THE EXPERIMENTAL RESULTS OF AN ISLANDING DETECTION METHOD FOR JAPANESE AC MODULES

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ABSTRACT

Recently, AC modules are familiarized in Europe and US. However, there are still several problems, which need to be dealt with, for instance islanding that is one of major requirements for grid connection of solar modules in Japan. In this study, an islanding detection algorithm has been newly developed according to a sequential approach and its basic operation has been confirmed. The purpose of this study is to find the optimum detecting thresholds by different experiments, that means by single and multiple operations. Here, several developed inverters together with newly developed ones with the algorithm were examined regarding islanding detections. In this paper, the results including test methods, conditions, observed waveforms are presented. This paper proposes an islanding detecting function for Japanese AC module from comparison of usual MIC and PVPC point of view.

1. INTRODUCTION

Photovoltaic (PV) system has been developed as a pioneer of renewable energy. Recently, AC modules, which typically consist of 1 square meter solar panels and a module-integrated converter (MIC) with control board, are familiarized in EU and US. The reason is that AC module has several advantages, for instance, it is more cost-effective in some cases and can be installed more easily than usual PV system. However it should be noted that AC module still has some problems. Although usual AC modules are installed in high density, in such a case, the inverters' control may affect other inverters and sometimes force other inverters to stop due to a misdetection issue. Although it becomes popular in Europe and US, however it doesn't spread in Japan. One of the reasons is the existence of the Japanese grid connection guideline [1] that requires different conditions from European or American codes. Furthermore the present Japanese guideline requires equipping a complete islanding protection in all inverters type including AC module because the latter is not yet specified anywhere. Therefore, both passive and active method should be provided. Based on the above-mentioned requirements, it is hoped to have an islanding detection method for AC module.

Islanding detection method for new developed inverter (PVPC) that had developed in the Regional Consortium Project [2] needs the following functions.

- To detect islanding safety and certainly.
- Not to affect another inverters in high-density institution.
- To satisfy the Japanese guideline.

This paper presents the experimental results of the islanding test of usual MIC and PVPC. Moreover, it presents the availability of islanding detection method of PVPC.

2. METHOD OF ISLANDING TEST

This islanding test investigates two usual MIC (inverter X, inverter Y) and a PVPC using scaled-down distribution network. For this purpose, a simulator had been developed by the authors [3]. Fig.1 shows a test circuit. Then, the islanding detection functions were tested under the following conditions:

- The load condition has two patterns, a RCL (resistance (R), capacitance (C), inductance (L)) and a RCM (R, C and induction motor (M)).
- Active power and reactive power are changed in steps of 10% at focusing on the balancing point among inverter output and load consumption.
- PV array I-V curve simulator imitates the PV array that its output is fixed to a rated output.
- All conditions are tested five times.

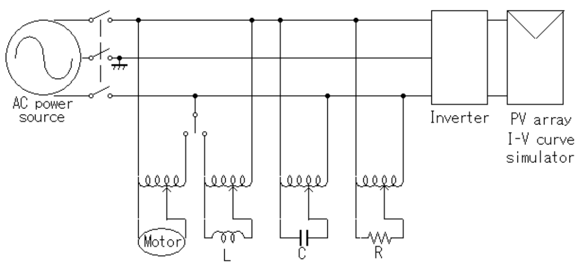

Fig.1 The experimental circuit

3. USUAL MIC IN EUROPE AND US

3.1 Performances of usual MIC

At present, AC modules are popular in Europe and US. These MICs have very high performances. For instance, efficiency of Maximum Power Point Tracking (MPPT) almost reaches over 90% at an explanatory note. In addition, they contain anti-islanding system that only observes grid voltage and frequency. However, this is not enough to detect islanding in Japanese guideline. Because the present Japanese guideline requires that all types of inverters including AC module equip a complete islanding protection. They should provide both passive and active methods.

Consequently, in this paper, it needs to confirm the availability of islanding detection method for usual MIC single, parallel and multiple operations.

3.2 Examination of a single operation for usual MIC

Firstly, islanding detection function of a single operation was tested. Figs.2-5 shows the test results respectively.

From these results, inverters X and Y have several islanding occurrence conditions in the worst-case. Especially, reactive power in near zero or -10% may easily occur an islanding phenomenon.

