Summary of research on stability of independent microgrid based on high permeability distributed generation

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Abstract. The independent microgrid with high-permeability distributed generation is greatly constrained by the natural environment and economy, and lacks the support of large grid in operation. At the same time, the large-scale use of power electronic equipment such as converter will cause its stability problem to have new characteristics compared with the traditional grid, and therefore become the key of research. This paper summarizes the characteristics of microgrid stability, points out the problems existing in applying the traditional definition of power system stability to microgrid, and gives the definition and classification of the stability of the independent microgrid with high permeability DGS; reviews the analysis methods of microgrid stability from three aspects of signal stability, transient stability and voltage stability respectively; discusses the guarantee of microgrid stability. The control method of signal stability and the technical measures to improve the transient stability of the microgrid are discussed. Finally, the key problems of the stability of the independent microgrid with high permeability distributed generation that need further study are summarized and prospected.

1. Introduction
As a controllable autonomous unit, microgrid mainly includes grid connected operation mode connected with large grid and island operation mode separated from main system [1]. In the grid connected operation, the voltage and frequency of the microgrid can be supported by the large grid, and the microgrid can be actively controlled to turn into island operation mode after the failure. For long-term islanding microgrid, such as island, warship, Pakistan community type independent microgrid, its operation control will face new features and challenges due to the lack of support of large grid: 1) photovoltaic array, fuel cell, energy storage device and other micro sources output DC, which need to be connected to AC bus through grid connected inverter or DC-DC converter; various high-frequency AC For example, the output of variable-speed wind turbine and gas turbine engine needs to be converted to AC or DC bus through AC-DC-AC or AC-DC, and these energy conversion needs power electronic devices as the interface to connect with the system, which results in significant power electronic characteristics of the microgrid. 2) high permeability DGS connected to microgrid through power electronic converter makes the system control flexible and response fast. However, due to the lack of inertia or low inertia of independent microgrid, the system is vulnerable to external disturbance and instability, and the nonlinear characteristics involved in power electronic converter
will also affect the stability of microgrid. 3) due to the objective constraints of natural conditions such as environment and climate, the output of renewable energy DGS such as wind turbine, photovoltaic array will be random, fluctuating and intermittent. 4) the independent microgrid lacks the support of large grid voltage and frequency, and the stability of small signal is easily affected by the micro source interface control loop. At the same time, the impedance change of load and line, constant power loads (CPLs) and system damping are too small. With the DC microgrid becoming a research hotspot in recent years, in order to solve the problem of DC bus voltage instability caused by a large number of CPLs with negative impedance property and power electronic devices with CPLs property, literature has made a special study on this problem.

Starting from the definition of stability, this paper summarizes the differences between the definition of microgrid stability and the traditional definition of power system stability, and gives the definition and classification of the stability of independent microgrid with high permeability DGS; reviews the analysis methods of microgrid stability from three aspects of signal stability, transient stability and voltage stability; summarizes and proposes Finally, the paper summarizes the work of the whole paper and looks forward to the research content of the stability of DGS with high permeability.

2. Stability analysis method of microgrid
For the stability of microgrid system, scholars at home and abroad have done a lot of research and put forward many analysis methods. At present, the methods of analyzing the stability of microgrid are similar to the traditional methods, but for the microgrid environment with many new features such as non-linear, small-scale, inertia missing, the stability analysis methods also have many new features and changes. In this paper, the main methods to analyze the stability of microgrid are summarized from three aspects: small signal stability, transient stability and voltage stability.

2.1. Small signal stability analysis
The characteristics of microgrid determine the existence of small disturbances in the system at all times. In reference [16], the influencing factors of the small dry dynamic stability of microgrid are classified as: the change of operation point, communication delay and the interconnection and interaction between source, source load, AC / DC network and multiple microgrids; in reference [2], it is pointed out that various power allocation strategies can significantly affect the small signal stability of microgrid, and the modal interaction between DGS can also lead to oscillation Happen. The analysis methods of small signal stability of microgrid mainly include eigenvalue analysis based on state space model, impedance analysis based on frequency domain theory and sensitivity analysis.

2.2. Transient stability analysis of microgrid
Small signal stability can ensure the gradual stability of the system balance point, but the boundary of the stability region cannot be determined and the stability margin of the balance point cannot be determined. Therefore, it is necessary to carry out transient stability analysis of the microgrid system [3]. At present, the main methods to analyze the transient stability of microgrid are time-domain simulation method and transient energy function method based on Lyapunov equation.

