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A DFIG Islanding Detection Scheme Based on Reactive Power Infusion

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Abstract. A lot of research has been done on photovoltaic (the “PV”) power system islanding detection in recent years. As a comparison, much less attention has been paid to islanding in wind turbines. Meanwhile, wind turbines can work in islanding conditions for quite a long period, which can be harmful to equipments and cause safety hazards. This paper presents and examines a double fed introduction generation (the “DFIG”) islanding detection scheme based on feedback of reactive power and frequency and uses a trigger signal of reactive power infusion which can be obtained by dividing the voltage total harmonic distortion (the “THD”) by the voltage THD of last cycle to avoid the deterioration of power quality. This DFIG islanding detection scheme uses feedback of reactive power current loop to amplify the frequency differences in islanding and normal conditions. Simulation results show that the DFIG islanding detection scheme is effective.

1. General background information

Islanding is a condition in which a part of grid, which consists of local load and generator, continues to generate power even though it is isolated from main grid. Islanding can be harmful to equipments and cause safety hazards. For example, if a distributed generation does not have the capacity to adjust voltage or frequency, islanding will cause great voltage shift and frequency shift in the system, which may damage the grid and electric devices connected to the grid [1]. It is very necessary to detect and eliminate islanding rapidly and exactly.

In recent years, a lot of research has been done on islanding detection schemes for PV power system and a variety of detection schemes has been developed [2]. There are mainly two types of islanding-detection schemes for PV power system, which are power line carrier communications-based anti-islanding scheme and local islanding detection scheme. Power line carrier communications-based anti-islanding scheme is not widely used due to its large expenses and complexity in design and installment [3] [4]. While local islanding detection schemes, which rely on the PV converter to detect islanding, is widely used. Under this method, islanding is detected based on changes in output voltage and current signals monitored by PV converter. If output voltage and current signals drift from the presumed threshold, islanding can be detected and the converter will stop working [5]. Local islanding detection scheme can be classified into two types include passive anti-islanding scheme [6]-[8] and active anti-islanding scheme. While active anti-islanding scheme can also be classified into several types, among which, active frequency drift scheme [9] and reactive power disturbance scheme [10] are widely employed to detect islanding in PV power system.

2. Islanding in wind turbine generation system



Experiments and real cases show that islanding may also occur in wind farm. In 2012, the China Electric Power Research Institute carried out a 330kV short-circuit experiment in Jiuquan, China. This experiment shows that islanding occurs in a large number of wind farms when breaker trips at 330kV power lines and islanding condition lasts for 22s at most.

In the experiment, it is noticed that voltage still existed in the circuit after breaker was turned off at 26s, which shows that islanding can occur in wind farm. Figure 1 shows the experiment results of 1.5MW wind turbine. Waveforms of voltage, current, active power and reactive power of phase A are as shown.

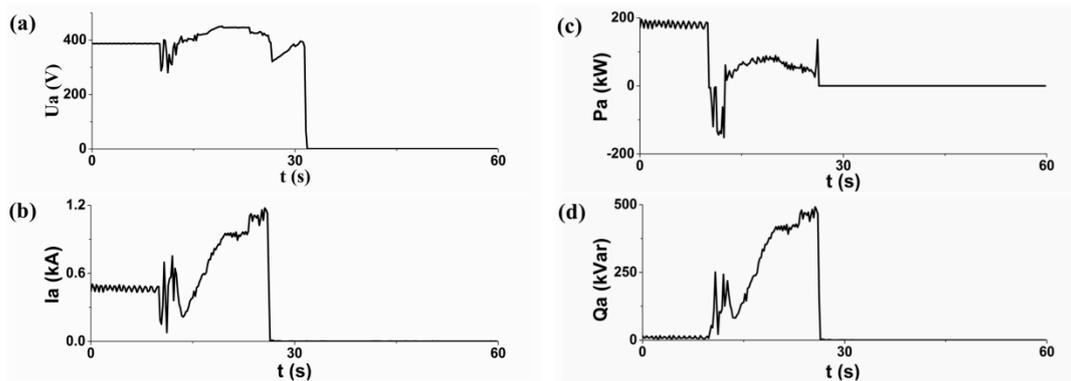


Figure 1. Diagram of phase A of 1.5MW wind turbine outlet.

