# CHALLENGES IN RECENT MICROGRID SYSTEMS: A REVIEW

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***ABSTRACT***
*This paper presents the current status and challenges of microgrid systems as well as the barriers that should be encountered for their integration to the electrical power network. The important issues related to the microgrid are its, autonomous operation, control strategies, regulatory barriers and protection in islanding operation which are being discussed in this paper. Some examples of practical installations worldwide will also be presented.*

***INDEX TERMS --*** *Distributed generation, Distribution systems, Embedded Generation, Intentional islanding, Interconnection, Microgrid systems, Power blackouts.*

## I. INTRODUCTION

In last few years, a number of major blackouts have occurred in some countries which virtually left the affected areas in a state of chaos. The lack of electric power unveiled one common fact that our modern society is so dependent on electricity that during the blackouts some areas like electrical transport system, financing activity, academic institutions, industries and health centers with no emergency or standby generation, public and residential lighting and even some communication systems failed to operate.

Following these undesired events, like the one occurred in Brazil in November 2009, there was a rush for seeking some alternatives to deal with them or at least try to diminish their impact. The establishment of microgrid systems within the electrical network appear as an alternative that may be used for such a purpose, thus, not only critical loads but also most of the abovementioned loads would be able to uphold their operation.

One of the key features of a microgrid is its ability to separate from the utility grid during the unscheduled periods of interruption to continue feeding its own islanded portion.

On this regard, the authors agree with the viewpoint found in [1] where it is mentioned that ‘under present grid protocols, all distributed generation must shut down during periods of power outages; however, these onsite micro sources could provide their greatest power services to local loads. Similar to a standard grid configuration, a microgrid may also be composed by generation, a distribution system and the loads as shown in Fig. 1. Distributed or dispersed generation (e.g. diesel generators, solar PV, wind turbines, small hydroelectric schemes and thermal units, among others) constitute the generation assets in a microgrid. Smart switches connected to the grid would ideally allow a fast islanding from the grid to run as an independent small scale grid. The characteristic of a smart microgrid is that, provided an agreement with the grid, it can supply its surplus generation to the utility during peak periods or whenever it has excess capacity.

One of the technical challenges that a microgrid faces resides in the availability of low-cost technologies for its safe and reliable operation.

The outline of this paper is as follows: a synopsis of the literature survey is presented in Section II. In Section III, the current microgrid standards recently issued are mentioned. Section IV addresses the main features concerning microgrid systems. In Section V, some practical examples of microgrid systems in the world are presented. Finally, in Section VI the main conclusions and further work are presented.

## II. LITERATURE REVIEW

There are several interesting references which have been found demonstrating design, operation, economics and regulation of Microgrid Systems. There may be some other references also having the same merit, although, due to space restrictions it will not be possible to include them all in this paper.

For example references [2] and [3] address the microgrid systems in a quite comprehensive way. Likewise, the current technologies and regulatory barriers for its implementation are discussed.

In [4], [5] and [6], some of the advantages of a microgrid system are listed while it is suggested that this form of grid may probably be the future type of grid.

In [7] the ongoing research, development and demonstration efforts of some microgrid systems currently in progress in some countries around the world, is presented.

In [8], a comprehensive information on microgrid systems, the role of CERTS (Consortium for Electric Reliability Technology Solutions) in the DER (Distributed Energy Resources) technology as well as some control methods and microgrid economics is presented.

In [1], [9], [10], a concept of microgrid systems and also some alternatives of its control, namely, the relation of both power and frequency droop as well as voltage and reactive power droop, are presented. The control strategies (i.e. active power versus frequency droops characteristic) to be used in a microgrid containing large amounts of small sized dispersed generation set in an islanded operation mode as well as exploit the local generation resources as a way to assist the power system restoration after a general blackout, is also presented in [5] and [11].

Reference [12], presents a control architecture for the identification of viable islands in a customer-driven micro-grid prior to a fault or disturbance.

