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A Review of Various Frequency Drift Based Islanding Detection Methods

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Abstract **– Islanding is a phenomenon where the PV module is still trying to energize the grid, even though the grid has been disconnected. This phenomenon can cause several problems, therefore many islanding detection methods have been introduced. One of the widely used methods is the active frequency drift. Yet, this method still has some drawbacks. Hence, many studies have been done to develop the conventional active frequency drift method, which can be classified as hybrid and non-hybrid methods. This paper will review both types of various developed frequency drift based islanding detection methods and compare their performances to the conventional active frequency methods.**

Keywords: Active frequency drift, islanding, hybrid methods, non-hybrid methods.

I. INTRODUCTION

Islanding is one of the phenomenon in electrical power system, where the PV module is still trying to energize the grid, even though the grid has been disconnected [1]. It creates several problem, such as, endanger the maintenance officers, generating a voltage and frequency that can damage electrical equipment, and when the grid is being reconnected, islanding creates an unsynchronized fault between the generator [2]. Therefore, islanding detection capability is one of essential parts in every PV inverter system.

An active islanding detection method injects a disturbing signal into the system to notify the protective relays that an islanding is occurring, so that the relays can stop the generator that is still trying to energize the grid [3]. Active islanding detection method works faster than the passive one, therefore it has been used widely around the world [4].

One of the active methods that are commonly used is an active frequency drift (AFD) method. When an islanding occurred, this method will either increase or decrease the frequency of the system to the value that is outside the normal frequency. Then, the protecting relays will disconnect the generator and stop the islanding [5]. However, the AFD method still has some drawbacks. It is considered not effective and is not able to detect islanding under the standard time limit [5]. Hence, many studies have been done to develop the AFD method.

Generally, there are two ways of developing AFD method. First, there are many studies that develop an existing frequency drift based islanding detection method directly, and therefore create a novel method. In this paper, this type is called the non-hybrid methods. The other ways is by combining two existing frequency drift based islanding detection methods to create an improved method. In this paper, this type is called the hybrid methods. This paper will review both types of various developed frequency drift based islanding detection methods and compare their performances to the conventional active frequency methods.

II. ACTIVE FREQUENCY METHODS AND THE MEASUREMENT STANDARDS

The AFD method is firstly introduced in 1997 and received a warm welcome because it offers a significant improved compared to the passive islanding detection methods and can be easily implemented [6]. In AFD, a short period of zero time is added to the inverter's output current, as can be seen in Fig. 1. The ratio of the zero time (T_z) compared to half the period of the voltage waveform (T_{grid}) is called the "chopping fraction (cf)"

$$cf = T_z/T_{grid} \quad (1)$$

However, this method still has some drawbacks. Reference [7] tested the conventional AFD method based on standard IEEE 929-2000 and this method failed to detect islanding when the load frequency is between 58.99 Hz and 60.19 Hz. Thus, many studies have developed the conventional method in order to meet the standard.

There are two standards that are commonly used in evaluating the performance of active frequency drift methods, which are IEEE Std. 929-2000 and IEEE Std. 1547-2003. Table 1 gives the comparison between these two standards.

Table 1. The Comparison of Two Standards in Evaluating AFD's Performance [8]

Standards	IEEE Std. 929-2000		IEEE Std. 1547-2003	
Parameter	Limits	Trip Time Limit	Limits	Trip Time Limit
Voltage	V<60	6 cycles	V<60	0.16 s
	60≤V≤106	120 cycles	60≤V≤106	2.0 s
	106≤V≤132	Normal operation	106≤V≤132	Normal operation
	132≤V≤165	120 cycles	132≤V≤165	1.0 s
	165≤V	2 cycles	165≤V	0.16 s
Frequency	59.3-60.5 Hz	Normal operation	59.3-60.5 Hz	Normal operation
	Otherwise	6 cycles	Otherwise	0.16 s
THD_i (%)	<5%	Always	5%	Always

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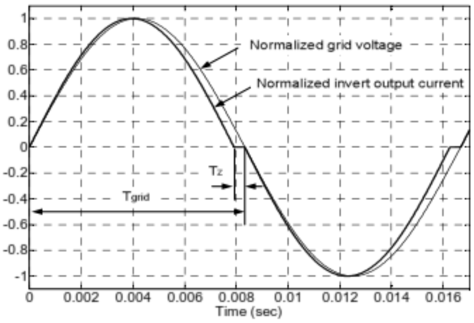

