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Control and operation of distributed generation in distribution systems

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ABSTRACT

Many distribution systems nowadays have significant penetration of distributed generation (DG) and thus, islanding operation of these distribution systems is becoming a viable option for economical and technical reasons. The DG should operate optimally during both grid-connected and island conditions, which can be achieved with change in operating strategy. Many islanding detection techniques have been developed but little work has been done to detect grid re-connection. This paper presents strategies to operate DG in grid connected and islanded modes and a new grid re-connection detection algorithm, which uses average rate of change of frequency (*Af*5) and real power shift (RPS), in the islanded mode. RPS will increase or decrease the power set point of the generator with increasing or decreasing system frequency, respectively. Simulation results show that the proposed method can operate the DG efficiently and is effective in detecting grid-reconnection.

1. Introduction

The way the distribution system is operated is changing due to significant penetration of distributed generation (DG). As a result, islanded operation of distribution systems with DGs is becoming a feasible option. Islanding can improve the quality of supply indices and reliability [1,2]. Furthermore, DG owners get additional revenue due to the increased power supplied during network outage on higher levels, and customers are benefited from the reduction of frequency and duration of interruptions from outages in the distribution network [3]. Many European distribution systems are characterized with a high penetration of fixed speed wind turbine generators (WTG) and small combined heat and power plants (CHP). They can take advantage of this high DG penetration and operate in island mode, during power outage, to increase the overall reliability of the power supply. However, there are various issues to be resolved. Most important issues are maintaining voltage and frequency within acceptable limit.

When a small synchronous generator based DG is connected to the grid in voltage control mode, it may cause either over or under excitation of the small generator [4]. Also, an excessive reactive current may result in overload or loss of generator synchronism [4]. According to [5], small generators' operation at a constant power or power factor control mode is justifiable. Furthermore, it makes economical sense to operate small DGs at unity power factor. However, when the distribution system is islanded, the voltage might go beyond the power quality limits. In such a case, the small generator has to maintain the distribution system voltage by controlling the reactive power. A control strategy for inverter based DG is proposed in [6] where the inverter acts as current source inverter while the system is connected to grid and a voltage source inverter while it is islanded. A control strategy where the DG operates at in a P-Q control scheme while it is connected to grid and a V-f control scheme while it is islanded is presented in [7]. A technique to control inverter based DG using local information and employing speed droop is presented in [8]. Another control strategy for inverter based DG employing speed droop is presented in [7]. A speed droop characteristic is used to control diesel generators for micro-grid operation in [9]. The speed droop controller changes its reference speed with a change in frequency and finds a new operating point for the generator. However, the frequency may settle outside the power quality limit when the distribution system is islanded if only a speed droop controller is used [10]. On the other hand, an isochronous controller can bring the frequency back to nominal value when the system is islanded. Unfortunately, when connected to grid, its operating point is driven to either the lower or the upper limit even with the slightest deviations in frequency [10]. Furthermore, isochronous controllers cannot be used with more than one generator connected to the same system since all the generators else would need to have the same speed set point; otherwise each generator will try to bring the frequency to its reference setting [11]. The frequency of the islanded distribution system can be controlled by operating one DG in isochronous mode and the other DGs, if any, in other control modes. One of the other possibilities can be isochronous controller with feedback, which is basically a PI controller like the isochronous controller but changes its speed

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reference, with a feedback, like the speed droop controller and it is explained in details in [10]. It will bring the frequency closer to the reference than the speed droop controller when the distribution system is islanded [10]. The optimal control strategy for the DG has to be chosen depending on the distribution system state (islanded or grid connected) and switching between control strategies can be done through state detection.

The shift from grid connected mode to islanding mode can be easily detected through an islanding detection techniques. Many islanding detection techniques have been developed in recent years. Recent developments in islanding detection are reviewed in [12]. However, little work has been done regarding grid re-connection detection. This can be achieved with communication devices. But, implementing such a communication system is considerable complex and requires high cost [8] and is not economical for small distribution system. Thus, there is a need to develop a new grid re-connection detection algorithm using local information. This paper presents strategies to operate the DG in grid connected and islanded modes and a new grid re-connection detection algorithm, which uses average rate of change of frequency ($Af5$) and real power shift (RPS), in the islanded distribution system. The proposed methodologies are presented in Section 2. The proposed methods are tested in a radial distribution system, which is presented in Section 3. The test system is modeled in DigSILENT PowerFactory 13.2.334 and the results are presented in Section 4. Section 5 concludes the paper.