In [13], [14] and [15] the protection issues related to a microgrid intentional and unintentional islanding forms as well as some of the protection problems that must be dealt with to successfully operate a microgrid, when the utility is experiencing abnormal conditions, are discussed.

Reference [16] addresses the problems of environmental regulatory issues. The various costs and benefits that customer-generators can impose on electric utilities are also discussed.

In [17], the barriers, investment deferment, reliability and other issues related to the dispersed generation in Brazil are analyzed.

Some issues of the customer-driven microgrid (CDM) are investigated in [18] and [19]. An overview of an existing power system model and its suitability for investigation of autonomous island formation within the microgrid is also presented. Additionally, a list of the existing and yet-to-be discovered techniques, for the implementation of a microgrid, is presented.

Reference [20] deals with the economic dispatch problem in a microgrid, to provide the optimal power reference of the distributed generators.

In [21], testing of some microgrid applications and the development of a new integration facility designed to accelerate the deployment of distributed resources are discussed.

In [22], an experimental model of a microgrid system that operates interconnected to the LV network, or in stand-alone (island) mode, is presented. Recently, the IEEE committee has release a guide (IEEE Std 1547.2-2008) that covers various topics related to microgrid systems and intentional islanding of systems containing distributed energy resources [23]. The IEEE preceding release, worth to look at (IEEE Std 1547-2003), can be found in [24].

In [25], the development of a microsource modeling and the definition of the control strategies to be adopted to evaluate the operation feasibility of a microgrid when it becomes isolated is presented.

In [26] the concept of a minimal microgrid for the purpose of defining the microgrid architecture is introduced. It is also presented a conceptual framework of a microgrid with a distributed control architecture regarding hierarchical agents.

Reference [27] reveals the operational analysis of a DC microgrid in which various types of distributed generation feed a DC system. The DC microgrid reportedly can operate with the grid-tied and also under the islanded mode.

In [28] some design and planning methods for the development of renewable energy microgrid in remote systems is presented.

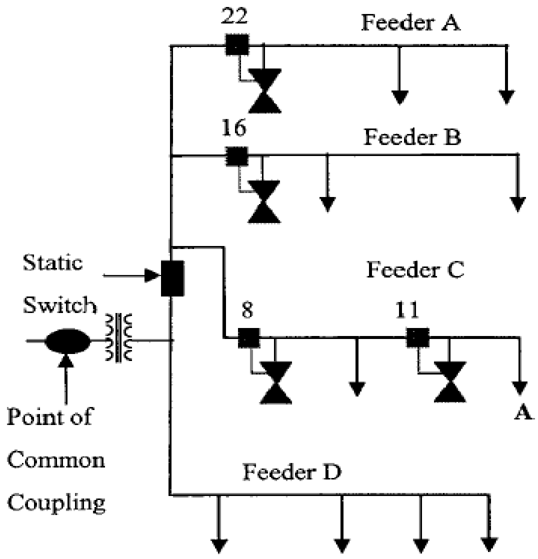


**Fig. 1** Microgrid Architecture Diagram

# III. CURRENT MICROGRID STANDARDS

Since last few years, equipment manufacturers, planning engineers, microgrid and system operators as well as all those linked with the microgrid and distributed generation technology have a guide (IEEE Std 1547, 2008) covering various aspects of these technologies. The IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems [23], addresses aspects such as intentional islanding in systems containing DERs (Distributed Energy Resources) connected with utility as well as the microgrid integration with the power system.

In Annex A of this reference guide, for example, it can be found aspects related to:

A.1.1 – Interconnection issues, which could be done through switch gears.

A.1.2 – Power source transfer, which can be automatic or manual. It also presents issues related to DER systems regarding the parallel operation.

A.1.3 – Metering and monitoring issues.

A.1.4 – Protection issues.

