DEVELOPMENT OF INTERCONNECTING MICRO CONTROLLER FOR PV SYSTEMS IN JAPAN

H. Koizumi*, K. Nagasaka*, K. Kurokawa*, N. Goshima**, M. Kawasaki**, Y. Yamashita**, A. Hashimoto#
* Tokyo University of Agriculture and Technology, 2-24-16 Naka-cho, Koganei-shi, Tokyo 184-8588, Japan
Phone: +81-42-388-7132, Fax: +81-42-385-6729, E-mail: koizumih@cc.tuat.ac.jp
** YEM Inc., 1-3-33 Okata, Atsugi-shi, Kanagawa 243-0021, Japan
# Yokogawa Research Institute Corporation, 2-9-32 Naka-cho, Musashino-shi, Tokyo 180-8750, Japan

ABSTRACT: Tokyo University of Agriculture and Technology (TUAT) and YEM Inc. have been developing a new interconnecting micro controller for PV systems in Japan. This paper presents the current steps and achievements of the development. The proposed controller aims especially at applying to AC modules and to the other inverters for PV systems. AC modules in the markets are mainly designed for the specification of Europe or US. To connect such a circuit to the distribution lines in Japan, appropriate interconnecting function must be added in the equipment. The proposed controller, which monitors the DC and AC waveforms at the input and the output ports of a PV inverter, provides all the functions for grid connection using a microcomputer.

Keywords: AC-Modules, Power Conditioning, Grid-Connected

1 INTRODUCTION

Recently PV systems for residential use have been increasing all over the world. Also in Japan, PV systems on the roof have been growing. These systems usually supply their generation power through a 3 kW to 4 kW class of power conditioner. Generally the residential area is bristling with houses buildings and plants. They often cast their shadows on the roof mounted PV arrays. Sometimes, the output power is reduced with the shady cells. Against the matter, AC modules give a solution. However, AC modules in the markets are mainly for Europe or US in their specifications. To connect such a circuit, appropriate interconnecting functions must be modified for the system in Japan [1].

Tokyo University of Agriculture and Technology (TUAT) and YEM Inc. have been developing an interconnecting micro controller. The function for grid connection is able to be installed as a program. The controller set to an inverter enables the system to be connected to distribution lines. A prototype board [2] has been made and tested. The second version board has been developed and is under the examination. There is still room for improvement. This paper shows the current steps and achievements of the first stage development.

2 DESCRIPTION OF THE CONTROLLER

Figure 1 shows a picture of the second version controller manufactured by YEM Inc. It consists of a microcomputer (SH7615 HITACHI [3]), CS-PLD, I/O ports, A/D and D/A converters, communication ports, and power supplies for ICs. The size of the board is 210 mm x 230 mm, which is widely designed to connect a probe over the microcomputer and for some experiments. Figure 2 shows a system model using the proposed controller. The controller monitors the inverter's condition by monitoring the input and output voltages and currents. These AC and DC waveforms are changed into digital signals. Isolation amplifiers are now set in the inverter to reduce the influence of switching noise. The output power of the inverter is controlled following the calculation results based on the captured data. Interconnecting protection and maximum power point tracking (MPPT) are set in the program files, which are

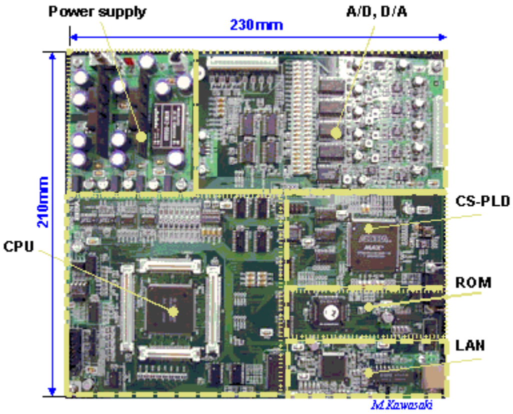

Figure 1: Interconnecting micro-controller board.