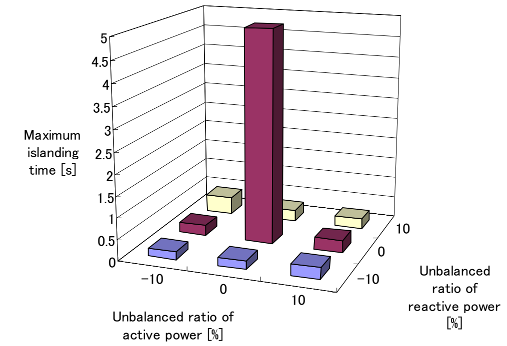

Fig.2 Test result of inverter X operation. (Load RCM)

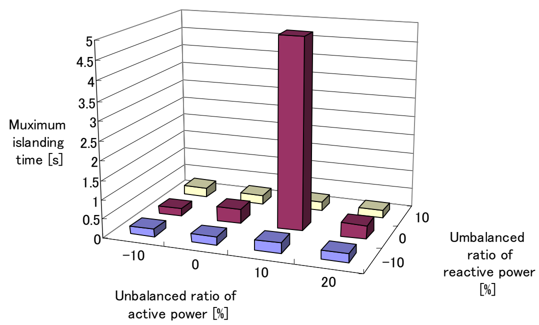

Fig.3 Test result of inverter X operation. (Load RCL)

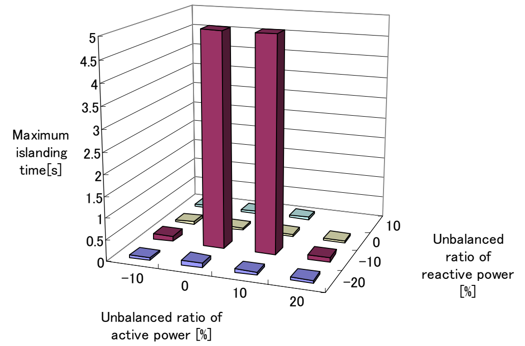

Fig.4 Test result of inverter Y operation. (Load RCM)

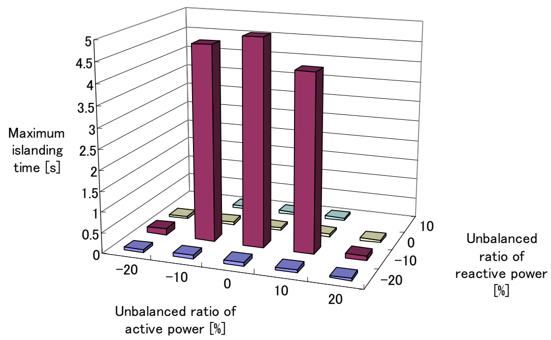

Fig.5 Test result of inverter Y operation. (Load RCL)

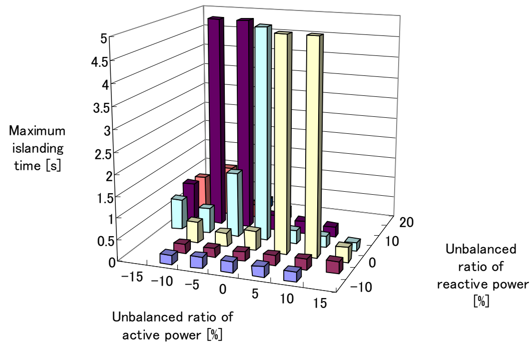

Fig.6 Test result of multiple operations. (Load RCM)

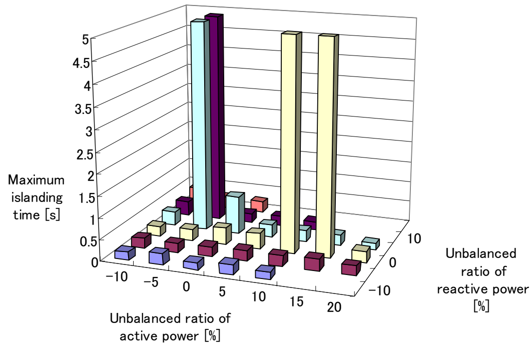

Fig.7 Test result of multiple operations. (Load RCL)

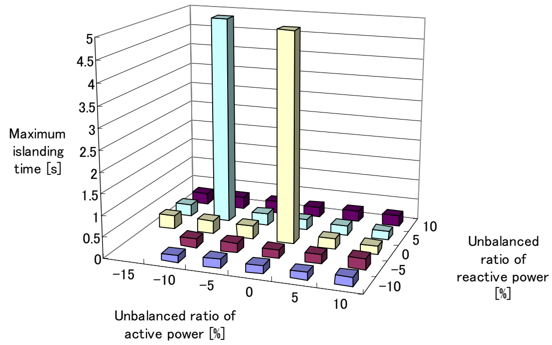

Fig.8 Test result of parallel operation. (Load: RCM)

