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Key technologies of active distribution networks control

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Abstract. Active Distribution Networks (ADNs) are modern and intelligent power distribution systems that integrate renewable energy sources and advanced control technologies to provide reliable, secure, and efficient electricity supply. The traditional power distribution networks are designed to deliver electricity in a one-way flow from the transmission system to the customers. In contrast, ADN enables two-way power flow between the distribution network and customers, allowing them to become active participants in the electricity system. The key technology behind ADN includes advanced metering infrastructure (AMI), Distribution Automation (DA), and energy storage systems (ESS). AMI provides real-time data on electricity consumption, generation, and distribution, enabling efficient load management and demand response. Other key technologies of ADN include renewable energy sources such as solar photovoltaic (PV), Wind turbines and small-scale hydroelectricity. These sources are connected to the distribution network through power electronic interfaces that convert the DC output of the renewable sources into AC for distribution. Smart grid technologies such as microgrids, virtual power plants, and energy management systems are also integrated into ADN to improve grid stability and resilience. ADNs have the potential to transform the electricity system by enabling more efficient, sustainable, and reliable energy systems that can better serve the needs of consumers and society. Thus, ADN is expected to become a critical technology in achieving a cleaner and more sustainable energy future.

Keywords: ADNs, communication detection technology, collaborative control technology.

1. Introduction

ADN is a two-way power supply distribution network, with the great development of the distributed generation (DG) penetration, which exposes more and more problems in system operation and management, so it is necessary to solve the problem of power transmission constraints which due to the original distribution network is more and more critical [1]. ADNs are an important aspect of modern power systems. They represent a significant evolution of the traditional distribution network model, which relied on centralized control and passive components such as transformers, switchgear, and cables. In contrast, ADNs are characterized by the integration of advanced control, communication, and energy management technologies, along with the deployment of DERs such as PV, wind turbines, ESSs, and electric vehicles (EVs). ADN is a developing trend of smart power network, and it is a key technology for new energy consumption [2, 3].

The main objective of ADNs is to improve the flexibility, reliability, efficiency, and sustainability of the power system by enabling a two-way flow of electricity and data between the grid and the end-users.

This means that the traditional role of consumers as passive recipients of electricity is changing to an active one, where they can generate, store, and manage their own energy, and also provide services to the grid. In this way, ADNs can facilitate the integration of high levels of renewable energy, mitigate the greenhouse effect, enhance grid resilience, and provide new business opportunities for utilities and customers.

In this paper, two main topics of ADVs will be discussed. One of them is communication detection technology of ADN, the other one is collaborative control technology of ADN. In the first part, the technology of Soft Open Points (SOP) and the application of Grey Wolf Optimization (GWO) of dynamic voltage control in ADN. In the second part, the distributed voltage and centralized voltage control would be discussed, besides, some challenges and related technologies in the collaborative control technology of ADN would also be discussed. In addition, the last part is the conclusion.

2. Communication detection technology of ADN

In recent years, due to the progress in grid technology, and the awareness of environmental protection, it is more and more important to improve the networks to reduce the loss and satisfy the environmentally friendly and economic requirements. Moreover, with the development of technology and renewable energy, the distribution network has become a complex system with high permeability of DG, flexible load, and SOP [4-7]. So, this part will focus on the two systems of SOP and load to reduce the loss of networks.

2.1. SOP control in AC/DC ADN

According to Ming [4], the AC distribution networks commonly consists 10Kv voltage, photovoltaic arrays, inverter, load and contact switch. In fact, to reduce the use of converter, in addition, to improve the permeability of distributed power supply, the AC-DC ADN frame which based on the SOP could be constructed. SOP which is defined as Soft Open Points, it could offer flexible, fast and accurate power exchange control and power flow optimization capability. This DC/AC ADN is consisted of one DC line and one AC line, two loads in both lines, there exist a SOP between two photovoltaic arrays in AC line, and there is more photovoltaic installation in the DC line. Besides, there is a converter station at the exit of the 10kv line and the other one is between these two lines. For the first converter, it would convert AC voltage to DC voltage. In view of the environmental considerations and system losses. The voltage of DC line is equal to the peak of AC voltage which value 15kV. By controlling SOP and the converter station VSC to achieve the power flow between feeders is controllable. Therefore, to optimize the system operation. In general, SOP is composed of back-to-back voltage converter, static synchronous series compensator and uniform power flow controller. *Sops* enable flexible interconnection between feeders, but it has high investment and operating costs [8]. For the B2B VSC, there exist two symmetric VSC, a filter capacitor, some resistors, and inductors. For the filter capacitor, it could provide DC side voltage support, besides, it also could reduce the voltage ripple in DC line. For the two symmetric inductors, the function of them is filter out the harmonics of converter which throw into the AC system. Besides, for both sides of symmetric resistors, resistance of resistors equals to the equivalent resistance of the loss between the converter and the AC system. In the symmetric three-phase system, to control the value of amount of active power regulation and reactive power regulation, only the VSC AC side output current needs to be adjusted.