Fig.1 Example of a waveform in AFD [9]

III. THE NON-HYBRID AND HYBRID METHODS

A. *Non-Hybrid Methods*

One of the improved active frequency drift method is called active frequency drift with pulsation of chopping fraction (AFDPCF) [9]. Unlike the conventional AFD method that uses a fixed value of cf, AFDPCF method uses a varied cf value based on the algorithm:

$$cf = \begin{cases} cf_{max} & \text{if } T_{cf\ max\_on} \\ cf_{min} & \text{if } T_{cf\ min\_on} \\ 0 & \text{otherwise} \end{cases}$$

where $T_{cf\ max\_on} = T_{cf\ min\_on} = 20$ cycles. The varied value of cf in AFDPCF method can be seen in Fig. 2. The AFDPCF method is tested based on standard IEEE 929-2000. This method can detect islanding in 0.674 – 1.108 s depends on the load conditions.

However, the AFDPCF method also has some drawbacks. This method requires long time to detect islanding and ineffective in capacitive loads. The modified AFDPCF (M-AFDPCF) is introduced in [2] to overcome these drawbacks.

The M-AFDPCF method uses different algorithm to vary the value of cf, which is,

$$cf = \begin{cases} cf_{\max} \text{ or } cf_{\min} & (T_{on}) \\ 0 & (T_{off}) \end{cases}$$

where cf_{max} and cf_{min} are the positive maximum and negative minimum value of cf, respectively. This algorithm will create a different pulsation of chopping fraction as can be seen in Fig. 3. When tested in standard IEEE 929-2000, the M-AFDPCF method has a significant improvement in islanding detection time, which is only 0.45 s.

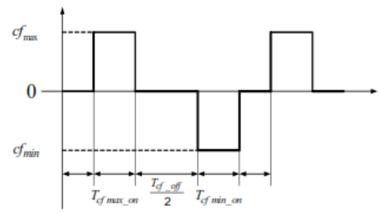

Fig. 2 The Value of cf in AFDPCF Method

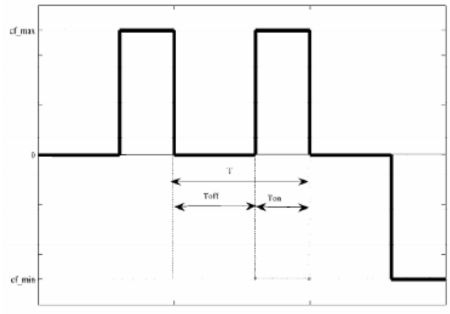

Fig. 3 The Value of cf in M-AFDPCF Method

Another improved method is called active frequency drift with double positive feedback (AFDDPF). Ref. [10] explains that the first positive feedback will determine the frequency of the grid current commands and the second one will adjust the weight of the first feedback. This method is then tested in a structure based on standard IEEE 929-2000. The experiment result is this method can detect islanding in 0.13 s with total harmonic distortion of grid current (THDi) = 2.97%. [10]

Reference [11] introduces an improved method that used alternate current disturbances between the odd and even cycle to drifts the frequency of inverter output current outside the range of over- and under-frequency relay (OFR/UFR. When tested in standard IEEE 929-2000, this method can detect islanding in 0.62 s.

B. *Hybrid Methods*

The other way of improving a conventional AFD method is by combining two developed AFD methods. This way usually creates a more effective hybrid method than each of the method when being operated separately.

One of the current hybrid methods is developed by combining a positive feedback frequency shift (PFFS) and reactive power variation (RPV) [12]. Unlike the common PFFS method, this hybrid method can effectively detect islanding while introducing a small degradation to the quality of power system. This method is tested using standard IEEE 1547-2003 and showed a great result. The hybrid method of PFFS-RPV can detect islanding in 0.2 s.

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Another hybrid method is introduced in [13]. This hybrid method combines slip-mode frequency shift (SMS) method and reactive power versus frequency (Q-f) as active method. This method is developed to overcome the drawback in SMS method, which is poor islanding detection in constant power controlled inverter. By combining SMS and Q-f, this hybrid method has faster islanding detection time for loads with high quality factor (Q_f) and smaller NDZ [13]. When tested in structure based on standard IEEE 1547-2003, both of the SMS and Q-f method cannot detect islanding in $Q_f \geq 1$. However, the new hybrid method can detect islanding in 0.1 – 0.6 s.

