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A novel islanding detection method for microgrids based on variable impedance insertion

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ABSTRACT

Islanding is the situation in which part of the power grid, consisting of load and distributed generation (DG) is isolated from the utility grid remaining active, i.e. serving load. The idea of islanding parts of the distribution network in case of faults, in order to increase the consumer quality of service, is the basic notion behind the formation of Microgrids. In the context of Microgrids, it becomes necessary to distinguish between intended islanding e.g. due to maintenance and unintended islanding due to faults at the upstream grid. When the emergency situation ceases, the Microgrid should reconnect seamlessly to the upper grid.

In this paper, an islanding detection method (IDM) is proposed that is based on the insertion of a suitable, variable impedance at the low voltage side of the Grid. Islanding detection is effected by an intelligent agent embedded into the Microgrid's Central switch, which is transformed to a hybrid automatic transfer switch (HATS). The HATS agent detects the operation mode of the Microgrid based on local measurements and supervises the grid status. Both simulation studies and hardware laboratory tests are presented showing the performance and feasibility of the proposed method.

1. Introduction

Islanding occurs when a section of the distribution system containing Distributed Generation (DGs) is disconnected from the main utility grid, while the DGs continue to supply fully or partially the load in the isolated section, termed as island [1].

Presently, the IEEE Std. 929-2000 [2] and the IEEE Std. 1547-2003 [3] require disconnection of the DGs connected to an islanded network. However, it has been recognized that the coordinated control capabilities of DGs in Microgrids can potentially increase the quality of service by serving critical loads during faults uninterruptedly [1]. Therefore, current practices dictating the disconnection of DGs after a disturbance might no longer be a practical or reliable solution. As a result, the IEEE Std. 1547-2003 states, as one of its tasks for future consideration, the implementation of intended islanding of DGs.

In the context of Microgrids, it becomes necessary to detect the islanding situation, as a detection failure can potentially harm generators and loads. During the unintended islanding condition the main grid is separated from the Microgrid, forming two independent systems. Unintended islanding can pose threat to utility and customer equipment, maintenance personnel and the general public due to large deviations of frequency and voltage from the nominal values. Another concern is the out-of-phase reclosing of the islanded Microgrid to the main grid during re-connection [4,5]. The Microgrid's central switch should be opened to avoid a possible re-connection of the two unsynchronized grids, when the Grid side breaker closes again, while the necessary steps should be followed to bring the Microgrid back into a controlled state. The IEEE 1547 and UL1741 interconnection standards [3] provide specifications on how rapidly DGs are required to be disconnected from the utility grid, in order to satisfy safety margins.

Several anti-islanding methods have been developed in the past, distinguished in remote techniques and local techniques. The first category is more expensive and subject to communication failures, but it does not have a non-detection zone (NDZ). The NDZ represents – in a 2-dimension plane – the values of the measured variables where the method fails to detect an islanding situation. The second category of local techniques can be further classified into active, passive and hybrid islanding detection methods (IDMs) [4].

Active IDMs [4–11] impose additional perturbation signals to cause power mismatches, so that a certain system parameter drifts, once islanding occurs. This may include phase shifting, active power variation, reactive power variation or harmonic power variation

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Next to the insertion of unwanted perturbations in the system, the main drawback of the active IDMs is the poor effectiveness in the presence of multiple inverters.

Passive IDMs are based on measuring a local parameter-index and comparing it with a preset value. So, they detect possible sags of frequency and voltage at the point of common coupling (PCC), voltage phase jump or total harmonic distortion (THD) indices, that serve as indicators of the grid operational mode [4,5,12,13]. In general, the main drawback of passive IDMs is the large NDZ, especially in cases where the Microgrid production is matched with the load. So, new IDMs aim at the reduction or elimination of this NDZ.

