Szymon BARCZENTEWICZ[1], Dariusz BORKOWSKI[1]

AGH University of Science and Technology, Department of Measurement and Electronics(1)

doi:10.15199/48.2015.11.27

Synchrophasor based Islanding Detection method

***Abstract**. Unintentional islanding is one of the most disturbing issues of distributed generation. It has serious consequences for electricity and it poses a threat to life and health of the personnel. This paper makes a comparison between two islanding detection methods. The first method is the well known over/under voltage and over/under frequency passive method. The second method is a synchrophasor based method. The simulations proved that the two studied methods have a good performance for parallel RLC.*

***Streszczenie.** Nieoczekiwane występowanie pracy wyspowej jest jednym z głównych problemów generacji rozproszonej. Praca wyspowa może mieć wpływ na jakość energii elektrycznej i stwarza poważne zagrożenie dla życia i zdrowia personelu. Ten artykuł porównuje dwie metody detekcji pracy wyspowej. Pierwsza metoda to dobrze znana metoda pasywna OUV/OUF (over under voltage and over under frequency). Druga metoda oparta jest na pomiarze synchrofazora. Symulacje wykazały, że obie metody sprawdzają się dla równoległego obciążenia RLC. (**Metoda detekcji pracy wyspowej oparta na pomiarze synchrofazora**).*

Keywords: Islanding detection, passive methods, synchrophasor measurement.
Słowa kluczowe: detekcja pracy wyspowej, metody pasywne, pomiar synchrofazora

Introduction

The expected growth of Distributed Generation (DG) creates new challenges for control and protection of electrical system. This concept of power generation uses renewable power sources e.g. wind turbines and photovoltaic systems. DG has many advantages, as it allows to avoid transmission and distribution capacity upgrades and reduces losses in transmission lines. In some cases it can even improve power quality and improve voltage profile of the system [1].

One of obligatory criterions for DG is an islanding detection. An island is formed when one or more distributed generation sources are disconnected from utility system and remain operational. Such situation creates dangerous hazards such as uncoordinated inadequate grounding and personnel safety issues. Thus it is important to have a protection system that can accurately identify islanding condition.

Islanding detection methods are divided into three groups: passive methods, active methods and communication based methods.

Passive methods are based on the measurements of parameters (e.g. frequency, voltage amplitude, phase angle or harmonics content) at the point of common coupling (PCC) [2, 3, 4]. Passive methods are characterized by simplicity; they do not disturb the network with any input signals. These methods can be effective in most situations. However, sometimes it is difficult to detect islanding state because the variations in voltage and frequency are relatively small at the PCC. The area where the islanding is not detectable is called non detection zone (NDZ). Active methods were proposed in order to minimize NDZ area. These methods are based on the observation of the response of the distributed grid to the intentionally introduced disturbance. Active methods have almost zero NDZ, but they are very complex and they may affect power quality [4]. Last group of methods are communication based methods. They usually operate on the basis of establishing communication channels between distributed generators and the main grid. Communication based methods can detect islanding conditions even when the power produced matches the power consumed. However, those methods are expensive and they need cooperation with the main grid provider.

In this paper a new islanding detection method based on synchrophasor measurement is proposed. Indicators of islanding condition are differences of voltage amplitude, phase and frequency between two different locations in electrical grid.

Methods of islanding detection

Simplified model used to test the performance of the proposed islanding detection method is shown in Fig. 1. The model is similar to the anti islanding testing circuit in IEEE 929 [5]. Active and reactive power $P_{inv}+jQ_{inv}$ generated by the photovoltaic system matches the power required by the test load $P_{load}+jQ_{load}$. Such operating conditions are required by the islanding detecting testing procedure.

