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Procedia - Social and Behavioral Sciences 238 (2018) 46 – 52

Procedia
Social and Behavioral Sciences

SIM 2017 / 14th International Symposium in Management

Microgrid supply management

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Abstract

Microgrids represent a means of improving the conventional electrical grid network, making it more reliable, secure, cooperative, efficient and, especially cleaner. This paper presents the management of a hierarchical DC-coupled microgrid with distributed architecture implemented in a microgrid laboratory containing two renewable sources, namely wind and hydro. Power supply management strategies are applied in order to supply a critical, non-dispatchable load. Due to effective management, the microgrid is robust and capable of handling most of the problems that are associated with renewable energies.

Peer-review under responsibility of SIM 2017 / 14th International Symposium in Management.

Keywords: microgrid management; renewable energy.

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1. Introduction

Today, conventional power systems are evolving towards microgrid systems. Microgrids are emerging power system infrastructure composed of small-scale low voltage power supply networks designed to supply electrical load for a small community etc. Microgrids represent a means to improve the conventional electrical grid network in order for it to be more clean, reliable, secure, cooperative, and efficient. Therefore, microgrids have the following objectives: higher penetration of renewable energy, integration of storage, delivery efficiency improvement, stronger resiliency, and improved flexibility. Microgrids are expected to be more robust and cost-effective than the traditional approach of centralized grids. However, in order to design a functional microgrid, intelligent control is required [Nejabatkhah 2015, Colson 2012, Wang 2010]. Intelligence is needed while designing the individual controllers, converters, battery chargers etc. Yet, a perfectly deigned microgrid would not yield much energy if it is improperly operated. Hence, intelligent design by itself is not enough, intelligent management is needed.

This leads to a huge need for intelligent microgrid management. Intelligent energy management of microgrids can be used to achieve a variety of objectives such as cost reduction, mitigation of heavy loads or matching the power generation and consumption profiles [Mohamed 2013, Wang 2010]. For example, an effective micro-grid

Peer-review under responsibility of SIM 2017 / 14th International Symposium in Management.
doi:10.1016/j.sbspro.2018.03.006

management system could ensure better handling of the renewable energies by connecting extra loads or storage elements at peak supply or disconnect dispatchable load during low supply, it can compensate low renewable power supply with power from the main grid, it can make decisions regarding how much energy should be bought from the main power system and how much energy should be sold to it, etc. according to the needs and characteristics of the microgrid in question. Considering the high initial costs and high maintenance cost typical to renewable energy sources, wind turbines in particular, operating the microgrid in a cost effective way is a priority. Such an operation of the microgrid requires intelligent management system.

There are two ways to approach microgrid management, namely supply management, which controls the production of energy sources so as to meet the constraints of the system and demand management, which refers to any strategy that reduces energy consumption [Divshali 2016, Davis 2003].

2. Types of microgrids

The power sources employed in microgrids are usually renewable or non-conventional distributed energy resources (DER) [Mohamed 2013, Wang 2010]. DERs are sources of energy located near local loads, designed for energy generation and storage of electrical power. Distributed energy resources range from small systems designed for one or several homes to very large ones for remote island grids or large communities, virtually any place where renewable energy resources are available. DER can provide a variety of benefits including improved system reliability, decreased transmission and distribution losses, increased efficiency. Some DERs are able to ensure electricity in the event of a power outage or disruption. Therefore, DERs are considered to be the solution for reducing the use of fossil fuels and conventional energy resources [Cultura 2011].

DER units are composed of distributed generation (DG) and distributed power or storage (DS) units with different capacities and characteristics. Distributed Generation (DG) technologies are power generation devices such as wind turbines, photovoltaic, micro-hydro, biomass, geothermal, ocean wave and tides, fuel cells and diesel generators.. Distributed power or storage (DS) stabilize and permit DG units to run at a constant and stable output, despite load fluctuations, providing provides the ride-through capability when there are dynamic variations of primary sources. DS is used when the generation and loads cannot be exactly matched. DS technologies include batteries, supercapacitors, and flywheels. Both DG and DS units are usually connected at low to medium voltage level in the host microgrid [Katiraei 2008, Cultura 2011].

DG units can be categorized into DC power sources, such as PV, fuel cell, and energy storages, and AC power sources, such as wind and hydro turbines. Microgrids that contain different types of DG are considered hybrid microgrids. These hybrid AC/DC microgrids are considered to be the future of distribution and transmission systems because they have advantages of both AC and DC power [Nejabatkhah 2015, Katiraei 2008]. It is therefore necessary to have a well-defined and standardized framework/procedure for integrating AC/DC sources and loads into a hybrid system. The methods can be generally classified into three categories: DC-coupled, AC-coupled, and hybrid-coupled [Patrascu 2017].

