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An Overview on Microgrid Concept with Special Focus on Islanding Protection Issues

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Abstract

Subscriber service is not feasible in the construction of large-scale traditional networks with the aim of providing more services. The high distance between production and consumption requires the definition of a transmission network as a challenging intermediary. The cost of transmission network and the risk associated with it cannot be ignored at all. The idea of a microgrid, which began with the local feeding of loads, can improve the reliability of the previous power system and, in addition, deliver the power to customers with more quality. Microgrids are the key to achieve low carbon networks by collecting distributed generation (DG) resources. Power management in the form of a microgrid causes other sensitivities. The need for storage systems besides the power intermittency of DGs, unintended islanding, and the protection of microgrids, especially in the island state, are the main issues discussed in this paper in a coherent format. This research work is a detailed reference for microgrids mainly in protection issues related to the islanded ones.

Keywords: Distributed Generation (DG), Islanding, Island protection, Low carbon networks, Microgrid.
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1. Introduction

Microgrids are a set of small sources of energy that connect to the main network. Microgrids are designed as combined heat and power (CHP) systems for small-scale low voltage (LV) networks, which provide thermal and electrical loads to a limited number of subscribers. With the connection of multiple microgrids to each other can provide additional heat and electricity needs. Effective operation of the heat consumed in CHP systems is one of the most important advantages of microgrids. Distribution sources used in microgrids can include various types of production technologies with a small carbon emission in the air. Typically, microgrids are exploited in two modes: interconnected to the network and island, in both operating modes, microgrids will have an impact on subscribers as well as on the main network. In this chapter, the sources of distributed generation (DG) used in microgrids, energy storage systems, the technical, economic and environmental impacts of microgrids and their protective issues are presented [1, 2 and 3]. In Fig. 1, a microgrid consisting of renewable and non-renewable energy sources with battery storage in interconnected mode is illustrated [24].

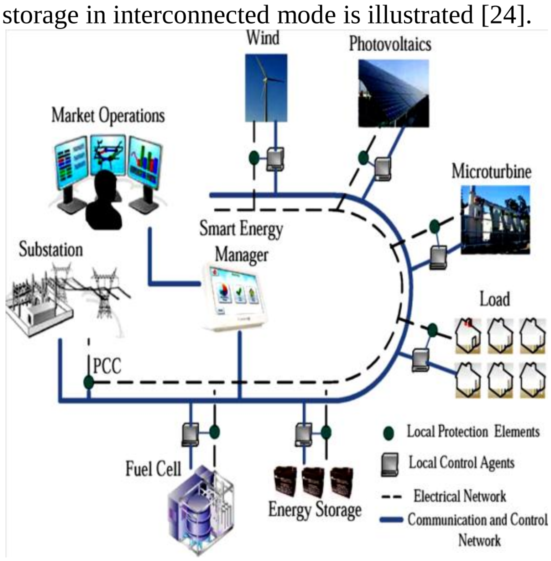

Fig. 1. Components containing a microgrid [4]

Microgrids will have a significant impact on future gas and electricity markets. To benefit from the micro-networks, they have to expand their participation in gas and electricity markets. In order to achieve this, appropriate market reforms should be made, as well as financial incentives to invest in microgrids [5].

Major changes are taking place in the electricity market of some countries. The participation of small networks in the market will increase the quality of power service in the main network. Thin networks can provide important secondary services such as voltage regulation by providing reactive power or power storage for the main network [6, 7].

- The first power plants built in the world are divided into three main categories, depending on the type of source:
- Hydro (use of running water from rivers or water stored in dams)
- Thermal (use of energy such as oil, gas or coal)
- Nuclear (using atomic energy)

Major power plants of any of the above types need to allocate suitable space for construction, which also has problems with finding this place, such as that the hydroelectric power plants should be constructed in a specific geographical area over a river with high water flow or that nuclear power plants should be protected in a local area and away from gathering centres, they should be built with high security.

