THE ISLANDING DETECTION ALGORITHM OF A NEW AC MODULE FOR THE GRID CONNECTION IN JAPAN

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ABSTRACT: The purpose of this paper is to develop an algorithm for islanding protection. It must satisfy conditions that it is not affected by high-density installation and is acceptable for the Japanese grid interconnection guideline. This research is one part of the Regional Consortium Project to develop a new 100W class micro-inverter for residential PV systems [1]. Feature of this algorithm is to combine a two-step passive detection and a current control of the inverter as an active component. The former can effectively suppress the misdetection and mutual interference among inverters. It is concluded that the developed algorithm works satisfactorily.

Keywords: Islanding, AC-modules, Grid-Connected

1 INTRODUCTION

AC module has many advantages that, for example, it seems to be more cost-effective than usual PV system and can be set up more easily. However AC module has some problems. Thus usually AC modules are installed in higher density, in such a case, the inverters' own control may affect other inverters and sometimes cause all the inverters to stop due to the misdetection. Although it becomes popular in Europe and US, it doesn't spread in Japan. One of the reasons is the grid connection guideline [2] that requires conditions different from European or American codes.

The present Japanese guideline requires equipping a complete islanding protection in all the type of inverters including AC module because the latter is not yet specified anywhere. It should provide both the passive method and the active method. This paper introduces an islanding detection algorithm and its experimental results obtained by using a network simulator.

2 METHOD OF ISLANDING DITECTION

2.1 Islanding detection of AC module inverter

Almost all AC module inverters marketed now have a grid connection protection unit to be concrete under voltage relay, over voltage relay, under frequency relay and over frequency relay. However if they are put into place in higher density, they may cause islanding. Because it cannot detect that the inverters output power and load condition are balanced. According to [3], islanding experiment in a number of inverter with parallel setting had been confirmed the islanding behavior. It is needed for islanding protection that the inverters exactly detect a balanced islanding condition and don't cause mutual interference among them. For AC module inverter it is very important to protect the islanding phenomena and to keep the grid connection standard.

2.2 The Active/Passive Series Method

The Active/Passive Series Method was invented by H.Kobayashi et al. [4] has a two-step passive detection and the current control of the inverter. Feature of this method is to combine a two-step passive detection and the current control of the inverter as an active component. Function of the two-step passive detection is to suppress all the inverters stopped at once by the misdetection. Function of the current control of the inverter is to suppress mutual interference among the inverters.

2.3 The islanding detection algorithm

Authors introduce the algorithm for a new AC module inverter that is suitable for the Japanese guideline. It consists of the inverter and the control board. The control board includes the total algorithm such as islanding algorithm and MPPT. Function of the control board is to run the total algorithm and to output the current indication value. This islanding detection algorithm simplified the Active/Passive Series Method.

While the inverter is operating, the control board is monitoring instantaneous values of the grid voltage by the grid cycle. (It's about 20[ms]) The control board outputs the current indication value in the grid cycle. The inverters' sampling frequency is 27.5 [kHz]. The total algorithm is calculated within 20 [ms].

Since the control board starts monitoring, each detection method calculates the instantaneous values of the grid voltage. After this, the two-step passive detection judges the values, and outputs the current indication value. Figure 1 shows the flowchart of the islanding detection algorithm at a static state.

The first-step of the passive detection is a low sensitive detection including the effective voltage, the grid frequency and the 3rd harmonic distortion. The second-step of the passive detection is a high sensitive detection including the rate of change about the grid frequency and the 3rd harmonic distortion.

