http://dx.doi.org/10.11142/jicems.2014.3.2.222
Journal of International Conference on Electrical Machines and Systems Vol. 3, No. 2, pp. 222~228, 2014 **222**

Development Tendency of Sliding Mode Frequency Shift Type Anti-Islanding of Japanese Companies

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Abstract – As tightened the grid connection related regulation for a distributed power generation Japan, islanding of the distributed power generation should be detected more rapidly. In this paper, it is introduced the development tendency of sliding mode frequency shift type anti-islanding technology in Japanese companies.

Keywords: Distributed power generation, Anti-islanding, Sliding mode frequency shift

1. Introduction

According to exhaustion of fossil fuels and global warming, researches and installations of renewable energy sources have been increased [1-3]. This generation systems are connected to a conventional electric grid, which systems compose to distributed generation (DG) system [4]. According to DG composition, standards and guide for DG have been set in order to prevent accident.

In Japan, an investment of renewable energy sources, which are composed to DG, has been increased much due to an atomic accident in 2011. These DGs have been installed by obeying standards and guides of Japan. However, Japanese standards and guides are tightened especially the grid connection. Islanding of DGs occurs when each DGs continue to operate and energize the grid line during the grid fault status. This islanding, also called unintended islanding, causes a hazard to the grid and electric equipment, maintenance personnel, and etc. Therefore, in order to prevent these problems, the anti-islanding algorithm should be adopted to DGs. As consolidated from 'Old Guide Line' to 'Grid Connection Regulation for the distributed power generation' in Japan on June 2006 [5], it is required to be detected islanding of the distributed power generation in 100ms and to be retained power factor up to 95% during the detecting time.

This paper presents and discusses developed anti-islanding methods in order to meet the consolidated standard for grid connection.

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Received 22 April 2014 ; Accepted 05 May 2014

2. Developed Anti-islanding Methods

2.1 The Needs of Anti-islanding

The distribution of electric power from utility companies to customers utilizes a network of utility lines connected in an electrical grid. The electrical grid consists of the main grid and many independent energy sources which supplies the electric energy to the grid. Each DG includes energy sources, such as photovoltaics, micro-turbines, fuel cells, wind, and engine-generator sets, and the power conditioning system (PCS) which includes a converter and an inverter, as shown in Fig. 1. Also, the energy storage system, such as the battery and flywheel, can be added. A typical feeder system consists of distribution lines that provide power from the grid to a customer load and the DGs via electrical disconnects and distribution transformers. Even with the presence of a DG connected to the grid, the utility company is still the main source of power and in many cases controls the system voltage and frequency within nominal values.

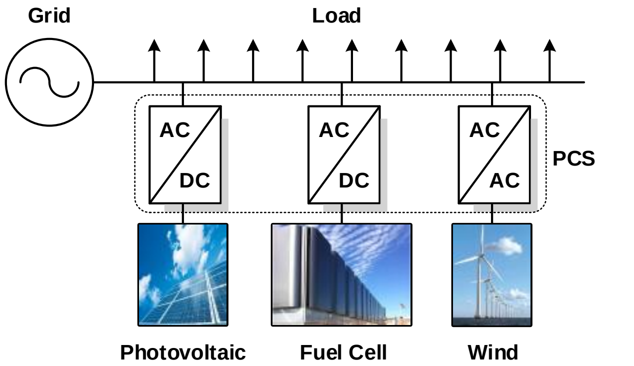

Fig. 1. Block diagram of DPGS and power grid

Under certain conditions, each distributed power generation system is disconnected from the grid and feeder system from the grid fault, leaving the DG directly tied to the load or disjointed grid branch, which is referred to as islanding. The isolated section of the grid being powered by the DG is referred to as an island. Unintentional islanding results in a situation where the voltages and frequencies on the faulted grid branch are outside of the direct control of the utility company because branch is primarily energized by one or more DG. Accordingly, monitoring and disconnecting schemes, referred to as anti-islanding schemes, are used to timely disconnect a DG from the feeder in the event that grid power from a utility company has been disconnected from the feeder.

Especially, IEEE Std. 929-2000 defines anti-islanding as "A condition in which a portion of the utility system that contains both load and distributed resources remains energized while isolated from the remainder of the utility system."

2.2 Kind of Anti-islanding Schemes

Recently, anti-islanding schemes have been commercial-ized and proposed in Japan include mainly active schemes or hybrid schemes.

Active schemes are based on active signal injection with monitoring of the resulting grid signals, such as impedance measurement for instance, or active signal injection with active controls, such as active frequency drift, Sandria frequency shift, harmonics injection or reactive power variation. Hybrid schemes are a combination of active schemes and passive schemes.

