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Review paper

A review on the classification of operating modes in microgrid systems

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Abstract

A microgrid is an independent electrical system, and it integrates different energy sources to produce power independently or in coordination with the main grid. In this paper, a brief review on the classification of microgrids and how they work in two operating modes is presented. Based on the distribution system, microgrids are classified into alternating current, direct current and hybrid. Microgrids can work in two operating modes, connected to the network and islanded, each of which has unique goals and specific advantages. System stability, integrated power transfer and management of the balance between production and demand are the main challenges in the transition between two modes of microgrid operation. Based on the operation of the microgrid, different control strategies and protection systems are needed. Some control strategies are stated in each mode and a comparison between the two modes is presented. The microgrid system depends on many variables, and therefore their power management and stability are of particular importance. This study will be useful for researchers who work in the field of microgrid application, and it can be used in the design of controllers and protection system of microgrids.

Keywords: grid-connected mode, islanded mode, microgrid, operation, photovoltaic system

1- Introduction

Increasing energy demand and lack of energy resources are important challenges of the modern power system. The output power of distributed generation sources such as photovoltaic systems depends on environmental conditions, and the power produced by renewable energy sources is variable and intermittent [1,2]. Energy use is very important for economic growth and social development. In today's modern society, sustainable industrial and economic development and reducing the adverse effects of fossil fuel consumption have increased the need to change from non-renewable energy sources to renewable energy sources [3,4]. Among the problems of centralized power generation systems, we can mention the dependence of power plants on fossil fuels, producing a large amount of electricity in one place and transferring it to remote and rural areas through transmission lines, causing power losses and voltage drops through transmission lines, and lack of provided an economic solution for electricity supply [5,6]. Providing electricity at the lowest cost is the main goal, and it only happens when transmission and distribution losses are almost zero [7,8]. With the expansion of deployment of distributed generation resources in the power system, energy security and flexibility of power networks have become important [9,10]. The production power from renewable energy sources depends on the environmental conditions, and is usually intermittent and variable, which can be referred to the fluctuations in the production of the photovoltaic system due to changes in solar energy [11,12]. The challenges of meeting the growing needs of electrical energy and trying to reduce the effects of climate change, the importance of microgrids in the integration of renewable energy sources has increased [13,14]. It is possible to install renewable energy sources by microgrid in the electricity network [15,16]. The integration of renewable energy sources in microgrids usually includes technologies such as photovoltaic modules, small hydro units and wind turbines [17,18]. A microgrid consists of loads, energy storage systems, and distributed generation sources, which can exchange power through a common connection point with the main grid. Based on the availability and reliability of the power grid, the microgrid can work in grid-connected or stand-alone mode [19,20].

Table 1: A number of review studies conducted in different fields of microgrids

Ref.	Subject	The main statement of the study
[21]	Transition between two operating modes	Sudden transition from network connection mode to island mode is the most critical operating mode of microgrid. Sudden changes can lead to malfunction of the control system. Various approaches have been proposed for smooth transition to independent mode, and their advantages and limitations have been reviewed.
[22]	Power sharing	One of the ways to improve the performance of power sharing is to change the output impedance of distributed generation units. Classification of different power sharing strategies based on impedance is classified. The methods of changing the line impedance of distributed generation units are divided into four groups: fixed virtual impedance, adaptive virtual impedance adjustment, impedance loss, and reconfiguration of internal loops.
[23]	Distributed secondary control architecture	Distributed secondary control architectures in inverter-based ac microgrids are reviewed. A hierarchical control approach for distributed generation sources is presented and the control scheme is divided into three hierarchical levels to overcome existing challenges such as power quality and communication in power systems.
[24]	Microgrid centralized controller	The central controller of the microgrid has the most important role to have a satisfactory performance of the microgrid in two functional modes. The centralized controller of the microgrid consists of three control levels, which are: the micro controller of the local source and load, the central controller of the microgrid system, and the distribution management system. An overview of the evolution and progress of technology and the classification of microgrid central controller is provided. The central controller has a role in microgrid protection, stability and power quality, which is also investigated.
[25]	Energy management with renewable energy	Energy management in microgrids is an information and control system that provides the necessary performance for energy supply in production and distribution systems with minimum cost. A review of energy management in microgrid systems using renewable energy has been done. A comparative analysis of optimization objectives, constraints and simulation tools applied to microgrids in two operating modes is presented.
[26]	Operation and control strategies	Strengthening the flexibility of the power system against natural events with low probability and high impact is very important. For this purpose, a lot of research has been done on advanced networked microgrid (NMG) based techniques to achieve a flexible power system. The control features and operational considerations of these networks have been reviewed. An integrated problem-solving approach for both configuration and control aspects of stable and reliable NMGs is also presented.
[27]	Control of AC microgrids based on inverter	With the increasing penetration of distributed generation systems in the grid, the challenge of combining a large number of them into power systems must be addressed and managed. It states the main objectives that must be provided by the microgrid controllers in two operating modes, connected to the network and independent from the network. Also, the advantages and disadvantages of centralized control and decentralized control techniques have been discussed and compared as potential solutions.