In case when the low sensitive detects a matter, the inverter backs to the waiting mode. The waiting mode means to stop the inverter operation. When the low sensitive doesn't detect anything and only the high sensitive detects a matter, the inverter output current changes to the half. Then, if the grid voltage exists, there is no influence in the system voltage waveform. If the grid voltage doesn't exist, the change of the inverter output current distorts the system voltage waveform. This distortion is detected by the low sensitive, then the inverter changes to the waiting mode. If the inverter doesn't detect anything both the low sensitive and the high sensitive, MPPT algorithm outputs the suitable current indication for the grid condition. [4]

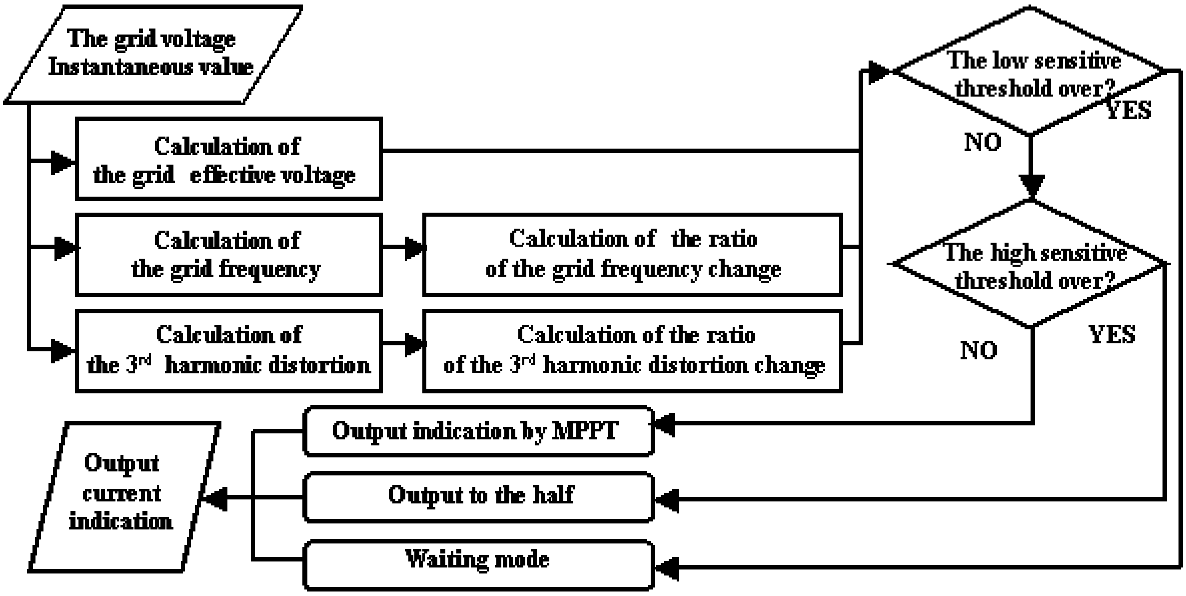

Figure 1: The flowchart of the islanding detection algorithm at a static state

2.4 Each detection method [5]

There are three kinds of methods in the low sensitive detection. Three detection methods are the effective voltage detection, the grid frequency detection and the 3^{rd} harmonic distortion detection. The effective voltage is calculated square root of the voltage instantaneous values about every cycle. The grid frequency is calculated the voltage instantaneous values from the first zero cross to the third zero cross. The 3^{rd} harmonic distortion is calculated the voltage instantaneous values with Discrete Fourier Transform.

There are two kinds of methods in the high sensitive detection. The rate of the grid frequency change and the rate of the 3^{rd} harmonic distortion change are calculated by use of moving average. Accuracy of each detection method is confirmed in the simulation.

2.5 Threshold of each detection method

Table1 shows the threshold of each detection method. The low sensitive threshold is defined along the Japanese guideline. The high sensitive threshold is simulated by [6]. To suppress the misdetection, the high sensitive threshold needs the further examination.

Table 1: The threshold of each detection method

Detection method	Threshold
The under effective voltage	90[V]
The over effective voltage	110[V]
The under grid frequency	47.5[Hz]
The over grid frequency	52.5[Hz]
The 3^{rd} harmonic distortion	3[%]
The rate of the grid frequency change	0.1[%]
The rate of the 3^{rd} harmonic distortion change	0.5[%]

3 EXPERIMENTAL CONTENTS

To connect the grid, the algorithm needs the exactness to detect the grid small disturbing such as instantaneous voltage change or frequency change. Consequently, the algorithm needs to be investigated against these phenomena.