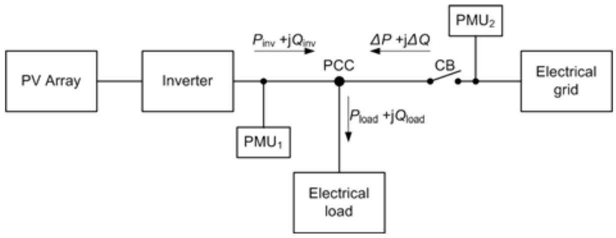

Fig.1. Power grid model overview (PMU_1, PMU_2 - phasor measurement units, CB - circuit breaker, PCC - point of common coupling)

A. OUV/OUF passive islanding detection technique

The over/under voltage and over/under frequency (OUV/OUF) is one of the most commonly used passive islanding detection technique. Thresholds for UOV and UOF are specified by the norm [6]. Typically V_{max} = 110% and V_{min} = 88% of the nominal voltage. Frequency thresholds are f_{max} = 51 Hz and f_{min} = 49 Hz.

The threshold of NDZ for *OUV/OUF* are given by [3]

$$\left(\frac{V}{V_{\max}}\right)^2 - 1 \le \frac{\Delta P}{P_{inv}} \le \left(\frac{V}{V_{\min}}\right)^2 - 1 \quad (1)$$

$$Q_f \cdot \left(1 - \left(\frac{f}{f_{\min}}\right)^2\right) \le \frac{\Delta Q}{P_{inv}} \le Q_f \cdot \left(1 - \left(\frac{f}{f_{\max}}\right)^2\right) \quad (2)$$

where Q_f is quality factor of the load. Value of quality factor for the islanding detection test circuit should be 2.5. Thus:

$$-17.36\% \le \frac{\Delta P}{P_{inv}} \le 23.46\% \quad (3)$$

$$-10.3\% \le \frac{\Delta Q}{P_{inv}} \le 9.71\% \quad (4)$$

These limits define NDZ shown in Fig. 2.

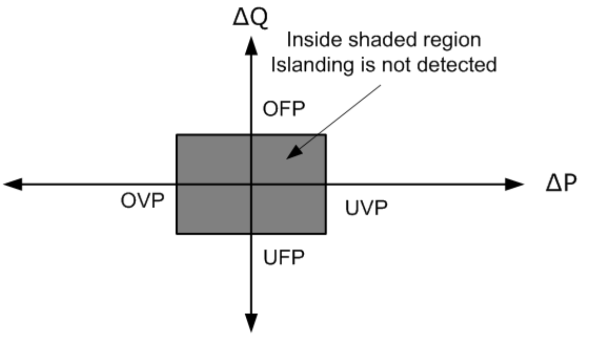

Fig.2. NDZ for UOV and UOF passive islanding detection method

When the islanding occurs the change of active and reactive power results in a change in voltage and frequency.

B. Synchrophasor based islanding detection technique

Synchrophasors are measured with Phasor Measurement Units (PMU) located across the network. Phasor data are collected in real-time and are accurately time-tagged. Upon the collection of phasor data, systems operator can determine quantities describing power system state such as power flow, phase angle difference between two locations and the rate of change of frequency.

Synchrophasor is a phasor representation of sinusoidal signal. For the following continuous time sinusoidal signal

(5) $$x(t) = X_m \cos(2\pi f_0 t + \phi) = X_m \cos(\omega_0 t + \phi)$$

the phasor is defined as [7]

(6) $$\mathbf{X} = (X_m / \sqrt{2}) e^{j\phi} = X_r + jX_i$$

where the magnitude $X_m / \sqrt{2}$ is the RMS (root mean square) value and f_0 is the system nominal (rated) frequency (50 Hz in EU). In the case where the frequency and the amplitude of the signal (5) are time varying, then (6) may be rewritten as follows

(7) $$x(t) = X_m(t) \cos(2\pi f_0 t + 2\pi \int g(t) dt + \phi) ,$$

where $g(t) = f_{in}(t) - f_0$ is the difference between the actual and nominal (rated) frequencies. In the case off time varying amplitude and frequency the phasor is defined as:

(8) $$\mathbf{X}(t) = (X_m(t) / \sqrt{2}) e^{j(2\pi \int g(t) dt + \phi)} .$$

The analysis of the time variations of the synchrophasor is proposed for the detection of islanding conditions.

