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Islanding Detection Based on Reactive Power Control
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Abstract:
Based on current utility practice, anti-islanding protection is one of the main protection requirements for interconnection of a distribution generation (DG) to the medium and low voltage grids. Intentional islanding describes the condition in which a microgrid, which consists of a load and a distributed generation (DG) system, is isolated from the remainder of the utility system. In this situation, it is important for the microgrid to continue to provide adequate power to the load. Under normal operation, each DG inverter system in the microgrid usually works in constant current (or constant power) control mode in order to provide a pre-set power to the main grid. When the microgrid is cut off from the main grid, each DG inverter system must detect this islanding situation and switch to a voltage control mode. In this mode, the microgrid will provide a constant voltage to the load. This paper describes a control strategy to implement intentional islanding operation of microgrids. The described method proposes two control algorithms, one for grid-connected operation and the other for intentional islanding operation.

Keywords: Distribution Generation (DG), Non Detection Zone (NDZ), Phase Locked Loop (PLL).

I. INTRODUCTION

The inverter-based distributed generation (DG) uses renewable energy such as wind power, photovoltaic, and micro-turbine to supply power [1]. Islanding is a condition in which a portion of the utility system that contains both the DG and load continues operating while this portion is electrically separated from the main utility [2-3]. Normally, islanding detection methods can be classified as communication based methods, passive methods and active methods. Although communication based method doesn’t have non detection zone (NDZ) in theory, it relies on communication too much. Additionally, the total investment is high enough and the implementation is usually complex and difficult [4]. The passive detection methods are used to detect the change of parameters in a distributed generation power system for determining whether the islanding operation occurs. For example, the passive detection methods include a system-frequency detection method, a voltage-amplitude detection method, and a harmonic-contained detection method. However, both amplitude and frequency will not change if the power supplied from the distributed generation power system is the same as the power demanded by the load. In this condition, these passive detection methods cannot detect the islanding operation, and it is named as the “non-detection zone”. Accordingly, these passive detection methods cannot meet the requirements of the islanding control standards.

A) Non-Detection Zone for Passive Schemes.
Any passive AI protection will have an NDZ; i.e. if the DG and the load power match closely enough, the passive protection may not be able to detect monitored signals, such as voltage, frequency or their derivatives, because they are too small. The NDZ is depicted in Fig 1. If the criterion is fast detection, so as to coordinate with circuit reclosing, the effective NDZ is expanded. Given the 100% DG/Load power-matching testing condition as defined in IEEE standards, any passive scheme will fail the AI testing. Furthermore, passive schemes tend to falsely trip, and widespread tripping of DGs due to a power-grid disturbance can be detrimental to grid security. In practical applications, passive schemes (relays) are still widely used as AI means, while the application limitations are normally specified, e.g. minimum load, minimum reverse power, etc. These specifications basically provide sufficient generation/load power mismatch so that traditional protection schemes can pick up the islanding event due to the fact that the power mismatch is outside of the NDZ of these schemes. This solution essentially limits the DG application and penetration in the long term. [5]

Figure 1. Non Detection Zone for Passive Scheme.

As to the active detection methods, it is used in the distributed generation power system with inverter interface, named as inverter-based distribution generation power system, and a small fluctuation is incorporated with the output current to inject into the utility [7]. When the utility is nominal, the small fluctuation results in a neglected change of load voltage because the utility is very strong. Conversely, when the utility is interrupted, the small fluctuation can cause a great change in frequency or amplitude of load voltage. In this way, a protection relay can immediately detect such a change and judge it as an islanding operation. Instantly, the inverter-based distribution generation
power system must be disconnected from the utility so as to avoid islanding operation.