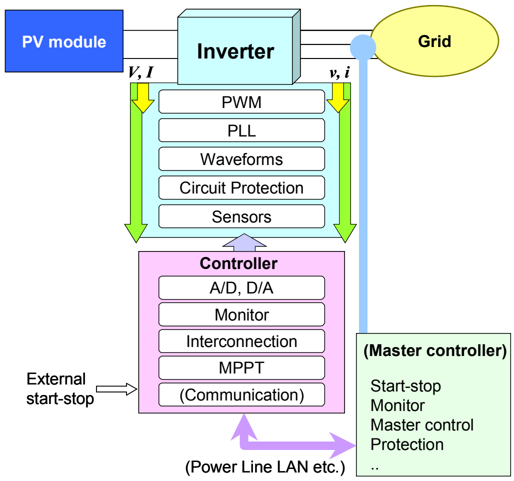

Figure 2: A system model using the micro controller.

rewritable. As shown in this figure, circuit protection, PWM, and voltage/current censers are in the main board of the inverter. On the present step, the master controller and inverter controller are set in the same board. These are able to be divided with keeping data communication. If an inverter has the functions shown in the model, the proposed controller is easily applied to it.

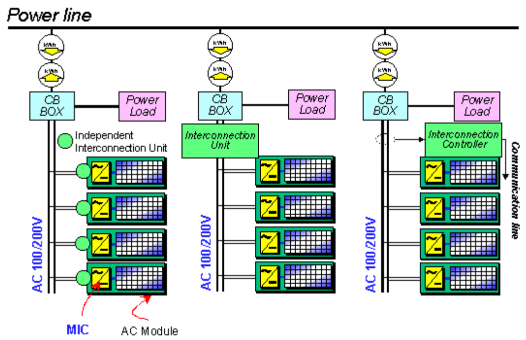

Figure 3: Total system configurations.
(a) Independent interconnection, (b) concentrated interconnection, and (c) monitoring interconnection.

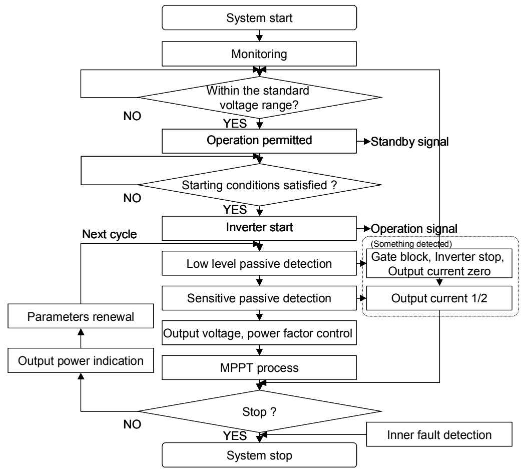

Figure 4: Flow chart.

2 TOTAL SYSTEM CONFIGURATIONS

This controller is assumed to be used in an AC module. As a total system, several models composed of some modules are expected. Therefore the required functions of the controller have to be adapted to each case. As shown in Fig. 3(a), conventional AC modules have all the functions as a power conditioner. In this case, even if a customer sets only one AC module, it is possible to use as a small grid connection system. However, in a roof system, usually many modules are mounted. Therefore the interconnecting function can be collectable in an extra controller, which has a possibility that the total cost is reduced in some cases. A system configuration shown in Fig. 3(b) is an example of interconnection system with a circuit breaker (CB) set in the CB box. In the system of Fig. 3(c), an extra unit is put independently to control each the AC module. In this way, communication system is required. At the present stage, all the systems and their fusion are under consideration for the final version. The prototype board and the second version have all the functions.

3 FUNDAMENTAL FUNCTIONS OF THE CONTROLLER

A fundamental flow of the control system is shown in Fig. 4. The system operation is started by a order which is to be a switch, the sun shine or a signal from the master controller. During the operation, the controller constantly monitors the input and output voltage and current of the inverter. The waveforms are sampled at about 500 points per one grid cycle and changed to digital data. When the grid voltage, that is equal to the output voltage, is within the standard voltage range, the controller permits the inverter circuit to be standby position. Then, the DC side condition is checked. If the open circuit voltage is in the normal range, the controller permits the inverter to start. The rms/average value, the grid frequency, and the third harmonic are calculated based on the stored data by the grid cycle. No sooner than a remarkable change is detected with the insensitive-passive detection algorithm, the inverter is stopped. Small deviation with possibility of islanding is detected with the sensitive passive detection algorithm. In this case, output power of the inverter is reduced to the half of it, which performs as an active detecting function and magnifies the deviation if in the islanding condition. This method is proposed as the active-passive series method [4]. Unless any matters are detected for one cycle, next output power is calculated in the MPPT process and indicated as the output current parameter. The system stops, if a trouble is found in the controller or the inverter, or if system stop command is given. The above process is usually synchronized to each the grid cycle.