2.3. Voltage stability analysis of microgrid
Because of the particularity of microgrid, its voltage stability is more hidden and unexpected than that of traditional grid. When the voltage is unstable, if the microgrid can not supply power to the load continuously, it will have a serious impact on the stable operation of the system. There are many reasons for the voltage instability of microgrid. The diversity of microgrid structure, the negative resistance of CPLs the complexity of power electronic interface micro source and its control process are the main factors that affect the voltage stability. Compared with the large grid, the load type and load dynamic change in microgrid are more likely to affect the bus voltage of the system, and the low inertia characteristics also lead to more voltage fluctuation. Easy to happen.
2.4. Other

Artificial intelligence algorithm, identification method, singular perturbation theory, dynamic vector method and other methods can also be used for stability analysis of microgrid.

Table 1 summarizes and compares the advantages and disadvantages of the above methods.

| project                     | Analysis method             | Existence advantage                                                                                           | Potential shortage                                                                                             |
|-----------------------------|-----------------------------|----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|
| Small signal stability      | Eigenvalue analysis         | Simple principle and strict criterion. It is unnecessary to determine the internal parameters of the micro     | It is difficult to obtain the precise parameters of the microgrid model; it is difficult to establish the high-order     |
|                             | Impedance analysis          | source subsystem and the load subsystem, and the stability of the system can be judged by the impedance matching | state space model; the state space model needs to be reestablished for the changes of parameters and structure,       |
|                             | Sensitivity analysis        | relationship between the micro source and the load. Clear physical concept and simple calculation.           | which greatly reduces the efficiency. Model of output impedance of grid connected inverter is difficult. The         |
|                             |                |                                                                                                              | sensitivity index belongs to the state index, so the influence of discontinuous factors such as DGS reactive power   |
|                             | transient stability        | It can adapt to a large number of controller models in microgrid, and can adapt to nonlinear and discrete      | exceeding limit cannot be considered.                                                                           |
|                             | Time domain simulation     | operation of various components.                                                                            |                                                                                                                |
|                             | Transient energy function  | The transient stability margin of microgrid system under the condition of large disturbance prediction is     | The order of state variables of microgrid system is high; the calculation amount increases significantly, and the   |
|                             | method                     | analyzed rapidly. The transient mechanism of DGS grid connection with power electronic interface is studied. | calculation speed cannot meet the needs of on-line monitoring and control [34]; the transient stability closure     |
|                             |                |                                                                                                              | solution cannot be provided [19].                                                                             |
|                             | Voltage stability          |                                                                                                              | If there is an error between the online data and the preset data, the result will not be ideal.                   |
|                             | Method based on power flow | The voltage stability margin related indexes such as weak voltage stability region or critical point of       |                                                                                                                |
|                             | equation                   | stability can be obtained [38]. Dynamic analysis of continuous changes of system parameters.                  |                                                                                                                |
|                             | Bifurcation theory         |                                                                                                              |                                                                                                                |
|                             | Artificial intelligence    | High efficiency and calculation speed. The model of order reduction analysis for microgrid system is simple   | High requirements for preset data, which may cause deviation of analysis results when inconsistent with actual data;     |
|                             | method                     | and more accurate than that of order reduction model.                                                       | failure to explore system instability mechanism; failure to dynamically change data. May cause errors. The precise   |
|                             | Singular perturbation       |                                                                                                              | model of microgrid is abandoned; its application in microgrid needs to be generalized.                           |
|                             | theory                     |                                                                                                              |                                                                                                                |
|                             | Dynamic vector method      |                                                                                                              |                                                                                                                |
3. Control method for improving the stability of small disturbances in microgrid

In general, the small disturbance caused by load change and output fluctuation of micro sources in microgrid can be solved by the control loop of DGS interface. Compared with the large-scale power grid, the control strategy is one of the most critical means to ensure the stable operation of the small-scale micro grid system. This section first discusses the master-slave control, peer-to-peer control and hierarchical control among DGS of microgrid, which are the necessary conditions for coordinated operation of DGS; then discusses three control methods and their improvements of power electronic device interfaces such as grid connected inverter, As shown in Figure 1, the selection of control methods is the premise for various analysis and modeling of microgrid system.

3.1. Control mode between DGS

For the independent microgrid with high permeability DGS, the coordination control among DGS is the first consideration for the stable operation of microgrid. Different microgrid structures, operation conditions or control objectives need to consider different control methods. For the microgrid with different operation environment and constraint background, the coordination methods can be divided into master-slave control, peer-to-peer control and hierarchical control.