With active schemes and hybrid schemes, some distortion would occur in the output current waveform of the inverter, thereby resulting in a tradeoff between islanding detection time and waveform distortion, i.e, the faster detection typically results in higher total harmonic distortion (THD).

3. Trends of Anti-Islanding Schemes

Japanese companies which develop and commercialize an anti-islanding schemes using active frequency shift, are Omron, Toshiba, Fuji Electric, Mitsubishi, Tokyo Electric Power, Panasonic, Denso, and Daihen etc..

Omron has brought a remarkable development during the second half of the 2000s to meet the consolidated standard for the grid connection in 2006. On the other hand, Fuji Electric has done a poor development activity during the 2000s while it had done a rich development activity related

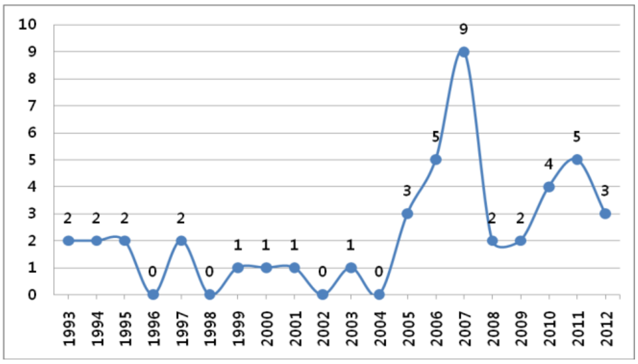

Fig. 2. Applications per year

to the anti-islanding schemes during the second half of the 1990s. And Toshiba has acted a steady development activity since 1993.There has been filed the most patent applications in Japanese Patent Office for 2 years, 2006 and 2007, since 1993, as shown in Fig. 2 [6-42].

3.1 Patent Appl. No. 1993-023894 (Toshiba Corp.)

When an imbalance between the reactive power of the inverter output and the reactive power of the load occurs, the frequency is varied. In the case of increased frequency, the inverter current phase is led so as to cause the frequency to rise still further. While, when the frequency has fallen, the current phase of the inverter is delayed, and the divergence in the direction to lower the frequency is affected. This positive feedback leads to the imbalance between the output of the inverter and the load rapidly. In the end, the islanding of the distributed power generation can be detected rapidly.

However, there is a shortcoming that the grid-connected inverter with an excessive positive feedback in this scheme cannot retain power factor up to 95%.

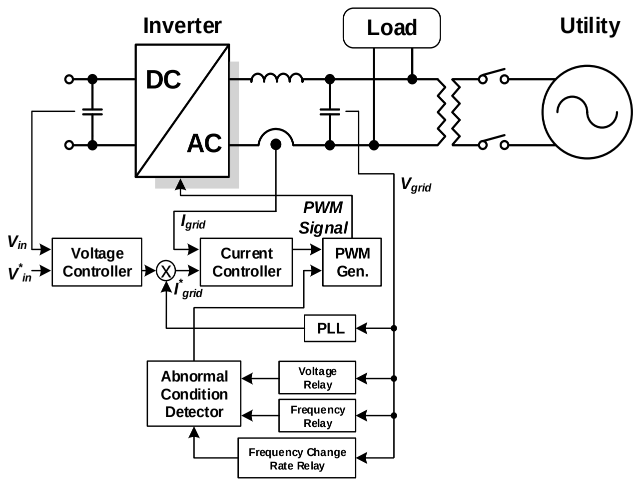

Fig. 3. Anti-islanding scheme in Patent Appl. No. 1993-023894

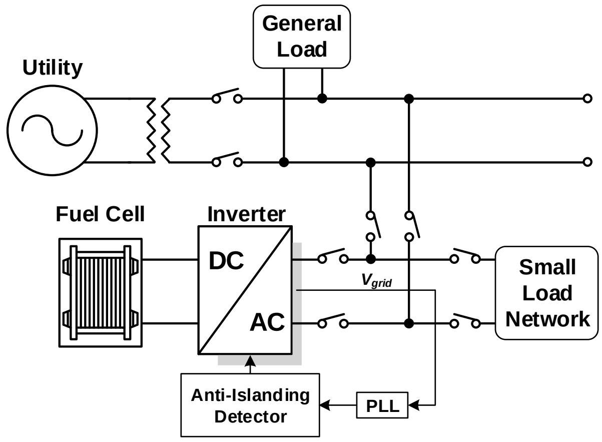

Fig. 4. Anti-islanding scheme in Patent Appl. No. 1994-201608

3.2 Patent Appl. No. 1994-201608 (Fuji Electric)

A grid-connected inverter controls the reactive power to have a very small periodic fluctuation continuously, monitoring whether a change of a frequency of the grid-connected inverter exists, integrating a deviation between the monitored frequency and the reference frequency, and determining the present state an islanding when an integration value of the frequency deviation is larger than the pre-determined value.