The hybrid method can also be comprised of two active frequency drift methods. Reference [14] introduces a new hybrid method by combining the conventional AFD method and SMS. However, this method has slower islanding detection time compared to the aforementioned hybrid methods. When tested in standard IEEE 1547-2003, this hybrid method can detect islanding in 1.2 s.

Reference [15] has better result in developing two active frequency drift methods. Instead of using the conventional AFD methods, [15] combined Sandia frequency shift (SFS) method with SMS method. When tested in structure based on standard IEEE 929-2000, this hybrid method can detect islanding in 0.06 s.

The comparison of the islanding detection time of all of the reviewed methods can be seen in Fig. 4 and Fig. 5. Fig. 4 shows the islanding detection time of all of the reviewed methods that are tested in standard IEEE 929-2000 while Fig.5 displays the comparison in standard IEEE 1547-2003.

In Fig.4 the islanding detection time of conventional AFD method is given 2 s since it is a maximum islanding detection time allowed in standard IEEE 929-2000. The other developed AFD method shows significant decrease in islanding detection time compared to the conventional AFD method. The AFDPCF method has a varied value of islanding detection time of 0.674 – 1.108 s depends on load conditions. However, in Fig.4 the minimum islanding detection time of AFDPCF is displayed.

In Fig.5 the hybrid of conventional AFD method still has a slow islanding detection time compared to other hybrid methods. This is probably caused by the fixed value of cf in conventional AFD causes an inefficient performance of the method. The hybrid method of SMS and Q-f has a varied value of islanding detection time of 0.1 – 0.6 s. However, in Fig.5 the minimum islanding detection time of the hybrid method of SMS and Q-f is displayed.

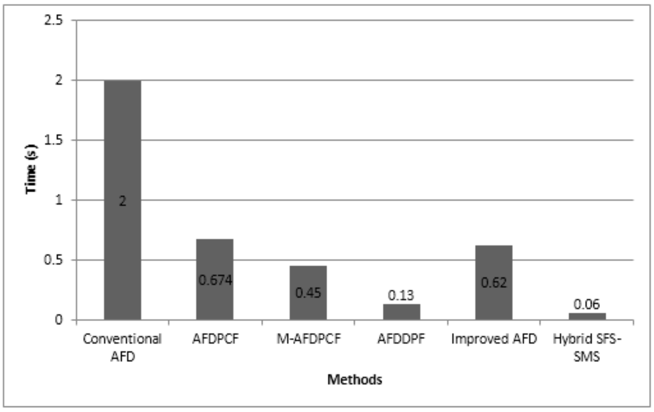

Fig.4 Comparison of islanding detection time of all of the reviewed methods in IEEE Std. 929-2000

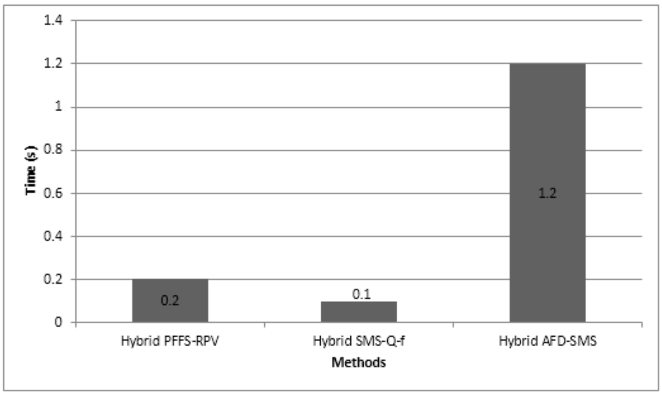

Fig.5 Comparison of islanding detection time of all of the reviewed methods in IEEE Std. 929-2000

IV. CONCLUSION

This paper reviews several improved active frequency drifts methods and compares their islanding detection time. Since islanding detection time is one of the main factors in determining an islanding detection method, this paper can be used to select a proper method to be applied in a PV inverter.

However, the other factors that can be used to evaluate the performance of an islanding detection method, such as, the non-detection zone value, the degradation in power system quality, etc must also be considered.

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