INTERCONNECTING MICRO CONTROLLER FOR PV SYSTEMS IN JAPAN

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ABSTRACT

Roof top system, which is the most popular PV system for residential use, has been growing all over the world. In Japan, almost all of the roof top systems have a power conditioner corresponding with the 3 to 4 kW of PV modules. These systems generate their maximum power under the ideal conditions, thus facing to one unified direction with adequate mount angle and without shadow. Generally residential area is bristling with buildings, which cast their shadows on PV arrays each other, and roofs of residences have various figures. Under these conditions, it is said that AC module that tracks each the maximum power operating point by a PV module is effective.

This study, a part of "Regional Consortium R&D Program", is focusing on the development of a 100 W class AC module that is suitable for the Japanese grid connection guideline. Our working group WG 2 has developed its controller part. This paper is a final report about the three years' activity of WG 2. A new controller and experimental results are introduced. The final conclusion and future view are also presented.

1. INTRODUCTION

Many kinds of residential PV systems have been developed, mounted and increasing on a lot of houses. These systems are generally classified into two types, one of them has DC (direct current) wiring and one inverter, the other one called AC module has AC (alternative current) wiring and a module integrated converter (MIC) behind each PV module. In Japan, almost all of the roof top systems belong to the former one. In this type, DC wires of PV modules are connected in series and/or in parallel to a power conditioner with 3 kW to 4 kW capacities. It is known that partially shaded modules perform as resistance component, which reduce the total output power of the series/parallel connected modules. The same is applied to another case in which several PV modules have different characteristics by means of the difference of irradiation and so on. Residential areas are usually bristling with buildings and plants, which often cast their shadows on roof mounted PV arrays. Furthermore, roofs of residential houses are in various shapes and sizes, therefore the generated power from each PV module is different by the part on a roof. Against these problems, it is said that AC module is effective, which tracks the maximum power operating point

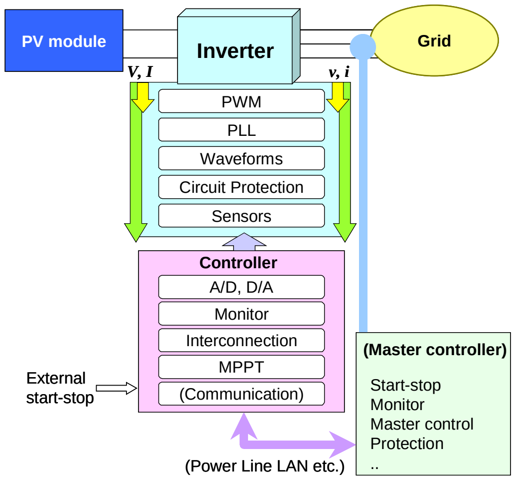

Figure 1: A system model of the proposed system.

by each PV module.

This study, a part of the "Regional Consortium R&D Program", is focusing on the development of a new AC module that is suitable for the Japanese grid connection guideline [1]. Our working group WG 2 has developed the interconnecting controller part under the program. This paper presents the final achievements of the WG 2 for three years. Three types of controller boards, the algorithm, the experimental results are shown. Then the activities of WG 2 under the research and development program are summarized.

2. SYSTEM CONFIGURATION

2.1 System Model

A system model with the controller is shown in Fig. 1. An inverter exists between a PV module and a grid. The developed AC module system is composed of two parts. One of them called inverter board has basic functions as a dc/ac power source including circuit protection. Sensors to sense its input and output voltage and current are also mounted on the board. The other one called controller board has functions to control the system as an inverter for grid connected PV system. The monitored values with the sensors on the inverter board are continuously given to the controller board through isolated operational amplifiers. The isolated operational amplifiers have been installed after

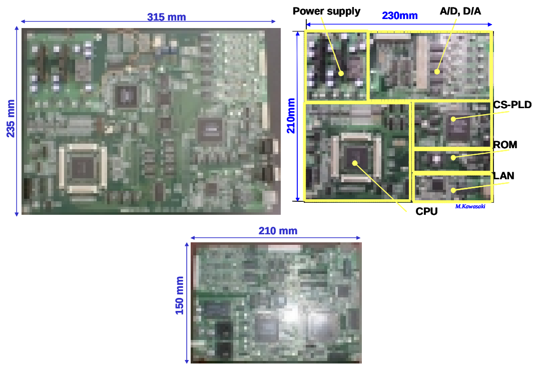

Figure 2: Controller boards, prototype (left), the second version (right), and the third version (bottom).