However, there is a disadvantage that the grid-connected inverter having the periodic fluctuation on the reactive power leads harmonics on the grid frequency and degrades the power factor.

3.3 Patent Appl. No. 2003-349487 (Omron Corp.)

A single operation detector of the distributed power source detects a single operation of the distributed power source when the AC system is power interrupted during interconnecting operation of the distributed power source and the AC system which transfers a power from the distributed power source to the AC system through a three-phase AC power source. The single operation detector includes a CPU for controlling an inverter so that a power is extracted from one phase (S-T phase) of three phases (R-S phase, S-T phase and R-T phase) of the three-phase AC power source, and a frequency change detector for detecting a frequency change based on the reactive power change from the power inputted by the reactive power change. The CPU judges whether this frequency change is a predetermined level or not when the frequency change is detected, and detects the single operating of the distributed power source when the predetermined level or higher is judged.

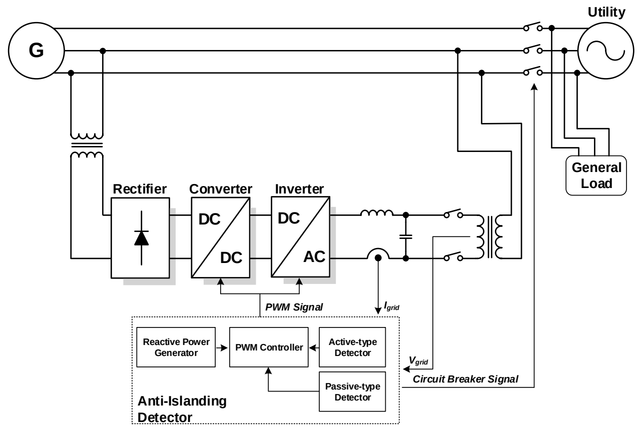

Fig. 5. Anti-islanding scheme in Patent Appl. No. 2003-349487

This scheme is advantage that a number of component as well as the influence of an input of an active change on an AC system is decreased because the single operation detector uses just one phase of three phases.

3.4 Patent Appl. No. 2007-168421 (Omron Corp.)

In the islanding detection method, the reactive power for detecting whether or not the distributed power supply is disconnected from the power system and is islanded is injected into the power system. In this method, the reactive power is injected into the power system when the system frequency has not substantially changed over multiple system periods in the past and the system voltage fluctuated. It is preferably determined that the system frequency has not substantially changed when the system frequency deviation has been continuously kept within a certain range over the multiple system periods in the past. It is preferably

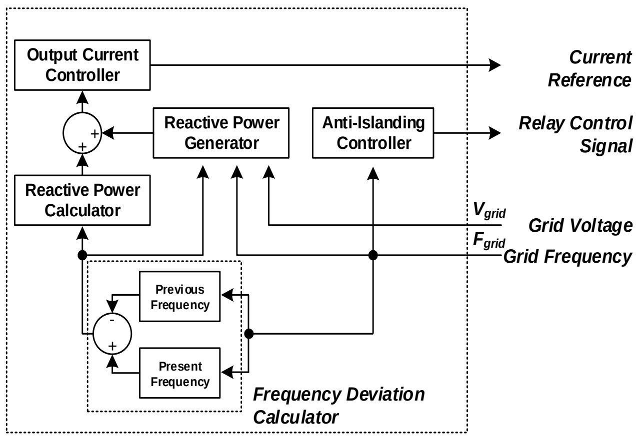

Fig. 6. Anti-islanding scheme in Patent Appl. No. 2007-168421

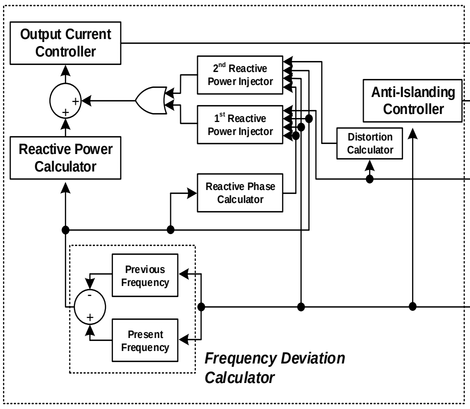

Fig. 7. Anti-islanding scheme in Patent Appl. No. 2007-309908

determined that the system voltage has fluctuated when the system voltage in each system period changes with a fluctuation margin specified for each system period relative to the average value of the respective system voltages of the multiple system periods in the past.