In the experiment, voltage and current of wind turbines were observed. Islanding occurred at 10s, outlet voltage dropped to 0 at 32s, current drops to 0 at 26.4s and islanding lasted for 22s. The experiment shows that islanding can occur in wind farms and can last for a period of time, which may lead to equipment damage and pose great danger to utility workers if they are not aware of it. Hence, it is very meaningful to carry out the study on islanding detection for wind turbine.

3. Islanding detection scheme of DFIG

3.1. Wind turbine system

Figure 2 shows a wind turbine generation system. Where $P_0 + Q_0$ is the output power of DFIG, $P_{load} + Q_{load}$ is the local load, $P_G + Q_G$ is the power transported to the grid, and U_0 is the voltage at the point of common coupling (the “PCC”).

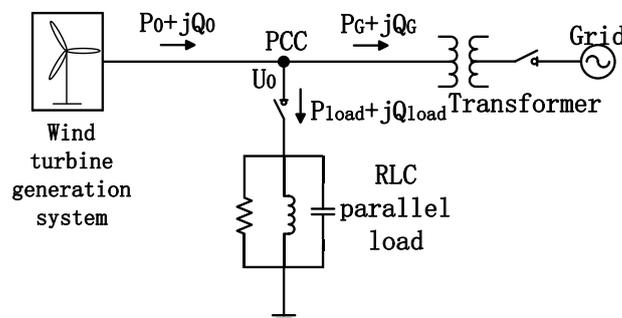


Figure 2. Islanding happens in wind turbine generation system.

If there is a big mismatch between the output voltage and local load in islanding condition, the voltage at PCC and angular frequency can be obtained as follows.

$$U = U_0 \left(1 + \frac{P_G}{P_{load}} \right) \quad (1)$$

$$\omega = \frac{2Q_f P_{load} \omega_0}{Q_G + \sqrt{Q_G^2 + 4Q_f^2 P_{load}^2}} \quad (2)$$

Where U_0 is the voltage of PCC and ω_0 is the angular frequency before the islanding is formed.

If there is a big mismatch between the output voltage and local load, P_G and Q_G will be large, and the change in U and ω before and after the islanding is formed will also be large. Hence, it is easy to trigger the voltage protection and frequency protection of wind turbines. While if the mismatch between output voltage and local load is small. The change in voltage and frequency may be too small to trigger the abovementioned protection system. Passive islanding detection scheme may fail to detect islanding. When the mismatch between the active/reactive power and load is small, the PLC load shown in Figure 2 will still satisfy (3) and (4).

$$Z \approx R + j \frac{\omega L}{1 - \omega^2 LC} \quad (3)$$

$$U^2 = P_{load} R = Q_{load} \frac{1}{j\omega L - \omega C} \quad (4)$$

According to (3), the imaginary part of the impedance Z of the RLC parallel load

$$Im(Z) = \frac{\omega L}{1 - \omega^2 LC} \quad (5)$$

And according to (4), the imaginary part of the conjugation of Z , which is expressed as Z^*

$$Im(Z^*) = \frac{P_{load} R}{Q_{load}} \quad (6)$$

Hence,

$$Im(Z) = -Im(Z^*) = \frac{P_{load} R}{Q_{load}} = -\frac{\omega L}{1 - \omega^2 LC} \quad (7)$$

From (7),

$$\omega = \frac{Q_{load}}{2Q_f P_{load} \sqrt{LC}} \pm \frac{1}{2} \sqrt{\frac{Q_{load}^2}{C P_{load}} + \frac{4}{LC}} \quad (8)$$

Where $Q_f = R \sqrt{\frac{C}{L}}$ is the quality factor of the RLC parallel circuit.

Considering that power generated by wind turbines in normal conditions is mainly active power while reactive power is approximate 0. And the value of ω is positive, $\frac{Q_{load}^2}{C P_{load}}$ can also be ignored, then

$$\omega \approx \frac{Q_{load}}{2Q_f P_{load} \sqrt{LC}} + \frac{1}{\sqrt{LC}} \quad (9)$$

During islanding, $P_{load} = P_0$, $Q_{load} = Q_0$. Hence, the angular frequency in islanding is affected by the active power and reactive power generated by the wind turbine. In normal conditions, since $P_0 \gg Q_0$, the change in reactive power will have a much greater effect on the frequency than the change in active power. Hence, this paper uses reactive power as the cause of change in frequency.