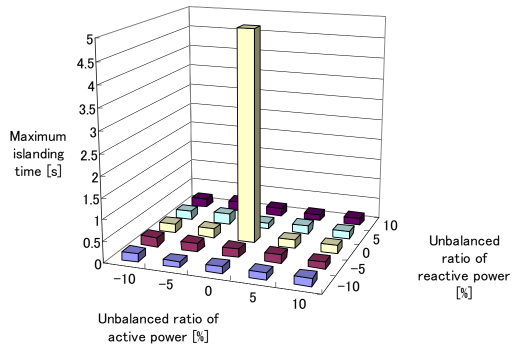

Fig.9 Test result of parallel operation. (Load: RCL)

3.3 Examination of multiple operations for usual MIC

As AC modules are almost connected to the grid through inverters, then, it becomes rather difficult to detect the islanding phenomena. Thus, four X inverters multiple operations were tested to pretend the worst case. Furthermore, different inverter parallel operations (inverters X and Y) were tested with the same distribution line. Figs. 6, 7 show the results of these multiple operations. Figs. 8, 9 shows the results of parallel operations with RCM and RCL load respectively.

From the results of multiple operations, the islanding conditions of four X inverters multiple operations increased as compare with the single operation. Because of this, it is considered that output power of each inverter makes interference with another inverters. Moreover, if dozens of MICs connected to the same distribution line, then the islanding occurrence condition will increase.

From the results of parallel islanding tests, as well as previous results, it is hard to detect the islanding phenomena by MIC's islanding protection.

According to usual MIC islanding tests, it shows that usual MIC connected single/parallel or multiple inverters have prospects of islanding.

4. NEW AC MODULE IN JAPAN

4.1 Performance of PVPC

The authors had developed an algorithm for a new AC module inverter that is suitable for the Japanese guideline. It consists of an inverter and a control board. The control board includes the total algorithm such as islanding protection and MPPT. The functions of the control board are to run the total algorithm and to output the current indication value.

Figure 10 shows the islanding detection algorithm flowchart. One of main feature of this algorithm is to simplify the Active/Passive Series Method [4], to combine a two-step passive detection and control the current of the inverter. The function of the two-step passive detection is to suppress the misdetection and mutual intervention.

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

When the low sensitive detects an islanding phenomenon, 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 an islanding phenomenon, the inverter output current decreases to half. Then, if grid voltage exists, there will be no influence on the system voltage waveform. If 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 a suitable current indication for the grid condition.

At present, accuracy of each detection method has confirmed in a simulation [5]. Additionally it was examined in basic islanding tests. From these basic islanding tests, the proposed algorithm exactly detected the small disturbance of the grid voltage and the grid frequency.

Table1 shows a threshold of each detection method. The low sensitive threshold is defined along the Japanese guideline. The high sensitive threshold is simulated by [5].

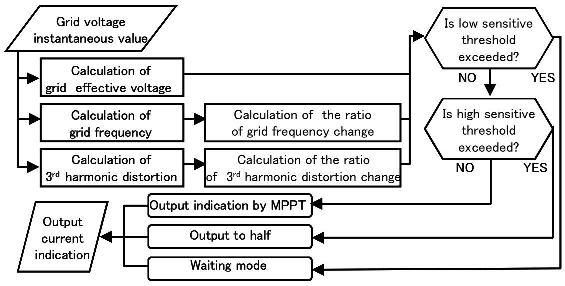

Fig. 10 The islanding detection algorithm flowchart.

Table 1. The threshold of each detection method.

Detection method	Threshold
Effective voltage level	90~110[V]
Grid frequency level	48.5~51.0[Hz]
3rd harmonic distortion	3[%]
Rate of grid frequency change	0.1[%]
Rate of 3rd harmonic distortion change	0.5[%]

4.2 Examination of a single operation for PVPC

In order to verify the islanding detection method for PVPC, a single islanding behavior was tested. The load conditions were taken similar to the usual MIC tests.

Then, at the single islanding test, PVPC tested without the high sensitive of islanding detection method. From this test, a PVPC islanding occurred due to maintain the grid system voltage and frequency. Fig11 shows the PVPC islanding phenomena without the high sensitive.

Figs.12, 13 show the test results with RCM and RCL loads, respectively. Based on the obtained results, it is confirmed that PVPC is exactly able to detect the islanding phenomena with worst-case load condition within 100 ms and the threshold of each detection method is propriety to detect islanding.