The delivery of fuel to thermal power plants also imposes costs on the overall power generation, which, the vicinity of the fuel supply, reduces this cost. On the other hand, it is essential for the design and construction of large networks of electricity transmission and distribution in order to deliver electrical energy to consumers, which requires significant investment in dispersed and decentralized areas and make the provided power in the place of consumption expensive [8, 9]. In many countries, the electricity industry also uses private capital as well as other industries.

Given this fact, the need to pay attention to other low-investment power generation technologies which requires a smaller investment, this priorities of private sector participation in the financing of the industry, thus reducing the size of the power plant and the size power networks, it can attract private funds and achieve the goals of development plans.

Among the technologies that can help us achieve these goals, are technologies such as wind, photovoltaic, microturbines and etc. In general, DGs can be divided into two groups of renewable and non-renewable, each of which consists of these systems, respectively.

- Hydro (use of running water from rivers or water stored in dams)
- Solar (photovoltaic and thermal), wind, geothermal, ocean
- Internal combustion engines, combined cycle, combustion turbine, microturbine and fuel cell

DG should not be assumed to be equivalent to renewable energy sources, since it can use unrenewable resources, such as fossil fuels, to generate energy and even environmental pollution [10]. But, to reduce greenhouse gas emissions, renewable energy are set at a higher level of importance and attention.

The rest of this paper is organized as follows. In section 2, the microgrid environmental effect is described, consequently, microgrid impact on the power system is addressed in section 3. Microgrid operation with a special focus on islanded mode is given in section 4. Consequently, the problem with islanding is presented in section 5. a brief review of the storage system in a microgrid is given in section 6. Required condition and protective strategies for islanding mode of operation are described in section 7. Finally, the research will be concluded in the last section.

2. Microgrid Environmental Effect

Micro-CHP systems and other low-carbon emission generators play an important role in reducing carbon emissions to air and global warming. Regardless of the sensitivity of the market, this is one of the most important advantages of using microgrids.

The US Environmental Protection Agency has identified six of the following pollutants as the most important contaminants [11]:

- Nitrogen dioxide (NO_2)
- Carbon monoxide (CO)
- Sulfur dioxide (SO_2)
- Lead (Pb)
- Ozone (O_3)
- Pending particles in the air

Vehicles and power plants are the largest producers of NOx gases [12]. In addition, large gas turbines and piston engines also contribute to the production of NOx due to their high operating temperatures. Conversely, microturbines and fuel cells, due to their low combustion temperature, emit less NOx in the air; therefore, their use as DG units will significantly reduce the combustion of nitrogen and carbon and the compounds of hydrocarbons. The amount of a microturbine depends on operating temperature, output power and combustion control. Reducing emissions in them is possible only with the precise and quick control of the combustion process.

For CHP resources, heat optimization is usually preferred to electrical optimization. This means that power generation is determined based on the customers' thermal needs. For large-scale CHP operational constraints are [13, 14]:

- The heat produced should be equal to the demand for heat per hour.
- Electric loads should be fed by the electrical energy produced, and other electrical needs can be removed by purchasing electrical energy.
- The release of NOx, CO2 and SO2 should be kept within a certain range.

3. Microgrid Impact on Power System

Microgrids have very important impacts on the network structure, system performance in the absence of sufficient production, system reliability, power quality, cost recovery, impact on environmental pollution, and so forth. In this section, we will examine the most important effects of the microgrids.

A) The effects of microgrids on Power Quality

Most electrical charges are subject to transient errors, voltage drops, harmonics, momentary defects, etc. They are called power quality-sensitive loads, so power quality and reliability are of great importance. Quality is a new concept that has recently been taken into consideration. In the past, the voltage drop was ignored for one or two continuous cycles, while today it will cut off the network. Similarly, transient errors, harmonics, and imbalance phases are also included in power quality studies [15]. Although power quality problems have severe economic effects on industrial processes, due to different industrial applications and variations in quality measurements, it is difficult to accurately calculate the costs of these problems. Some of the power quality problems that cause economic losses due to network disconnection are [16]:

- The amount and time of an event continuity, such as an increase in the voltage
- Disconnecting or naturally damage of equipment
- Frequency problems
- Time of occurrence. For example, did this incident happen during peak hours of use or during low hours?
- Forecast subscriber status before the incident occurrence