3.1 Experimental circuit for imitation islanding test

Figure 2 shows the experimental circuit for imitation islanding test. In the experiment, AC power source takes the place of the grid, and PV array I-V curve simulator takes the place of PV. AC module inverter consists of the inverter and the control board. Due to investigate the islanding detection availability of the inverter, there is no load on this circuit.

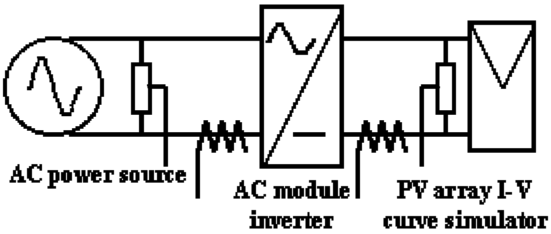

Figure 2: Experimental circuit for imitation islanding test

Table 2: PV array I-V curve simulator’s parameters

Setting parameter	Established value
Pmax	100[W]
Vop	40[V]
Iop	2.5[A]
Voc	45[V]
Ioc	2.5[A]
FF	0.79
Amount of solar radiation	$1kW/m^2$
Temperature	25℃

3.2 Experimental condition

Table 2 shows PV array I-V curve simulator’s parameters. The inverter is still under the development, however the static operation is controlled. Static operation is more strictly for islanding phenomena than dynamic operation condition. The experiments were carried out under the static operating conditions.

4 EXPERIMENTAL RESALTS

4.1 Experiments of voltage quick change

This experiment focused on the algorithm behavior under the voltage quick change. The grid voltage was changed from 100[V] to 80[V] or 120[V] among 10[ms]. The grid frequency was kept constant 50[Hz]. Figure 3 shows the analytical result. The result shows that the voltage quick change was detected by the rate of the grid frequency change and the effective voltage detection. Judging from the measured data of the rate of the grid frequency and the rate of the 3rd harmonic distortion, the rate of the grid frequency change didn't over the threshold, however the rate of the 3rd harmonic distortion change went over the threshold. Then, the output current indication changes to the half. However, due to exist the grid, there was no influence to the grid voltage.

Another experiment result under the voltage quick change from 100[V] to 120[V] among 10[ms] was also detected by the high sensitive detection.

These results show that the algorithm can exactly operate in voltage quick change.

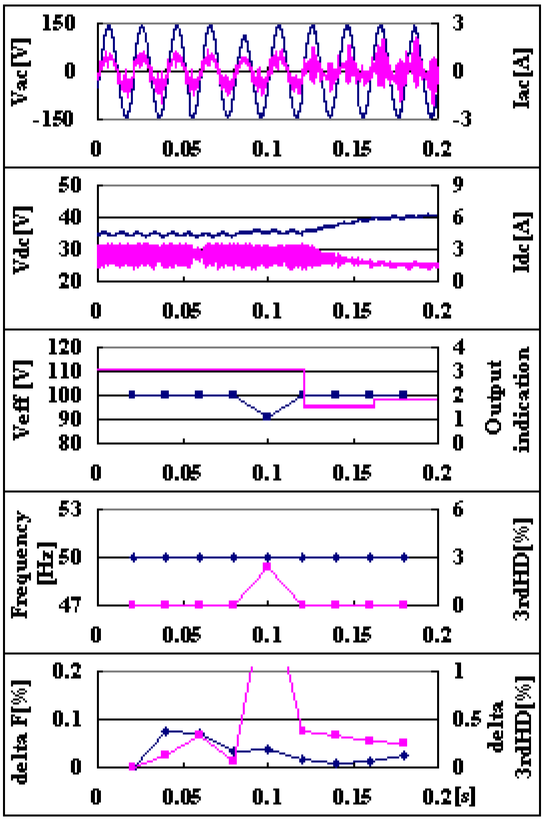

Figure 3: Measured data at the experiment of voltage change from 100[V] to 80[V] among 10 [ms].

4.2 Experiments of the grid frequency smoothly change

This experiment focused on the algorithm behavior under the frequency smoothly change. The grid frequency was smoothly changed from 50[Hz] to 51[Hz] or 49[Hz] among 0.4[s] and from 50[Hz] to 53[Hz] or 47[Hz] among 1.0[s]. The grid voltage was kept constant 100[V]. Figure 4, 5,6,7 shows the analytical result.