Direct current (DC) electrical systems are gaining popularity due in part to high efficiency, high reliability and ease of interconnection. In a DC-coupled configuration, different DGs and DSs are connected to a common DC bus. The DC bus is linked to an AC bus through interfacing converters. This structure can be used when DC power sources are major power generation units in the microgrid. AC loads can be connected either to the AC bus or to the DC bus through an inverter. Depending on the power exchange requirement between DC and AC buses the interfacing converters might be required to provide bidirectional power flow between the AC and DC buses. The DC-coupled microgrid does not require any synchronization when integrating different DGs. However, synchronization may be needed in the operation of the interfacing converters (synchronizing with each other or with the grid in grid-connected mode). DC microgrids have been proposed to improve point-of-load energy availability and to integrate distributed renewable energy sources with energy storage. Also observed is an extended efficiency to batteries, small wind turbines, fuel cells, and variable speed DC generators [Nejabatkhah 2015, Patrascu 2017, Mohamed 2013].

In AC-coupled hybrid microgrids, various DG are connected to the common AC bus through interfacing converters, one for each source. In some AC-coupled microgrids, multiple-port converters are used to replace several power conversion stages, combining different power sources in a single power converter. This structure is commonly used when dominant generation sources in the microgrid produce AC voltages. AC/ DC loads can be connected to the common bus with/without power electronic converters. The DSs need bidirectional converters to provide the bidirectional power flow capability. According to the frequency of the AC bus, there are two types of AC-coupled microgrids.

- PFAC - operation at industrial frequency
- HFAC - high frequency operation

In AC-DC-coupled hybrid microgrids, DGs and DSs are connected to both DC and AC buses. The buses themselves are linked by an Interlinking Converter. The AC-DC-coupled hybrid microgrid requires more coordination for the voltage and power control between the DC and AC subsystems. In general, this structure is preferred if major power sources include both DC and AC powers. This structure improves overall efficiency and reduces the system cost with reduced number of power converters by connecting sources and loads to the AC and DC buses with minimized power conversion requirements. Although the idea of AC-DC-coupled hybrid microgrid is promising, it requires further investigation, particularly for the energy and power management aspects. Control of such a system needs to consider both DC and AC bus voltages (and frequency), as well as the power balance within the DC and AC subsystems.

All three of these configurations can be considered, to some extent, "hybrid microgrids" [Wang 2010, Nejabatkhah 2015].

Microgrids are expected to be able to work in grid-connected or stand-alone operation (islanded) modes. The microgrid normally operates in a grid-connected mode through the substation transformer. However, it is also expected to provide sufficient generation capacity to supply at least a portion of the load after being disconnected from the distribution system, functioning in islanded mode. The existing power utility practice often does not permit accidental islanding and automatic resynchronization of a microgrid, primarily due to the human and equipment safety concerns. Due to the intermittent nature of renewable energy resources, other energy sources (such as diesel) and storage elements are critical part to enable the stand-alone operation of microgrids or to smooth the microgrid power during grid connected operation. However, the high amount of penetration of DER units potentially necessitates provisions for both islanded and grid-connected modes of operations and smooth transition between the two to enable the best utilization of the microgrid resources [Nejabatkhah 2015].

Microgrid control architectures can be centralized, decentralized, and distributed. These refer to unique methods of decision-making.

- Centralized decision-making arises when all the decisions of the system are made in a central location (node). All the information of each subsystem node ends up at the central node, communication throughout the system being aggregated there. Centralized control architectures reduce the number of individual subsystem controllers in favor of reliance on communication and computational complexity at the central supervisor.
- Decentralized control consists in assigning a controller to each subsystem. All control decisions are made with local information only, therefore no communication is required between subsystems because. However factors such as stability and optimality of system-wide objectives cannot be assured.
- Enhanced decentralized (hybrid decentralized or distributed) control does not rely on a central supervisor, but is also not purely decentralized. Instead, each subsystem may have its own controller capable of sharing information with other controllers. This sharing may allow better decisions to be made without complete reliance on local information alone [Colson 2012].

3. Microgrid management strategies

Renewable energy has begun to be seen as a long-term sustainable energy source only due to the increase in energy demand worldwide and environmental concerns. However, there are two major limitations that prevent widespread adoption: availability and variability of the electricity generated and the cost of the equipment [Patrascu 2017, Shadmand 2015]. While incorporating such renewable resources does bring great environmental benefits, it imposes challenges: generation management in microgrids while dealing with the uncertainties of fluctuant, climate-dependent renewable energy sources, namely to achieve a good match between power demand and supply [Wang 2010].

