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전압 불평형율을 이용한 분산전원의 고립운전 검출 기법

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An Islanding Detection Method for Distributed Generations Using the Voltage Unbalance

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Abstract - This paper introduced and proposed the voltage unbalance of DG terminal output as new monitoring parameter for power islanding detection. This paper also presented a simple and novel detection algorithm, which effectively combines the detection results of the conventional parameter, voltage magnitude, and a newly proposed parameter. We tested the proposed method using several distribution network conditions including not only islanding operation conditions, but also non-islanding conditions of normal network load variations. The test results showed that the proposed parameters and algorithm are capable of correctly detecting the islanding operation not affected by variation of DG loading and also have a good selectivity for islanding conditions and non-islanding conditions.

1. Introduction

Distributed generation units are rapidly increasing and most of them may be connected in parallel with distribution networks and therefore supply power into power grids as well as local loads. Distributed generation (DG) must be operated in such an inherently safe manner that DG should supply the generated power to the network loads only if the utility power supply is present. If DG is feeding the power to the networks without the utility supply, then it produces several negative impacts on utility power system and the DG itself, such as the safety hazards to utility personnel, the quality problems of electric service to the utility customers, and serious damages to the DG if utility power is wrongly restored. As such, the connected DG must detect the loss of utility power and disconnect itself from the power grid as soon as possible [1-3].

The conventional islanding detection method for DG can be classified into two groups. The active techniques directly regulate the DG output, measure the variation of the DG output, and decide whether the DG is operating in islanding condition or in normal condition. Despite of their effectiveness in detecting island operation of DG, these active techniques need to continuously vary the DG output and may negatively affect the operations of the DG and the utility system. Other detection methods can be called passive techniques since they detect islanding operation of DG by monitoring the system parameters such as voltage magnitude, phase displacement, the rate of change in frequency, and impedance monitoring. Even though they are unlikely to influence the operating strategies and management of utility power system, if there are little changes in the DG loadings after islanding, these methods have difficulties in finding out the islanding operation.

In General, after loss of main source, the DG has to take charge of the remaining network and the connected loads; therefore, the loading condition of the DG is suddenly changed after islanding. Therefore, this paper proposes a new monitoring parameter, the voltage unbalance considering the change of power output of DG for detecting the islanding operations of DG. The proposed method utilizes not only a new monitoring parameter but also voltage magnitude used in the conventional islanding detection techniques. We tested the proposed method using the radial distribution network of IEEE 34 bus model. The test results showed that the method correctly detects the islanding operation even in case of little changes in DG loadings after islanding and does not mal-operate for normal variation of network load.

2. Proposed Islanding method

2.1 Modeling of Distribution Network with DG

A. Modeling of DG system

In this study, we assume that the three-phase distributed generation system rated 0.14 MVA consists of a DC source, an inverter, a filter, a transformer, and a controller. This kind of DC-AC inverting DG structure is easily found and commonly used in photovoltaic systems, micro-turbines, and wind power systems [3]. The inverter regulates the voltage magnitude, phase, and frequency of DG using the Pulse Width Modulation (PWM) method and the Phase Locked Loop (PLL) method.

B. Modeling of distribution network

We used an IEEE 34-bus distribution networks in [4], which consist of single-phase and three-phase laterals connected with R-L bus loads and distributed loads. For the purpose of the realistic islanding operations of DG, we modified R-L network load on the IEEE 34-bus. Fig. 1 shows the circuit diagram of the distribution network connected with several DGs. In simulations, we assumed that the islanding operations of DG occur after loss of main source power by operation of the upstream circuit breakers or switches.

2.2 Islanding Operation of DG

A. The large variation in the loading for DG after islanding

In the distribution network model of Fig. 1, we locate the DG at Bus 840 and open the circuit breaker between bus 834 and bus 860. Then, the loading for the DG abruptly increases since the DG takes charge of all the loads within power island. Immediately after islanding, due to the large variation in the loading for the DG, there were sudden changes in the voltage magnitude, frequency, and phase displacement of the DG. Therefore, there are no problems to detect this kind of power islanding condition using the conventional monitoring parameters.

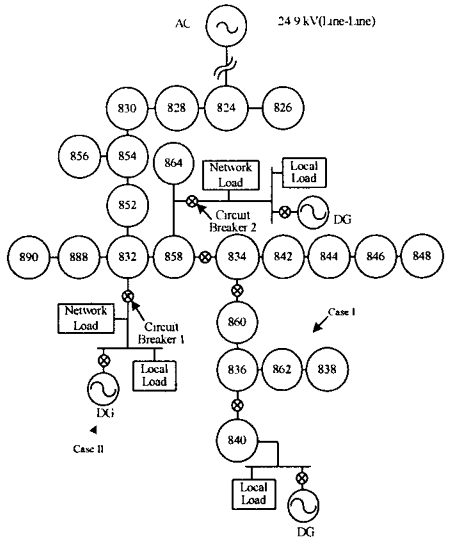

Fig. 1 The IEEE 34 bus model with DG

B. The small variation in the loading for DG after islanding

The power islanding condition having little changes in the loading for DG is simulated by locating the DG at bus 832 and then opening the circuit breaker 1. As we expect, after islanding, voltage magnitude, phase, and frequency do not change enough to detect the islanding operation. Though these monitoring parameters do not vary enough to detect the loss of main power, there was large variation in the voltage unbalance after islanding due to the change of loading condition of DG; therefore, this parameter can be effectively utilized to detect the islanding operations.