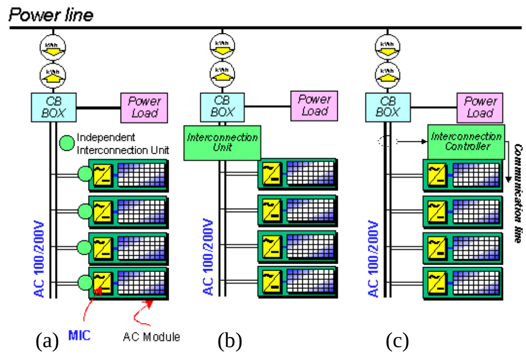

Figure 3: Total system configurations.
(a) Independent interconnection,
(b) concentrated interconnection,
(c) monitoring interconnection.

the second version to reduce the switching noise from the inverter board. Measured AC and DC waveforms are changed into digital data and stored in buffers on the controller board. Their root mean square (rms) values or average values and harmonic components are calculated with the CPU. Based on these data the controller monitors the condition of the system. The output power of the AC module is calculated and indicated to the inverter board as a parameter to control its output current. The functions of interconnecting protection and maximum power point tracking (MPPT) are included in the program.

Several functions which can be integrated into one common unit in a group of AC modules using communication system are shown in a square of the master controller in Fig. 1. These functions are still installed into each controller board at the present stage.

2.2 Controller Boards

The controller boards have been developed on main three steps. Figure 2 shows pictures of the controller boards manufactured by YEM Inc. The second version, as an example, consists of a microcomputer (SH7615 HITACHI [2]), CS-PLD, I/O ports, A/D and D/A converters, communication ports, and power supplies for ICs. All the functions mentioned in the previous subsection are covered. The other two boards have also the same function units on the board. The prototype was built in December 2001, which was 315 mm x 235 mm. It had been improved on the noise protection and the integration. The second version had been developed by August 2002, which was reported in 'PV in Europe' in October 2002 [3]. The final version was completed in December 2002. Its size has been reduced to 150 mm x 210 mm with four layers.

2.3 Discussion about Total System

As a group system, several models composed of some AC modules are expected. Some functions installed into the controller board are able to be separated and shared in the group. A master controller is composed of these functions as shown in Fig. 1. Figure 3 shows three models of total system. The Japanese grid connection guideline requires an interconnection circuit breaker (CB) between the generation systems and the grid system including the inner wires. Therefore CB box is drawn in all the three models. As shown in Fig. 3(a), conventional AC modules have all the functions as a power conditioner. From small systems composed of a few modules to larger ones, this type is equally adopted. However, in roof top system, several functions can be collectable in an extra controller as shown in Fig. 1, for example start/stop, monitoring, islanding detection and protection, and system protection. A system configuration shown in Fig. 3(b) has a concentrated interconnection unit in or by the CB. If the communication is available between the concentrated interconnection unit and AC modules, the functions can be divided to them, for example monitoring, detecting, and communicating are set in the unit and operating, protecting, and communicating are in each the module. This model is shown in Fig. 3(c). It was also discussed about the MPPT function. If a high-speed communication system with high reliability was available in low price, it could be realized with cost advantage, however we agreed that MPPT function should not be shared in the present stage.

The proposed controller is built as the all in one, therefore it is adaptable to an AC module, a CB as an interconnection unit, and a master controller.

