DYNAMIC RESPONSE OF MAXIMUM POWER POINT TRACKING FUNCTION FOR IRRADIANCE AND TEMPERATURE FLUCTUATION IN COMMERCIAL PV INVERTERS

Hirotaka Koizumi*, Takashi Kaito*, Yukihisa Noda*, Kosuke Kurokawa*, Masayasu Hamada** and Liu Bo**
* Tokyo University of Agriculture and Technology
2-24-16 Naka-cho, Koganei, Tokyo, Japan 184-8588,
Phone: +81-42-388-7132, Fax: +81-42-385-6729, E-mail: koizumih@cc.tuat.ac.jp,
** Myway Labs Co., Ltd.
1-19-3 Shinyokohama, Kohoku-ku, Yokohama, Kanagawa, Japan 222-0033
Phone: +81-45-476-3722, Fax: +81-45-476-3723

ABSTRACT: This paper presents test results of Maximum Power Point Tracking (MPPT) functions of commercial PV inverters for residential use against rapid fluctuation of irradiance and temperature with a PV array I-V curve simulator. PV array simulator is greatly effective in test of PV inverters, because an experimental condition can be reproduced many times. In this study, a PV array simulator was used, which had been developed by Tokyo University of Agriculture and Technology (TUAT) and Myway Labs Co., Ltd. Characteristics of the simulator with dc load, basic response for each tested PV inverter, and test results of MPPT function of the inverters are clearly reported.
Keywords: MPPT - 1: I-V curve simulator - 2: Inverter - 3

1. INTRODUCTION

Maximum Power Point Tracking (MPPT) function is normally installed in PV inverters to gain the maximum power from PV array. Many kinds of algorithms have been proposed and various MPPT systems are installed in power conditioners. In this paper, MPPT function of commercial PV inverters for residential use is tested and reported. Comparing different types of inverter, we have to serve the same condition for experiment. In the series of tests, a PV array I-V curve simulator was used, which is developed by Tokyo University of Agriculture and Technology (TUAT) and Myway Labs Co., Ltd. That is based on the active power load (APL) of Myway and software for I-V curve simulation of TUAT. The characteristics of I-V curve by Matsukawa et al. [1] can be realized with the simulator. So, irregular pattern caused by shading etc., can be simulated. In our previous research [2], one commercial PV inverter has been tested with the simulator. In this paper, basic response of the simulator and inverters, and their dynamic response of MPPT function are tested and reported.

2. PV ARRAY I-V CURVE SIMULATOR

A basic structure of PV array I-V curve simulator including APL [3] is shown in Fig. 1. A personal computer (PC) and the APL are connected by optical fiver with RS232C. At first, an I-V curve is generated in the PC. Then the data of the I-V curve is transmitted to APL. Following the data, the APL performs as a PV simulator. During the operation, parameters are transmitted from APL to PC and monitored every one sec. The I-V, P-V curves, value of maximum power P_{MAX} and output power are also indicated. Advantages of the PV array I-V curve simulator are summarized as follows.

1. Simulating irradiance every one second, maximum for 9 hours
2. Preinstalled standard patterns of irradiance fluctuation (Additional files are able to be installed.)

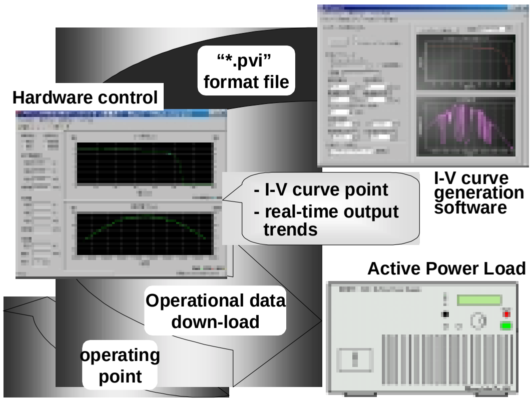

Fig.1: Basic structure of PV array I-V curve simulator.

3. Faithfully simulated output characteristics of PV array (Parameters are able to be set.)
4. Size, weight, and cost reduction
5. Operation by a PC with convenient handling
6. Simulating an enough scale of PV array for a standard residence
7. Further utilization as constant voltage and/or current power supply.