2. Proposed methodologies

The flow chart for the DG control is shown in Fig. 1. The methodology checks when the system is islanded. Any islanding detection techniques, that are currently available, can be used for islanding detection. The DGs are here operated in constant power factor mode with a speed droop governor when they are connected to grid. But, when the islanding detection technique determines that the distribution system has been islanded, the DGs change to operate in voltage control mode. The largest DG, with power control capability, will operate in isochronous mode while the others will operate with isochronous controllers with feedback. By changing the control strategies; both the voltage and the frequency can be kept within limits. However, this is limited to DGs which can control its power. DGs like fixed-speed stall-regulated wind turbines cannot control its power. When the system is re-connected to the grid, it is necessary to detect this and change the DG control strategy accordingly, and go back to speed droop control and power factor control. It should be noted that a change in control strategy is similar to a change in the power set point of the generator. Hence, the behaviour of the system frequency will be determined by the turbine governor characteristics. The proposed algorithms for grid re-connection and detection are presented in the following sections.

2.1. Re-synchronization

A grid re-connection algorithm is implemented in the substations where the distribution system is connected to the grid. It is based on [13] and will connect the distribution system with the transmission system when the following criteria are met:difference in frequencies is less than 0.1 Hz;difference in voltages is less than 3%; andthe two systems are in phase.

2.2. Grid re-connection detection

The flow chart for the grid re-connection detection algorithm is shown in Fig. 2. The frequency is measured every voltage cycle

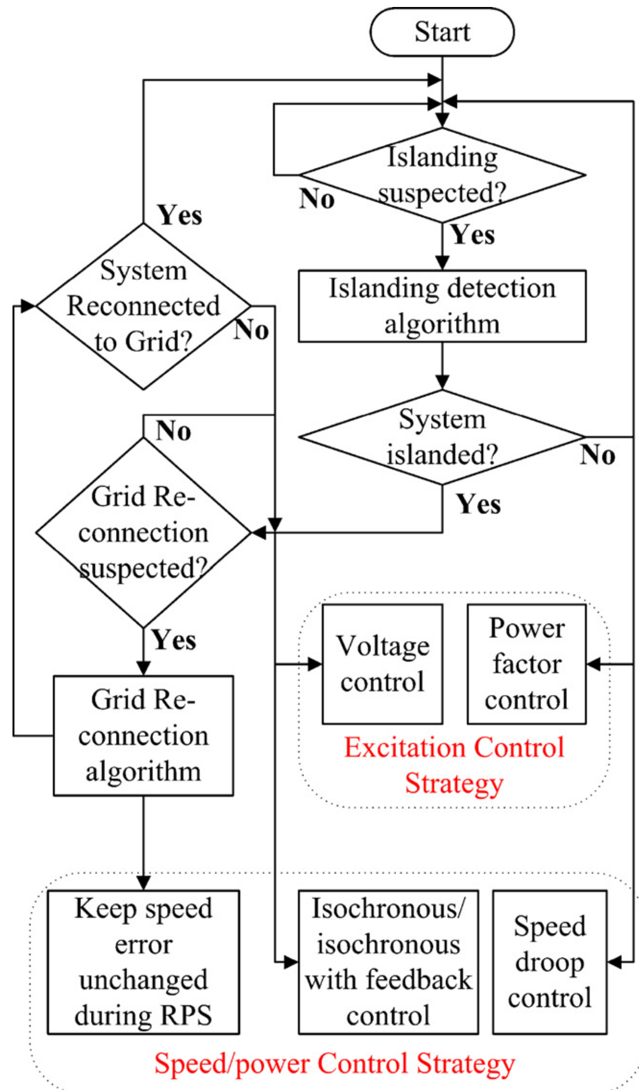

Fig. 1. Flow chart for DG control.

and grid re-connection is suspected when there is a change in frequency. However, all the events in power systems result in a change in frequency. Thus, the magnitude of average rate of change of frequency over five periods ($Af5$) is calculated when the frequency changes. If the frequency goes outside the range of 50 ± 0.1 Hz, it is obvious, that the system is still islanded as frequency is maintained with in the range of 49.9–50.1 Hz in the Union for the Co-ordination of Transmission of Electricity (UCTE) system or European interconnection [14]. However, if $Af5$ is greater than the set point to suspect grid re-connection (F_{sp}) and frequency is within the range of 50 ± 0.1 Hz, real power shift (RPS) is initiated to determine if the system is still islanded or already re-connected to grid. RPS will increase or decrease the power set point of the generator with increasing or decreasing frequency, respectively. During the RPS, the speed error is kept constant. If the speed error is not kept constant, then it will counteract the RPS. As a result, the desired change in power, to correctly detect grid re-connection, may not be achieved. If the system is still islanded, the RPS will push the frequency outside the range of 49.9–50.1 Hz. However, if the distribution system is re-connected to grid, the frequency will remain within the range of 49.9–50.1 Hz. After 2 s, the RPS is disabled and grid re-connection is detected. A small delay is added to account for transients due to the RPS.