Hybrid IDMs combine the effects of both categories. In [14] a *remote IDM* based on the insertion of impedance is proposed. A capacitor bank is connected at the medium voltage side/utility system side via a switch, which is normally open. When the grid switch opens, the capacitor bank switch is commanded to close after a short delay. The large capacitor upsets the balance between generation and load, causing a step change in phase and a sudden drop in frequency. This method's drawbacks are the cost and the communication delays between the switches. Ref. [15] proposes a new hybrid islanding detection method by combining the active methods of Slide Mode frequency Shift (SMS) and Q-f droop curve and the passive method of Under Frequency Protection/Over Frequency Protection. The hybrid method is integrated into the DGs inverter controller and is modified accordingly in case of multiple converter system. The detection time ranges between 70 ms and 520 ms and depends on the resonant frequency and the different quality factor Qf of the load. Ref. [16] proposes a hybrid method that combines the voltage unbalance (VU) passive method with the high frequency impedance (HF) active method. In this method, the HF signals that are injected to the inverter interface cause harmonics that needs to be filtered while the calculations for the control is quite sophisticated. Also, the detection time is estimated to be 32 ms; however this method has not been tested for multi converter system. Ref. [17] uses both Positive Feedback Frequency Shift (PFFS) and Reactive Power Variation (RPV) methods that are integrated into the converter's controller. The method is suitable for multiple converters system, but needs additional filtering that causes some delay. The detection time is estimated to be less than 250 ms. Ref. [18] proposes an hybrid islanding that implements the rate of change of frequency (ROCOF) protection in conjunction with reactive current injection scheme that causes an apparent drift in ROCOF value. The method also computes the CSROCOF index as an indication of the islanding state. This method eliminates the possibility of false tripping due to other disturbances and the detection time is estimated to be 100 ms. This method's drawbacks are the power quality deterioration due to the reactive current injection while it has not been tested for multiple converters system. In [19], a link inductor is inserted between the utility and the inverter. The inductor voltage is monitored and when its value approaches a preset value, a disturbance is added via the inverter's controller to perturb the link inductor voltage. If the link inductor voltage is still close to the preset value, islanding operation is detected. The detection time is estimated at 68.27 ms. The main drawback is that a disturbance via the inverter controller is added to the system. Moreover, the method has not been tested for multiple converters system. As seen above, most hybrid methods are based on sophisticated modifications of the converters' control that has to be adapted according to the converters mode of operation, i.e. constant power, constant current control etc. Also, their effectiveness may be affected in multiple converter systems. The hybrid systems based on hardware insertion may lack reliability [14] or add unwanted perturbations [19]. All the above methods claim negligible NDZ without further analyzing it.

In this paper, a novel hybrid IDM is proposed. It is based on the insertion of a large variable impedance at the low voltage side of the Grid, inside the structure of the Microgrid Central Switch. The variable impedance is always connected to the system, so extra switches and, thus time delays are avoided. This feature makes the proposed IDM fast and accurate. As the impedance values are large, the energy losses are negligible and there are not unwanted perturbations injected in the system. The measured current through the impedance serves as an indicator of the Microgrid operating status, thus the method is free of communication overheads. The proposed method does not interfere with the power quality of the system and its effectiveness is not affected by the operational mode of the inverters, i.e. Voltage Control or Current Control mode (VC or CC). It is independent from the operation of many inverters in the Microgrid and it presents a satisfactory NDZ, as explained later. As it is based on local measurements, it is attractive due to its simplicity. The proposed IDM's action is implemented within a hybrid automatic transfer switch (HATS) that is employed as the Microgrid Central switch.

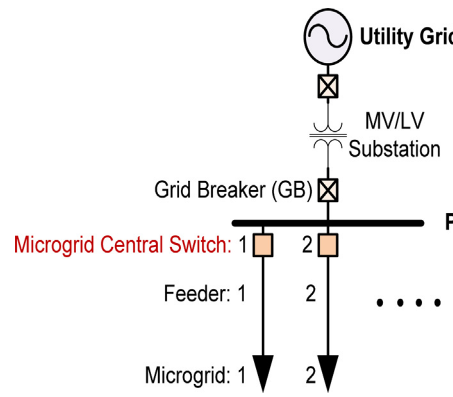

Fig. 1. Grid–Microgrid interface.

The remainder of the paper is structured as follows: In the next section, the HATS advantages are briefly discussed and the variable impedance hardware implementation is presented. Section 3 analyzes the IDM method and the HATS agent. Section 4 provides a simulation and simple laboratory proof of the proposed method. Section 5 presents simulation results, where the proposed IDM is evaluated under a more complicated Microgrid structure and the last section concludes the paper.

2. Hybrid automatic transfer switch (HATS)

The interconnection switch ties the point of connection between the Microgrid and the rest of the distribution system. Fig. 1 shows the general Grid–Microgrid interface.

The interconnection switches are designed to meet grid interconnection standards (IEEE 1547 and UL 1741 for North America) to minimize custom engineering and site-specific approval processes and cost [20]. This paper employs as the Microgrid Central switch the 400 V/1000 kVA HATS, as presented in [21].

The HATS is a combination of an automatic transfer switch (ATS) and a solid-state switch (STS) consisting of a pair of anti-parallel thyristors and a specially designed mechanical parallel switch. The HATS can open the circuit, while it is able to realize low power consumption under normal situation and fast transfer, when required. In our study, a switch power rating of 220 V/3100 kVA is assumed, different from the rating in [21]. This choice does not affect the effectiveness of the proposed switch, but only the dimensions of the thyristors and of the mechanical switch. The opening circuit speed is quite high (few dozen msec) and within the standard limits (<2 s).

An interesting feature of the proposed HATS concerns the provision of system grounding during islanding: current practices allow