Analysis of the Development of DC Distribution Network with Renewable Energy and Flexible Energy Storage

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Abstract. In order to meet the increasing demand for DC load of electric vehicles, information equipment and semiconductor lighting systems in today's increasingly urbanized distribution networks, and to prevent the deterioration of environmental problem, a large number of intermittent, unstable renewable energy are integrated into the DC distribution network. According to the characteristics of renewable energy, the mixed energy storage mode can be used to realize the separation of power generation and electricity utilization in the space and time. It is reasonably planned to realize the safety, economy, high quality and reliability of the DC distribution in the future.

1. Introduction

In recent years, with the continuous expansion of the scale of the alternating current (AC) system, its security and stability issues have become increasingly prominent [1]. It is no longer realistic to only rely on traditional installation stability devices to solve this problem. Coupled with the worsening environmental problems, there is a growing demand for renewable energy sources [2, 3]. A large number of renewable energy with gap and instability will be connected to the distribution network on a large scale, which will bring severe challenges to the AC distribution network. Therefore, the traditional AC distribution network should be converted to direct current (DC) mode. DC distribution network technology has become a hot issue in the international power industry, which is pregnant with great innovation and emerging industry development opportunities [4, 5].

In this paper, the advantages of dc distribution network are introduced, and the renewable energy generation can be introduced into dc distribution network, so as to realize the robust development of dc distribution network under hybrid energy storage mode.

2. Characteristic Analysis of DC Distribution Network

2.1. Characteristics and advantages of DC distribution network

Compared to the AC power supply system, DC power distribution network has some unique advantages: high power capacity, low line loss, the user-side power quality, good transient stability and convenient way of flexible renewable energy into DC distribution network and so on.
2.1.1. Analysis of power supply capacity of DC distribution network

With the rapid development of the city, the load electricity is increasing and the power distribution line is needed to carry more capacity. In addition, the development of the city has led to the rising value of land, and the expropriation of the corridors of the new distribution lines will be paid more, so it should be tried to transport more capacity on the existing corridors [6].

The rated voltage of the existing line is VAC, the rated line current is IAC, and the power factor cos φ = 0.9; then the rated power of the existing line is $P_{ac} = \sqrt{3}V_{ac}I_{ac}\cos\phi$. If the DC distribution network adopts a bipolar structure with a rated DC voltage VDC and a rated current IDC, the transmission rated power of the line is $P_{dc} = 2V_{dc}I_{dc}$. Therefore, at the same insulation level, the same wire cross-section and current density, $\frac{P_{dc}}{P_{ac}} = \frac{2\sqrt{2}V_{dc}I_{dc}}{\sqrt{3}V_{ac}I_{ac}\cos\phi} = \frac{2\sqrt{2}V_{dc}I_{dc}}{2\sqrt{3}V_{ac}I_{ac}} = 1.05$.

From the formula (1), for bipolar DC power distribution network structure, the transmission power and the original AC line power roughly equal. When the width of the corridor and the cost of construction are at the same situation, the transmission power of the DC line is about 1.5 times of that of the AC line. Obviously, the DC distribution can effectively improve the power supply capacity.

2.1.2. Reliability of DC distribution network

If the DC distribution network adopts a bipolar system, when one of the poles fails, the other pole can continue to transmit power for the load. Compared with the AC distribution network, the technical difficulty of connecting the energy storage equipment such as batteries and super capacitors into the DC distribution network is relatively low. Therefore, the DC distribution network fault crossing ability and power supply reliability are higher [7].

2.1.3. The feasibility of energy saving and DC distribution to households

In fact, a large number of household appliances now use DC in the AC distribution network, the corresponding rectifying circuit module needs to be configured. However, if the DC distribution network is used to directly provide DC to the home users, the converters can be omitted, and the conversion times from AC to DC can be reduced. It can reduce the loss of the AC to DC exchange and reduce the cost of equipment manufacturing [8].

