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Feasibility of adaptive intentional islanding operation of electric utility systems with distributed generation

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ABSTRACT

As the process of deregulation of the electric utility industry proceeds, the importance of power quality is increasing. A fundamental aspect of power quality is the continuity of power supply that is the absence of momentary, temporary and sustained power interruptions. In this paper a network reconfiguration strategy is proposed which allows the distribution network to separate into a certain number of autonomous islands, supplied by local distributed generation, in case of permanent fault within the grid. Intentional islanding of portions of the grid is automatically carried out with an adaptive network reconfiguration depending upon the local generation/load state at the time of outage.

1. Introduction

Distributed generators and distributed energy storage systems are proliferating in the electrical utility system, due to economic issues, environmental concerns associated with central electric power plants and rapid technological developments of DG systems. The increase of DG penetration within the distribution system, beside modifying traditional economies of scale and changing the face of electricity generation and transmission, leads to new opportunities for a more flexible and efficient operation of the distribution system. In particular, in the event of an upstream supply network outage, the presence of dispersed generators embedded in the distribution networks might be exploited for improving the continuity of the power supply to local loads (intentional islanding) [1–4].

Even though the distribution network operation in islanded mode is currently not allowed, this operation mode is encouraged by the rapid ongoing development of new, small-sized electrical power generation technologies (micro-turbines, wind generators, fuel cells and photovoltaic plants) which can be connected to the grid by flexible and reliable static interfaces.

In order to exploit such emerging potential of distributed generation a system approach, which views local generation and loads as a possible autonomous subsystem, should be adopted.

In fact during network outages, the generation and neighbouring loads could be separated from the rest of the distribution system in order to maintain loads service continuity regardless of the grid's vicissitudes.

Unfortunately, there are several issues that limit or prevent island operation. These include personnel safety, the risk of insufficient fault levels on relays, difficulties in maintaining acceptable voltage and frequency levels and the risk of out-of-synchronous re-closure. These problems, which are discussed in the following, should be thoroughly tackled and the necessary provisions taken before allowing any intentional islanded network operation.

In this paper a method which allows the distribution network to separate into a certain number of autonomous islands during loss of main, is proposed. In particular intentional islanding of generation and loads is automatically carried out with an adaptive configuration that depends on the local generation/load state at the time of outage. This forms a sort of loads back-up and has the potential to provide a higher local reliability than that provided by the power system as a whole.

This article is a revised version of the original paper presented at the WESC 2006 Conference [1].

2. Problems of intentional islanding

In order to implement any intentional islanding operation mode on an active distribution network, a number of problems must be analysed and solved, the most stringent regarding protection systems, distributed generator control schemes, post-islanding reconnection schemes and availability of a suitable communication systems. As regards this latter aspect, recent developments indicate that distribution line carrier (DLC) technology could be a reliable

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and cost-effective means for data communication in MV distribution networks [5].

2.1. Innovative protection systems

Any type of protection scheme isolates the faulted section from the distribution system. In general traditional switches installed along a feeder have no breaking capacity, therefore as soon as a short-circuit event is detected all the distributed generation units should be immediately disconnected by their protection systems. These protection typologies are not suited for island operation. For this scope future protection systems for active networks should be able to adapt their settings to the running mode since fault currents will depend on the embedded generators rated power and size of the islanded area.

An important feature of protection devices in the active network is the sensitivity to the current direction. Fuses, re-closers and relays are the traditional protection devices but only relays can be easily made direction sensitive because fuses and re-closers have no directional features.

It would be economically impractical to replace all fuses and re-closers by direction-sensitive protective devices (like relays) all through the distribution system, therefore a detailed analysis is required to identify exactly the problems in fuse–fuse and fuse–re-closer coordination due to high penetration of DG. Once the problems are identified, solutions need to be sought which are practically acceptable and independent of size, number, and placement of DG in the distribution system.

For instance, an interesting system-independent adaptive protection scheme for distribution systems with high DG penetration that would not undermine the system reliability after connecting DG unit is suggested in [3].