3. RESPONSE TIME OF PV ARRAY I-V CURVE SIMULATOR

Basic response of the PV array I-V curve simulator is tested. A circuit model for this measurement is shown in

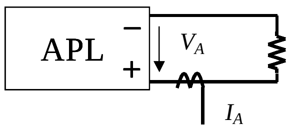

Fig. 2: Circuit model for measurement.

Fig. 2. Tests for sudden irradiance fluctuating and for rapid load variation have been carried out. Array configuration is assumed to be 6-series 7-parallel. The simulator was loaded with an resistance of 20 Ω. Array temperature was assumed to be 25 deg constant. Under this condition, electrical power supplied from the PV array simulator becomes 3.0 kW for irradiance of 1.0 kW/m^2 and 0.30 kW for 0.1 kW/m^2 respectively. At first, irradiance was stepped up from 0.1 kW/m^2 to 1.0 kW/m^2 and stepped down from 1.0 kW/m^2 to 0.1 kW/m^2. Against sudden irradiance fluctuation, output voltage and current of the simulator changed with transient response time 26.8 msec and 20.7 msec for stepping up and down respectively.

In the same system, rapid load variation tests were carried out. Load resistance was stepped up from 40 Ω to 20 Ω and v.v. During the tests, irradiance was kept at 1.0 kW/m^2. The rapid load variation was caused by turning a DC-circuit breaker on and off which was connected to a parallel resistance of 40 Ω. The observed transient time against rapid load variation was 12.8 msec and 16.0 msec for stepping up and down of the load respectively.

In the same experimental system, temperature variation tests were carried out with constant irradiance 1.0 kW/m^2 and load resistance 20 Ω. The temperature of PV array was set to step up from 40 deg to 60 deg and v.v. The simulator changed its output voltage and current within 16.9 msec for stepping up and 13.0 msec for stepping down of the temperature.

4. TESTS OF COMMERCIAL PV INVERTERS' BASIC RESPONSE TIME

Four kinds of commercial PV inverters for residential use were tested with the PV array I-V curve simulator in the experimental system shown in Fig. 3. The output of PV inverter is connected to an independent AC power source of 1ϕ 3W 100/200 V_{rms} at 50 Hz. Between the inverter and the AC power source, a load resistance of 20 Ω is connected. Array configuration was set 6-series 7- parallel to feed 3.0 kW for irradiance of 1.0 kW/m^2. Rated output power and the input voltage range of the tested power conditioners are shown in Table I.

4.1 Tests for Sudden Irradiance Variation

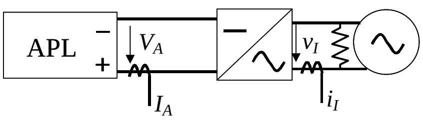

Fig. 3: Circuit model for tests of inverter.

Table I: Rated output power and the input voltage range of the tested commercial PV inverters.

Inverter	A	B	C	D
Rated power (kW)	4.0	4.5	4.5	3.5
Input voltage range (V)	0-350	0-350	70-370	0-400

In this test, irradiance was stepped up and down between 1.0 kW/m^2 and 0.1 kW/m^2. Concerning to this test, data for Inverter D are not shown, because it had stopped just after the irradiance stepping down and didn't restart under the condition of 0.1 kW/m^2 irradiance. We suppose that this phenomenon was caused by protective function of the inverter. Observed waveforms were complex and quite different by the inverters. The response time read from the waveforms and time to achieve the maximum power point (MPP) are shown in Table II. Waveforms of V_A, I_A, v_I, and i_I, which are DC voltage and current from the PV array simulator and AC voltage and current from an inverter, were observed. In the series of the tests, transient waveform was not observed about v_I. Therefore, except v_I, we defined the transient response time of the other waveforms as follows, V_A: the time from the stepping transition to the first temporary steady state, I_A: the time from the stepping transition to the end of the over/under shoot, and i_I: the time from the stepping transition to the first temporary steady state, especially about stepping up just after the cycle with maximum amplitude. As shown in the Table II, all the values of measured response time were within one second. During this term, it was observed that the inverters tried to get close to the MPP rapidly with large steps. After the term, inverters controlled their operating point to MPP slowly with small steps following their own algorisms.