2.1.4. Convenient access to DC distribution network of clean energy and energy storage equipment

The large-scale distributed network-connected of new energy sources such as wind energy and solar energy has become a trend. The DC generated by photovoltaic cells is random and intermittent, so it needs to configure the corresponding converter and energy storage device, and it needs to adopt complex control strategy to realize AC grid-connected [9]. For example, wind power is generated by a random fluctuation of AC energy that requires AC/DC/AC converter and some appropriate energy storage devices and can be incorporated into the AC network by complex control. All kinds of energy storage devices, such as batteries and super capacitors, only store electrical energy in the form of direct current. It is necessary to use the bi-directional DC/AC converter and complex control in the AC power grid. However, if the DC distribution network power supply mode, whether new energy distributed grid-connected, or energy storage device interface and control technology, is much simpler.

2.2. Network structure analysis of DC distribution network

The topological structure of DC distribution network needs the following characteristics [10]:

1) The DC network must be able to connect with the large power grid, and the grid-connected converter must have a bidirectional flow of power to facilitate the transmission of excess energy from the distributed generation (DG) to the power grid.

2) The DC distribution system must be able to provide a relatively constant DC voltage for the DC load.
3) DC distribution system must have high safety reliability.

3. Renewable Energy Analysis

3.1. Renewable energy power generation
Renewable energy power generation includes hydroelectric power generation, wind power generation, biomass power generation (including direct burning of agricultural and forestry wastes and gasification power generation, waste incineration and landfill gas generation, biogas power generation), solar power generation, geothermal power generation and marine power generation[11]. Among them, 2010-2016 annual global renewable energy power generation progress comparison is shown in.

Table 1 2010-2016 annual global renewable energy power generation progress comparison

|                        | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   |
|------------------------|--------|--------|--------|--------|--------|--------|--------|
| Investment             | 2270   | 2790   | 2440   | 2794   | 2700   | 2859   | 2416   |
| Renewable electricity  |        |        |        |        |        |        |        |
| and fuel new investment |        |        |        |        |        |        |        |
| / billion dollars      |        |        |        |        |        |        |        |
| Power                  |        |        |        |        |        |        |        |
| Hydroelectric power    | 935    | 960    | 990    | 1000   | 1055   | 1064   | 1096   |
| capacity/GW            |        |        |        |        |        |        |        |
| Biomass power generation capacity/GW | 71   | 79    | 82    | 88    | 93    | 106   | 112   |
| Geothermal power       | 11.2   | 11.5   | 11.6   | 12.0   | 12.8   | 13.2   | 13.5   |
| generation capacity/GW |        |        |        |        |        |        |        |
| Photovoltaic power     | 40     | 71     | 100    | 139    | 177    | 227    | 303    |
| generation capacity/GW |        |        |        |        |        |        |        |
| Solar power generation | 1.1    | 1.6    | 2.5    | 3.4    | 4.4    | 4.8    | 4.8    |
| capacity/GW            |        |        |        |        |        |        |        |
| Wind power generation  | 198    | 238    | 283    | 318    | 370    | 433    | 487    |
| capacity/GW            |        |        |        |        |        |        |        |

From table 1, in recent years, the use of renewable energy sources for power generation is becoming higher and higher, while renewable energy power generation in the entire power grid to play an increasingly important role. It can be foreseen in the future that the renewable energy power generation technology and scale will continue to innovate, and the construction of the DC distribution network will become more and more perfect.

3.2. Energy Storage Configuration and Dispatching Scheme for Renewable Energy
In view of the randomness and intermittence characteristics of renewable energy power generation, energy storage units with a certain capacity should be allocated to stabilize the power fluctuation of renewable energy, and the scheduling scheme should be coordinated with the load [12]. When the node Pi of the load increases (or decreases), the output active power PDG of the distributed power supply increases (or decreases).

According to the situation of load forecasting in the region, the power output of the energy storage equipment is adjusted for the distributed power supply, and the change of the power output at different times is basically the same as that of the node. If the output of the distributed power supply is always less than the node load’s, that is, Pi-PDG is always greater than zero, the distributed power supply and the node load can be equivalent to a basically constant load Pi-PDG; if the distributed power supply output is always greater than the node load’s, that is, is always less than zero, the distributed power supply and the node load can be equivalent to a basic constant output PDG-Pi. The scheme can improve the line loss and voltage distribution of the DC distribution network, and it is also possible to avoid the unpredictable situation of the injection power of the node.