3.2. Control theory of DFIG islanding detection scheme based on reactive power infusion

Under the traditional reactive power infusion scheme, continuous reactive power disturbance will be applied to the wind turbine system, which may lead to the system to become unstable.

To improve stability of wind turbine system, this paper presents a new wind turbine islanding detection scheme, in which the change rate of voltage harmonic distortion and the reactive power disturbance are used to detect islanding. In this scheme, voltage harmonic distortion rate of the voltage

waveform output by wind turbines is to be monitored. At the moment when islanding is formed, a large proportion of harmonics can occur and the THD can increase dramatically. After islanding is formed, THD increases slowly due to the output characteristics of the wind turbine. Hence, THD can be monitored continuously and a trigger signal can be obtained by dividing the voltage THD by the voltage THD of last cycle. Use K as the trigger signal for reactive power infusion. If K is greater than the threshold value, then compare the frequency of the turbine and the threshold value. If the frequency is greater than the threshold value, then shut down the wind turbine. If not, start to infuse reactive power into the system. If voltage frequency is greater (less) than 50Hz, then infuse reactive power by $\Delta Q = 0.01\text{pu}$. ($\Delta Q = -0.01\text{pu}$). During the infusion, monitor the voltage frequency for 10 subsequent cycles. If the change of frequency stays within the threshold value, increase reactive power infusion by $\Delta Q = 0.1\text{pu}$. (when the frequency increases) and $\Delta Q = -0.1\text{pu}$. (when the frequency decreases). During the infusion, continue to monitor the voltage frequency. If the frequency drifts from the threshold value, shut down the wind turbine; if not, stop the infusion and start to monitor the voltage THD.

To testify the rationality of using K as trigger signal, this paper uses the experiment data of the abovementioned 1.5MW wind turbine islanding experiment. And to make it more convincing, long term data of phase A voltage waveform are used. The THD and the trigger signal K are as shown in Figure 3.

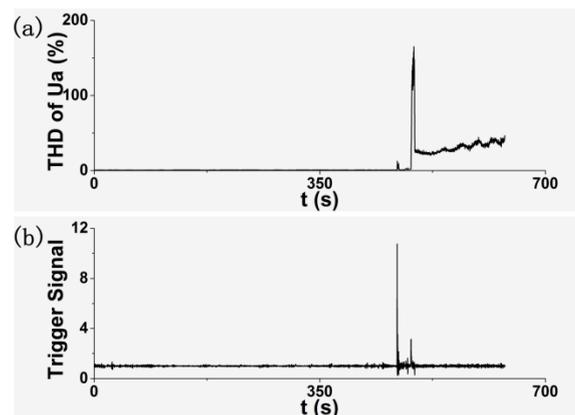


Figure 3. THD and Trigger signal of U_a in experiment.

As shown in Figure 3, when the system is in normal operation, phase A voltage THD is approximate 0.8% and the trigger signal is 1. At the moment islanding is formed, THD increases to 10% and the trigger signal rapidly increases to 11. During islanding, THD increases slowly and the trigger signal decreases. Hence, it is rational to use K as the trigger signal for reactive power turbulence.

Compared to PV converter and direct-driven wind turbine generator, the structure of DFIG is much more complex. In DFIG, stators are directly connected to grid, rotor is excited by three-phase PWM converter, electromagnetic power is transferred via both stator and rotor routes [11]. The reactive power of DFIG is generated by stator and controlled by the rotor excitation current. Hence, rotor current is used to control the reactive power of DFIG. Figure 4 shows the control block diagram of reactive power infusion of DFIG which is controlled by grid voltage vector orientation.

Where P_s is stator active power, Q_s is stator reactive power, ω_{slip} is slip angle frequency, ψ_{sdq} is d and q component of stator flux linkage vector, i_{rdq} is d and q component of rotor current vector, U_s is stator voltage vector, U_{sdq} is d and q component of stator voltage vector, L_s is stator inductance and L_m is mutual-inductor of stator and rotor.