In the United States, the effects of the aforementioned cases on power quality-sensitive equipment have been achieved and it has been determined that the cost of disconnection due to power quality is about $ 25 billion to $ 150 billion in a year. Microgrids are capable of controlling the quality of power in accordance with the needs of subscribers even at an hourly rate. However, it is difficult to control the power quality of a particular subscriber in a traditional power grid. Traditional electricity networks typically provide a level of quality and service to all subscribers (regardless of the needs of a particular subscriber). In recent years, some countries have taken steps to improve the power quality of the power grid. For example, in Australia, those manufacturers who provide higher quality products with fewer cut-off will be encouraged. Australian power grid regulators also believe that power producers should be responsible for external events such as severe storms, power outages and lack of production capacity. While the topics are not true for the microgrid. Because the subscribers connected to a microgrid will be able to meet their quality needs without any additional cost [16, 17].

B) The Effects of Micro Networks on Productive Cost

Microgrids have played a major role in reducing the costs of developing power networks by postponing urgent needs in terms of increasing capacity of transmission lines or the construction of new transmission lines. Through proper investment management, they lead to the optimal use of distributed and transmission networks and provide subscribers satisfaction. Recent studies in the United States of America have shown that microgrids have a significant impact on reducing power costs by omitting the needs of network expansion. In [18] the benefit over microgrid application is examined.

Microgrids, by feeding their loads with DG sources, reduce stress on the transmission networks. In addition, many industries suffer from severe financial losses due to excessive overloads in transmission lines. Energy Department of United States reports has shown that microgrids will liberate the capacity of the transmission lines and, as a result, reduce power over them. In general, the following can be cited as the general benefits of micro-networks from cost aspect.

The cost of production in microgrids effectively depends on the efficiency of its generators, which can be calculated in future with regard to the cost of generating electricity and primary fuels.

- Using combined heat and power (CHP) resources can dramatically increase production efficiency.
- Frequency problems

- One of the main advantages of microgrids is to provide power over the peak hours of the main power grid.
- The proximity of the resource to the loads, as well as the ability to exploit the networks in the island state, will increase reliability and power quality.
- In conventional large networks, losses in distribution and transmission lines vary from 5% to 20%. This loss rate is greatly reduced by the optimal location of CHP resources. In addition, the physical proximity of resources and loads will reduce losses on the lines.
- Using low carbon technologies in microgrid plays a significant role in improving ambient air quality.

4. Microgrid Operation

Microgrid as a controllable unit can operate in synchronous with the main power network (inter-connected mode) or independently and island (independent mode). Under normal circumstances, microgrids are connected to the existing distribution system and only in the unusual conditions at the point common coupling (PCC) will be separated from the distribution system and are operating as an island.

A) Islanding

One of the important issues related to DGs is the islanding phenomenon. The IEEE-1547 [19] standard defines islanding as a condition which, a part of a network including the load and resources of the DG separate from the network for local power supplying [20]. The islands of the power grid can be divided into two groups: Unintentional islet and intentional islet.

Unwanted islands are not desirable because they may cause large changes in the voltage and frequency on the island's part of the grid and provide electricity under unusual conditions until the system disrupt or unbalance between production and consumption. Unwanted islanding could also endanger the network operator's personnel.

On the other hand, island performance may be beneficial and even desirable. For example, in the case of a global blackout or long-term failure of distribution feeders (due to major problems on the transmission network), the island's performance of distribution feeders provides the ability to provide customers with the power to recover the system.

Island Performance Advantages:

- Enhance reliability
- Reduce cut-off rates
- Increase profits

Disadvantages of island performance:

- Reduce personnel security
- Damage to equipment due to poor quality
- The sophisticated operation when networking islanding
- The possibility of damaging resources that are still in the system (such as DGs) in case of inappropriate usage

In general, islanding consists of two status unintentional and intentional modes that will be analyzed further.