4. Mixed Energy Storage

4.1. Energy Storage Analysis in DC Distribution Network
After the energy storage devices are connected to the DC distribution network, the power generation and the electricity utilization are separated from the space and time [13]. The power is no longer the
real-time transmission, the electricity utilization and the power generation are no longer to maintain a balanced relationship in real time. The influence on traditional distribution network is summarized as the following:

1) Peak shaving and valley filling
An energy storage device can store excess electrical energy as a load during a power dip, and provide electrical power as a power supply at peak power consumption.

2) Suppress the oscillation of the grid
Theoretically, the power balance of the system can be maintained in any case as long as the installed energy storage capacity is large enough and the response is fast enough.

3) Improve the quality of electricity
Large capacity energy storage technology can provide spare, FM, peaking, phase modulation and so on, which not only improves the power quality of the distribution network, but also improves the stability of the system voltage.

4) Reduce costs.
The energy storage system can improve the utilization of equipment in power generation and transmission and distribution links, thus reducing the cost of power supply and power grid construction.

4.2. Energy storage technology
Currently in the DC distribution network in the application of more mature energy storage technologies are: battery energy storage, super capacitor, flywheel energy storage, pump storage, compressed air storage and so on. With the constant mention of renewable energy, large-scale development of energy storage technology is an inevitable development trend; but the premise is that the research direction is zero pollution, low cost and long life.

4.2.1. Battery storage
In the distribution network, the battery energy storage is the most widely used, the most mature technology, with relatively large energy capacity [14]. Generally speaking, batteries mainly include the following: liquid flow batteries, lithium batteries, lead-acid batteries and sodium sulfur batteries. They are now widely used in distribution systems. However, the battery volume is relatively large, its life is short, it is very large in the charge and discharge process by the impact of environmental temperature. The frequent charge and discharge will seriously affect the service life of the battery; the scrapped battery will pollute the environment to a certain extent.

4.2.2. Super capacitor storage
Super capacitors use special materials to make electrolytes and electrodes, and the mechanism is the electrochemical double layer theory [15]. The capacity of the capacitor can reach 20~1000 times of the ordinary capacitors’. Super capacitors can generally be divided into Faraday quasi capacitor and double layer capacitor. Among them, the double layer capacitor is widely used in the power system. The super capacitor has the characteristics of high energy density, fast charge and discharge, long cycle life, small amount of maintenance, high reliability, multi load for smooth and short time, high power electric energy quality peak power applications. But super capacitors are expensive and have high instantaneous power, but they are generally suitable for long-term storage because of their small capacity.

4.2.3. Superconducting storage
Superconducting Magnetic Energy Storage System (SMES) uses the superconducting coil to store the magnetic field energy and, if necessary, returns the stored magnetic field back to the power grid [16].

4.2.4. Flywheel storage
The flywheel energy storage uses an electric motor to drive the flywheel to rotate at high speed, stores the electrical energy in the form of mechanical energy, and the flywheel drives the generator to generate electricity when necessary[17]. The advantage is that there is no frictional loss, a long life, no impact on
the environment, almost no maintenance; the disadvantage is that the power density is relatively low, it’s not as super-capacitor’s as the rapid release of its stored energy, and expensive to ensure high system security. It’s commonly used in wind power generation system to improve the power output quality.

4.3. Analysis of Mixed Energy Storage System Model
From the above analysis, it can be seen that a single energy storage device has its unavoidable disadvantages. In recent years, the allocation and control strategy of the mixed energy storage system in DC distribution network has aroused widespread concern [18].

The mixed energy storage systems generally use small capacity, high life, high power ratio energy storage systems to match large capacity, low cycle times, relatively high energy ratio, low power ratio energy storage system. The former is more typical such as super capacitor energy storage, flywheel energy storage, etc.; the latter is such as batteries and other chemical battery energy storage. According to the time characteristic, the mixed energy storage system classifies the power fluctuation of the DC distribution network to obtain the system stability and economy, which is obviously superior to the single energy storage’s.

5. Conclusion
By analyzing the characteristics of DC distribution network and its network architecture, DC distribution network can meet the large scale, distributed renewable energy power generation and grid-connected power generation. At the same time, in order to avoid the uncertainty and the intermittence of renewable energy, the mixed energy storage technology is used to achieve flexible access to renewable energy power generation, and the stable and reliable operation DC power distribution network is achieved.

Through the access to DC distribution network of renewable resources and flexible mixed mode of energy storage management, the development of the future DC distribution network will be greatly promoted and the global urbanization process will be accelerated.

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