Monitor the THD and frequency of three-phase voltage stators. K equals to THD divided by THD of the last cycle. If K is greater than the threshold value, reactive power infusion will be triggered.

Reactive power disturbance $\Delta Q_1 = \pm 0.01pu.$ will be infused to outer reactive power loop to affect the three-phase PWM converter of rotor side and then to control the reactive disturbance power of DFIG. If voltage frequency increases (decreases), increase the infusion of reactive disturbance power by $\Delta Q_2 = \pm 0.1pu.$ Continue to monitor the output voltage frequency. If voltage frequency becomes greater than the threshold value, shut down DFIG.

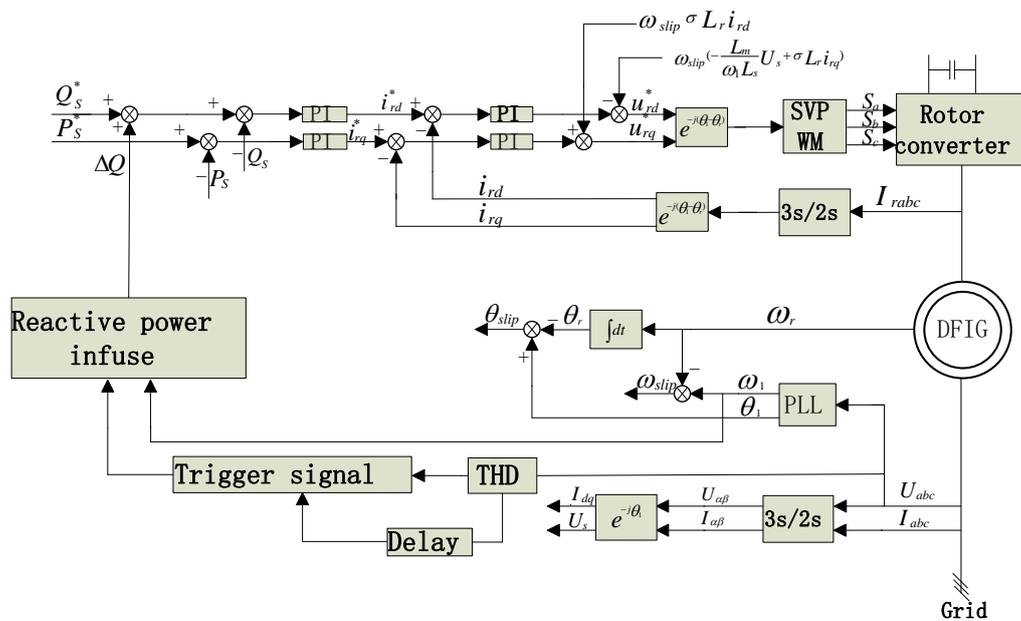


Figure 4. Schematic diagram of island detection and control for DFIG.

3.3. Simulation

To examine the feasibility of the proposed scheme, a simulation model of electromagnetic transient process in 1.5MW DFIG is established by MATLAB/Simulink. The model consists of wind speed model, DFIG model, RLC parallel load model, as well as power system model. It is as shown in Figure 5.

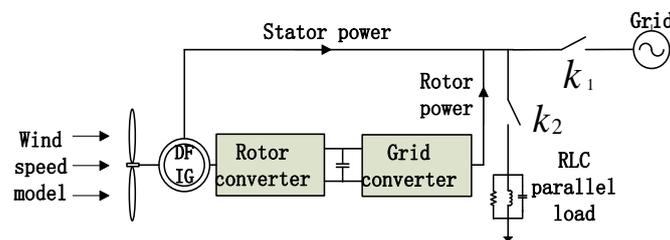


Figure 5. Structure diagram of islanded DFIG simulation.

The simulation test shows the situation in which islanding detection fails due to lack of active anti-islanding scheme. In this test only frequency protection and voltage protection are used. In accordance with the technical rule for connecting wind farm to power system under GB/T-19963, the allowable range of voltage is $0.9pu. < U < 1.1pu.$ and the allowable range of frequency is $48Hz < f < 50.5Hz.$ DFIG will be shut down if the voltage amplitude or frequency is beyond the allowable range.