A.1.7 – Dispatch, communication and control with the DER (e.g. energy management system/SCADA area). Other issues discussed in the guide include: impact on voltage, frequency, stability issues, power quality, existence of PCC (Point of Common Coupling) and multiple PCCs, identification of steady-state and transient conditions, understanding interactions between machines, reserve margins, load shedding, demand response, and cold load pick-up (The phenomenon that takes place when a distribution circuit is re-energized following an extended outage of that circuit). For example, it can occur due to the heating system or air conditioning system and appliances left on during the outage. When power is restored, this load cause a huge drain on the power lines and can cause line protection equipment to take the overloaded lines off line because the heavy load acts the same as a fault on the line.

Today, many owners of emergency and backup generation are considering interconnecting their DER units with the utility. However, the use of generation designated as emergency (or possibly backup if it is used for safety) for other purposes (e.g., peak-shaving) must be carefully analyzed because many emergency and backup generation sources may be limited to 200 or fewer hours of operation each year. Operation as a peak-shaving installation may exceed this limit [23]. Also there may be air quality permit issues.

# IV. MAIN FEATURES CONCERNING MICROGRID SYSTEMS

## A. Autonomous Operation

During severe voltage drops, faults, blackouts etc. the microgrid can switch to island operation using local information. This implies an immediate change in the micro generators power control as they pass to control the frequency of the islanded section.

The transition to islanded operation mode should be done maintaining suitable voltage and frequency levels for all islanded loads. Though, depending on the switch technology, momentary interruptions may occur during these transitions. If power is lost, the DERs assigned to provide power to the intentional island should be able to restart and pick up the island load after the switch has opened [29]. According to [8], [9], a basic issue for distributed generation within the microgrid is the technical difficulties related to control of microsources and the reconnection of the microgrid which should be achieved autonomously once the tripping event is no longer present. This synchronization between the grid and the microgrid can be achieved by comparing both frequencies preferably ensuring a transient free operation procedure. Both automatic and manual reconnection procedures should be available at the Point of Common Coupling (PCC) between both grids.

## B. Power and Frequency Control

According to the literature surveyed, the most common control strategy for microgrid generators is the power – frequency droop control [10], [22]. Additionally, in order to control the local voltage, it is also proposed the use of the voltage-MVAR droop control [10].

**Power vs. Frequency Droop**

When the microgrid operates with the grid, loads receive power from the grid and from the local micro-sources, depending on the load position [10], [22]. If the grid power is lost, due to any event (faults, etc), the DERs within the microgrid will face voltage droops. Each machine will need to have the ability to react towards this condition. When regulating the output power, each source has a constant negative slope droop on the P-f (Hz) plane (Fig. 2). Normally, a droop governor lowers the speed reference from 3 to 5 % of the reference speed over the full range of the governor output.

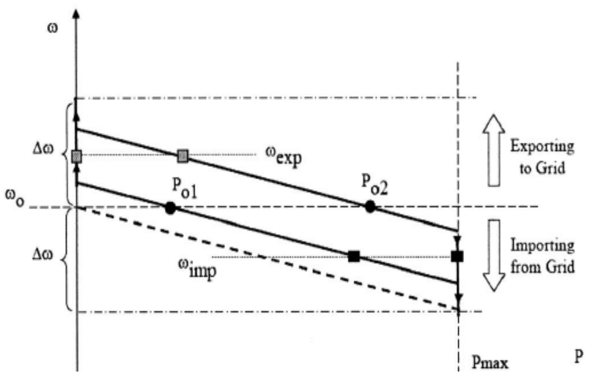


**Fig. 2** Frequency droop control

The instant when the DERs are separated from the grid is reflected in them as if they were overloaded. So, in order to reach the 60 Hz frequency, the speed governors adjust the machine speed so that it increases the speed and thus its frequency. The opposite behavior will occur when the power from the grid is restored and reconnection occurs. The characteristic shown in Fig. 2 is for steady state conditions, during dynamic conditions the trajectory will deviate from this characteristic. This procedure will be followed when importing or exporting power to the grid. Of course, the P-f slope of one machine may differ from another, thus, the control of the various units will not be as straightforward as it may seem.

