility under the high proportion of renewable energy access. Based on the flexibility demand of power system, the unified system framework of flexibility resources in multi-time scale and multi-level market environment is established. Comprehensive and clear resource sorting can lay a theoretical foundation for updating flexibility resource development strategies and improving flexibility service capacity of power system in the market environment. In the market, the development of virtual power plant technology can promote the combination of flexible resources on source side, load side, storage side and net side. Through trade and regulation mechanism, the complementary coordination of various resources can be promoted, and the establishment of integrated energy system can be realized, the efficiency of resource utilization can be improved, the cost of energy consumption can be reduced, and the quality of energy supply can be provided.

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