3. BASIC ALGORITHM

A fundamental flow of the controller, assuming an all in one system, is shown in Fig. 4. The system operation is started by a start command. During the operation, the controller continues monitoring the system condition from the data of input and output voltage and current. When the grid voltage, that is equal to the output voltage, is within the standard voltage range, the controller permits the system to be the standby position. Then, the PV side condition is checked. If the open circuit voltage is in the normal range, the controller permits the system to start. The rms/average value, the grid frequency, and the third harmonic component are calculated based on the stored

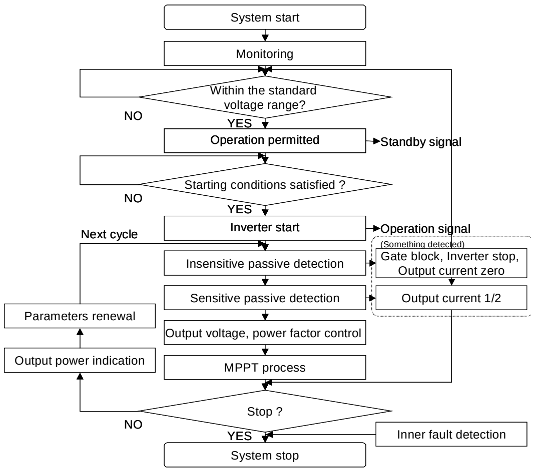

Figure 4: Flow chart.

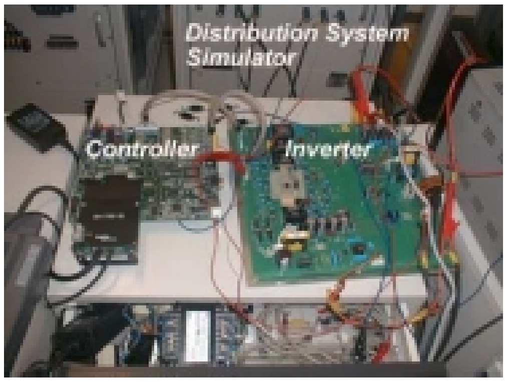

Figure 5: Experimental system with the second version controller and a fly-back inverter.

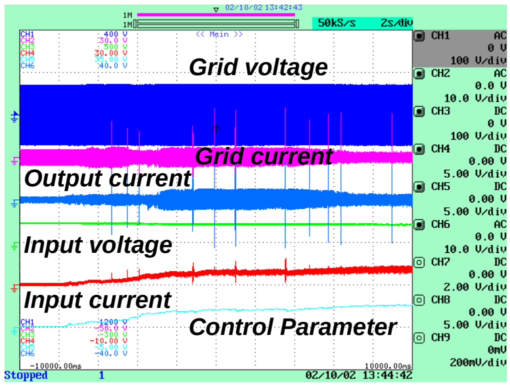

Figure 6: Observed waveforms in the second version system.

data. No sooner than a remarkable change is detected with the insensitive-passive detection algorithm, the inverter operation is stopped, which means a serious fault is occurred in a grid. The insensitive passive detection continuously checks the rms value of AC voltage and the third harmonic component, frequency, and phase shift with the thresholds. This function operates also as a low speed circuit protection system. Small deviation with possibility of islanding is detected with the sensitive passive detection algorithm. It checks the changing ratio of the grid frequency and the third harmonic component. Even if only one parameter goes over the threshold, the controller orders the inverter to reduce the output current to the half of the present value. If the inverter is in islanding phenomenon, the power decrease amplifies the fluctuation, which should be detected by the insensitive detection. This function operates as an active detecting function required in the guideline [1]. The combination method is proposed as the active-passive series method [4]. The algorithm used in the proposed controller is simplified with comparing to the original [5]. Unless any matters are detected, usual operation is continued.

The MPPT function is based on the algorithm which consists of Incremental conductance method (IncCond) and constant voltage (CV) method [6]. In our program, the present operating position on the I-V curve is found with the DC input voltage and current values by a cycle. Comparing to the present values and the last ones, a target value is calculated following the IncCond method and given as a DC target voltage. The output current is controlled to make the input voltage close to the objective. When the monitored DC voltage comes close to the aim, the program renewals the data and calculates the next target voltage. When it is difficult to keep the maximum power point by means of rapid changing of irradiation, or when the monitored input voltage is less than 24 V, the algorithm is changed to CV method. In this mode, the target voltage is kept to the 85 % of the open circuit voltage for a while.

The system stops, if a trouble is found in the controller or the inverter, or if stop command is given. At first the above process was synchronized to each the grid cycle however it was impossible to keep its stable operation during islanding phenomenon. Then it has been improved to synchronize with the inner clock.