The scheme of Fig. 6 is advantageous in the case of the detection of anti-islanding when injected reactive power is balanced with load reactive power.

3.5 Patent Appl. No. 2007-309908 (Omron Corp.)

In the case in which an additional injected reactive power is injected for a predetermined period when injected reactive power is balanced with the reactive power of the load. This islanding detecting method includes: determining that additional injection reactive power is injected at a phase corresponding to the system frequency deviation (initial determination); re-determining the phase of the additional injection reactive power based on the code of the system frequency deviation after a period shorter than the above period elapses from the additional reactive power injection; and newly injecting the additional injection reactive power of the phase corresponding to the code of the system frequency deviation for a predetermined period, if the phase of the additional injection reactive power from the code of the system frequency deviation when re-determined is reverse to the phase of the additional injection reactive power when initially determined or and continuing the injection of the additional injection reactive power at the same phase for residual period until a predetermined period elapses from the additional injection reactive power injection at the initial determination, if the phase is the same.

The scheme of Fig. 7 is much more advantageous in the case of the detection of anti-islanding when injected reactive power is balanced with load reactive power.

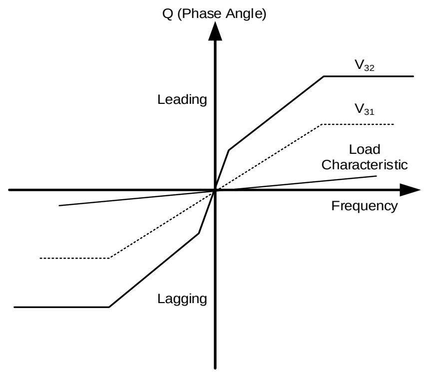

Fig. 8. Frequency change rate of inverter in Patent Appl. No. 2008-287930

3.6 Patent Appl. No. 2008-287930 (Toshiba Corp.)

The individual operation detection device of an inverter converts DC power to AC power and operates while being systematically connected to an AC power system. The device includes a drive means which performs reactive power control on the output of the inverter while synchronizing with the voltage phases of the AC power system and an output of the inverter and exerting control to a predetermined current phase and which performs control so that the reactive power of the inverter changes based on a frequency (f) and a frequency change rate (df/dt) of the output voltage of the inverter when the inverters is separated from the AC power system. The drive means makes control in such a direction that the frequency or frequency change rate of the output voltage of the inverter promotes the change by positive feedback.

There is a merit that this scheme can shorten the detecting time of anti-islanding and retain power factor up to 95% during the detecting time.

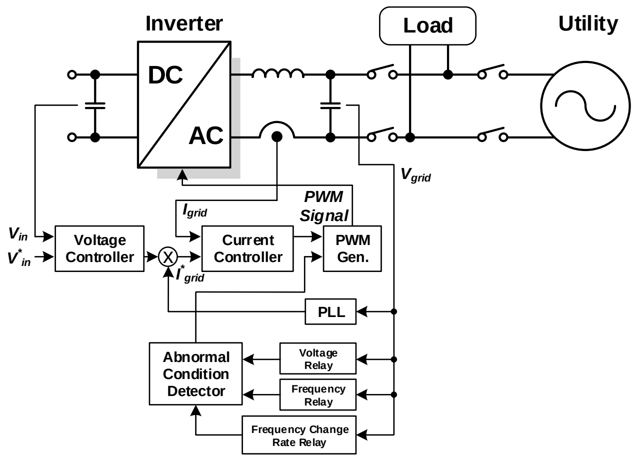

Fig. 9. Anti-islanding scheme in Patent Appl. No. 2010-053522

3.7 Patent Appl. No. 2010-053522 (Toshiba Corp.)

The inverter of the system is operated in a manner such that if the frequency deviation is positive, the phase of the reactive power of the load is controlled to be leading. If the frequency deviation is negative, the phase of the reactive power of the load is controlled to be lagging. Moreover, when the frequency change is in normal state, the inverter is controlled to move the characteristic curve of the reactive power over the frequency into the point which the reactive power is nearly zero, in order to follow the frequency change so slowly. Whereas, when the frequency change is large in abnormal state, the inverter is controlled to be the positive feedback in order to aggravate the change rate of the frequency.

We think that the inverter of this system can meet the grid connection related regulation which is required to be detected islanding of the distributed power generation in 100ms and to be retained power factor up to 95% during the detecting time.