In accordance with the test method of the anti-islanding testing code for inverter of utility-interconnected photovoltaic power station of NB/T 32010-2013, switch on breaker k1, switch off

breaker k2 and monitor the DFIG output value of active power and reactive power. The value of active power is P_0 and the value of reactive power is Q_0 . Then, adjust the RLC load capacity to P_0 and Q_0 . Hence, the DFIG output of the simulation model is almost the same with the local load.

When wind speed is 15m/s, DFIG power reaches the power rating. In this model, constant wind speed is set at 14m/s. Then $P_0 = 1.325\text{MW}$, $Q_0 = 0$.

The simulation period is 6s and islanding is formed at 2s. Breaker k1 is switched on and breaker k2 is switched off at the beginning of the test. At 2s, breaker k1 is switched off and breaker k2 is switched on. Islanding lasts for 4s. As shown in Figure 6, under the condition that the active power and reactive power outputted by DFIG equates to the local load, the voltage and frequency stay within the range of $0.97\text{pu.} < U < 1.03\text{pu.}$ and $49.9\text{Hz} < f < 50.1\text{Hz}$. In this situation, neither passive frequency protection nor passive voltage protection can detect islanding.

As shown in Figure 7, at 2s, THD zooms from 3% to 12% and trigger signal zooms from 1 to 3.6. Although THD has a large shift after islanding is formed, the value of trigger signal remains less than 3 after 2s. Hence, it is proved that change rate of voltage harmonic distortion can be used as the trigger signal.

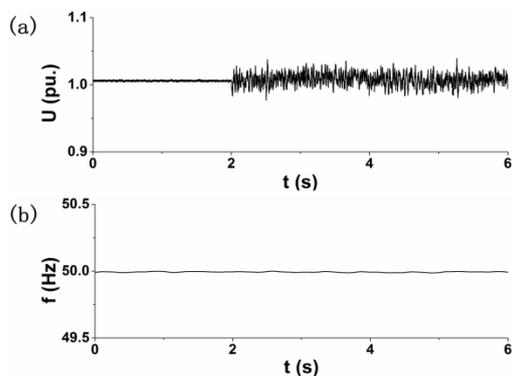


Figure 6. Voltage amplitude and frequency of DFIG after islanded.

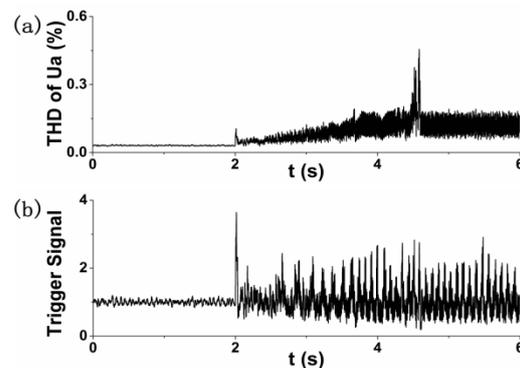


Figure 7. THD of U_a and Trigger signal in simulation.

The second stimulation test is to examine the feasibility of reactive power infusion scheme in this simulation model. Reactive power infusion model is added to this stimulation model. The simulation period is still 6s. Breaker k1 is switched on and breaker k2 is switched off at the beginning of the test. At 2s, breaker k1 is switched off and breaker k2 is switched on. Islanding lasts for 4s. The threshold of reactive power infusion trigger signal is set as $K=3$. The diagrams of DFIG output voltage, frequency, active power of this test are as shown in Figure 8.