There is a number of synchrophasor measurement methods which differ by their response time and accuracy [15]. In this paper we estimate the synchrophasor with the use of Bertocco-Yoshida Interpolated DFT (IpDFT) with leakage correction [8, 9].

In the first step of this method DFT X_k of measured signal is computed. DFT is computed with the use of Sliding DFT [10]. Then the DFT bin with the highest amplitude $|X_{k\,max}|$ is chosen. After that the ratios of DFT bins R and r and λ coefficient are computed

(9) $$R = \frac{X_{k_{\max}-1} - X_{k_{\max}}}{X_{k_{\max}} - X_{k_{\max}+1}}$$

(10) $$r = \frac{-e^{-j\omega_{k\max}} + e^{-j\omega_{k\max-1}}}{-e^{-j\omega_{k\max+1}} + e^{-j\omega_{k\max}}}, \ \omega_k = (2\pi / N)k$$

(11) $$\lambda = e^{j\omega_{k\max}} \frac{r - R}{r e^{-j2\pi/N} - R e^{j2\pi/N}}$$

The frequency, amplitude and phase are given by

(12) $$f_{in} = \mathrm{Im}\{\ln(\lambda)\} / (2\pi \Delta t)$$

(13) $$X_m = \left| 2X_{k_{\max}} / c \right|, \quad \phi = \angle(2X_{k_{\max}} / c)$$

where $c = (1 - \lambda^N)/(1 - \lambda e^{-j\omega_{k\max}})$.

Finally, the leakage correction algorithm is applied. The leakage correction for multifrequency exponential signal is described in [11], and the example of implementation for harmonic signal is given in [12].

This particular method was chosen because it was proven to be potentially useful for protection class PMU's (Phasor Measurement Units) [6]. It means that the method is characterized by a fast response which is indispensible in protection applications.

The proposed algorithm of islanding detection compares measurements from two points of the system, as it was introduced in [13]. One of the PMUs is installed inside an island and the other one inside the main grid. Phasor data from this measurements are compared to determine islanding condition. Since this method measures parameters in PCC and in the main grid, it can be classified as a hybrid of passive and communication based method Amplitude and frequency differences are given by

(14) $$\Delta X_m = X_{m\,PMU_1} - X_{m\,PMU_2}$$

(15) $$\Delta f = f_{PMU_1} - f_{PMU_2}$$

Islanding is indicated when any of the parameters exceeds the given threshold.

Simulation results

The simulation uses the Matlab/Simulink to evaluate performance of both OUV/OUF passive method and proposed synchrophasor based method.

The model shown in Fig. 3 represents grid tied inverter. Parallel RLC load is connected to the system. An island is created when a circuit breaker CB is opened. Inverter is controlled using synchronous d-q reference frame to inject a controlled current to the load and to the grid. To lock grid frequency and phase a phase-locked loop (PLL) was used [14]. The parameters of the system are presented in Table 1.

Table 1. System parameters

Parameter	Value
Grid voltage	380 V
Nominal frequency	50 Hz
V_{dc}	680 V
LC filter	3.1 mH, 12 μF
R_{load}	40 Ω
L_{load}	50 mH
C_{load}	202.5 μF
Q_f	2.5

Fig. 4 shows waveforms of voltage and currents of the system. Islanding condition occurs in 0.048 s. All power produced by the inverter is received by the load which means that $\Delta P+j\Delta Q \approx 0$, therefore model is operating in NDZ of OUV/OUF method. Since system is operating in the NDZ voltage in PCC did not change significantly when islanding happened. Current of the inverter I_{inv} and current of the load I_{load} differs from themselves when inverter and load is connected to the grid.