Normally, the value of R/X is large, which means when many distributed powers is connected, the change of active power 'reactive power in the system would have a great impact on the lines' energy loss and node voltage. So, through reasonable control methods of the system which include SOP, the AC line node voltage can be adjusted to improve the energy loss of line. According to Ming [4], to set up an optimization model to reduce the networks' losses and improve voltage overruns. The improved genetic algorithm is used to solve the above optimization model. Improved genetic algorithm by improving the parameters of genetic operator in traditional genetic algorithm, the algorithm converges faster and is not trapped in local solution. Set up the structure of the AC/DC ADNs in the program and simulate it to verify the correctness of AC-DC ADN structure and optimal control strategy. In the program, set the line resistance equals to Z=4.6+3.2j, and set the value of rated capacity of both converter stations 5MW, loss equal to 2% of the capacity. The rated capacity of the distributed power supply is 2MW, the loss power equals to 5% of the capacity. The rated capacity of the SOP is 5MW.

After the simulation and calculation, the results of the initial system and the loss of distribution networks is almost 5000kW However, the loss of distribution networks of the optimization system is around 2300kW. So, the loss of the whole system has a significant decrease. Besides, it also shows that through coordinated control of the output of SOP and converter station VSC, the real-time adjustment of the operating state of the distribution network can be realized, effectively solving the problems such as the increase of system loss and voltage limit caused by the access of the distributed power supply, realizing the system economy and efficient operation, it could satisfy the development requirements of the future ADN.

According to Li [5], to improve the operating level and economy of the ADN, load changes in actual distribution network still need to be considered. For the calculation formula for each moment of time at each node of the load could be expressed as:

$$S_1 = P_{max} \tag{1}$$

$$S_2 = Q_{max} \tag{2}$$

$$P_1 = P_1' \times S_1 (i = 1,2,3, \dots ,24) \tag{3}$$

$$Q_t = Q_t' \times S_2 (i = 1,2,3, \dots ,24) \tag{4}$$

In this series of formula, t means the t_{th} moment, P_t and Q_t which are in equation (3) and (4) means the active and reactive power at the I moment nodes. Besides, $P't$ and $Q't$ is the node corresponds to the active and reactive percentages at the t_{th} moment of the typical daily load curve. In addition, S1 and S2 which are in equation (1) and (2) is the basic value. According to Li [5], using the Grey Wolf Optimization (GWO) to applied to dynamic voltage control in ADNs to get the Pareto solution set, in addition, to make the three objective functions which present voltage deviation, network loss and system lowest point voltage within reasonable range. After the calculation of GWO, the results show that under the operation mode of maximum load, the optimization strategy improves the voltage of each node, and the voltage of each node meets the requirements of voltage deviation, the net damage has been significantly reduced, in addition, it also satisfies the requirements for economic operation of distribution network. Due to the power requirement is large at the operation mode of maximum load, so this kind of system could satisfy requirement when under other modes of load, to realize the economic and reliable operation of the distribution network.

Overall, in both systems, which are after optimization, the losses of the networks have significantly decreased, and also satisfy the economic requirements. For the first system, the improved genetic algorithm was used to solve the mathematical model, and the simulation results verified the rationality of the constructed AC-DC ADN structure and the effectiveness of the proposed optimal control strategy on energy saving, loss reduction and voltage over limit improvement. The strategy can cooperate to improve the running state of the power grid in real time and meet the requirements of the economic operation and green development of the ADN. For the second system, the optimization strategy can realize dynamic voltage coordination control, avoid the disadvantages of frequent operation caused by load changes, and improve the operation level of ADN.

2.2. Collaborative control technology of ADN

Cooperative control techniques for ADNs have attracted much attention due to their potential to enhance the efficiency and reliability of power systems. ADNs are intended for the integration of DERs, for example solar photovoltaic (PV) systems, wind turbines, and energy storage systems into the power grid. These DERs are typically located close to the end-users and can help reduce the need for expensive transmission lines. The collaborative control technology of ADNs involves the use of advanced control algorithms and communication technologies to manage the interaction between DERs and the power grid. The main objective of collaborative control is to optimize the operation of DERs in such a way that they can provide maximum benefit to the grid while maintaining a stable and reliable power supply.

For the intelligent distribution system, it is mainly composed of micro-grid at the ground level and ADN at the middle and high voltage level, scientific and reasonable access of distributed energy into the distribution network, in addition, scientific and reasonable treatment of distributed power control is one method to optimize the intelligent distribution network system to a certain extent.

According to Bu [9]. Combined with the current distribution system, power control can be effectively divided into three kinds, first is distributed control, and second is centralized control, the third is centralized and distributed control. In addition, for the centralized control, it means through the relevant information system, the centralized controller can be established to a certain extent and can be effectively combined with the whole network voltage regulating equipment, which could provide a relatively voltage to the grid. Besides, for the distributed control, which refers to the use of voltage regulator equipment or using some information of adjacent equipment to control voltage plays an important role in voltage quality work, which can not only consider the overall situation, but also optimize it scientifically and reasonably. However, these two control ways could not combine well yet. Therefore, a more scientific and reasonable method is needed to combine the advantages of the two ways.