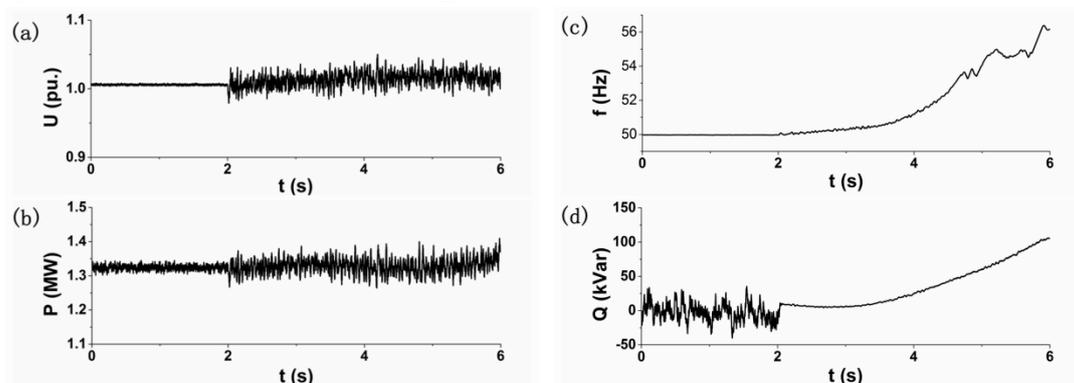


Figure 8. Diagram of voltage amplitude and frequency, active and reactive power with reactive power disturbances.

As shown in Figure 8, in islanding, the shift of active power and voltage amplitude of DFIG is very small. When islanding is formed, reactive power increase from 0 to 10kVar (0.007pu.) in 1s and increases to 110kVar (0.073pu.) in 4s frequency increases gradually and reaches the frequency threshold of 50.5Hz in 1.51s and reaches 56Hz in 4s. Islanding lasts for 1.51s in this test.

4. Conclusion

Islanding not only exists in PV system, but also wind turbine system. More work should to be done to solve this problem. When islanding happens, the mismatch between the output reactive power of the turbine and local reactive load will cause frequency shift of the isolated grid. So it is easy to detect the islanding by infusing a small reactive disturbance into the system and monitoring the frequency of the system, if the frequency drifts from the threshold value, then shut down the wind turbine. However, the continuous infusion of reactive power may cause grid voltage instability, especially when the number of the turbine is large. So a trigger signal was proposed. The rate of harmonic distortion which can be calculate as $K = THD(N)/THD(N - 1)$ is a reliable and simple value to be this trigger signal and it will not do harm to the grid during the process of calculation.

Acknowledgments

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References

- [1] Xie D 2014 Research on islanding detection technology for multi-grid connected inverter based distributed generation Hefei Univ. of Technology Anhui China.
- [2] Chao Y, Wu G and Zeng X J 2009 Protection technology for distributed generation systems *Power System Protection and Control* **2** 99.
- [3] Ropp M, Larson D and Meendering S 2007 Discussion of a power line carrier communications-based anti-islanding scheme using a commercial automatic meter reading system *Proceedings of the 4th IEEE Conference on Photovoltaic Energy Conversion* 2351.
- [4] Dysko A, Booth C, Anaya-Lara O and Burt G M 2007 Reducing unnecessary disconnection of renewable generation from the power system *IEEE Renew. Power Gener.* **1** 41.
- [5] Redfern M A, Usta O and Fielding G 1993 Protection against loss of utility grid supply for a dispersed storage and generation unit *IEEE Trans. on Power Delivery* **8**(3) 948.
- [6] Francesco De M, Marco L and Antonio D A 2006 Overview of anti-islanding algorithms for PV systems Part 1: Passive Methods *12th International Power Electronics and Motion Control Conference* 1878.
- [7] Vieira J C M, Freitas W and Wilsun X 1993 Performance of frequency relays for distributed generation protection *IEEE Trans. on Power Delivery* **3** 1120.
- [8] Jang S I, Kim K H 2004 An islanding detection method for distribution generation using voltage unbalance and total harmonic distortion of current *IEEE Trans. on Power Delivery* **19** 745.
- [9] Ropp M E, Begovic M and Rohatgi A 1999 Analysis and performance assessment of the active frequency drift method of islanding prevention *IEEE Trans. on Energy Conversion* **3** 810.
- [10] Jeong J B, Kim H J and Ahn K S 2005 A novel method for anti-islanding using reactive power *27th International Telecommunications Conference* 101.
- [11] He Y K, Hu J B and Xu L 2012 *Grid-connected Operation of Wind-turbine Driven Double Fed Induction Generators* (Beijing: China Electric Power Press) 278.