Optimal Model for Scheduling of Cooperative System of Source and Load Storage Considering Economic Benefits

Yantao Wang[1,a], Miaohong Gao[1,b,*], Yu Shi[2] and Minglei Jiang[2]

[1]School of Economics and Management, Northeast Electric Power University, Jilin, Jilin, China

[2]Economic and Technological Research Institute of State Grid Jilin Electric Power Co, Ltd, Changchun, Jilin, China

[a] wangyantao@neepu.edu.cn, [b] gmh17753610918@yeah.net

*corresponding author

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Abstract: Aiming at the problems of low absorption rate, abandoned wind and high light rate of renewable energy, this paper establishes distributed photovoltaic power supply model, distributed wind power supply model, gas turbine model and lead-acid battery energy storage model. On the basis of these models, this paper comprehensively considers the operating cost of renewable energy generation and other units, the cost of buying and selling electricity with distribution network, and the efficiency of renewable energy absorption. On the premise of satisfying the constraints of the unit, an optimization model of the source-load-storage cooperative system is established, which aims at the maximum economic benefit of the source-load-storage cooperative system. When the load of the system is fixed, the economy of the system is the highest, the amount of abandoned wind and light is the smallest, and the operating cost of the cooperative system of source load and storage is reduced.

1. Introduction

From the point of view of the utilization and development trend of renewable energy in the world, wind power generation and photovoltaic power generation are the most widely used renewable energy power generation technologies and have been rapidly developed and widely used. As the representative of renewable energy, wind power and photovoltaic have many advantages, such as no pollution and sustainability, and have broad prospects for development. However, the inherent randomness and intermittent characteristics of intermittent power sources such as wind energy and photovoltaic lead to its large-scale access to power grid power generation scheduling, peak-shaving frequency modulation and standby capacity planning, which will also adversely affect the safe and stable operation of power grid and power quality. The uncertainty of distributed power supply force leads to the need to configure a certain energy storage device in the source load storage cooperative system. At the same time, the energy storage element plays a key role in buffering the randomness and intermittent nature of renewable energy force in microgrid. Common energy storage components are lead-acid batteries, flywheel energy storage, supercapacitors and so on. Lead-acid batteries have fast response speed, are not affected by geographical and other external environmental factors, have low cost, good reliability and relatively perfect technology, and are widely used in energy storage of source-load storage cooperative system. By coordinating the dispatching resources between the power generation side and the user side, the source and storage cooperative system can effectively improve the flexibility and reliability of the system operation, and is an effective way to solve the problem of new energy absorption. Has become the current power industry research hot spot and the development trend.

Scholars at home and abroad have carried out a lot of research on the optimization and scheduling of source and load storage cooperative systems containing wind power or photovoltaic. Literature [1] and literature [2] consider battery constraints, Combined with the time-sharing price optimization system, Improve the overall operation efficiency of microgrid. Document [3] use dynamic programming method to optimize the capacity and operation strategy of battery peak-shaving, The dynamic programming method has fast calculation speed and good convergence. Document [4] the establishment of a thermoelectric power supply microgrid system including wind turbine, photovoltaic power station, diesel generator, energy storage and other distributed power sources, Considering multiple constraints, Based on the objective function of minimum operating cost and minimum pollution control cost, An improved particle swarm optimization algorithm, The scheduling strategy of microgrid in different scenarios is studied and analyzed. Document [5] the objective is to minimize the operating cost and pollutant discharge cost of conventional units, The optimal dispatching model of power system based on "source-network-load-storage" coordination is established, But the model only considers the total absorption of wind power and photovoltaic, "Load" and "storage" are only used to reduce the operating cost of conventional units, Without considering the high permeability of renewable energy and the phenomenon of wind abandonment, Its effect on wind power and photovoltaic absorption rate is not very obvious. Document [6] Optimizing scheduling of conventional units, energy storage devices and load side dispatching resources simultaneously, The optimal dispatching model of power system based on "source, load and storage" is established. Document [8] through battery energy storage system with wind farm to achieve hourly generation scheduling, At the same time, the charge-discharge rate, the load state feedback control limit and the life span of the battery are considered.

Based on the existing research, this paper studies the influence of power transaction between the energy storage device and the system and the distribution network on the operation economy of the system, and establishes the optimal scheduling model of the source and load storage cooperative system. And in the model, the behavior of abandoning wind and light is punished.