3.2. Control method of microsource interface

The interface mode of micro source can be generally divided into power electronic converter interface and rotary motor interface [4]. With the increase of DGS permeability and the use of energy storage elements, the control method of power electronic energy conversion device becomes particularly important for the output effect of micro source and the stable operation of micro network. The grid connected inverter usually adopts double loop control. The outer loop control realizes different control purposes, and generates the inner loop reference signal. The inner loop control makes fine adjustment to improve the dynamic characteristics of the system. What kind of control strategy the grid connected inverter adopts depends on the type of DGS and the operation mode of microgrid. The control strategy is mainly embodied in the outer loop, mainly including droop control, PQ control and VF control.
Virtual impedance and virtual synchronous generator technology are the improvement of droop control.

4. Technical measures to improve transient stability of microgrid

In terms of transient stability of microgrid, this section mainly discusses how to improve the stability of microgrid from the aspects of energy storage device, load/machine switching and transient probability stability assessment.

4.1. Application of energy storage technology in microgrid

Considering that the inertia of the microgrid is very small, even if there is capacitor energy storage at the DC side of the microsource, its storage energy is far less than the rotating energy storage of the rotating motor, so it is difficult to ensure the stable output in small disturbance [5]. When the transient energy cannot be supplied in time, additional energy storage devices will become an essential part of the microgrid system. Therefore, the energy storage device is usually used with the power electronic device, hoping to solve a series of problems brought by the microgrid power electronics.

As an energy buffer, energy storage can provide energy buffer, balance and backup for DGS, and can effectively improve the stability of independent microgrid. The energy storage system has good adaptability in different forms and structures of microgrid. The following is discussed in detail: 1) in the joint control system of energy storage equipment, diesel generator and DGS, the fast response characteristics of energy storage equipment can be used to prevent the system collapse during the working process of other micro sources. 2) in the transition process of grid connected operation, off grid operation and seamless switching of microgrid, through the control function of energy storage equipment, the smooth switching of microgrid operation mode can be realized [96-97]. 3) in case of micro source trip, load change and other disturbances in the microgrid, the energy storage system can ensure the stability of the system by injecting active power (or reactive power) into the microgrid before the standby diesel generator set or other means are put into the site.

In the stability analysis of microgrid based on energy storage device, it mainly focuses on the application of super capacitor and flywheel energy storage system. The flywheel energy storage is connected to the microgrid system through a back-to-back converter. The first converter is driven by the flywheel to maintain the DC side voltage. The grid side converter injects active and reactive power based on the measured voltage and frequency values. Similarly, the converter can also use droop control and other methods to get the appropriate frequency and voltage of the system. In reference [98], three battery energy storage systems including back-to-back buck/boost bidirectional three-phase converter are accurately modeled; in reference [6], the application of superconducting magnetic energy storage in frequency transient stability control of microgrid is studied, and the performance parameters of super capacitor and superconducting energy storage are compared. The conclusion shows that superconducting energy storage can be used as energy buffer of microgrid to improve the frequency transient stability of the system. In document, the coordinated control of energy storage system and diesel generator in independent microgrid is studied; in document, the research status of application of various forms of energy storage devices in microgrid is reviewed, and it is pointed out that the energy storage technology in microgrid is not mature, and the high cost is the obstacle for the widespread application of energy storage technology, and the key is to improve the conversion efficiency and reduce the cost.

4.2. Emergency control scheme such as load cutting/machine cutting

When the net balance power of the microgrid is destroyed and reaches the hard limit, the scheme of load or power cut can be adopted in the microgrid. In island operation, load cut and power cut are also important means to ensure the power balance, system frequency and voltage stability of the independent microgrid.

In order to maintain the frequency stability of the system in the islanding operation mode of microgrid, it is of practical significance to cut off the machine, load and other emergency control
schemes. In reference [103], frequency stability control is realized through active regulation of energy storage or photovoltaic system, low-frequency load shedding and high-frequency machine cutting. After large-scale wind power is connected to power system, transient stability will be affected to some extent. In reference [7], emergency control measures for wind power machine cutting with high permeability wind power system are studied, and optimal machine cutting decision-making model based on wind power generator is proposed. Type.

Load shedding is an important means of frequency emergency control in small-scale power grid. First of all, the method of load shedding should ensure the priority service for important loads. Load grading is to sort the loads according to the importance of loads. When the DGS capacity of independent microgrid is insufficient, the load with low priority level should be cut off first, and then the cut load should be put into use again when the power capacity is sufficient. In practice, the non-sensitive load can be divided into controllable load and uncontrollable load. Some controllable load can be used to reduce peak load or smooth load curve, or such load can be arranged in a specific power consumption period. When the intermittent DGS such as fans and photovoltaic have additional capacity, the controllable load can be supplied with power. For the uncontrollable part of the non-sensitive load, the It is the first choice for load rejection under special circumstances such as failure and insufficient micro source capacity.