(B) Non-Detection Zone for Some Active Schemes.
Some active schemes use an actively injected disturbance added to the normal control signals. The concept of these schemes is to create a power mismatch when the DG output and load-power demand are closely matched. However, these schemes still could have an NDZ; i.e., when the power mismatch already exists, then the disturbance could coincidently balance the power mismatch. As a result, an island still could be formed. In this case, the NDZ is not centered at the origin, but shifted as shown in Fig. 2. [5]

Figure 2. Non Detection Zone for Active Scheme.
A technical challenge to enable an electronically-coupled DG unit and its local load to remain operational in both grid-connected and islanded modes is to equip the coupling voltage sourced converter (VSC) with controllers that can accommodate both modes of operation and the transition process between the two modes. The conventional control strategy for an interface VSC, in the grid-connected mode, is based on current-controlled operation of the VSC [6]. In this approach, the grid dominantly dictates frequency and voltage at the point of common coupling (PCC) of the DG unit and the VSC controls its exchanged real and reactive power components with the grid based on the dq-current components. This paper presents control for autonomous operation of a VSC-coupled DG unit and its local load subsequent to islanding from the host grid. In the grid-connected mode, the interface VSC is controlled based on the conventional dq-current control strategy [7].

II. ISLANDING DETECTION GENERAL PRINCIPAL

III. When the micro grid disconnect from the mains in islanding operation, Distributed Generation (DG) and load power difference will change the frequency, voltage. Switching off the mains, the active or reactive power will be changed, lead to micro-grid frequency and voltage variation, which consists a feedback to regulate the inverter active or reactive power and match the load power imbalance increasingly in order to accelerate change of voltage/ frequency, thus fastly detect island. Fig. 3 shows islanding detection principle. Parallel in the mains, DG is connected to point of common coupling (PCC) of the main power grid, providing power to the load, to get: $P_{load} = P + \Delta P$  
$Q_{load} = Q + \Delta Q$  
$P_{load} = \frac{V_{pcc}^2}{R}$

Figure 3. Islanding detection general principle
Formula: $V_{pcc}$ is common coupling point voltage; $P, Q$ is the inverter active, reactive power output; $\Delta P, \Delta Q$ is supplied by the main power grid active power, reactive power. $P_{load}$, $Q_{load}$ is consumed by the load active power, reactive power. The above three simultaneous equations can be obtained:

$$W = \frac{1}{2\sqrt{LC}} \left\{ \sqrt{\left(\frac{Q_{load}}{Q_f P_{load}}\right)^2 + 4 - \frac{Q_{load}}{Q_f P_{load}}} \right\}$$

$Q_f = \frac{1}{P} \sqrt{Q_L Q_C}$

On the other hand, the frequency of an resultant feeder can have different values depending on the power variation between the load and generation in the island. Excess generation will increase the frequency and lag in generation will result in the decrease of frequency. Accordingly, if there is a large power variation in an islanding, the frequency-based anti-islanding scheme will be able to detect islanding condition dynamically. If the power mismatch is small, then it will take longer time to detect is landing condition [8]. According to the IEEE Std. 929-2000 and IEEE Std. 1547-2003, the recommended generic system for islanding detection study is shown in Fig 3. It consists of an inverter-based DG, a parallel three-phase RLC load, and the distributed network represented by a three-phase source behind impedance. The DG is usually located near the local load and the length of the line connecting them is short. Therefore, the line loss is negligible and the RLC load and the DG are connected at the PCC in the generic system. The output power can be considered to be constant during the detection because the detection time is very short. Therefore, using a constant dc source behind a three-phase inverter, the DG is designed as a constant power source to control the active and reactive power independently based on the dual closed-loop control structure in the $d-q$ synchronous reference frame[10]. The Park’s transformation is used for this purpose. Inverter switching signal is determined by the magnitude and angle of the modulating signal.

IV. BLOCK DIAGRAM OF DG INTERFACE CONTROL

Figure 4. DG interface control for constant power operation.
Fig. 4 presents the block diagram of the DG interface control for constant power operation. The phase-locked loop (PLL), the outer power control loop, and the inner current control loop are the three main parts. Based on the input of three single-phase voltages at the PCC, the PLL can offer the voltage phase angle as a benchmark phase to realize synchronous Park transformation and calculate the frequency of the input voltage. In the outer power control loop, PI regulators are introduced to transform the errors between active and reactive power of the DG output and their preset values into the reference values of active and reactive current \(i_{d_{ref}} \) and \(i_{q_{ref}}\), respectively. In the inner current loop, the errors between the measured and reference \(d-q\) values of the DG current are also passed through PI regulators. Meanwhile, the feed-forward compensation from the \(d-q\) voltages at the PCC realizes the decoupled control of the \(d-q\) components of the DG current as well as the DG active and reactive power output. According to the Park transformation, the output of the inner current control loop \(ed\) and \(eq\) is transformed into the voltage pulses on the inverter switches are gained by sinusoidal pulse width modulation.