- *Unintentional islands:*

When a protective device (such as a breaker, re-closer or disconnector) between the DG and the main network is located, there will be the possibility of forming an island. In Fig. 2, area A is a result of an accident and is separated by CB1 breaker from the main grid, but the area remains energized by the DG1 generator. As shown in Figure B, zone B is also susceptible to islet due to the breakdown of CB2 [21].

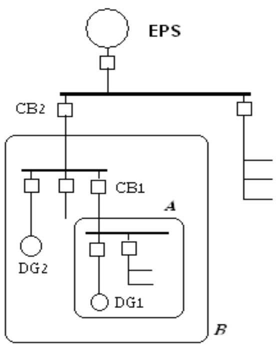

Fig. 2. In areas A and B, there is a probability of islanding

The maintenance of the system and the lack of identification of the island is an unpleasant and dangerous condition for personnel of repair and equipment [22, 23]. The outage of the DGs from the synchronous condition is the first result after the island's occurrence. In this situation, the generator's operation and load handling with out of range parameters will damage the load equipment and the DG. On the other hand, the function of the re-closer which is generally installed on the distribution network feeders is to connect the island back to the network. Therefore, protective devices should quickly disconnect DGs after the onset of the island (See Fig. 3).

The main problem, in this case, is when the difference in the electric charge of the island portion with the amount of electrical energy produced on the island is low. Under these conditions, the voltage and frequency variations in the island part are slow and the protective equipment cannot detect the formation of the island.

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If the load and production are not close to the island (their ratio is at least 3 to 1), the voltage and frequency will change rapidly and, as a result, prevent the creation of an unintentional island through the operation of the protective equipment.

Generally, when irregular islands where the DGs are feeding the island through PCC, the existing protective system should identify the island's formation and, within a maximum of 2 seconds after the emergence of the island expels DGs.

– *Intentional islands:*

This type of operation is usually performed during the global blackout and for power supply to subscribers until network recovery. Distribution networks are currently not designed to operate in island mode with the presence of DGs. If the problem of islanding is solved, this scheme can be an appropriate way to increase the reliability of the network (See Fig. 4).

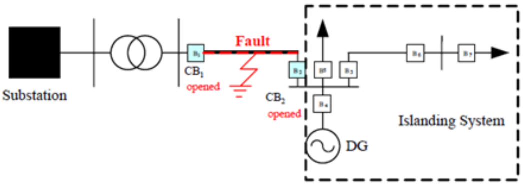

Fig. 3. An intentional island

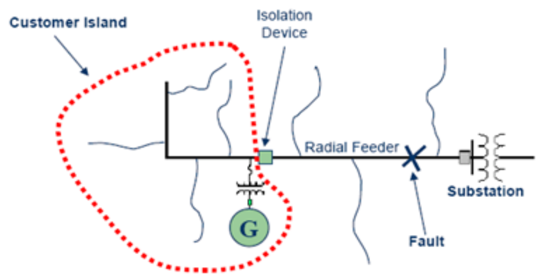

Fig. 4. Intentional island

5. Problem with Islanded Microgrid

One of the problems of islanding is the need to investigate issues in the distribution network that normally occur only in the transmission network, such as multi-direction fault feeding, and new operating and control instructions. Another problem is the reduction of the error rate in the island state.

In an island system, active and reactive power balance must be maintained so that the voltage and frequency are within their permissible range. Also, the DG units of the island should participate in frequency control [24].

Even in times of emergency removal of load or reduction of production load balancing and production can also be achieved.

For some reason, an island network error may have more serious effects than an interconnected network. Due to the shortening of the short-circuit current in the island, error detection and separation will be delayed. Also, if the radial or circular island is weak, the partitioning of the affected part may cause a collapse of the network or cause severe sustainability problems [25].

The main problems of exploiting the islands are as follows:

A) Generators loading in Black-Start:

Many times, they must be connected step by step starting from the smallest load. Due to the type of network design and the nature of the loads, in sometimes it is not possible to adjust the load. In addition, due to the cold startup phenomenon, when restoring the system, the load may be greater than the pre-shut down state.

B) Feeding the automation and telecommunication system before the island operation:

The ability of telecommunication and automation equipment during the shutdown (island operation) is limited by the capacity of the batteries, which is usually about a few hours.

