Control and optimization of micro-grids with electric and heat energy resources

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Abstract
Several drivers, usually recognized as electricity market, renewable energy sources and smartgrids are behind the concept of increasing distributed electricity generation from solar PV systems, wind turbines and CHP systems. These microsources have been installed as a consequence of government incentives aiming to secure supply of energy and to reduce the CO_2 emissions by using renewable energy. If they are properly allocated in the network some of their benefits to the power system are: postponed investment in transmission and distribution capacity, losses reduction, energy savings, ancillary services, higher power quality and reliability. The better way of their utilization is to take a system approach in which views generation, storage and associated loads as a controllable subsystem. That subsystem is defined as microgrid. The paper describe mostly recognized architectures and control concepts for microgrids.

Keywords: microgrid, microsources, renewable energy, control, optimization

1. Introduction

Microgrid is defined as a cluster of distributed energy sources (both electrical and heat), storage devices and controllable loads in one or more locations that are connected to the MV distribution network through the point of common coupling. Control of microgrids could be distributed and/or centralized control. Distributed control is realized by coordinated microsource controllers with the main function of independent control of the power flow and load-end voltage profile of the microsource in response to any disturbance and load changes. Overall control of microgrid operation and management is performed by central controller which usually has two main functional modules: Energy Management Module (EMM) and Protection Coordination Module (PCM). Energy Management Module has main optimization task to minimize energy cost, system losses and greenhouse emissions with highest possible efficiency of microsource operation and at the same time supply heat and electrical loads to customer satisfaction. Grid connected mode and island mode of microgrid operation make optimization problem more complex. Hybrid and electrical vehicles are additional microsources and loads that will exist in microgrids in the near future and their behavior is also a challenge for the microgrid optimal operation.

2. Microgrid energy resources

One of the major objective of microgrids is to combine all benefits of low-carbon generation technologies, renewable energy sources and high-efficiency combined heat and power (CHP) systems. Microgrid's electricity and heat generators are known as distributed energy sources (DERs) or microsources. Choice of a distributed energy sources depends on geographic position of the country or region and fuel availability. Most of the countries are coming up with supporting mechanisms for exploitation of the renewable energy sources for meeting up global carbon commitment. The following distributed energy sources are prospective for integration in microgrids:

- combined heat and power (CHP) systems
- wind energy conversion systems
- solar photovoltaic (PV) systems
- other renewable energy sources
- storage devices.

The key differences between a microgrid and conventional plant are as follows:

- microsources are much smaller in size with respect to the generators in power plant
- microsources are normally installed close to the consumer so that electrical and heat loads can be efficiently supplied with neglected losses

Looking from the network point of view, the main advantage of a microgrid is that it is tretaed as a controlled entity within the power system. The operation within microgrid is more complex because at the same time customers request satisfactory level of their supply with electricity and heat and electricity generation is faced with variable and stochastic electricity production from some types of

renewable energy sources. Therefore some operational features of will be given for the better understanding of the microsources.
The main advantage of CHP system is energy-efficient power generation by better utilization of waste heat. Micro-CHP systems are usually installed in homes, commercial buildaings, hospitals, shopping centers, etc. and generate heat as the primary commodity with electricity as a by.product. Their operating model is mainly dictated by the heat demand and therefore variable electricity production. In short time electricity production from micro-CHP system could be managed to be more flexible and meet the request for microgrid stability and higher electricity demand. Since transportation of electricity is far easier and more cost-effective than of a heat, it is suitable to place micro-CHP plants near heat lodas than electrical loads. For Micro-CHP systems are mostly used following proven technologies:

- internal combustion engines
- Stirling engines
- microturbines
- fuel cells

The primary fuel is natural gas or liquid fuel, but usages of biofuels are more promoted nowadays. They are provided with power electronic interfaces for connection to the electrical network of microgrid.
Wind power conversion systems, solar PV systems and small-scale hydroelectric power generation forms a group of renewable energy sources. The electricity production from these generators suffers from the variations in primary energy source – variations in wind speed, solar irradiation and water flow. Wind and solar microsources are provided with power electronic interfaces for network connection and hydroelectric microsources used induction generators.
There are some other technologies that are also treated as renewable energy sources like landfill gas, biomass, municipal waste, etc. but locations of these generators is determined by the availability of these resources. Therefore, these microsurces could be find only in some types of microgrids.
Storage devices are not typical distribution energy resources. With their possibilities to store surplus of electricity generation from renewable energy sources and with proper management to supply network loads in case of variable electricity production they advantage is to provide ride-through capabilities during system changes. Power electronics is used for their connection to the network. Typical storage devices that can be included in microgrids are:

- storage batteries
- flywheels
- hybrid and electrical vehicles.