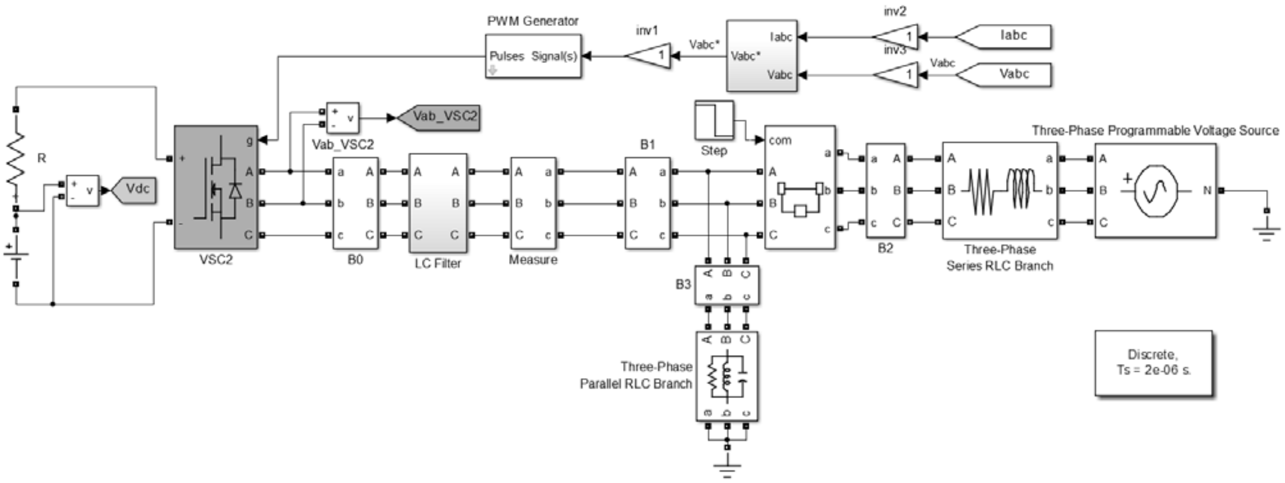

Fig.3. Simulink model of system

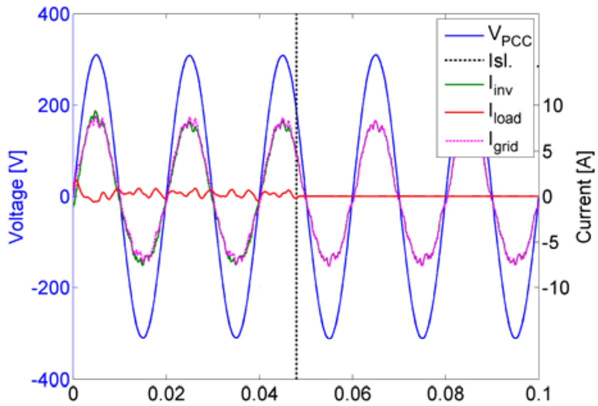

Fig.4. PCC voltage (V_{PCC}) and inverter output current (I_{inv}) in case of islanding for $\Delta P+J\Delta Q\approx 0$.

Signals used for the simulations were sampled with sampling frequency f_s=20kHz. After sampling, magnitude of the voltage and voltage frequency were estimated with the use of IpDFT Bertocco-Yoshida order 1 method. The developed simulation system has been tested for three different conditions.

A. Case 1: $P_{inv}+jQ_{inv}\approx P_{load}+jQ_{load}$

Power produced by the inverter equals the power consumption of the load. Fig. 5 shows amplitude difference ΔX_m and frequency difference Δf in case of islanding condition.