C) Control the basic parameters (voltage and frequency) during island operation:

In a small system, the effect of load variations on the normal mode of the network is much higher and can make more changes to the basic network parameters.

D) Design and installation of protective systems

In the context of protection issues, we will encounter two difficulties (i.e. multi-direction supplying of faults and reduction of fault current). Further explanations and solutions will be provided to each of them in the following:

– Multi-direction fault Feeding: By the presence of DG in the distribution network, the fault flow is fed in many ways. Today, the problem of this multi-direction supplying has been eliminated by the rapid operation of protective equipment and trip generator. In this case, the protective equipment will not allow the DG to be connected until the network is reinstated. This does not allow island operations. If we want to use the grid as an island, the error should be disconnected without DG trip. In this case, the fault must be cut-off by both the DG and the network.

– Fault current reduction: When the islands are operating, the network short circuit capacity is low and the network is weak. This means that the fault currents are reduced for a specific fault and thus it will be difficult to detect load currents among them; therefore, if the over-current relay settings are the same as normal network operation, the error recovery time will be increased due to a decrease in the fault current rate. This will reduce the power quality by the voltage drop during the fault. Or, in other words, the increase in short-circuit impedance will increase the voltage drop during the fault and, as a result, power quality becomes worse.

Therefore, there is a different situation in an island system for protection relays than normal conditions; in traditional distribution systems, over-current relays were used for short circuit protection that worked well for radial systems, but in systems with DGs due to Multi-direction current feeding; over-current relays cannot provide sufficient protection for the network [26]. In addition, if such networks are exploited as islands, the conditions will be much more complicated; therefore, in an island system, the protection relay settings need to be reassessed, or new protection systems (such as impedance or differential relays) replace old systems; directional relays can easily detect network-side and DG-side errors, and thus more conservative coordination. Also, the use of differential protection can completely solve security problems, but this is costly.

E) Use of power storage systems for frequency control:

In large interconnected networks, there is a certain benchmark for determining the reserve capacity to be available for frequency control; however, a suitable benchmark for determining the reserve size of an island network should be determined. There is a different research in this area that sets criteria for 10-50% of island production capacity as a reserve required for frequency control.

6. Storage System in Microgrid

The electrical energy in an alternating current system cannot be stored electrically and should be produced as needed. However, to store this energy, it can be easily converted into another type of energy, of course, any kind of system requires a good converter for proper operation. The expansion of technology for storing electrical energy to maintain the power required as needed is of particular importance in the current power system. Also, as the electricity sector is undergoing major changes, energy storage is a very important choice to cover issues such as restructuring in the electricity market, the introduction of renewable resources and help to increase DG products, improve power quality and help network performance under the environmental protection discipline.

Therefore, the use of energy storage system (ESS) resources, for storing power and usage is one of the solutions that are of great interest today [27].

According to the definition of a physical system, energy absorption for dispatching and replacement of electricity at a shifted time are called an ESS source of electrical energy.

7. Required Conditions for Island Operations

In short, successful island exploiting requires:

- The ability to control the voltage and frequency quickly, which can be provided by a synchronous generator or power electronics equipment.
- The presence of cutable loads during when Black-Start.
- The existence of an energy storage source for setting up generators during Black-Start and supporting auxiliary systems.
- Reset the protection systems of the generator and lines according to the island conditions.

A) Island detection

According to the previous explanations, identifying islands is essential for power system control, the performance of the islanded microgrid is of particular concern and should prevent the formation of unintended islands. Electricity companies are responsible for the security of power systems, because the electrical energy can be dangerous for humans, and in certain circumstances, it may damage the equipment connected to the network. If a part of the power system acts as an uncontrolled island (i.e. unwanted island), it may be dangerous for repairing and maintaining personals of the network and even may cause to die, and thus identifying parts of the network that act as an island is important and necessary.

To prepare for islanding and the possibility of proper exploitation of this phenomenon, many methods have been proposed to identify the island in the power system [28, 29, and 30].