3. Microgrid architecture design

Microgrid is essentially an active distribution network because it is conglomerate of distributed energy sources and loads, mainly at the low voltage distribution level. Microsources are located near loads, such as homes, commercial buildings, industrial sites and therefore in some cases microsources connected to the same low voltage network could be spatially widespread. In some countries it is problem to extend electricity network in remote areas and for such cases autonomous microgrid is only feasible solution. Therefore three types of microgrid architecture are proposed regarding location of microgrid in distribution network, type of connection to the distribution network, type of ownership and purpose:

- utility microgrid
- industrial or commercial microgrid
- autonomous microgrid

Autonomous microgrid is type of industrial or commercial microgrid applied for the provision of energy in remote residential areas, developing countries and (geographic) islands. Localy available renewable energy sources are used for electricity production and micro-CHP systems. For some purposes DC microgrid is used instead AC microgrid []

4. Utility microgrid

Utility microgrid is a feeder for the LV distribution grid with local energy sources and loads (Figure 1). This type of microgrid can allow a large-scale integration of distributed energy sources and locally accept growth in electricity production, so congestion problems in the network are not expected. A utility microgrid can also provide ancillary services to the network, for example voltage regulation and reactive power delivery and the guarantee power quality for the local users.

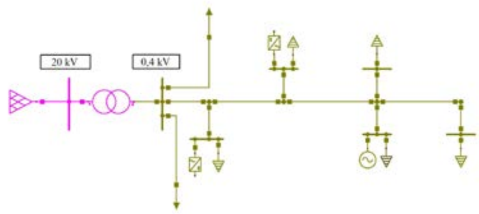

Figure 1. Utility microgrid

The principal objectives for the implementation of this architecture are the reduction in impact of network faults and the simplification of connecting distributed energy sources.

5. Industrial or commercial microgrid

This type of microgrid is typical for the collection of distribution energy sources and loads that are geographically closed. Microgrid is coupled with the medium voltage network through the PCC (point of common coupling) regularly MV/LV transformer station (Figure 2). It is operated in two modes: grid connected and standalone or island operation. In grid-connected mode, the microgrid remains connected to the main grid, either totally or partially, and imports or exports power from ot to the main grid. In case of any disturbances or faults in the main grid, the microgrid switches over to the standalone mode while still feeding power to the local loads.

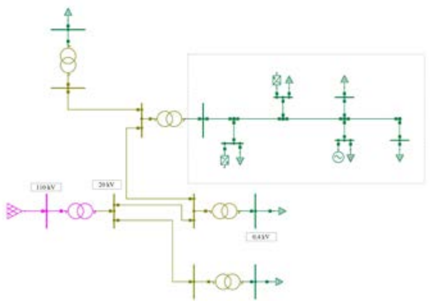

Figure 2

Typical examples are a university campus, a shopping center, a factory, an industrial installation or a residential neighborhood. The principal aims of this microgrid architecture are an increase of the power quality, better reliability and also frequently energy efficiency compared to the electricity network. Potentially, different parts of microgrid with sensitive or critical loads can be further subdivided into groups according to the required grade of power quality and reliability. The microgrid can switch over to island operation in the event of a grid fault, during maintenance, periods of poor power quality, or when grid energy prices are high.

6. Control concepts of microgrid

Typical microgrid configuration is shown in Figure 3. It consists of microsources (both electrical and CHP), storage devices and electrical/heat loads. The loads (especially the heat loads) are placed close together to minimize heat losses. The microsources and storage devices are provided with power electronic interface devices that enable control, metering and protection function in all modes of operation Control concept of microgrid is based on following objectives [2]:

- properly work of microsources at predefined or near predefined operating point within operating limits
- exchange of active and reactive power with the distribution network;
- disconnection and reconnection processes are conducted seamlessly;
- market participation is optimized by optimizing production of local microsources and power exchanges with the distribution network;
- heat utilization for local installation is optimized
- sensitive loads are supplied uninterruptedly;
- in case of general failure, the microgrid is able to operate through black-start; and
- storage devices can support the microgrid and increase the system reliability and efficiency.

