Islanding Detection Using RT-Lab

Yu-Chi Wu¹, Jiajun Lin², Jun-Han Chen¹, Ming-Yu Hsieh³

¹Department of Electrical Engineering, National United University, 360 Miao-Li, Taiwan

²Department of Electrical Power, South China University of Technology, 510641 Guangzhou, China

³Department of Chemical Engineering, National United University, 360 Miao-Li, Taiwan

Abstract. As renewable energy is widely used, distributed power generation systems are also used in wide range. However, some problems in renewable power systems have to be addressed. Among these problems, the islanding operation has the most important impact to the safety of utility workers and the service lives of equipment. This paper studies islanding detection for a microgrid system with unbalanced loads and its implementation on a real-time simulator (RT-Lab) to accelerate simulations. The presented islanding detection approach utilizes rate of change of frequency (ROCOF), under/over frequency, and negative sequence current injection methods. Decoupled double synchronous reference frame software phase lock loop (DDSRF-SPLL) is used to synchronize the grid-connected power converter with the utility voltages under unbalanced load conditions. Two cases are tested in real time. The presented approach detects the islanding in 0.09 seconds after the fault occurs, and the voltage at the point of common coupling (PCC) returns stable in 0.1 seconds after the fault occurs, satisfying the IEEE Standard 1547-2003.

1 Introduction

Lately, the phenomenon of global warming has become more and more obvious. Many countries around the world have devoted to the development of renewable energies in order to reduce emissions of greenhouse gas. Therefore, renewable energy and energy-saving technologies are widely developed and used. However, some problems in renewable power systems, such as short-circuit current, protection coordination, and islanding operation, have to be addressed. Among these problems, the islanding operation has the most important impact to the safety of utility workers and the service lives of equipment. Islanding operation means that when the main grid fails, the distributed generator continues to power the load in the distributed power system. If the islanding operation continues, when the power of the grid suddenly resumes this power will directly supply the isolated distributed system. The frequencies and phases are not synchronized, resulting in large inrush currents to cause a series of accidents, such as protection relay tripping and damage of electrical equipment. Therefore, to have the ability to detect islanding and operate the system under islanding situation is important for renewable energy systems. This paper studies the methods of islanding detection under balanced and unbalanced load conditions.

Islanding detection has drawn a lot of attention during the last decade [1][2], becoming an interesting research topic. There exist many islanding detection techniques which can be broadly classified into passive and active techniques. Passive techniques are based on

detection of transient changes at distributed power system site, for example, under voltage (UV)/over voltage (OV) [3], under frequency (UF)/over frequency (OF) [4][5], phase criteria [6], rate of change of frequency (ROCOF) [7][8], vector surge relay (VSR) [9], and rate of change of phase angle difference (ROCPAD) [10]. However, the so-called non detection zone (NDZ) inheres in the passive techniques when low or zero power imbalance condition occurs [11].

Active techniques intentionally perturb a system's local parameter and observe the resulting signal changes for identifying islanding, for example, active frequency drift [12][13], Sandia frequency shift [14][15], and current injection based techniques [16][17]. These techniques have smaller NDZ, but they may deteriorate the power quality.

Various hybrid techniques integrate passive and active techniques, for example, positive feedback, voltage unbalance (VU) and total harmonic distortion (THD) [18], average rate of voltage change and real power shift [19], and intelligent islanding detection [20].

In the control of grid-connected power converter and islanding detection, one of the most important aspects to consider is the proper synchronization with the utility voltages, especially the detection of the fundamental-frequency positive-sequence component of the utility voltage under unbalanced and distorted conditions. This paper implements ROCOF, under/over frequency, and negative sequence current injection methods based on decoupled double synchronous reference frame software phase lock loop (DDSRF-SPLL) [21] to cope with islanding operation under balanced and unbalanced loads.

Simulations are performed on a real-time simulator (RT-Lab) for fast validation.