2.3 A New Islanding Detection Method

In this study, we propose a new monitoring parameter for detecting the islanding operations of DG: voltage unbalance considering the change of DG's generating power. Additionally, the voltage magnitude is also utilized as one of monitoring parameters, which is conventionally used for power islanding protection

A. Voltage unbalance variation

Generally, even though the loading for DG has little changed after the loss of main source, due to the topology changes of the networks and the load, the voltage unbalance varies. So, if we keep monitoring the unbalance of three-phase output voltage of the DG, then it is possible to effectively detect an islanding operation of DG. In order to do this, we define the voltage unbalance at the monitoring time t by (1),

$$VU_t = \frac{NS_t}{PS_t} \times 100 \tag{1}$$

where NS_t and PS_t mean the magnitude of negative and positive sequence of voltage at t, respectively.

This study defines the one-cycle average of voltage unbalance as (2), and also defines the voltage unbalance variation as (3), which measuring how much the monitored voltage unbalance deviates from the steady state and normal loading conditions.

$$VU_{avg,t} = \frac{1}{N}\sum_{i=0}^{N-1} VU_{t-i} \tag{2}$$

$$\Delta VU_t = \frac{|VU_{avg,s} - VU_{avg,t}|}{VU_{avg,s}} \times 100 \tag{3}$$

where N is the sampling number of one-cycle, t is the monitoring time, and $VU_{avg,s}$ is the VU reference value initially set for the steady state and normal loading conditions. After $VU_{avg,s}$ is initially set, if VU_t remains within 50% through +50% for one-cycle, the $VU_{avg,s}$ is updated by the $VU_{avg,t}$ in order to adapt to the normal load variation. And also, to avoid inaccurate decisions during too short transient state, if there are abrupt changes in $VU_{avg,t}$ above 0.05% during 1/4 cycle, as defined in (4), this method discards the value and goes to the next time step.

$$VU_{DE,t} = |VU_{avg,t} - VU_{avg,t-p}| \tag{4}$$

where p is set to be 1/4 cycle (4.17 ms).

B. Variation of DG's generating power

The three phase instantaneous power of DG at the monitoring time t is derived as (5),

$$P_{DG,t} = (v_a^t i_a^t + v_b^t i_b^t + v_c^t i_c^t) \tag{5}$$

where v_a, v_b, v_c and i_a, i_b, i_c are instantaneous voltages and currents of phase A, B, and C, respectively.

The average of P_{DG} over one-cycle is defined as follows,

$$P_{avg,t} = \frac{1}{N}\sum_{i=0}^{N-1} P_{DG,t-i} \tag{6}$$

where N is the sampling number of one-cycle.

We also define the P_{DG} variation as (7),

$$\Delta P_{DG,t} = \frac{|P_{avg,t} - P_{avg,t-T}|}{P_{rated}} \times 100 \tag{7}$$

where P_{rated} is the capacity of DG and T is the constant value representing the time interval, where it is set to be 3 cycles (50 ms). And, if there are changes in $\Delta P_{DG,t}$ above 5 %, this method discards the value and goes to the next time step.

C. Variation of DG's generating power

In this paper, the proposed method also monitors the variation of the voltage magnitude defined in (8) as the three-phase average rms value of line to line voltage.

$$V_{avg,t} = \frac{1}{N}\left[\frac{\pi}{3\sqrt{2}}\sum_{i=0}^{N-1}\{Max(v_a^{t-i}, v_b^{t-i}, v_c^{t-i}) - Min(v_a^{t-i}, v_b^{t-i}, v_c^{t-i})\}\right] \tag{8}$$

where N is a sampling number of one cycle, v_a, v_b, v_c are instantaneous voltages of phase A, B, and C, respectively, and t is the monitoring time.

D. Proposed islanding detection method

At every sampling time, this method calculates $VU_{avg,t}$ of three phase voltages, $P_{DG,t}$ of three voltages and currents, and $V_{avg,t}$ of a line to line voltage. In the first, it checks whether the $V_{avg,t}$ is lower than the preset value (0.5 pu). If the value is below the preset value, then this method immediately makes a trip signal for islanding protection. In this manner, we can easily and rapidly detect the power islanding operation in the case of the large variation in the loading for DG. Otherwise, the method checks the other monitoring parameters: $P_{avg,t}$ and $VU_{avg,t}$. If $\Delta P_{DG,t}$ and ΔVU_t have been satisfying the following logic equation in (9) during more than one cycle, the method decides it as an islanding condition in the case of little variation in the loading for DG.