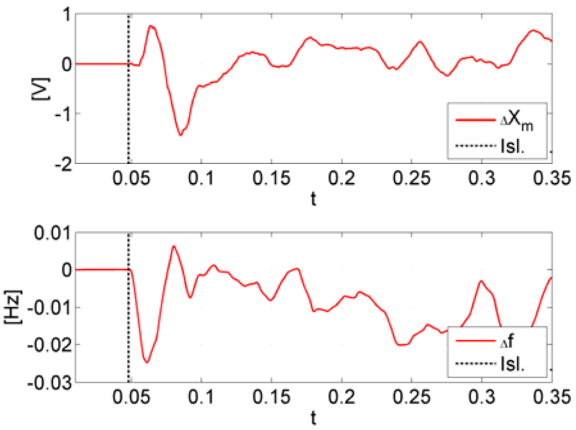

Fig.5. Amplitude difference ΔX_m and frequency difference Δf in case of islanding condition.

In case of operating in the NDZ OUV/OUF technique is ineffective. Fig. 5 shows that the differences of the voltages and frequencies measured by the PMUs differs the most soon after grid disconnection. Depending on the thresholds islanding can be identified in time smaller than one cycle of nominal frequency.

B. Case 2: $P_{inv}+jQ_{inv}>P_{load}+jQ_{load}$

Power produced by the inverter is bigger than power consumption of the load, therefore before islanding inverter is feeding power to the grid.

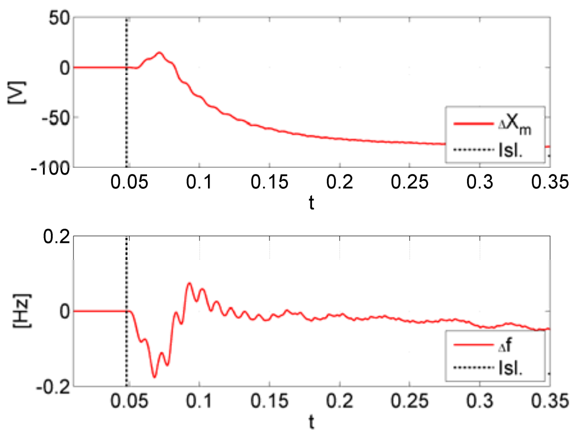

Fig.6. Amplitude difference ΔX_m and frequency difference Δf in case of islanding condition.

Fig. 6 shows that soon after islanding frequency change is the most significant. Voltage difference ΔX_m is growing with time. This is because the voltage in PCC is growing. In this case both of the methods are able to identify islanding.

C. Case 3: $P_{inv}+jQ_{inv}<P_{load}+jQ_{load}$

Power produced by the inverter is smaller than power consumption of the load, therefore before islanding grid is feeding the rest for the power to the load

Fig. 7 shows that soon after islanding the frequency change is the most significant. Voltage difference ΔX_m is growing with time. This is because the voltage in PCC drops. In this case both of the methods are able to identify islanding.

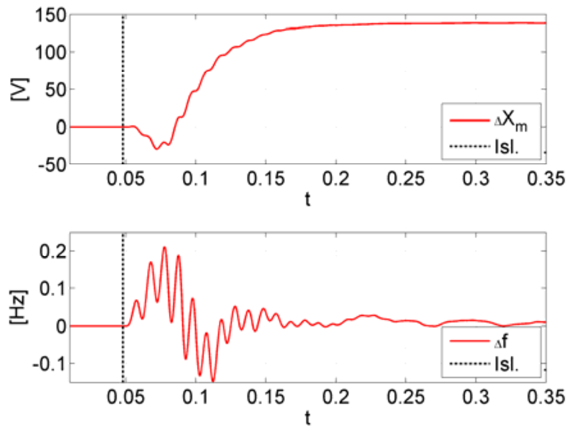

Fig.7. Amplitude difference ΔX_m and frequency difference Δf in case of islanding condition.

Conclusions

This paper discussed two islanding detection techniques. OUV/OUF and the synchrophasor based islanding detection method which is a hybrid of passive and communication based method. Simulations showed that PMU device could be used for both of these methods, since it gives information about voltage amplitude and frequency.

The advantage of the synchrophasor based method is that it can identify islanding in NDZ of OUV/OUF, because user can choose thresholds by himself. The use of IpDFT Bertocco-Yoshida phasor estimation method assures the accuracy of the algorithm and the use of Sliding DFT gives us information about phasor sample by sample. Thus the response time of the proposed method can be very short. According to chosen thresholds islanding can be identified in a time shorter than one cycle of measured signal, what is desired in protective automation systems.