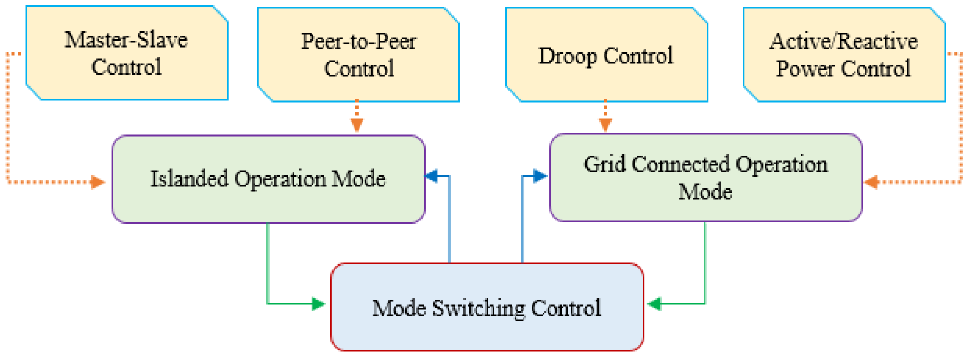

Fig. 1 Microgrid performance modes and control methods

Considering the expansion and practical importance of microgrids, there are still various challenges in their development. Many studies have been done in the field of microgrids. Table (1) contains a number of review articles on various fields of application of microgrids.

In this paper, the aim is to study two modes of microgrid operation and micro-grid classification based on different parameters. The structure of the paper is as follows. Classification of microgrids based on different parameters such as power source and control strategy is provided. In the section 2, the operation modes of the microgrid are presented along with the advantages and disadvantages of each operation mode. Finally, the conclusion is stated in the section 3.

2- Microgrid performance in operating modes

Microgrids are divided based on different criteria such as voltage type, distribution system, structure and operating modes [28,29]. Based on the characteristics of the power injected into the distribution network, microgrids are classified into three groups: dc microgrid, ac microgrid, and hybrid microgrid [30,31]. The choice between direct current and alternating current microgrids depends on their application and the specific goals of the system [32,33]. Hybrid microgrid combines the advantages of dc and ac microgrids because ac and dc buses are connected to each other by means of an electronic power converter [34,35].

A microgrid can work in two functional modes, including independent from the grid and connected to the grid. Microgrid control strategies depend on how it works [36,37]. The purpose of using control methods is to stabilize the performance of the microgrid. When designing a controller, the operating mode of the microgrid plays a vital role [38,39]. Various factors such as network stability or maintenance of a part of the network may cause the need to transition between two operating modes of the microgrid. Fault currents are affected by microgrid operation modes. During the change of the microgrid state from the state connected to the network to the state independent of the network, the error flow paths can be different [40,41]. In this section, a comparison between two functional modes of microgrid is provided.

2-1- Microgrid performance in stand-alone mode

Due to the error on the side of the network or from the economic point of view and to maintain the power quality required for sensitive loads, the microgrid works in partial mode. The islanded microgrid is considered a weak grid, which has less inertia compared to conventional power systems. In this case, there is no connection to the host grid, and the microgrid must meet all the requirements of the connected loads. It is also prone to frequency changes compared to the regular city grid. The capability of the microgrid in independent mode for synchronization is closely related to its physical topology. By