4 PROTECTION FOR GRID CONNECTION

4.1 Islanding protection

As mentioned above, the active-passive series method is applied to the islanding detecting function of the controller. The details are explained in a relating paper of OE6.3 [5] in this conference record. The algorithm is simplified with comparing to the original. The insensitive passive detection simply checks the rms value of AC voltage, frequency, phase shift, and the third harmonic with the thresholds. This function can be also used as a protection system. The other one, the sensitive passive detection is specified to detect a small sign of an islanding phenomenon. It checks the changing ratio of the grid frequency and the third harmonic. 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 the islanding system, the power decrease causes the system voltage reduction. It should be detected by the low sensitive detection. At first, the algorithm was tested with a personal computer using some data sets observed in some islanding phenomena [6].

4.2 Islanding test

Islanding phenomena are tested in a grid simulator. In our study, a reduced scale distribution system simulator was built for the tests [7]. Figure 5 shows the reduced scale distribution system simulator. The simulator consists of an AC power supply, *L*-*R* circuit as a distribution line, and the load of *R*, *L*, *C*, and an induction motor. In this system, 4 commercial power

Figure 5: The reduced scale distribution system simulator.

conditioners have been tested. Two of them are able to be set the islanding detections off. Islanding phenomena can be meanly realized using a power conditioner in the off-detecting mode. These data have been used to test the detection program. In the prototype, the noise component of the waveforms prevented the algorithm from the correct detection. In the second version, islanding tests have been repeated [5]. About the second version controller, more sivier tests have been carried out. Thus, an assumed deviation is once given by the programable AC power sourse and it keeps on supplying after the modification without any matter. The performance of the controller was agrreed with the theoritical prediction.

4 MAXIMUM POWER POINT TRACKING

A lot of MPPT algorithms have been proposed [5]. In this study, three conventional algorithms, perturbation and observation (P&O), Incremental conductance (IncCond), and constant voltage (CV) have been built and simulated with assumed data. At the present stage, the IncCond was selected and installed. In our program, the present operating position on the I-V curve is found with the input voltage and current. Comparing to the present values and the last ones, a target value is decided as a value of DC voltage. To close to the value, the output current is controlled. The indication parameter is sent to the inverter by the grid cycle. When the monitored DC voltage becomes close to the aim, the program renewals the data and calculates the next aim [8].

5 EXPERIMENTAL RESULTS

The prototype controller of TUAT and YEM was connected with a fly-back inverter of Tokyo Metropolitan Univ. and Niwa Elec. Inc. with the interface board (IF) as shown in Fig 6. The MPPT, islanding detection, and increased voltage protection programs were installed into the microcomputer (SH7615) in the controller. The circuit protection, PWM, and PLL functions were in the inverter circuit itself. The observed waveforms in the test with PV array simulator are shown in Fig. 7. In this test, I-V curve was fixed. The MPPT function sought to track the maximum power point. In this version, only the basic operation as a PV inverter system composed of an inverter and a controller was confirmed. However it was impossible to test the islanding detection and interconnection with the rated

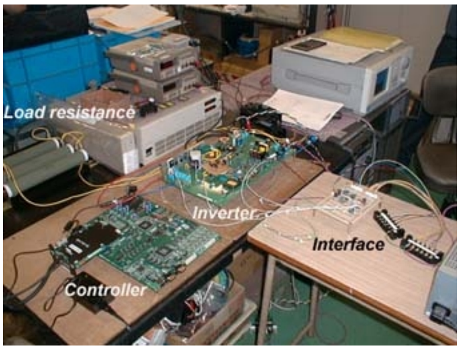

Figure 6: Experimental system with the prototype controller and the inverter.

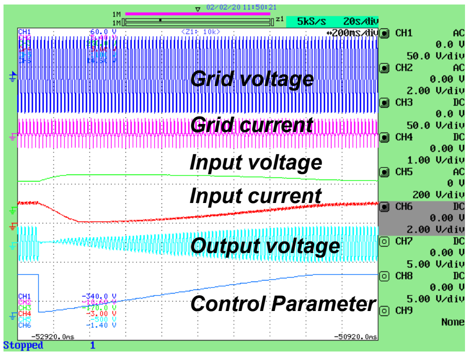

Figure 7: Observed waveforms in the prototype system.

power because of the noise interference on the controller in case of grid connection. When the Fig. 7 was observed, to confirm the parameter's performance and the other waveforms, the inverter was forced to operate without grid connection.