## C. Protection Issues

The protection of low voltage distribution grid where feeders are radial with loads tapped-off along them is usually designed by assuming a unidirectional power flow and is based on over current (OC) relays with time-current discriminating capabilities [14].

According to [15], the emerging standards specify mandatory voltage and frequency trip settings for measurements made at the PCC (Point of Common Coupling). The information received/sent by the

PCC should be fast and reliable if the microgrid control system is to separate from the conventional grid due to a fault within the grid. Also, it is not fully clear what will be the voltage drop tolerance to separate from the grid under “non-fault conditions,” if that is case.
As it was seen in Section II, the IEEE Std 1547, 2008 [23] offers a good basis on the protection issue. Although, care is to be taken while analyzing the low-voltage protection devices when they operate connected to the grid and in the islanded mode.

## D. Regulatory Barriers

Below listed are the most significant barriers that microgrids encounter to operate as legal entities:
i) Regulatory policies
Regulatory policies are needed to create a more consumer driven electricity system [2]. As an example of a policy barrier it could be pointed out that utilities may have the exclusive right to run power lines across public streets, which in effect prohibits communities from making infrastructure improvements of any significance. A renewed regulatory structure would unlock the benefits of smart microgrids and invite innovation and investment at a significant competitive advantage. The fact is that even nowadays most regulatory officials are still unfamiliar with the microgrid concept and uncertain about the policy developments related to this new architecture [16].
ii) Microgrid Ownership Models
A survey made in the US by [16] showed that many regulators observed either explicitly or implicitly that all micro-grid applications are not the same in the eyes of the law. Moreover, the differences among micro-grids that matter most to regulators are not in the technical details of the microgrid installation and operation, but rather in the micro-grid ownership and business practices. [16] Proposes the existence of five different models that can be used to categorize micro-grids by their ownership and business practices.
**1) Utility model** – the distribution utility owns and manages the microgrid to reduce customer costs and provide special services (e.g. high power quality and reliability) to customers on the system.
**2) Landlord model** – a single landlord installs a micro-grid on-site and provides power and/or heat to tenants under a contractual lease agreement.
**3) Co-op model** – multiple individuals or firms cooperatively own and manage a micro-grid to serve their own electric and/or heating needs. Customers voluntarily join the micro-grid and are served under contract.
**4) Customer-generator model** – a single individual or firm owns and manages the system, serving the electric and/or heating needs of itself and its neighbors. Neighbors voluntarily join the microgrid and are served under contract.
**5) District heating model** – an independent firm owns and manages the microgrid and sells power and heat to multiple customers. Customers voluntarily join the micro-grid and are served under contract.
Note that each of these models present pros and cons, but this can be discussed future.
iii) Choice of voltage level
From a regulatory standpoint, interconnection at high voltages does not necessarily result in different rules; however, it indicates participation in the wholesale market [16].
iv) The legality of microgrids
This issue is related to the case whether a microgrid is defined or perceived to be a public utility. Should that be the case, it stands little chance of being permitted to operate, especially within the service territory of another public utility. According to [16], three stipulations were most commonly cited for systems that want to operate with non-utility status:
1) The micro-grid owner(s)/operator(s) must be the primary consumer(s) of the electricity.
2) Micro-grid customers must be on or contiguous to the site where power is generated.
3) A micro-grid may serve only a limited number of customers.
v) Service territories
Distribution utilities have traditionally been granted monopoly power to provide service to customers within pre-defined service territories. This is to avoid redundant wires (from different utilities) crossing a city or town. Service territories reduced the utility’s financial risks by guaranteeing a customer base through which capital investments could be recovered, and gave customers assurance that they would receive electric service.