2. Planning and Configuration Model of Source-Dockstock Collaborative System

The goal of the planning and configuration model of the source and storage cooperative system is to minimize the comprehensive target cost of the microgrid by optimizing the power supply, energy storage device and adjustable load of the microgrid system under the premise of satisfying the operating constraints of the system. The source-load-storage synergetic system consists of four parts: distributed power supply, gas turbine, energy storage device and load. By considering the basic structural characteristics of the source-load-storage synergetic system and its power exchange with large power grid, the output of each part is coordinated, thus reducing the operating cost of the system, reducing the disposal of wind and light, reducing the configuration of fossil fuel power generation capacity, maximizing the load demand and power supply close to the time scale, increasing the system income and improving the economy of the system.

2.1. Volatility of Electricity Prices in the Electricity Market

The paper In the power market, electricity is a special commodity, and the fluctuation law of power price accords with the fluctuation law of market value. With the deepening of the reform, the degree of electricity marketization deepens, and the power price plays an important role between the power supply curve and the power consumption curve, so as to realize the balance between supply and demand and form the market electricity price. Electricity price is easy to be affected by external factors, thus showing certain fluctuation characteristics.

The uncertainty of the prediction of renewable energy output is one of the important factors affecting the local absorption level of the source and storage cooperative system. Its accuracy is obviously different in different time scales. The maximum prediction error of wind power and photovoltaic will decrease gradually. The scheduling is carried out every 24 hours before the day, and the scheduling plan for the next 24 hours is made based on the short-term forecast value of wind power photovoltaic and baseline load. The unit scheduling time is 1 hour. Based on the short-term prediction data of photovoltaic, the system scheduling is carried out on the day-to-day time scale to determine the scheduling plan which can adjust the scheduling resources quickly in order to reduce the level of abandoned wind and light in the source and storage cooperative system.

2.2. Source and Storage Collaborative System Planning Configuration Model

The economic optimization and dispatch of source-charge-storage cooperative system mainly consider photovoltaic power generation, wind power generation, lead-acid battery energy storage, micro-gas turbine power generation and load demand. In order to optimize the revenue of the source and load storage cooperative system, reduce the energy storage capacity allocation, reduce the abandoned wind and light, optimize the energy storage capacity allocation, and improve the economy of the microgrid scheduling before the day. The objective function is as follows:

$$\max\left[\sum_{t=1}^{T} c_{grid,sell} P_{gout,t} + \sum_{t=1}^{T} c_{pr,t} P_{load,t} - \sum_{t=1}^{T} c_{grid,buy} P_{gin,t} \right.$$
$$\left. - C_{fuel} - k_{bat,num} U_{bat} - \sum_{t=1}^{T} c_{abd,pvt} P_{abd,pvt} - \sum_{t=1}^{T} c_{abd,wt} P_{abd,wt} \right]$$

The formula is:The $C_{grid,buy}$ and $C_{grid,sell}$ are the electricity price of the source storage cooperative system to buy and sell electricity to the large power grid; the c_{pr} is the electricity price; the $k_{bat,num}$ is the cost coefficient of each conversion of lead-acid battery; the $c_{abd,pvt}$ and $c_{abd,wt}$ are the penalty coefficient of discarding light and wind respectively; the $P_{abd,pvt}$ and $P_{abd,wt}$ are the discarding light and wind power at the t time of the system ;the $P_{load,t}$ is the prediction value of t time load power of the system $U_{bat,t}$ for lead-acid battery charge and discharge conversion times during scheduling.

2.3. Constraints

2.3.1. System constraints

1)The Power Balance Constraints

The basis of safe and stable operation of source storage cooperative system is to keep the power balance at all times. The following is the power balance constraint condition of the system:

$$P_{pv,t} + P_{w,t} + P_{gin,t} + \sum_{n=1}^{N_{mt}} P_{mt-n,t} + P_{batd,t} = P_{load,t} + P_{abd,pvt} + P_{abd,wt} + P_{gout,t} + P_{batc,t}$$

The $P_{mt-n,t}$ is output power of the n gas turbine at the t time;and the N_{mt} is the number of gas turbines.The network loss of the system is not considered in this formula.