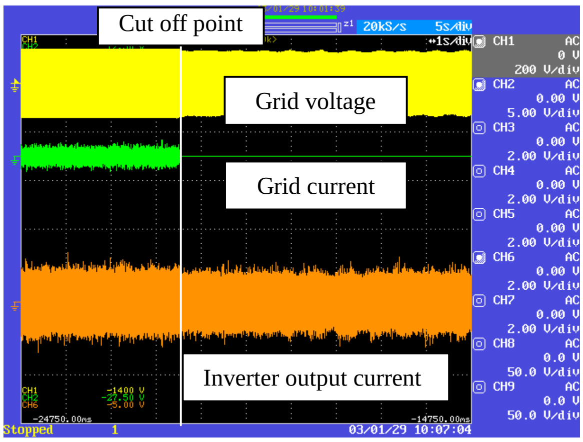

Fig. 11 Test result of PVPC without the high sensitive.

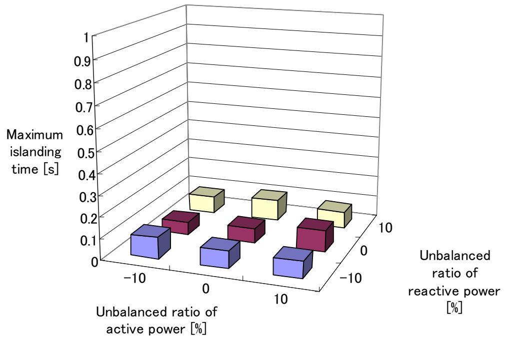

Fig.12 Test result of PVPC single operation. (Load RCM)

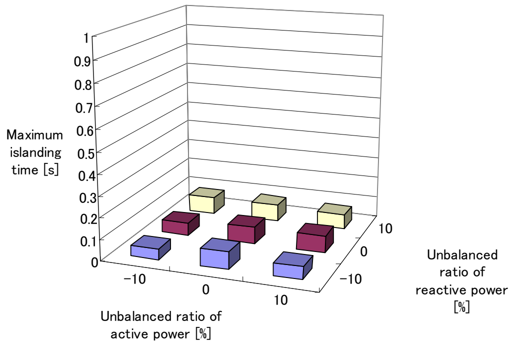

Fig.13 Test result of PVPC single operation. (Load RCL)

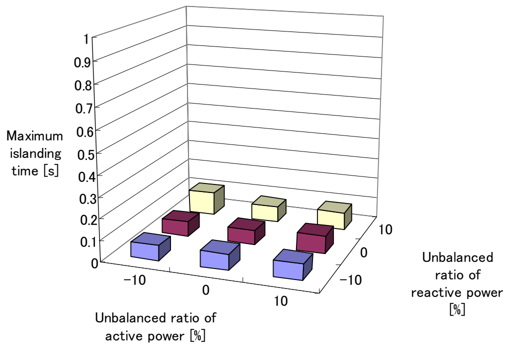

Fig.14 Test result of PVPC parallel operation. (Load RCM)

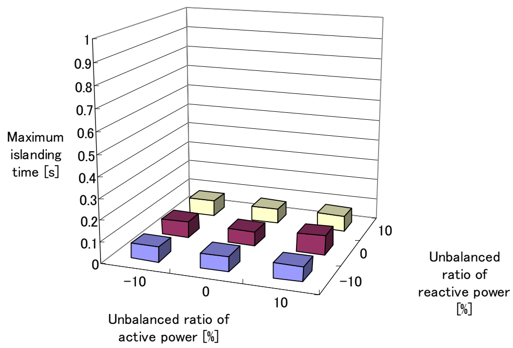

Fig.15 Test result of PVPC parallel operation. (Load RCL)

4.3 Examination of multiple operations for PVPC

As mentioned earlier, most serious problem of PV inverters is to cause islanding phenomena, especially, multiple operations are easy to cause islanding phenomena. Consequently, four PVPC were tested with the same conditions. Figs.14, 15 show the islanding test results of the multiple operations for PVPC.

From these results, it is obvious that there is no effect on interference of each output power, load condition and cut off point. All tested islanding phenomena were detected by PVPC within 100 ms.

According to PVPC islanding tests, it shows that PVPC connected single or multiple inverters are able to detect islanding phenomena.

5. CONCLUSION

In this paper, the experimental results of usual MICs and PVPC were presented. From the obtaining results, it is confirmed that in worst-case condition usual MIC can not detect the islanding phenomena in case of single and multiple operations. However, in the other hand, PVPC can overcome this shortage and detect the islanding phenomena in case of single and multiple operations. Consequently, it was clarified that developed islanding detection method for AC module is able to detect the islanding.

Ultimately, there are still some rooms for the future development of the present study. For instance, how to deal with the situation, when dozens of different AC modules have to be connected to the same distribution line, they may occur the islanding phenomena. Therefore, perfect optimal inverters suitable for preventing these phenomena are desired.

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