These methods are mainly divided into two groups of local and remote methods. Remote methods are based on the communication between the electricity company and energy sources. Although these methods have more reliability than local methods, their implementation is expensive and may not have an economic justification. Local methods rely on information obtained from the source side and are divided into passive and active methods [20].

Passive methods are based on measuring network parameters in the DG output. Quantities such as voltage, current, frequency, power or harmonic disturbances are measured. When the islanding phenomenon occurs, these values change, and if these changes are outside the range defined for relays, the DG Breaker open command is issued.

The points to be made about these methods are that determining the range of operation of the relays is of paramount importance. Applying high sensitivity on it can lead to unwanted and false performance that is not desirable; on the contrary, the extent of its limitation also results in no performance during the occurrence of some of the islanding incidents, which is dangerous. In relation to active methods, it should be said that, in some cases, passive methods are not able to detect the occurrence of the island, and this is because of the balance between load and DG. In active type of protective devices, a disturbance is applied by the DG system to the network. The occurrence of the island is detected by examining its response. This means that the non-change in the parameter measured in the point of common coupling (PCC) means the presence of the DG connection to the network. These types of methods are much more effective than passive methods.

But the issue to be considered in these types of systems is the response time and the feedback to the system, which has a time delay inherent. This means that after the occurrence of the island, the cut-off command of the PCC breaker is delayed, which, in view of the time of the re-closer relay protection, must be in such a way as to prevent interference between relays operation.

Other disadvantages for the active methods are the inability to run for various types of DGs. Due to the fact that the nature of DG's functions is different, its protective system should be selected based on the type of generator.

Creating disturbances to the system is also a disadvantage to these types of protection systems. Depending on the nature of their performance, the detection of DG and electric power system (EPS) connections can be done by injection of a disturbance; this disturbance can include active or reactive power. The reactive power reduces the power factor.

In telecommunication-based methods, commands are required to be isolated from the control centre and sent via telecommunications to relays at DG's premises. In fact, these methods are based on remote control systems that are sent to supervisory control and data acquisition (SCADA) (i.e. EPS measuring equipment, telecommunications platform and equipment at the distribution substation), and in the event of an island phenomenon occurrence and its detection, the cut-off command is sent through this communication way to the DG.

The used telecommunication systems include [31]:

– Radio
– Optical fibre
– Internet
– DLC (Data link control)
– Leased Line

As we mentioned earlier, DGs are based on two types of synchronous-based and inverter-based, and the use of DG protection against islanding depends on the type of DG system. The main advantage of remote-based methods is the lack of dependence on the type of generator and DG technology, and therefore, it will be used for both types of DG.

However, despite the high precision and optimal performance, these methods have some problems. The cost of high initial investment is due to the complexity of the techniques used, the change in network topology over the time and the need to update the central algorithm are among the barriers to use these methods. In addition, with the problem of far distance, this will weaken the exchange signals and sometimes require signal amplification along the path that increases the cost. Aerial and terrestrial lines, capacitor banks, branches and ... are among the factors of signal degradation. If this increase is exceeded, then the amplifier should be used.

B) Anti-islanding protection

In order to prevent unwanted islanding, the following notes should be observed during the installation of DGs [32]:

– The total capacity of installed DGs in a local network should be less than one-third of the minimum load on that local network.
– DG units must have passed anti-islanding testing.
– The installed DGs should have the minimum power or reverse power protection so that, if the power flow from the grid is reversed to the local network or reduced to a certain amount, the distributed generation unit will be disconnected from the network.
– Dg units should have other anti-islanding equipment such as voltage and frequency shifts and transfer trip.

8. Conclusion

In this paper, a detailed definition of a microgrid is presented. The environmental impact micro networks have been reviewed. The research elaborate that local load feeding in microgrid structure can be enough challenging while offering more qualified service. Intentional island operation of a microgrid is addressed by this paper as the main issue in this respect. Some modern protection and communication method for securing microgrids are discussed. The necessity to storage system regarding the power intermittency in renewable DGs and frequency problems are mentioned. The methods of islands detection and preventing unwanted islanding are presented in detail. This study presents comprehensive information on microgrids and their main challenges.

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