The adaptive scheme proposed offers in this case an acceptable solution to the protection problem that is independent of size, number, and placement of DG in the distribution system. The scheme is suited to temporary as well as permanent changes in a distribution network and its region of implementation can be extended to more than one feeder, but it needs to insert other circuit breakers in the MV feeders, to use a fast reconfiguration tool during a MV short circuit, and to communicate regularly with the centralised controller.

2.2. Dispersed generator controller

It should be noted that many of the generators used in DG systems have little or no regulation capacities on their own and can only operate in parallel to the network, being unable to sustain the voltage by themselves. However, for technical and economic reasons the majority of medium–small-sized generators are provided of power factor controllers.

Integration of a large number of small generators into an islanding network is not possible if generators are equipped solely with basic P-Q (i.e. power factor) controls, since voltage regulation is necessary for local reliability and stability. Without local voltage control, systems with high penetrations of micro-sources could experience voltage and/or reactive power oscillations. The requirement that dispersed generation should be operated to control the power factor when grid-connected but to control voltage in isolated mode needs the adoption of a control technique capable to distinguish between the two operating modes [6–8].

Traditional diesel engines, gas turbines and small hydroelectric generation plants (mini-hydro) are directly interfaced to the network through synchronous or asynchronous generators. Conversely, new technologies (such as fuel cells, photovoltaic systems, micro-turbines, and wind generators) generate power in the form of direct current or in the form of alternate current at frequencies different from the required industrial frequency (50/60 Hz) and thus their grid connection requires a static converter (inverter) interface (with an adequate control system). The penetration level in distribution networks of such types of DG technologies is rapidly increasing and it is expected to increase further in the future.

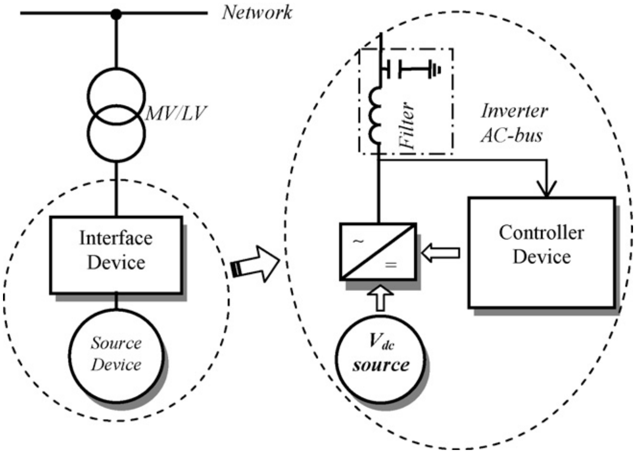

Fig. 1. General model of a DG system and interface scheme of an inverter-interfaced DG.

A general inverter-interfaced DG model is depicted in Fig. 1 [8]. It comprises

(i) a PWM voltage-source inverter, interfacing the DC stage of the static DG system to the AC system,
(ii) a low-pass LC filter that limits the inverter generated high frequency harmonics and makes the inverter islanded operation possible, and
(iii) the inverter control system.

The dynamic performance of the static generators greatly depends upon the inverter controller.

Depending on the DG operation mode, different control schemes may be adopted for the inverter device [7–11].

A grid-connected inverter is generally controlled by means of a PQ-scheme, whose set values are the active and reactive power injected into the network, whereas an inverter operating in islanded mode should adopt a Vf-control scheme, which regulates the voltage and frequency of the islanded network.

In a previous work [8], a model of controller capable to switch between the two operation modes, depicted in Fig. 2, has been proposed. The PQ-control scheme performs a transformation of the inverter output current from the (physical) a–b–c reference frame to the stationary d–q reference frame. So, the controller implements the correlation existing between active power and direct current component i_d and between reactive power and quadrature current component i_q. The PQ-control is achieved by regulating i_d and i_q in order to meet the current reference values $i_{d_}$ref and $i_{q_}$ref, which are dynamically set on the basis of the prevailing network voltage and the user defined active and reactive power setpoints.

The generated voltage signals vmd and vmq are transformed into the real and imaginary components vmr and vmi. Finally, the vmr and vmi signals are transformed into the amplitude and the phase angle of the PWM-control modulating-signal, which are respectively vm and ϑ.

The Vf-control regulates the voltage and frequency of the islanded network by controlling the amplitude and frequency of the