When the grid frequency was smoothly changed from 50 [Hz] to 51 [Hz] or 49 [Hz], the rate of the grid frequency change was over the threshold. At the time, the output current indication value was instantaneously changed to the half. That makes DC voltage and DC current quickly changed.

If the grid doesn't exist, the voltage waveform is distorted by the inverter output current. Even if under the condition that the inverter's output power and load are balanced, the rate of frequency change detection and the rate of the 3rd harmonic distortion change detection will detect the small disturbing in the grid voltage. Then, the balanced condition turn into a non-balanced islanding condition. Consequently, it is to be detected by the low sensitive detection, and the inverter backs to the waiting mode.

When the grid frequency was smoothly changed to 53 [Hz] or 47 [Hz], the grid frequency was over the threshold. At the time, output current indication was instantaneously changed to zero. Then, the inverter backs to the waiting mode.

These results show that the algorithm can exactly operate in the grid frequency smoothly change.

5 CONCLUSIONS

This paper introduces an islanding detection algorithm for the Japanese guideline and investigated the availability of this algorithm in the simulated islanding experiment.

In the experiments, this algorithm exactly detected the small disturbance of the grid voltage and the smoothly changes of the grid frequency. Experimental results showed the availability of this basically algorithm.

It is felt, however, that further experiments are required for verifying proper functions for the multiple operation of a number of AC modules.

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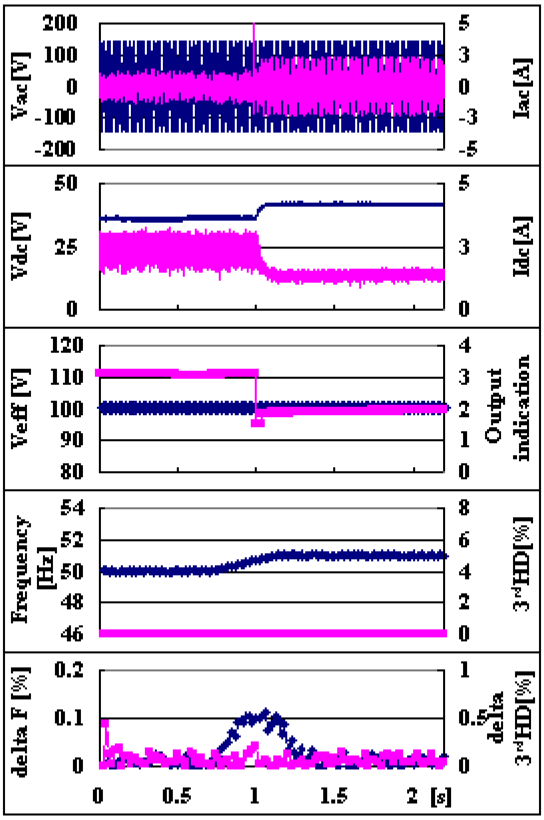

Figure 4: Measured data at the experiment of frequency smoothly changes from 50[Hz] to 51[Hz] among 0.4 [s].