2 Model of micro-grid system

For the test and verification, a microgrid power system as shown in Fig. 1 is adopted in this paper. Fig. 2 is its Simulink model. The distributed energy source, grid and load are connected at the point of common coupling (PCC). The breaker between PCC and the grid will be turned off to form an islanding situation. Sensors at the electrical system send voltage and current data to the controller system. And the controller system sends gate signals to the inverter of the distributed energy resource. Two breakers are used to simulate undulatory loads. The period of Load1 is 0.2 seconds. The period of Load2 is 0.08 seconds. Load3 is always connected. These load variations are shown in Fig. 3. The settings of these three-phase loads are shown in Table 1. The undulatory loads, as shown in Fig. 4 and Fig. 5, are combined with these three loads.

Fig. 1. Schematic of microgrid system.

Fig. 2. Simulink model of microgrid system.

Fig. 3. Load variations.

Table 1. Load settings.

Power of each phase		Load1	Load2	Load3
P(W)	A	1000	1200	3000
	B	2000	1100	
	C	1500	2000	
Q(Var)	A	100	10	200
	B	90	400	
	C	110	180

Fig. 4. Three-phase undulatory active power.

Fig. 5. Three-phase undulatory reactive power.

A phase-locked loop or phase lock loop abbreviated as PLL is a control system that generates an output signal whose phase is related to the phase of an input signal. Keeping the input and output phase in lock step also implies keeping the input and output frequencies the same [22]. In order to detect the voltage phasor, frequency and phase of voltage at the PCC, the most used method is SRF-SPLL (synchronous reference frame software phase lock loop). The SRF-SPLL method transforms ABC three-phase quantities to d-q coordinate axis plane by Park transform. SRF-SPLL performs well when three-phase loads are balanced. However, in reality three-phase loads are often imbalanced and there are often harmonics. Pedro Rodríguez and Ignacio Candela proposed a method called DDSRF-SPLL (decoupled double SRF-SPLL) [21] that can solve this defect. Fig. 6 shows its control block diagram, and Fig. 7 shows its Simulink model.

Fig. 6. Control block diagram of DDSRF-SPLL.

Fig. 7. Simulink model of DDSRF-SPLL.

3 Islanding detection

3.1 Passive methods

Passive islanding detection methods include any system that attempts to detect transient changes on the grid, and use that information as the basis as a probabilistic determination of whether or not the grid has failed, or some other condition has resulted in a temporary change [23]. However, in passive islanding detection techniques there exists the problem of NDZ ("non-detection zone"). Some common used passive methods are (1) under/over voltage, (2) under/over frequency, and (3) rate of change of frequency (ROCOF). In this paper, ROCOF is defined as the difference between the average frequency of the first eight cycle and the frequency of the twenty-first cycle divided by the time between the first and the twenty-first cycle. The thresholds for under/over frequency follow the IEEE Std. 1547-2003. Should the ROCOF be greater than a certain value, the distributed generator will be disconnected from the network [24]. For a 60-Hz power system, the typical setting value of ROCOF is 0.1~1.2 Hz/s [25]. Fig. 8 shows the Simulink model for ROCOF and under/over frequency detection.

Fig. 8. Simulink model for ROCOF and under/over frequency detection.

3.2 Active methods

Active islanding detection methods generally attempt to detect a grid failure by injecting small signals into the line, and then detecting whether or not the signal changes [23]. There is no NDZ in these active methods. Nevertheless, since the active detection method will deteriorate the power quality (that is, the power factor becomes smaller and the harmonic distortion rate becomes larger), the value of injection should not be too large. However, small disturbance will reduce its detection efficiency. Therefore, the value of disturbance here must be chosen properly. Some common used active methods are (1) negative-sequence current injection, (2) impedance measurement, (3) slip mode frequency shift, and (4) frequency bias.

4 Detection of NDZ

There exists the NDZ problem in passive islanding detection methods. Currently, the best detection technique is to mix the passive methods with active methods. Therefore, it's necessary to judge when to switch from the passive method to the active method.