**Specifications of the tested system are:**

**Grid:**
- Voltage \(=400\text{V}\),
- Frequency \(=50\text{ Hz}\),
- Grid resistance \(=0.1\ \Omega\),
- Grid inductance \(=1.5915\ \text{mH}\).

**DG Inverter:**
- \(kp_{1}/ki_{1}=0.025/2\),
- \(kp_{2}/ki_{2}=1.5/0.01\),
- \(Pref=200\text{ kW}\).

**Load:**
- \(R=0.8\ \Omega\),
- \(L=2.0034\ \text{mH}\),
- \(C=3130.4\ \mu\text{F}\),
- \(Q_{f}=1\).

**V. INTENTIONAL ISLANDING DETECTION ALGORITHM**

When system is islanded, there may be active power mismatch \((\Delta P)\) between active power of DG and load. Hence, \((\Delta P = P_{\text{Load}} - P_{DG} = P_{\text{Grid}})\) is not zero which results in increase or decrease in the value of PCC voltage. So continuous monitoring and measuring of instantaneous voltage and frequency is necessary. The amount of voltage deviation \((\Delta V)\) depends on the value of \(\Delta P\). According to IEEE Std.929 and IEEE Std.1547, the voltage thresholds are typically set at 88% and 110% of the rated voltage value [9]. After measuring the instantaneous voltage calculate rate of change of voltage by using following equation.

\[
\text{ROCOV} = \frac{dV}{dt}
\]

If this value is within threshold value, then system is grid connected but if its value exceeds the threshold value, then third harmonic of output current is injected as a disturbance signal into the system through \(d-q\) current controller. If system is grid connected then disturbance signal flows into the low impedance path offered by utility and doesn’t change the system parameter significantly. When system is islanded, disturbance signal affects the system parameter such as voltage and frequency. Their values exceeds from their allowable limits and islanding is easily and accurately detected by using over/under voltage or over/under frequency relays. The flow chart of the proposed methodology is shown in Fig. 5.

**Figure 5. Intentional Islanding Detection Algorithm**

**VI. SIMULATION RESULTS**

The main system parameters are given above. Adopting the interface control presented in Fig. 5, the DG performs as a constant power source. The DG’s active power reference \(P_{ref}\) is set to 200 kW and a wide variety of active power mismatch conditions can be created by changing the value of the load resistance. The performance of the proposed islanding detection algorithm is tested under a wide variety of conditions.

**Figure 6. Simulink Model**

The performance of the proposed control strategies was evaluated in Fig. 6. The system was operated initially in grid-connected operation. The grid was disconnected at 1.5 second. The control mode was changed from current- to voltage controlled operation and the respective powers are shown below. After grid is disconnected, the inverter increases its power and supply the load as required as shown in fig 7.
Inverter provide power nearly equal to the source. There are losses due to source resistance and inductance. The active and reactive power are shown in fig 9.

In this paper a controller is designed for grid connected operation. Thus the paper summarizes the traditional independent inverter and Grid-connected inverter control strategy, combining the distributed power and micro-grid inverter characteristics, a suitable micro-grid inverter control strategy is put forward. The inverter-based DG can generate both active and reactive power simultaneously under constant power control. Forthe DG of this kind, this paper analyzes the relationship between the active/reactive power mismatch and frequency deviation respectively during islanding. This paper also presents an innovative islanding detection algorithm for the DG based on reactive power control. In this algorithm, the large voltage deviation due to the sufficient active power mismatch is utilized to detect islanding rapidly according to the OVP/UVP method. Wherever an islanding condition occurs between 49.3 and 50.5 Hz, there will be the reactive power mismatch according to the strategy. With the frequency changing, the mismatch becomes sufficient to drive the frequency to deviate outside the thresholds eventually. Therefore, the OFP/UFP method has the zero NDZ property for the DG equipped with the proposed strategy. Moreover, the reactive power reference for the DG depends on the PCC voltage value that is determined by the active power mismatch during islanding. Simulation results verify that the proposed algorithm can detect islanding rapidly.

VIII. REFERENCES