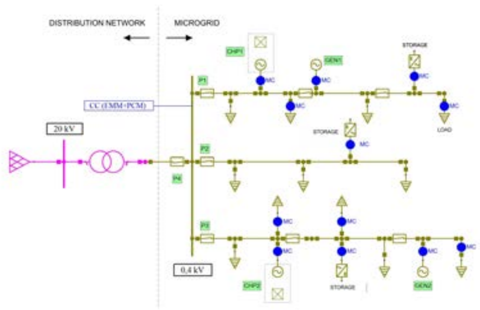

Figure 3. Typical configuration of microgrid

Based on the objectives and the controller coordination, the microgrid controls can be classified as hierarchical or centralized controls, decentralized control and control in island operation. In general the operation and management of microgrid in different modes is controlled and coordinated through local microsource controller. The main function of microsource controller is to independently control the power flow and load-end voltage profile of the microsource in response to any disturbance and load changes. The most common methods to regulate power flow (active and reactive power) are droop-based active and reactive power controls. These droop controls are scale-down versions of droop-based controls in utility. The droop-based controls consist of voltage reactive power and frequency-active power droop controls.

Microcontroller also participates in economic generation scheduling, load control/management and demand side management by controlling the storage devices. The most significant aspect of micro controller is its quickness in responding to the locally micrograds and active distribution networks monitored voltages and currents irrespective of the data from the neighboring micro controllers. This control feature enables microsources to act as plug-and-play devices and facilitates the addition of new microsources at any point of microgrid without affecting the control and protection of the existing units.

6.1. Hierarchical or centralized control

Hierarchical or centralized control of microgrid can be explained based on typical configuration of the microgrid in Figure 3. This type of microgrid control is best in case when the owners of microsources and loads have common goals and seek cooperation in order to meet their goals. The control level of hierarchical system can be classified as follows:

- local micro controllers attached to microsources, storage devices and controllable loads;
- microgrid central controller

The microgrid central controller may have different roles ranging from simple coordination of the local controllers to the main responsibility of optimizing the microgrid operation. Its objectives are to maintain specified voltage and frequency at the load connection points through power-frequency (P-f) and voltage control and to ensure energy optimization. The central controller also performs protection coordination and provides the power dispatch and voltage set points for all the micro controllers. Central controller has distribution management system consist of two main functional modules – energy management module (EMM) and protection coordination module (PCM).

EMM provides the set points for active and reactive power output, voltage and frequency to each micro controller. This function is coordinated through local communication network.

Protection Coordination Module responds to microgrid and distribution network faults and loss of network supply scenarios in a way so as to ensure correct protection coordination of the microgrid. It apply adaptive algorithms for microgrid protection regarding the changes in fault current levels during changeover from grid connected operation to island operation mode. For achieving this function, proper communication must exist between the PCM and the micro controllers as well as with upstream distribution network control system.

The functions of the central controller in the grid-connected operation are as follows:

- monitoring system diagnostics by collecting information from the microsources and loads;
- performing state estimation and security assessment evaluation, economic generation scheduling and active and reactive power control of the microsources and demand side management functions by using collected information;
- ensuring synchronized operation with the distribution network maintaining the power exchange at priori contract points;

The functions of the central controller in the stand-alone mode are as follows:

- performing active and reactive power control of the microsources in order to maintain stable voltage and frequency at load connection points;
- adopting load interruption/load shedding strategies using demand side management with storage device support for maintaining power balance and bus voltage;
- initiating a local black start to ensure improved reliability and continuity of service;
- switching over the island operation to grid-connected mode after main grid supply is restored without hampering the stability of either grid.

6.2. Decentralized control

Decentralized controls have similar description to the centralized controls. In decentralized controls, the main responsibility is given to micro controllers that compete to maximize their production in order to satisfy the demand and probably provide the maximum possible export to the distribution network taking into account current market prices. The decentralized control is aimed to maximize autonomy of the microsources and loads.

Decentralized control implement intelligent based methods to optimize production and profit of microsources such as peer-to-peer algorithm, multi-agent-based and gossip-based algorithms..

Decentralized control is best used for microgrids with the following characteristics [2]:

- microsources can have different owners in which case local operational mode is optimized;
- microgrids operating in a market environmen;,
- presence of micro-CHP systems that produce heat for local installations, keep the voltage locally at a certain level and provide a backup for local critical loads in case of island operation.

6.3. Control strategies in island operation

When a microgrid is connected to the distribution network, it behaves as a controllable load or source. If its operation shifts to the island mode the microgrid controll is faced with the following issues:

- voltage and frequency management
- balancing between supply and demand
- power quality
- microsource issues
- communication among microgrid components.

Six cooperation strategies concerning island operation of microgrid are described and compared in [1]:

- pure droop control
- inverter modes control
- primary energy source control
- reverse droop control
- autonomous control
- multi-agent based PQ control

Interesting result of this analysis is that beside expected technical issues like power quality and stability the most important issues for successful operation of microgrid in island mode are presence of intermittent microsources and microgrid/ microsurce ownership.

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