A flow of the proposed method is that it can be expensive because of the costs of the PMUs. However, the expected development of smart grid technology suggests that the needed infrastructure could be already installed in the system.

Acknowledgement

This research was funded by Polish National Science Centre under decision DEC-2012/05/B/ST7/01218.

REFERENCES

[1] Acharaja N., Mahat P., Mithulananthan N., An analytical approach for DG allocation in primary distribution network, *International Journal of Electrical power & Energy systems*, vol. 28, 669-678.

[2] Jang S. I., Kim K. H., An islanding detection method for distributed generations using voltage unbalance and total harminic distrotion of current, *IEEE transactions on Power Delivery*, 19(2004), No. 2, 745-752.

[3] Ashour M., Ben-Brahim L., Gastli A., Al-Emadi N., Fayyad Y., Matlab/Simulink Implementation & Simulation of Islanding Detection using Passive Methods, *IEEE GCC Conference and exibition*, Nov. 2013

[4] Teodorescu R., Liserre M., Rodriguez P., Grid Converters for Photovoltaic and Wind Power Systems, Willey, 2011, 93-96.

[5] *IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems*, IEEE Standard 929-2000, April 2013.

[6] Photovoltaic (PV) Systems characteristics of the utility interface, IEC 61727, December 2004.

[7] *IEEE Standard for Synchrophasor Measurements for Power Systems*, IEEE Standard C37.118.1-2011, Dec. 2011.

[8] Barczentewicz S., Duda K., Borkowski D., Compliance Verification of the Phasor Estimation Based on Bertocco-Yoshida Interpolated DFT with Leakage Correction, *Signal Processing algorithms, architectures, arrangements, and applications, SPA'2013,* Sep. 2013.

[9] Duda K., Zieliński T. P., Magalas L. B., Majewski M., DFT based Estimation of Damped Oscillation's Parameters in Low-frequency Mechanical Spectroscopy, *IEEE Trans. Instrum. Meas.*, 60(2011), No. 11, 3608–3618.

[10] Duda K., Accurate, Guaranteed-Stable, Sliding DFT, *IEEE Signal Preccessing Mag.*, 59(2010), 124-127.

[11] Wu R. C., Chiang C. T., Analysis of the Exponential Signal by the Interpolated DFT Algorithm, *IEEE Trans. Instrum. Meas.*, 59(2010), No. 12.

[12] Duda K., Zieliński T. P., "Efficacy of the Frequency and Damping Estimation of Real-value Sinusoid," *Instrumentation & Measurement Magazine*, 2000, 48–58.

[13] Cardenas J., Mikhael G., Kamiński J., Voloh I., Islanding detection with phasor measurement units, *Annnual conference for Protective Realy Engineers*, 2014.

[14] Nandurkar S. R., Rajeev M., Design and Simulation of three phase Inverter for grid connected Photovoltaic system, *Proceedings of Third Biennial Conference*, NCNTE-2012, 2012

[15] Belega D., Macci D., Petri D., 'Fast Sunchroneus Estimation by Means of Frequency-Domain and Time-Domain Algorithms, *IEEE Trans. Instrum. Meas.*, 63(2014), No. 2

***Authors**: mgr inż. Szymon Barczentewicz, Akademia Górniczo-Hutnicza, Wydział Elektrotechniki, Automatyki, Informatyki i Inżynierii Biomedycznej, al. A. Mickiewicza 38-059, Kraków, E-mail: barczent@agh.edu.pl; dr inż. Dariusz Borkowski, Akademia Górniczo-Hutnicza, Wydział Elektrotechniki, Automatyki, Informatyki i Inżynierii Biomedycznej, al. A. Mickiewicza 38-059, Kraków, E-mail: borkows@agh.edu.pl.*