RULE: $\{(\Delta VU_t > +50\ \%)$ or $(\Delta VU_t < -100\ \%)\}$ AND
$\{(\Delta P_{DG,t} < 5\ \%)$ (9)

The preset criteria for the monitoring parameters were selected through the various simulations for different islanding operation conditions and also normal load variation conditions on the distribution network model shown in Fig. 1 using PSCAD /EMTDC. We conducted 40-case simulations in total by moving a 0.14 MVA DG to different locations.

3. Test Results

3.1 Islanding Operation Conditions

We made a typical islanding condition of the DG connected at Bus 858 in Fig. 1 by opening the circuit breaker 2 at 53 ms. Due to the little variation in DG loadings, if we apply the previously used criteria of the conventional parameters, the islanding operations are not able to be detected since the voltage magnitude, phase displacement, and frequency do not change enough as shown in Fig. 2 and 3. However, unlike other parameters, the changes in the voltage unbalance are large enough to detect the islanding operation. The proposed method provides the trip signal for islanding detection at 120 ms as shown in Fig. 3. This result shows that the propose method can outperform the conventional approaches, which have some difficulties to detect the islanding operation conditions.

3.2 Normal Load Variation Conditions

A case for unbalanced load variations was simulated by connecting three single-phase loads rated 27.6 kVA, 27.6 kVA, and 55.2 kVA at phase A, phase B, and phase C in the primary side of transformer, respectively. In this case, the DG was connected at Bus 840. Due to the unbalanced load variation, the test case for normal load changes show the similar behaviors with islanding. However, the simulation results show that the proposed method does not mal-operate on these normal load variations. This simulation result is depicted in Fig. 4.

3. Conclusion

This paper introduced and proposed the voltage unbalance of DG terminal output as new monitoring parameter for power islanding detection. This paper also presented a simple and novel detection algorithm, which effectively combines the detection results of the conventional parameter, voltage magnitude, and a newly proposed parameter. We tested the proposed method using several distribution network conditions including not only islanding operation conditions, but also non-islanding conditions of normal network load variations. The test results showed that the proposed parameters and algorithm are capable of correctly detecting the islanding operation not affected by variation of DG loading and also have a good selectivity for islanding conditions and non-islanding conditions.

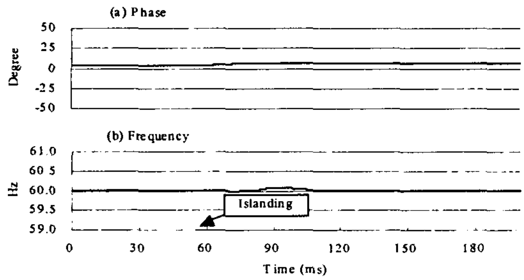

Fig. 2 The conventional parameter values for islanding operation with small variation in the loading of DG located in Bus 8

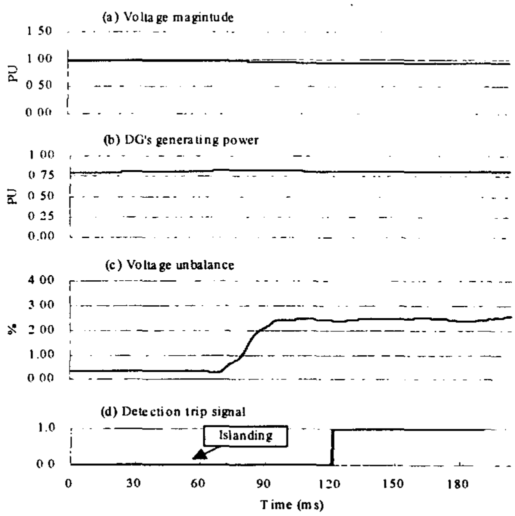

Fig. 3 The result for islanding operation with small variation in the loading of DG located in Bus 8

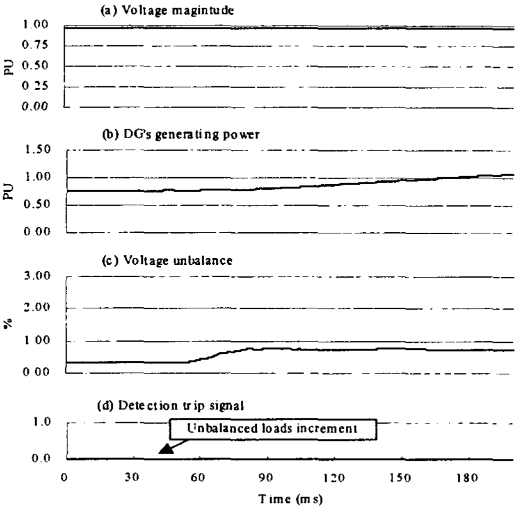

Fig. 4 The test result for connecting unbalanced three-phase loads

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