4.2 Tests for Sudden Temperature Variation

In the same experimental system, temperature parameter of PV module was stepped up from 40 deg to 60 deg and v.v. with irradiance of 1.0 kW/m^2. The measured

Table II: Measured response time and time to achieve MPP of the tested commercial PV inverters against irradiance fluctuation.

Inverter		A	B	C	D
Measured response time from 1.0 kW/m^2 to 0.1 kW/m^2 (ms)	V_A	894	194	84.9	-
	I_A	19.2	5.98	5.31	-
	i_I	28.9	52.0	21.9	-
Time to get MPP (s)		12	171	8	-
Measured response time from 0.1 kW/m^2 to 1.0 kW/m^2 (ms)	V_A	23.0	120	92.2	-
	I_A	12.1	13.9	4.39	-
	i_I	136	50.1	77.0	-
Time to get MPP (s)		57	371	29	-

Table III: Measured response time and time to achieve MPP of the tested commercial PV inverters against temperature.

Inverter		A	B	C	D
Measured response time from 40 deg to 60 deg (ms)	V_A	20.9	12	46.0	88.4
	I_A	3.11	16.9	35.1	14.6
	i_I	30.4	19.9	60.5	50.8
Time to get MPP (s)		296	67	110	52
Measured response time from 60 deg to 40 deg (ms)	V_A	49.8	52.0	216	94.2
	I_A	7.99	13.3	3.60	65.2
	i_I	40.1	58.1	120	82.2
Time to get MPP (s)		261	55	89	125

response time of each inverter is shown in Table III. Response time of each parameter was measured following the same definitions in irradiance fluctuation. Also in this test, observed waveforms were complex and quite deferent by the inverters. And the values of measured response time are various. Comparing Table III with Table II, no relations are found in our tests. Thus, MPPT function and transient response are not so simple, and they might have different operation by the cases of directions or values of variation, or transient time and so on.

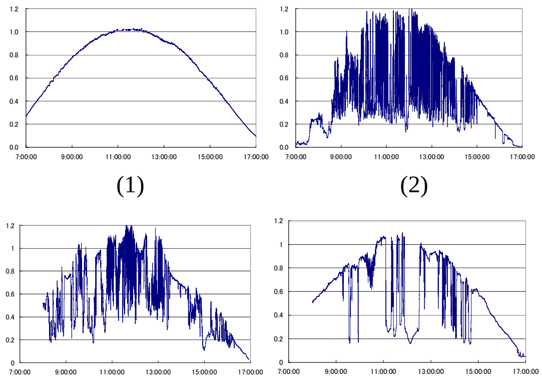

Fig.4: Default irradiance patterns: (1) Clear; (2) Vary-1; (3) Vary-2; (4) Vary-3.

5. TESTS OF PV INVERTERS FOR MPPT FUNCTION

5.1 Default Data of Irradiance Fluctuation

The commercial PV inverters were tested for MPPT function. The test system shown in Fig. 3 was used under the same condition to the basic response tests except array configuration set to 6-series 6-parallel in this test. Figure 4 shows the default data sets prepared for a typical clear sky pattern “Clear” and three kinds of fluctuating patterns “Vary-1”, “Vary-2” and “Vary-3”. These are chosen from actual observation with 1 second sampling at Tsukuba around 4 years since 1996. In the series of the tests, the data from 12:00 to 13:00 were used. A factor K_{PM} is defined for evaluating the inverter’s MPPT control capability.

$$K_{PM} = \frac{\sum PV\ array\ Output\ Power}{\sum P_{MAX}} \times 100[\%] \qquad (1)$$

5.2 Assumption of Array Temperature Variation

Presumption of array temperature usually requires many parameters and complex calculation. In this paper we assume the following equation for simplifying the calculation,

$$T_{CR} = T_A + \Delta T,$$
$$\Delta T = (-6.036 + 0.274 \cdot V + 0.071 \cdot V^2) + H_{AE} \cdot (45.63 - 5.91 \cdot V + 0.333 \cdot V^2), \qquad (2)$$

where, T_{CR}, T_A, V, and H_{AE}, are array temperature, air temperature, wind velocity, and irradiance. T_A = 25 deg and V = 1.0 m/s are assumed. The PV array simulator allows an operational mode of high-speed irradiance fluctuation and followed temperature variation.