3.8 Patent Appl. No. 2010-185488 (Toshiba Corp.)

The inverter of the system controls the output power of the inverter by adding the output of the first function circuit and the output of the second function circuit. The first function circuit is related to the phase of the reactive power of the load which is controlled to be leading when the frequency is positive. And the phase of the reactive power of the load is controlled to be lagging when the frequency deviation is negative. The second function circuit is related the phase of the reactive power of the load controlled to be leading if the frequency deviation is positive, and the phase

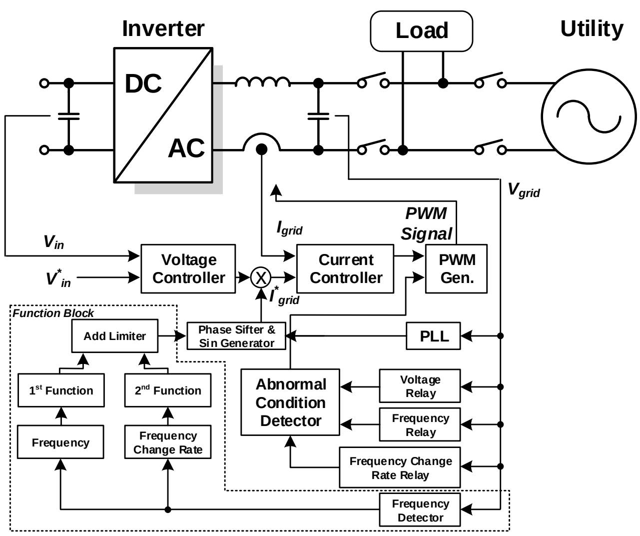

Fig. 10. Anti-islanding scheme in Patent Appl. No. 2010-185488

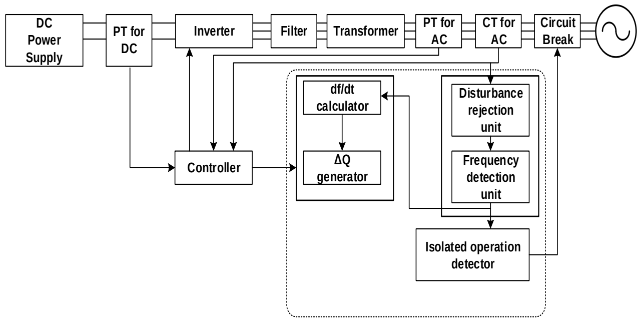

Fig. 11. Anti-islanding scheme in Patent Appl. No. 2011-243276

of the reactive power of the load which is controlled to be lagging if the frequency deviation is negative. Specially, the inverter of the system increases the gain of the second function circuit when the third, the fifth or the seventh harmonics output voltage is higher than the predetermined value.

There is an advantage that this control scheme can suppress the change of the reactive power in a normal state and increase the gain of the positive feedback of the frequency in an abnormal state to detect islanding shortly.

3.9 Patent Appl. No. 2011-243276 (Daihen Corp.)

An anti-islanding detection apparatus 7 inputs the fluctuation control signal to the control device 6. The amplitude of the fluctuation control signal is varied proportional to the rate of change of frequency generated by fluctuation control signal generator 71. The apparatus 7 increases an amplitude variation of an inverter output voltage as the rate of change of frequency increases. An unbalanced component included in the three-phase output voltage of the inverter 2 detected by the AC output voltage detector and harmonic components are removed by the band-pass filter of the complex coefficient. The apparatus 7 detects the frequency by using only the fundamental wave component outputted from the band-pass filter of the complex coefficient. If the frequency variation exceeds a predetermined threshold, the apparatus judges the inverter 2 being in the islanding state.

There is a merit that this scheme can shorten the detecting time of anti-islanding by using only the frequency of the fundamental wave component.

4. Conclusion and Future Works

In order to satisfy the consolidated grid connection related regulation for a distributed power generation, Japanese companies have developed the various methods using the positive feedback more precisely.

Since 2006, Japanese companies have commercialized or proposed anti-islanding schemes which vary to promote the change of the gain itself such as the change rate of the grid frequency in a specific period to meet the regulation relating to power factor. And other schemes detect the islanding state shortly by way of injecting of the additional reactive power when the injected reactive power is balanced with the load reactive power.

However, these schemes have the periodic fluctuation on the reactive power which leads harmonics on the grid frequency and degrades the power factor.

Hereafter, there is a need to include non-detection zone in these anti-islanding schemes to meet the consolidated standard for grid connection.

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