4.3. Transient stability control of microgrid based on probability evaluation

The traditional power system transient stability analysis is based on the deterministic model, while the microgrid contains high permeability DGS, and the renewable energy sources (RES) is the main power generation unit of the independent microgrid. The random and intermittent power generation mode has uncertain influence on the microgrid stability, so the transient stability evaluation based on the deterministic method will not be applicable, the evaluation method based on probability will have research value in the microgrid system with high permeability DGS.

The random changes caused by external factors such as light time and intensity, wind speed and so on may have different effects on the output of micro sources. Any change of a variable will have an impact on the whole system and it is difficult to analyze it in detail. Therefore, considering the uncertainty of the influence of DGS, a powerful decision tree can be trained to deal with the changes of network topology. Monte Carlo method is used to cluster each simulated emergency event in order to determine the unstable generating units, and a probability framework for online recognition of power system dynamic behavior by res is established; a probability framework for transient stability assessment of power system with high permeability res is proposed, and the key micro sources with uncertainty are identified by hierarchical clustering. Four kinds of transient stability indexes and observation values are analyzed to study the effects of high permeability res and network topology changes. A probabilistic small signal stability analysis of independent microgrid considering the uncertainty of res is proposed. Based on Monte Carlo simulation of wind speed and light uncertainty, the critical damping ratio and the track distribution of oscillation frequency are studied. Res will it leads to the dynamic change of power sharing strategy and affects the stability of small signal.

The poor control effect may be the main reason for the microgrid system to be closer to its stability margin. In this case, the correction control may be the key to ensure the stable operation of microgrid. For the transient stability of microgrid, the frequency and voltage of microgrid can be adjusted and controlled by using probabilistic stability assessment. Some scholars have put forward the control technology and algorithm for real-time identification of dynamic behavior of the system. The measurement system can basically help the system identify the dynamic behavior of the microgrid system in real time through data analysis technology and correction control algorithm. Online dynamic security assessment can predict whether the system can maintain stability through data mining technologies such as decision tree, support vector machine and artificial neural network. This information is also very effective for auxiliary correction of load shedding, machine cutting, application of facts and other measures. considering the randomness of wind power, a static stability probability evaluation method based on l-index is proposed, which can identify the weak links of the
system; a probability framework for online identification of dynamic behavior of non power system is established, which uses a number of pre trained decision trees to identify whether the system is stable or not. In the microgrid system, the probability framework can be used to identify unstable DGS based on the predicted dynamic information. This kind of prediction is usually carried out in second level units. The prediction information can be used to correct and control effectively. This method can be used to ensure the stability of the microgrid system and prevent the occurrence of cascading failures.

5. Summary and Prospect
As a carrier of distributed generation technology and an effective supplement to large power grid, microgrid can alleviate the disadvantages of large power grid and promote the sustainable development of power industry, and its development is widely concerned. Similar to the independent microgrid in the remote mountainous area of Pakistan, the constraints of natural environment conditions and power supply economy have to be taken into account. Considering the wide access of DGS, the stability of the microgrid power is different from the traditional power grid due to the electronization of the microgrid power, especially the power angle stability, which is the focus of the traditional definition of power grid stability. Therefore, from the point of view of the definition of microgrid stability, this paper discusses the characteristics of microgrid itself and the differences between microgrid and large grid stability. On this basis, it summarizes various methods for analyzing microgrid stability at present, and summarizes the control methods for maintaining microgrid stable operation and the technical measures for improving microgrid transient stability. However, the stability of the independent microgrid with high permeability DGS studied in this paper is still worthy of further study.

1) The definition and classification of microgrid stability have not been clearly defined. In fact, since the concept of microgrid was proposed by certs, North America, EU, Japan and China have established their own microgrid demonstration projects. However, there is no clear and unified specification for the specific definition and form of microgrid. The definition and classification of microgrid proposed in this paper can be used for reference and need further discussion and improvement.

2) The new control strategy is worth further study. Reference [7] defines the feasibility of control strategy to ensure the stable operation of microgrid in islanding operation mode, but when large disturbance occurs, there are few control methods to improve the transient stability of microgrid through power electronic equipment, and the control strategy deserves continuous attention in the future research.

3) Conversion efficiency and cost are always the bottleneck of energy storage technology's application in microgrid. New energy storage materials and energy storage technology need further research. The revolution of energy storage technology is the key technology of microgrid system stability and popularization.

4) Transient stability control can dynamically control frequency and voltage when power supply, load, fault and other large disturbances are realized through probabilistic stability assessment, which is an important idea for future research to improve transient stability of microgrid, but at present, this method is rarely used in actual microgrid, so how to use it effectively in specific environment is worth further research.

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