vi) Utility tariffs
It should be defined whether direct customer-generator tariff arrangements are even applicable to microgrids or there may be other ways to set tariffs.
vii) Interconnection procedures & technical requirements
According to [16], utilities have been reluctant to let distributed energy resources interconnect with the grid, citing safety and system stability concerns. System operators and regulatory authorities are still working on ways to alleviate these concerns by formalizing the interconnection process in a manner that fairly places responsibilities and burdens of proof on both microgrids and the utility.
viii) Microgrid & customer interaction
Although some regulators have expressed concern over the manner in which microgrid firms might provide service to its customers, it is unclear how this relationship is defined in regulatory law. There certainly should be an entity in between regulating this issue, protecting the public (consumers) against unreasonable rates, bad service, and negligence that results in safety hazards, etc.
ix) Environmental and siting laws
This is another important issue regarding the current environmental regulations. Environmental issues are typically handled by a state agency, whereas siting is often handled by local agencies. It is also unclear the availability of jurisdictions regulating the environmental impacts of microgrids. Reference [16] cites some recommended regulatory changes that may be considered by the relevant regulation agent.

## V. SOME EXAMPLES OF MICROGRIDS

Although still under test levels, there are currently some practical applications of microgrid systems.
The Kythnos island project (Greece), is a pilot installations where long term field tests on microgrids have been (and still are being) performed in low voltage grid segments [6]. It is expected that this microgrid will be connected to the main grid in the near future. It provides electricity to 12 houses in a small valley in Kythnos (Aegean sea region). The Kythnos mini-grid consists of 10 kW solar PV capacity distributed in five smaller sub systems, a battery bank of 53 kWh capacities and a diesel generator of 5 kVA and three 4.5 kVA battery inverters to form the grid. The systems were installed in 2001 under the framework of European projects PV-MODE and more.
Bronsbergen residential microgrid (Netherlands). This is reportedly the first microgrid in the Netherlands [30]. It is basically constituted by PV schemes installed on top of the residential roofs.
Continuo's MV/LV facility (Netherlands) [7]. This project operates a holiday camp with more than 200 cottages. The total PV capacity is 315 kW. Because the daytime load is low, during this period most of the PV power is injected into the MV grid. However, during the night-time some support from the grid is necessary.
In the USA, there are projects presently being investigated, namely [2]: Fort Bragg microgrid (NC, USA). It had been conceived to enhance power reliability while reducing costs. This is actually a U.S. Army base installation, perhaps the largest project of its kind. It has its own electric distribution network and is able to monitor various generations from a central energy management center. The various generation technologies are fully integrated with the distribution network, information technology and also the communications infrastructure.
In [31], a handful of other microgrid projects in the USA can be found. Although some of them were built a long time ago, when microgrids were not characterized yet, they do fall onto the present general definition of a microgrid.
Other microgrid demonstration projects are currently being run in Denmark, Canada, Italy, Portugal, Japan, and Spain [7]. It was also found out that some other microgrid pilot projects are being deployed within university campuses and military bases.

## VI. CONCLUSIONS AND FURTHER WORK

From the study and analysis developed, the following conclusions can be drawn:
- Since it has been retaken as an alternative idea to support the grid, the microgrid technology has drawn considerable attention from the energy sector in many countries worldwide. The term 'retake'

used here is because this was the first grid configuration back in 1880s (though they were fed by dc current) when the idea of the centralized grid had not been conceived yet.

- As for the regulations and standards available today, they will probably be improved and gradually consolidated and will occur in time as practical microgrid installations are inserted to the network.

- From the information available, it was found out that some of the public utilities are still skeptical or find it soon to integrate them to the network until this alternative becomes a little bit more mature. Others, mainly the public opinion, are in favor of its fast integration to help to alleviate system overloads and blackouts.

Subsequent to the above study, it is the intention of the authors to futurely present more in-depth studies and results of some simulations regarding the control, energy exchange and the islanding operation of microgrids.

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