4. EXPERIMENTAL RESULTS

The proposed controllers have been tested. At first the prototype controller with a fly-back inverter was tested in December 2001. The operation as a system was observed however it was difficult to test each the function because of the noise. Mainly the experiments have been carried out with the system composed of the second version controller and a fly-back inverter shown in Fig. 5. This system was connected to an reduced scale distribution system simulator [7] at the AC side and connected to a PV module simulator at the DC side. Basic operations following the algorithm have been confirmed and tuned the levels of the amplifier's gain between the inverter and controller. Figure 6 shows observed waveforms in an interconnecting test. In this time, the I-V curve simulator was set and fixed at the fill factor 0.8 with the maximum out put power of 94 W. The observed pulse noise was caused by the inverter operation and it has become better and disappeared by improvement of the elements. The MPPT operation is observed in the waveforms. The control parameter was raised to the maximum power point and tracked around it. Against rapid 10 W down and up of irradiation parameter, the MPPT function was able to adapt them. The MPPT operation tests have been repeated and tuned under many kinds of I-V curves with various fill factors from 0.4 to 0.85. The islanding detection and protection have been also tested and confirmed under different conditions for example with resistance load, reactive load, and capacitive load and/or with additional PV inverters. Furthermore, four copies of the second version system were connected in parallel to the grid simulator and tested. The proposed system has been well detected the islanding phenomena and stopped within 0.1 second in all cases. Especially, even if one proposed system was connected in parallel to the grid simulator with a conventional PV inverter with masked islanding detection, the proposed one stopped within 0.1 second. The details about the series of test results are reported in 6P-D5-15.

The third version was also tested at the final term of the project. About the controller, all the functions are the same to the second one. Figure 7 shows a system composed of the third version controller, an inverter and an interface board. Each the inverter and the controller have been improved in the size. The interface is a part of the fly-back inverter shown in Fig. 5. The interface exists only for noise protection therefore it is to be removed by the choice of inverter application or improvement of the board. Figure 8 shows observed waveform in this system under a fixed I-V curve condition with 0.7 fill factor and 95W maximum power. Compared to Fig. 6, the pulse noise has disappeared. The other performance is similar to the last one. This system was tested to confirm the operation as the final trial product.

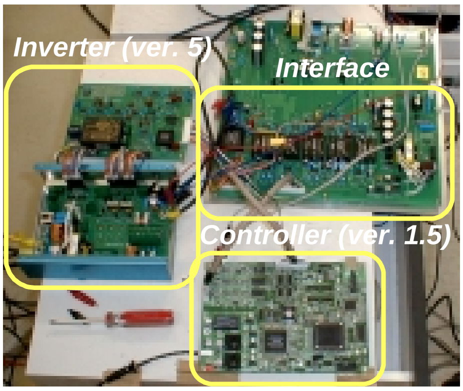

Figure 7: Experimental system with the third version controller and a fly-back inverter.

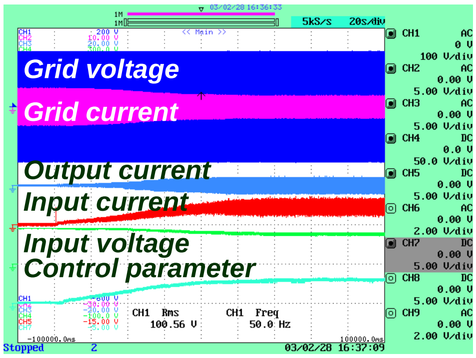

Figure 8: Observed waveforms in the third version system.

5. SUMMARY

An interconnecting micro controller for Japanese PV system has been developed with a 50 MHz class microcomputer and simple interfaces. Trial models as an AC module have been built and tested. Basic functions as an AC module including MPPT and islanding protection have been confirmed with the trial models. Islanding tests with a distribution system simulator have been carried out. The proposed system shows excellent performance in islanding protection. Total system configuration and application of the controller have been discussed. The proposed controller is adaptable to an AC module controller, a master controller, or an independent interconnecting equipment. Application to these systems and development of control methods as a group system of AC modules are subjects in the future study.

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