That is, a method to detect NDZ is needed. In this paper, it is considered to be in the NDZ if the current from the grid to the PCC is smaller than 1% of the current from the distributed source to the PCC. Fig. 9 shows the Simulink model of NDZ detection. Once the system is detected to enter the NDZ, active islanding detection technique will be triggered. Here, negative-sequence current injection, shown in Eq. (1) [25], is utilized.

$$I_{qm} = I_d \left(\frac{2(f_{ave} \pm 0.26)}{f_{ave}} - \frac{\sqrt{\left(\frac{I_{lq}}{I_{ld}}\right)^2 + 4} - \frac{I_{lq}}{I_{ld}}}{2(f_{ave} \pm 0.26)} \right)$$

$$I_{q_dis} = I_{qm} - I_q \quad (1)$$

If the current frequency is larger than the average frequency, the system runs in the situation that the inductive reactive powers are imbalanced. If the current frequency is smaller than the average frequency, the system runs in the situation that the capacitive reactive powers are imbalanced. This decides the selection of 'plus and minus' in Eq. (1).

Fig. 9. Simulink model of NDZ detection.

5 Implementation and results

Fig. 10 shows the model with islanding detection implemented on the real-time simulator, RT-Lab. Two cases were tested.

Fig. 11 shows signals for NDZ and islanding detection for Case 1: balanced and constant three-phase load. At 3.6186 s, the grid is completely cut off (breaker: red line changes from 1 to 0). No current flows from grid to PCC. Therefore, at 3.61916 s, the NDZ is immediately detected (NDZ signal changes from 0 to 1) and the active detection method starts to inject a disturbed negative-sequence current (I_{disturb} : green line) at the P/Q control block. At 3.7039 s (0.0853s after cut-off), islanding is detected (Islanding signal changes from 0 to 1).

Fig. 12 and Fig. 13 show the voltage at PCC and the frequency/phase, respectively. The voltage at PCC return to be stable in around 0.1 seconds (stable after around 3.72 s). Fig. 14 shows the active and reactive power for inverter, grid, and load. After islanding is detected, the distributed generator power system operates in voltage/frequency mode and the load is supplied by the distributed generator. The voltage and frequency are

maintained at rated values as shown in Fig. 12 and Fig. 13. No power is from the grid.

For Case 2, unbalance load is set as depicted in Fig. 4 and Fig. 5. Fig. 15 shows signals for NDZ and islanding detections. At 3.44564 s the phase B of grid is cut off (breaker: red line changes from 1 to 0). At 3.49858 s (0.05294s after cut-off) islanding is detected (islanding signal: dark red line changes from 0 to 1). A triggering signal is sent to the breaker between PCC and grid. Since there are no current flowing from grid to PCC, an NDZ is detected (dark green line changes from 0 to 1). However, current injection is not needed since an islanding signal is already activated. Fig. 16 and Fig. 17 show the voltage at PCC and the frequency/phase, respectively. The voltage at PCC returns to be stable in around 0.08 seconds (stable after around 3.51 s). Fig. 18(a)~(c) show the active and reactive power for inverter, grid, and load. The voltage and frequency are maintained at rated values.

Fig. 10. RT-Lab model for islanding detection.

Fig. 11. Signals for NDZ and islanding detections—Case 1.

Fig. 12. Voltage at PCC—Case 1.

Fig. 13. Frequency and phase—Case 1.

Fig. 14. Active/reactive power—Case 1.

Fig. 15. Signals for NDZ and islanding detections—Case 2.

Fig. 16. Voltage at PCC—Case 2.

Fig. 17. Frequency and phase—Case 2.

Fig. 18.(a) Active/reactive power of inverter—Case 2.

Fig. 18.(b) Active/reactive power of grid—Case 2.

Fig. 18.(c) Active/reactive power of load—Case 2.

6 Conclusions

In the two cases, islanding is detected in 0.09 seconds (in 5 cycles) after the fault occurs. Voltage at PCC returns to be stable in 0.1 seconds after the fault occurs. These results satisfy the IEEE Standard. That means the detection and operation method adopted in this paper is effective.