There are two ways to approach:

- Supply management represents programming the production of energy sources so as to meet the constraints of the system. Supply management strategies focus in two directions: isolated microgrids and grid-connected microgrids. The first of these aims to minimize costs in addition to meeting the technical requirements of the system. The second focuses on planning in order to minimize operating costs and maximize the profit of the distribution system [Divshali 2016, Souto 2016].
- Demand management refers to any strategy that reduces energy consumption or remodels the use of energy on the customer's side of the electricity grid as an alternative to increasing supply capacity. Demand management strategies may include preservation programs, shift tasks, and an increase in strategic task. One aspect of demand side management is load control. In terms of power flow control, load can be either dispatchable or non-dispatchable. The output power of a dispatchable unit can be controlled externally, through set points provided by a supervisory control system. In contrast, the output power of a nondispatchable DG unit is normally controlled based on the optimal operating condition of its primary energy source. In practice, part of the noncritical load can be considered dispatchable load and entered into a demand control strategy to either reduce the peak load and smooth out the load profile, or to schedule the load serving for specific time intervals when additional power, for instance, from intermittent DG units, is available. The uncontrollable part of a load is subject to load shedding. Optimum use is obtained when the load demand curve matches that of supply availability. The management strategy must also ensure that the critical loads of the microgrid receive service priority [Davis 2003, Katiraei 2008].

From a mode detailed perspective there are 4 stages of management:

- Energy management: is concerned with costs including the usage of fuels, the consumption of energy, heating/cooling/ventilation of facilities, the manipulation of mechanical subsystems, and the optimization of energy flows during operations.
- Power management: the monitoring, analysis, and manipulation of set points, operational status, and system characteristics of electrical components in order to affect the immediate operational conditions within an electrical system towards the desired parameters (power, voltage and frequency) and equipment status. Power management is a component of energy management.
- Resource management: the analysis and control of resource procurement and exploitation, including energy, water, and other necessary supplies and materials for operation. Resource management is a component of energy management.
- Distribution management: the monitoring, analysis, and manipulation of electrical distribution components towards ensuring the desired delivery of electrical power (power flow, load management, voltage control, etc.).

These management stages are separated only in theory; in practice they tend to fall into overlapping categories, as can be seen in Fig. 1 [Colson 2012].

Fig. 1. Stages of management.

4. Microgrid Structure

This paper presents a DC-coupled nanogrid structure, which can be seen in Fig. 2, using real components implemented in a microgrid laboratory. In accordance with the literature in this domain, the system will be referred to as a “microgrid” [Patrascu 2017].

The microgrid contains a DC Bus. The renewable power sources (DG sources) are wind and hydro Hardware-in-the-loop simulators, both of them being connected to the DC Bus through DC/DC Converters. These converters are, in the case of the wind energy conversion system, a Xantrex MPPT Charge Controller (CC) and, in the case of the hydro energy conversion system, a bidirectional hybrid DC-DC (HBDC) converter. The CC and the HBDC are responsible for maintaining the voltage on the DC Bus based on the amount of energy available from the renewable sources. Both converters are connected to a central management system but work most of the time independent of it.

The DC Bus is connected to the main grid through a Hybrid Inverter (HI). The HI is also responsible for supplying the load, a high priority non-dispatchable load.

The HI contains an integrated AC transfer switch, capable of being grid-interactive or grid-independent. The local AC loads are usually supplied by the renewable sources through the DC Bus. If their energy output does not suffice and the microgrid is in on-grid mode, the grid will provide the power deficit through the HI. If this situation occurs while the grid is in off-grid mode, the loads are disconnected [Patrascu 2017].