Firstly, for distributed voltages, one of the main advantages is it can reasonably use of local information. Which means it could solve the problem of slow speed of the voltage control. In fact, the requirements for communication are low, so one of the solutions is access corresponding distribution generation (DG) points to increase the power itself. Secondly, for the centralized voltage control, it could control distribution information, also necessary to transmit to the centralized voltage controller according to the corresponding communication system. Besides, due to the centralized voltage control also includes the initial single control to the advanced computer control transition, which could better to improve the local information distributed voltage control scheme. However, in the centralized control of voltage, it is generally necessary to do a good job of the corresponding optimization countermeasures, but also need to effectively combine the information of the whole network together. In this way, the voltage equipment of the whole network can be controlled directly.

Recently, the high penetration of renewable energy in the distribution network brings new challenges for voltage control [10, 11], in fact, high-voltage (HV) transmission grid cannot flow down to the customer. Besides, medium voltage (MV) and low voltage (LV) distribution networks cannot influence voltage levels in the distribution system operator. So, it is necessary to redesign the voltage control system in the distribution grid, in addition, it is also needed to control by the flexible assets of low and medium voltage networks. The flexible assets of LV and MV means they could provide flexibility for active or reactive power consumption and production. In fact, there exist many aspects of implemented flexible assets, such as wind power plants, energy storage, electrical vehicles, and supermarkets. According to Pedersen [10], the flexible assets can effectively reduce the risk of potential problems arising from the high penetration of renewable energy sources in the middle and low voltage networks.

According to Zhang [12], in an intelligent power distribution system, the access of DG changes the original voltage distribution of the distribution system, which not only causes a single type of voltage sag and voltage imbalance, but also causes more complex random voltage fluctuations. For the traditional distribution system is a passive network, and the power flow flows one-way from the substation to the load, so the voltage fluctuation problem rarely appears. In the intelligent power distribution system, due to many intermittent DG such as photovoltaic, there will be serious voltage fluctuations. In intelligent distribution system, voltage fluctuation has become one of the most serious short-time voltage quality problems instead of voltage sag. It is an effective way to solve these problems to improve the voltage control ability of intelligent distribution system through active management of distributed power supply. The previously proposed zonal voltage control of intelligent distribution system does not effectively take advantage of the structural advantages of large number of "central-distributed" access of distributed power supply, which hinders the improvement of voltage control speed of intelligent distribution system and permeability of distributed power supply.

The implementation of collaborative control technology is the need to manage the diverse and dynamic nature of DERs. Unlike traditional power plants, DERs are often highly variable in terms of

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their output and can be affected by factors such as weather conditions and user demand. As a result, effective collaborative control requires sophisticated control algorithms that can adapt to changing conditions in real-time. In fact, another important aspect of collaborative control technology is the need for robust communication infrastructure to support the exchange of data between DERs and the control center. This requires the use of advanced communication protocols and technologies such as the Internet of Things (IoT) and cloud computing.

All in all, collaborative control technology is a critical enabler for the integration of DERs into the power grid. It offers significant benefits in terms of increased efficiency, reliability, and flexibility of the power system. However, the successful implementation of collaborative control technology requires the development of sophisticated control algorithms and communication infrastructure that can adapt to the dynamic and diverse nature of DERs.

3. Conclusion

In conclusion, ADNs are one of the advanced forms of power distribution systems which could integrate renewable energy sources, energy storage systems, and advanced communication technologies. The communication detection technology of ADN enables efficient monitoring and control of power generation, consumption, and distribution in real-time, ensuring optimal utilization of resources and grid stability. Moreover, the collaborative control technology of ADN facilitates active participation of end-users and local generators in managing the distribution system, leading to improved reliability and efficiency of the network. Overall, ADN technology has the potential to revolutionize the power sector by promoting the integration of renewable energy sources and enabling more flexible and resilient power distribution. ADN represents a significant shift towards a more flexible, sustainable, and customer-centric electricity system.

In fact, after the research, this paper has found that the SOP and the GWO could effectively reduce the loss of grid and save costs. Besides, it is still necessary for robust communication infrastructure to support the exchange of data between DERs and the control center to make centralized control and distributed control have a better combination. In addition, for the problems of intelligent distribution system, one of the effective solutions is through the active management of distributed power supply.

For the future of ADN, there are some recommendations. Firstly, communication detection technology. In the future, communication detection technology could be enhanced using blockchain-based authentication and encryption techniques, which would enable secure data exchange among different ADN entities, such as utilities, grid operators, and DERs. Secondly, future collaborative control systems could be designed to leverage advanced control algorithms, such as model predictive control and reinforcement learning, to optimize grid performance and reduce energy costs. Additionally, these systems could incorporate advanced data analytics and visualization tools to enable real-time monitoring and control of grid operations. Otherwise, as ADN evolves and becomes more complex, it will be critical to establish interoperability standards for the different components of the network.

As ADNs continue to evolve and become more integrated with renewable energy sources and smart technologies, they will play a crucial role in the future of the energy industry. It is believed that with the right investments and policies in place, ADNs have the potential to transform the way people produce and consume energy, and help people build a more sustainable future for generations to come.

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