controlling the storage devices, the voltage and frequency can be kept constant at the nominal value [42,43]. The coordinated operation of distributed energy sources and loads is necessary for the reliable operation of an islanded microgrid [44]. There is continuous monitoring in the microgrid by the controller [45,46].
Appropriate power sharing between parallel inverters to supply common load is one of the main challenges in islanded microgrid operation. Unbalanced and nonlinear loading in this mode produces negative sequence components and harmonics in current and voltage, which, in the absence of an external controller, cause power sharing errors and voltage distortion at the output of inverters [47,48]. Setting the frequency and voltage without the help of the external network can be done by inverters in independent microgrids. Active power division is easily guaranteed with the help of frequency control, but reactive power division is difficult due to the mismatch of network impedances and voltage sensor error [49,50].
Control strategies in islanded microgrids are mainly divided into master-follower control and peer-to-peer control [51,52].
Various control strategies in microgrids in grid-independent mode such as hierarchical control [53,54], strategy Decentralized control for optimal frequency [55] and centralized model predictive control method for transient frequency control have been presented so far [56,57].
In general, the advantages of microgrid operation in independent mode are:
A. Increasing energy flexibility by providing a reliable power source
B. Facilitating the integration of renewable energy sources
C. Reducing dependence on fossil fuels
Among the disadvantages of microgrid operation in island mode, the following can be mentioned:
A. Optimum balance between production and demand
B. The need for energy storage systems to deal with fluctuations in energy production from renewable sources
C. The need for an advanced control algorithm to have a stable frequency level and voltage level

2-2- Microgrid performance in grid-connected mode

In the grid-connected mode of operation, energy management is the main role of the controller. A static transfer switch connects the microgrid to the power grid at a common connection point (PCC). In this case, the microgrid is not able to control the frequency and voltage, and to adjust the active and reactive power, it changes to the active-reactive control method (PQ). The frequency and voltage at the common connection point are mainly determined by the main grid, and the role of the microgrid is limited to performing ancillary services. The active and reactive powers produced in the microgrid should be balanced according to the demand of local loads. Each distributed generation unit is a controllable current source that exchanges active and reactive power with the grid using the current state control strategy [58,59].
The stability problem of microgrids in the grid-connected state mainly involves the stability of individual components such as specific distributed energy sources or a set of local loads and their impact on the system [60,61].
In general, the advantages of microgrid operation in network-connected mode are:
A. Providing a reliable and stable power supply using the infrastructure of the electricity network
B. Reducing the need for energy storage systems by using the surplus production capacity of the network
C. Making it possible to integrate renewable energy sources and reduce air pollution
D. Saving money by providing the possibility of net metering and transfer of excess production to the main network

Among the disadvantages of microgrid operation when connected to the network, the following can be mentioned:
A. Failure to work independently in conditions of interruption or instability of the main network
B. The need for advanced control strategies to have a stable connection
Figure (1) shows the operation modes of the microgrid and the connection between them along with the used controllers. The comparison between two microgrid performance modes based on different parameters is summarized in Table (2) [62,63].

Table 2: Comparison between two functional modes of the microgrid

Parameter	Grid-independent microgrid	Microgrid connected to the grid
Sensitivity to load fluctuations	The inertia of the system is low and the microgrid is very sensitive to load fluctuations.	The microgrid acts mostly as a constant source or load and its sensitivity is relatively low.
Connection to the main network	The microgrid works independently and is not connected to the main network.	The microgrid is connected to the network through a static transfer switch at the common coupling point.
Control complexity	Relatively complex control	Relatively simple control
Purpose of control	Voltage and frequency control	Active and reactive power control
Control method	Voltage-frequency (V/f) control, master-follower control, peer-to-peer control	Active power-reactive power control (P/Q)

3- Conclusion

The progress of control strategies and energy management systems along with the integration of renewable energies has made the role of microgrids important in the future of sustainable and decentralized power generation. In this article, a brief overview of the types of microgrids and their different modes of operation has been done. Sub-grids improve energy security and network reliability by integrating renewable energy sources. The balance between production and demand is necessary and important due to the high penetration of distributed energy sources. Microgrids can maintain changes in voltage, phase angle and frequency during the period of time when the production of renewable energy sources fluctuates. The two main operating modes of microgrids include grid-connected mode and island mode, each of which has different goals and advantages. In the island mode, the load demand of remote areas is met with lower cost and minimal losses. In the state connected to the network, the microgrid supports the main network with voltage control and frequency control, and makes it provide more flexibility, control and reliability.

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