Against the problem, the second version of the controller has been made, and the inverter has been also improved. Figure 8 shows an experimental system composed of the new circuits. This system is connected to the reduced scale distribution system simulator. All the basic operations have been confirmed. The operation from zero output power to the rated output power was confirmed in the condition of grid connection. Figure 9 shows the observed waveforms in an interconnecting experiment. The I-V curve simulator was set on the fill factor of 0.8 with the maximum out put power of 94 W. The MPPT operation is observed in the waveforms. It is shown that following the increase of the output current, the grid current decreased. The AC current waveform includes pulses. The reasons are now under the study. In some cases, these pulses cause a miscalculation to the micro controller. The output current indicating parameter was controlled to track the maximum power point. The I-V curve was fixed in this test. Against rapid changes of the irradiation, this program kept the operation. Now the MPPT operation is still under the tests for many kinds of I-V curves with various fill factors and irradiance conditions. Especially MPPT operation in low power conditions with low FF is a problem to be solved immediately. The islanding detection was also tested and the operation was confirmed. The details are reported in [5].

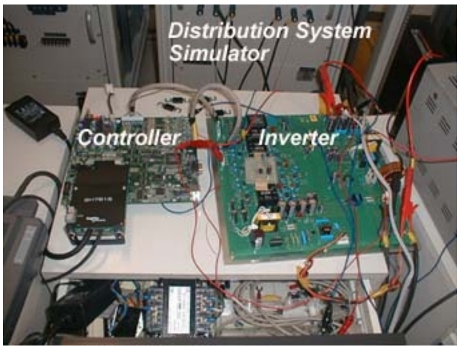

Figure 8: Experimental system with the second version controller and the inverter.

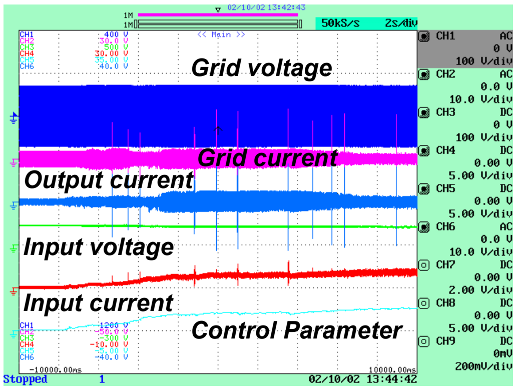

Figure 9: Observed waveforms in the second version system.

6 CONCLUSION AND FURTHER RESEARCH

Development of the interconnecting controller for Japanese PV systems has been introduced. The prototype controller and the second version have been described. The main algorithms have been shown. The experimental results by the present stage have been reported about both the circuits. The basic functions of the second version controller are still under the development, however many good performances have been confirmed as a PV inverter controller for a grid connection system.

The following items are still under the study for the next version.

- Total system configurations and communication
- Interface to the inverter
- Power supply to the controller
- Evaluation about the dynamic response against irradiation change
- Size and cost reduction

The next version will be presented in WCPEC-3 in Osaka Japan.

This development has been carried out as a part of the "Regional Consortium R&D Program", funded by the New Energy and Industrial Technology Organization (NEDO) from FY2000 to FY2001 and by the Ministry of Economy, Trade and Indusrty (METI) in FY2002.

REFERENCES

[1] Agency of natural resources and energy, "Guideline to regulate utility-connection technology '98", Denryoku shinpo-sha, 1998 (in Japanese).
[2] NEDO et al. "The 2nd annual report on the regional consortium R&D: development of distributed power conditioner for PV systems" (in Japanese).
[3] http://global.hitachi.com/New/cnews/E/1999/991206B.html.
[4] H. Kobayashi et al. "Method for preventing islanding phenomenon on utility grid with a number of small scale PV systems", *Proc. The 22nd IEEE PVSC*, pp. 695-700, Oct. 1991.
[5] T. Mizuno et al. "The islanding detection algorithm of a new AC module for grid connection in Japan", Proc. PV in Europe, OE6.3 Oct. 2002.
[6] T. Mizuno et al. "Inference of islanding detecting factor in commercial PV inverters", *Proc. 13th Annual Conf. of Power & Energy Society. IEEJ*, vol A, pp. 597-598, Aug. 2002 (in Japanese).
[7] Y. Noda et al. "The development of a scaled down simulator for distribution grids and its application for verifying interference behavior among a number of module integrated converters (MIC)", *Proc. The 29th IEEE PVSC*, May 2002 (to be published).
[8] T. Kaito et al. "A study on MPPT function of digital inverter", *Proc. 13th Annual Conf. of Power & Energy Society. IEEJ*, vol A, pp. 603-604, Aug. 2002 (in Japanese).