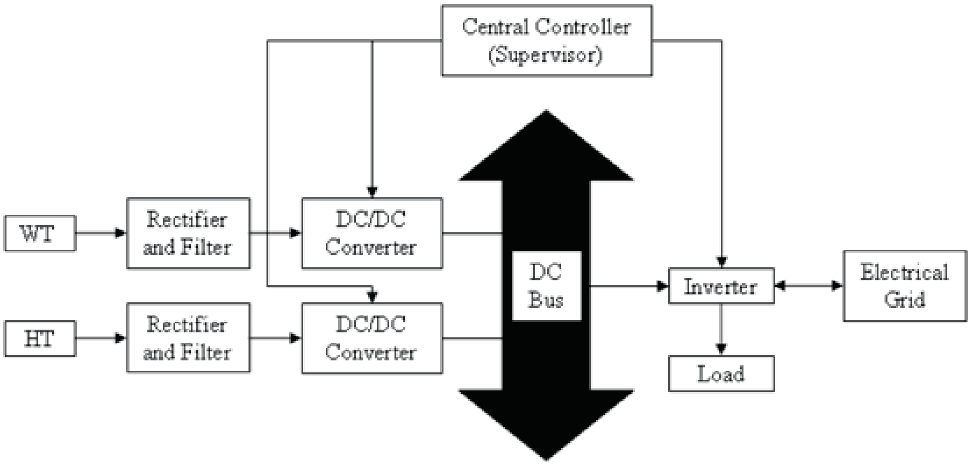

Fig. 2. Microgrid structure.

The general data regarding the converters are summarized in the table I.

Table 1. The converter parameters.

Component	Parameters
Charge Controller [CC]	Xantrex XW MPPT 60/150 Charge Controller
	U_{in}=400 (V), I_{in}=16.6(A), U_{out}=600 (V), I_{out}=6(A), P_{out}=4 (kW)
Hybrid DC-DC Converter [HBDC]	V_{LowDC}=50(V), V_{HighDC}=400(V), P_N = 5(kW)
Hybrid Inverter [HI]	Schneider Xantrex Hybrid Inverter
	U_{in}:=48(V), I_{in}=96(A), U_{out}≈240(V), I_{out}=40 (A), P_{out}=4.5 (kW)

5. Microgrid functionality

The control of the microgrid is done on the basis of a distributed architecture using the principals of power supply management. The microgrid has a hierarchical control scheme, the converters and the inverter being connected to a central controller (Supervisor). The microgrid system central controller faces the challenge of effectively utilizing the highly fluctuant renewable energies in order to fulfill the load requirements. The Supervisor software is based on Artificial Intelligence. An important task of power supply management is to maintain a good match between power generation and consumption at the minimum cost. The central management system is connected to the local controllers using a local network based on Ethernet [Patrascu 2017, Wang 2010].

The microgrid was designed to operate in two modes: on-grid and off-grid. A normal operation mode is defined as follows: the renewable energy sources produce enough power to supply the AC loads. The converters send a level of power to the DC bus that is enough to keep the AC loads supplied. This level is prescribed by the supervisor.

In on-grid mode, in a case of excess power, meaning more power than is necessary for the loads, the DC bus voltage increases and the HI sends the supplementary power to the main grid. There are certain limitations to how much power can be transferred to the bus, limitations included in the control algorithms of the converters. If the DG sources produce more power than can be sent to the DC bus, the converters are ordered by the supervisor to a lower power point.

If the power supplied by the renewable energy sources decreases bellows the point in which the loads can be sustained, the HI attempts to compensate the shortage using power from the main grid.

In off-grid mode, when a sudden surge of power appears, the converters send excess energy to the DC bus.

In the case of a fall in power supply, during off-grid mode, the converters start operating at the maximum power point. If this action is not sufficient, the loads are disconnected and the system fails [Patrascu 2017].

6. Conclusions

This paper presents a hierarchical DC-coupled microgrid using real components implemented in a microgrid laboratory. The microgrid is centred on a low voltage DC bus. It contains two renewable sources, namely wind and hydro, and a critical, non-dispatchable load interconnected in an intelligent energy system. The AC loads being critical loads, great care is taken to maintain a constant supply of energy that can meet their demands.

This microgrid can work in both grid-connected and islanded modes.

This microgrid can be considered a Smart Grid through the fact that is uses “smart” technologies (real-time, automated, interactive technologies), digital information and control technology in order to achieve dynamic optimization of grid operations and resources. This improves reliability, security, and efficiency of the microgrid. It also incorporates the use of distributed resources and generation, such as renewable resources. These characteristics are included in the definition of the Smart Grid given by the Energy Independence and Security Act of 2007 (EISA-2007).

The presented system works well ensuring the loads are supplied at all times due to the supply side management system. The microgrid is robust and capable of handling most of the problems that are associated with renewable energies. From a different perspective, the supervisor ensure adequate a power management system within the microgrid. The elements of originality in this paper consist of state-of-the-art industrial equipment together with complex control software in order to obtain a functional energy management system based on supply management. It is also a fine example of distributed control which, considering the fact that most of the traditional grid and microgrid control systems are centralized, is in itself a slight novelty. There are very few examples of renewable energy microgrids with distributed control.

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