By applying RT-Lab, the simulation time is largely reduced. RT-LAB is a powerful tool to accelerate the efficiency of research. The most important advantage of this RT-LAB is its characteristic of real-time simulation.

References

1. K. N. E. K. Ahmad, J. Selvaraj, and N. A. Rahim, *Renewable and Sustainable Energy Reviews*, **21**, 756-766 (2013)
2. C. Li, C. Cao, Y. Cao, Y. Kuang, L. Zeng, and B. Fang, *Renewable and Sustainable Energy Reviews*, **35**, 211-220 (2014)
3. J. C. M. Vieira, D. S. Correa, W. Freitas, and W. Xu, *IEEE Transactions on Power Systems*, **20**, 1660-1662 (2005)
4. W. Bower and M. Ropp, no. SAND2002-3591, *Sandia National Labs.*, Albuquerque, Livermore, NM, CA, US, (2002)
5. M. Yingram and S. Premrudeepreechacharn, *IEEE International Conference on Renewable Energy Research and Applications (ICRERA)*, 1-5 (2012)
6. M. E. Ropp, M. Begovic, A. Rohatgi, G. A. Kern, R. H. Bonn, and S. Gonzalez, *IEEE Transactions on Energy Conversion*, **15**, 290-296 (2000)
7. J. C. M. Vieira, W. Freitas, W. Xu, and A. Morelato, *IEEE Transactions on Power Delivery*, **21**, 1878-1884 (2006)
8. C. F. Ten and P. A. Crossley, *IET 9th International Conference on Developments in Power System Protection*, 523-528 (2008)
9. W. Freitas, W. Xu, C. M. Affonso, and Z. Huang, *IEEE Transactions on Power Delivery*, **20**, 1315-1324 (2005).
10. A. Samui and S. R. Samantaray, *IEEE Transactions on Smart Grid*, **2**, 391-398 (2011)
11. R. S. Kunte and W. Gao, *40th North American Power Symposium*, 1-8 (2008)
12. M. E. Ropp, M. Begovic, and A. Rohatgi, *IEEE Transactions on Energy Conversion*, **14**, 810-816 (1999)
13. A. Yafaoui, B. Wu, and S. Kouro, *IEEE Transactions on Power Electronics*, **27**, 2367-2375 (2012)
14. X. Wang, W. Freitas, W. Xu, and V. Dinavahi, *IEEE Transactions on Energy Conversion*, **22**, 792-794 (2007)
15. H. H. Zeineldin and S. Kennedy, *IEEE Transactions on Power Delivery*, **24**, 486-487 (2009)
16. G. Hernandez-Gonzalez and R. Iravani, *IEEE Transactions on Power Delivery*, **21**, 1698-1705 (2006)
17. P. Gupta, R. S. Bhatia, and D. K. Jain, *IEEE Transactions on Smart Grid*, **6**, 26-35 (2015)
18. V. Menon and M.H.Nehrir, *IEEE Transactions on Power System*, **22**, 442-448 (2007)
19. P. Mahat, Z. Chen, and B. B. Jensen, *IEEE Transactions on Power Delivery*, **24**, 764-771 (2009)
20. H. Vahedi and M. Karrari, *IEEE Transactions on Power Delivery*, **28**, 84-89 (2013)
21. P. Rodríguez, J. Pou, J. Bergas, M.J.I. Candela, R.P. Burgos, and D. Boroyevich, *IEEE Transactions on Power Electronics*, **22**, 584-592 (2007)
22. https://en.wikipedia.org/wiki/Phase-locked_loop
23. https://en.wikipedia.org/wiki/Islanding#Islanding_detection_methods
24. Y.-L. Chen, S.-K. Wang, *Taiwan Wind Energy Seminar* (in Chinese) (2010)
25. S.-K. Wang, B.-H. Lin, C.-C. Chen, *Proceeding of Power Symposium* (in Chinese) (2017)