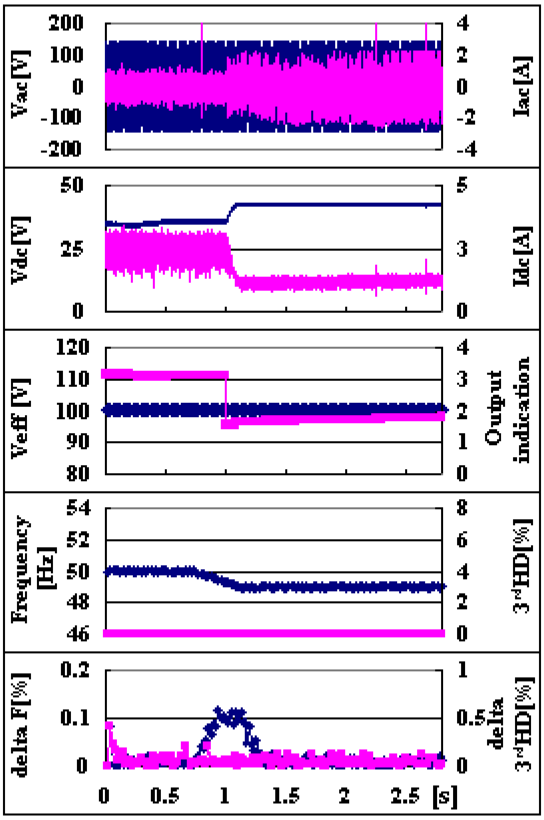

Figure 5: Measured data at the experiment of frequency smoothly changes from 50[Hz] to 49[Hz] among 0.4 [s].

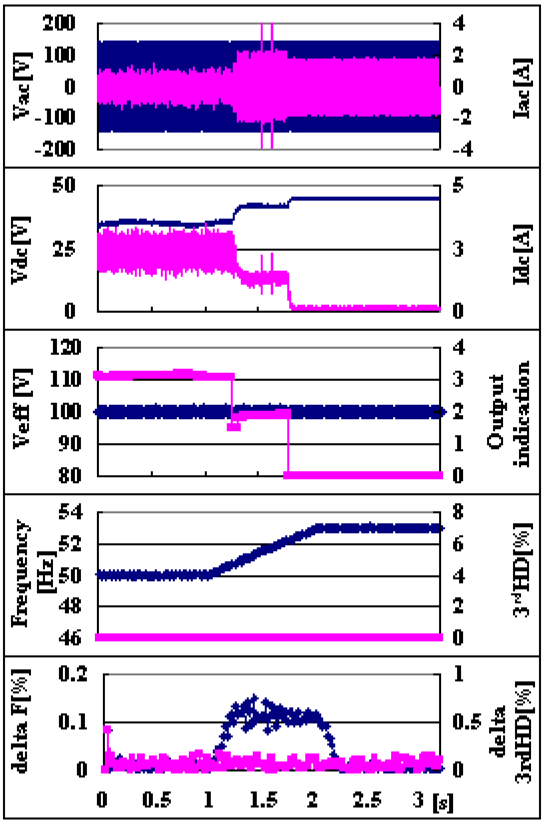

Figure 6: Measured data at the experiment of frequency smoothly changes from 50[Hz] to 53[Hz] among 1.0 [s].

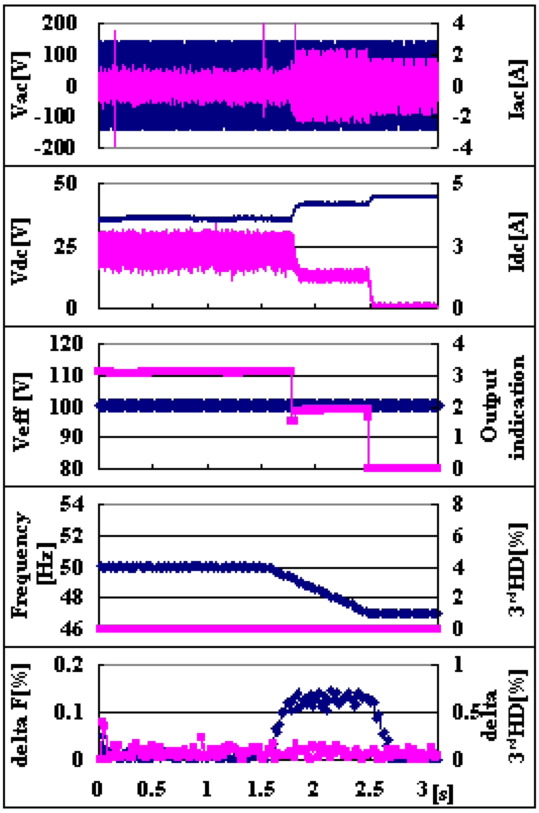

Figure 7: Measured data at the experiment of frequency smoothly changes from 50[Hz] to 47[Hz] among 1.0 [s].