2)Transmission Power Constraints in Large Power Grid

However, due to the intermittent and unstable photovoltaic power generation, too much electric energy will affect the stability and power quality of large power grid. Therefore, the switching power between the system and the large power grid should be controlled. The following is the transmission power constraint condition of large power network:

$$\begin{cases} P_{line,\min} \le P_{gin,t} \le P_{line,\max} \\ P_{line,\min} \le P_{gout,t} \le P_{line,\max} \end{cases}$$

In the formula,the $P_{line,\min}$ and $P_{line,\max}$ are the minimum and maximum switching power on the tie line between the unit period system and the large power network.

2.3.2. Constraints of conventional units

1)Force Constraints

the output power of wind power, photovoltaic power supply and gas turbine needs to be kept between the minimum and maximum force constraints. The following is the force constraint condition of each unit:

$$\begin{cases} P_{pv,\min} \le P_{pv,t} \le P_{pv,\max} \\ P_{w,\min} \le P_{w,t} \le P_{w,\max} \\ P_{mt-n,\min} \le P_{mt-n,t} \le P_{mt-n,\max} \end{cases}$$

The formula,the $P_{pv,\min}$ and $P_{pv,\max}$ are the minimum and maximum output of photovoltaic generator set,the $P_{w,\min}$ and $P_{w,\max}$ are the minimum and maximum output of wind turbine,the $P_{mt-n,\min}$ and $P_{mt-n,\max}$ are the minimum and maximum output of small gas turbine.

2) Continuous Hours on and off

The following is a continuous start and stop hours constraint:

$$\begin{cases} T_i^{on}(t) \ge T_{i,\min}^{on} \\ T_i^{off}(t) \ge T_{i,\min}^{off} \end{cases}$$

The $T_i^{on}(t)$ and $T_i^{off}(t)$ are the continuous operation time and continuous outage time of the unit i in the t period, and the $T_{i,\min}^{on}$ and $T_{i,\min}^{off}$ are the minimum continuous operation time and the minimum continuous outage time allowed by the unit i.

3) Climbing Constraints

The rate of power increase or decrease will be affected by the rate of upward and downward climbing. The following is the unit climbing rate constraint:

$$\begin{cases} P_{Gi}(t) - P_{Gi}(t-1) \le r_{ui}\Delta t \\ P_{Gi}(t-1) - P_{Gi}(t) \le r_{di}\Delta t \end{cases}$$

The $P_{Gi}(t)$ is the unit output during the t period, and the r_{ui} and r_{di} represent the maximum rate of rising and decreasing power of the unit, respectively.

2.3.3. Lead-acid battery confinement

1) Battery Capacity Constraints

Overcharge and overdischarge will reduce the service life of energy storage components, battery SOC should be within a reasonable limit. Therefore, the power in lead-acid batteries will be restricted by the upper and lower limits of battery charge. The following is battery capacity constraint:

$$SOC_{\min} \le SOC \le SOC_{\max}$$

The $SOC_{\max}$ and $SOC_{\min}$ are the minimum and maximum of charge of lead-acid battery, respectively.

2) Charge-discharge Power Up and Down Constraints

Battery charge and discharge can not be carried out at the same time, and charge and discharge power can not exceed the limit value. The following is the upper and lower limit constraints of battery charge and discharge power:

$$\begin{cases} U_{batd,t} + U_{batc,t} \le 1 \\ U_{batd,t}, U_{batc,t} \in (0,1) \end{cases}$$

$$\begin{cases} U_{batc,t}P_{batc,\min} \le U_{batc,t}P_{batc,t} \le U_{batc,t}P_{batc,\max} \\ U_{batd,t}P_{batd,\min} \le U_{batd,t}P_{batd,t} \le U_{batd,t}P_{batd,\max} \end{cases}$$

The $P_{batc,\min}$ and $P_{batc,\max}$ are the minimum and maximum charging power of lead-acid battery, and the $P_{batd,\min}$ and $P_{batd,\max}$ are the minimum and maximum discharge power of lead-acid battery, respectively.

3. Conclusion

In this paper, the optimization model of source-load-storage cooperative system is established with the goal of maximum system economic benefit. The model comprehensively considers the generation compensation cost of wind power and photovoltaic, the cost of buying and selling electricity to distribution network, the cost of abandoning wind and light, the cost of unit start-up and shutdown, the fuel cost of small gas turbine, the charge-discharge loss and load cost of lead-acid battery. By using the energy storage device to charge and access the Internet to absorb the excess electric energy of the system, reduce the cost of abandoning air and light, improve the stability of the system, improve the absorption level of renewable energy and the economic benefits of the source and charge storage cooperative system through this model.

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