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Design criteria for a power management system for microgrids with renewable sources

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ABSTRACT

The paper describes the control functions that a power management system (PMS) needs for controlling a microgrid, with both conventional and renewable sources. According to the IEEE 1547.4, distributed resources island systems – or in brief "microgrids" – are active networks containing both loads and distributed generators, and may require a modification of their control logic if they are connected to a grid or not. A fast load or generator shedding actions may also be required to preserve system stability in case the microgrid switches from connected to islanded. Today, most industrial networks are designed to run also in islanded mode, while in public networks transmission system operators (TSO) generally do not allow islands. The presence of renewable sources that are partially not controllable requires the re-definition of the control logic compared with microgrids where only fully controllable generators are present. PMS of a microgrid has a double function:

- to guarantee the stable operation of the system in presence of the unpredictable variations caused by renewable sources and loads,
- to optimize the energy production of renewable and conventional sources.

The logic described in the paper was implemented in a PMS that was tested with a software simulator prior to the installation in a real microgrid. The paper reports the results of tests.

1. Introduction

A power management system (PMS) is a supervisory control and data acquisition (SCADA) that implements a set of specific functions necessary for controlling an industrial power system, or in more general terms, any electrical system that contains both loads and generators. A typical industrial power system is composed by one or more connections to the national grid at high or medium voltage, one or more step-down transformers, a distribution network at medium and low voltage, and one or more generators both from conventional sources (gas or steam turbines) and from renewable sources (mainly photovoltaic). In some cases, a battery storage system may be present. If the installed power of the power system is below few MWs and its size within few kilometers, it is sometime called a microgrid.

The power management system of a microgrid has several goals that include the safety of the plants, the service continuity, the optimization of the power flows, the fulfillment of the contract with the TSO, etc.

These goals are achieved with the implementation of different specific functions, such as:

- *Control and regulation:* these are the functions that allow obtaining the desired power exchange when the system is connected with the grid, stabilizing the system when it runs islanded, controlling the re-synchronization of the system with the grid (to switch from islanded mode to parallel mode), etc. While performing these functions, the PMS must also optimize the energy efficiency, maximize the production from renewable sources and minimize the conventional generators wear;
- *Emergency management:* the PMS shall actuate the countermeasures against events that may jeopardize the system integrity. The emergency functions are intended to preserve the system stability and to guarantee the power supply to loads that are vital for

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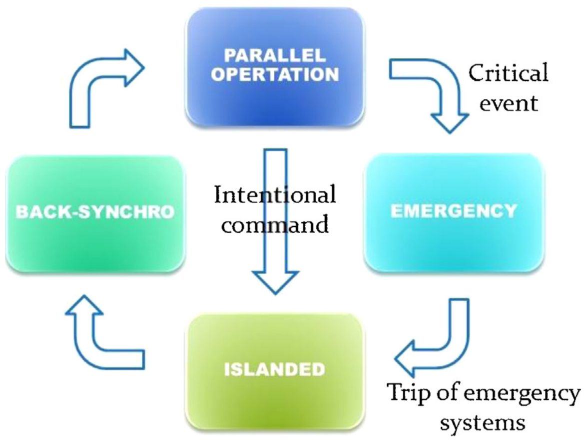

Fig. 1. Operating modes of a microgrid.

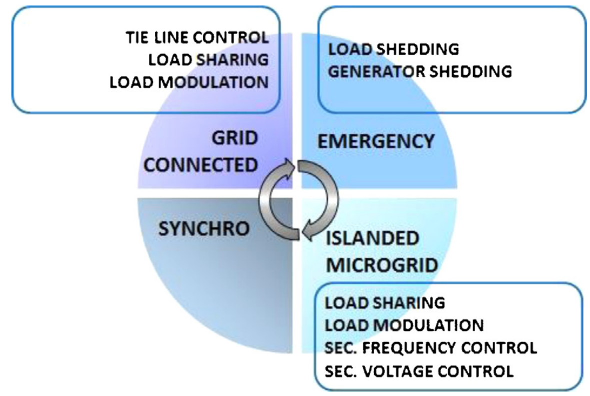

Fig. 2. PMS main functions related with the possible microgrid configurations.

the personnel safety and the plant integrity. If intelligent protections are used, the PMS may update their setting to the current conditions of the plant.

Other functions exist dedicated to services that are typical of a generic SCADA, such as:

- *Supervision:* through an HMI for real-time monitoring of the system and for storing the relevant data for off-line analysis (historian);
- *Alarms management:* for collecting and presenting the alarms from the plant to the operator(s);
- *Back-up management:* for increasing the availability of the PMS and for facing failures and abnormal operating modes.

By means of all these functions the PMS can supervise and control the power system in all its operating modes shown in Fig. 1. In case of failures, the microgrid may switch from its normal operating mode (in parallel with the grid) [1,2] into an emergency mode (in parallel with some violation of operating limits for one or more equipment) or into islanded mode (not connected to the grid) [3]. The operator may intentionally command the transition into islanded mode. The synchronization with the national grid leads the islanded microgrid back to parallel mode.

To achieve satisfactory operation, the PMS must identify the current operating mode of the microgrid, and it must actuate the specific control logic for each mode. The relevant parameters of the microgrid must be acquired (typically frequency, voltage, and active/reactive power flows), and the proper logic activated to obtain the required goals that are different according to the operating mode. Basically:

- in parallel mode: the target is the power exchange control, the reactive power balance, the maximization of the renewable sources;
- in islanded mode: the target is regulating the island frequency and voltage.

Starting from the circuit breakers position, the PMS determines how the bus bars are aggregated and which generators and loads are connected to the same cluster.

2. Target of the PMS

A large-scale electrical power system is conventionally divided into homogeneous subsystems according to their main function: producers, transmission and distribution networks and consumers. These subsystems are functionally and geographically separated and are hierarchically organized following a top-down logic (from the power plants to the loads). The TSO coordinates and supervises the different subsystems for stabilizing the entire system.

Today the different stakeholders of a power system can freely associate to form a “smart grid” where generation and load distributed across the entire network are integrated together. Microgrids optimize the power exchange within the main grid and, in many cases, can run separated from the main grid (islanded mode). The expected benefits of microgrids are:

1. increase of the availability of the electrical supply,
2. improvement of the power quality,
3. reduction of pollutant emissions,
4. energy cost reduction.

Often, the various targets do not converge; reducing the energy cost may reduce the availability of the system, or improving the power quality may increase the machinery wear, and so on.

According to the current operating mode, the PMS shall find the best compromise between these targets [4].

When the microgrid is in parallel with the grid, the control is focused mainly on maximizing the renewable source [5,6] to reduce the energy cost, while in case the microgrid is islanded the control is focused mainly toward the system stabilization.

The transitions between these two steady states may require emergency actions, that is load or generator shedding.

The PMS runs different functions for each of the four operating conditions of the microgrid, as shown in Fig. 2 and detailed in Section 4.

3. PMS architecture

3.1. Software architecture

The control logics summarized in Fig. 2 are the “core” of PMS system. To run properly, this core needs other ancillary functions to manage the input data, to support control logics decisions, and to increase the reliability of the system.

The supporting functions for control logics are:

- *Configuration detection:* this function identifies the current microgrid configuration and activates the proper control logic (involving only the elements that constitute the microgrid);
- *Protection management:* this function evaluates the short circuit current for the current configuration of the microgrid and optimizes the tripping thresholds of the relays (intelligent electronic device are requested).