5.3 Experimental Results

Using the irradiance default patterns, PV inverters were tested. Figure 5 shows the experimental results for each inverter under the various irradiance fluctuation. The power P_{max} and voltage V_{pmax} at PMAX point, the output power P_A and voltage V_A of PV array simulator, and mismatch P_M between P_{max} and P_A are shown as functions of time. Array temperature was assumed to be constant at 25 deg from (a) to (d). Then, array temperature was fluctuated following the moving average of irradiance data with 1 min averaging spans for data set of Vary-2, which is shown in (e). The factor of MPPT control capability K_{PM} is calculated and shown in Table IV. As shown in Fig. 5 (a), the inverter D stopped and restarted during the test using the data Vary-1 by its protective function. That caused the low value of K_{PM}. Comparing all the figures in Fig. 5, generally, we can find that inverter A and inverter B kept low mismatch and stable tracking. Their low mismatches are also shown numerically by the values of K_{PM} in Table IV. However, any adequate explanations are not found from the data in Table I and II. In the next stage of the study, we need to review the definitions of transient response time. Temperature variation, as shown in Fig. 5 (e) and Table IV, also has influences on the performances of MPPT function. To evaluate this effect, more correct prediction of module temperature is required.

6. CONCLUSIONS

Dynamic response of the MPPT function and basic response against irradiance or temperature variation of each tested inverter have been shown. Tests of the inverters have been carried out under the same conditions by means of the PV array I-V curve simulator and the default data sets. Effectiveness of the simulator for evaluation of PV inverters has been also shown. As a factor for evaluation of MPPT control, K_{PM} has been defined and calculated. The experimental results show that under the same conditions commercial PV inverters have quite different performances by own algorisms and suitable conditions for their operation are different by the inverters. In the future research, more detail analysis during transient response time for each inverter is required.

Table IV: Calculated MPPT control capability K_{PM}.

Inverter	A	B	C	D
K_{PM} (Clear) (%)	97.65	97.68	97.17	97.59
K_{PM} (Vary-1) (%)	97.16	97.52	97.12	83.66
K_{PM} (Vary-2) (%)	97.54	97.60	96.70	96.40
K_{PM} (Vary-3) (%)	97.55	97.43	97.30	97.24
K_{PM} (Vary-2-Temp.) (%)	95.34	96.99	95.05	95.82

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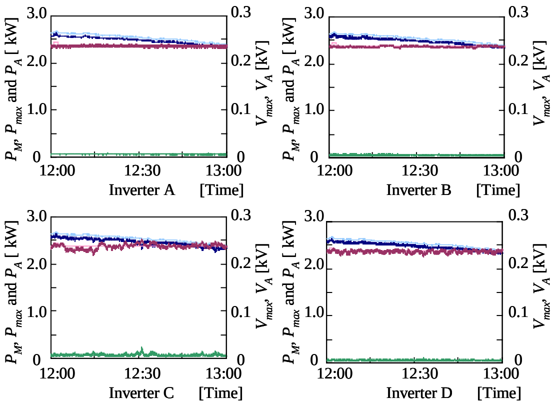
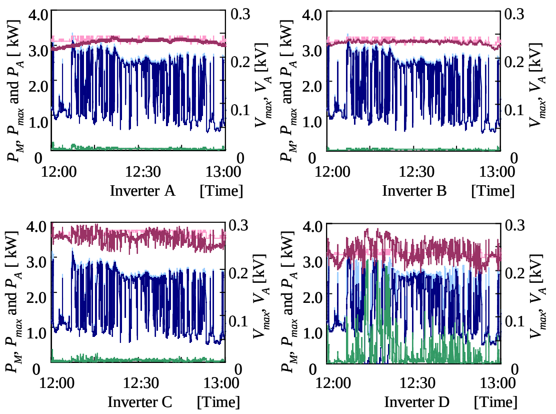
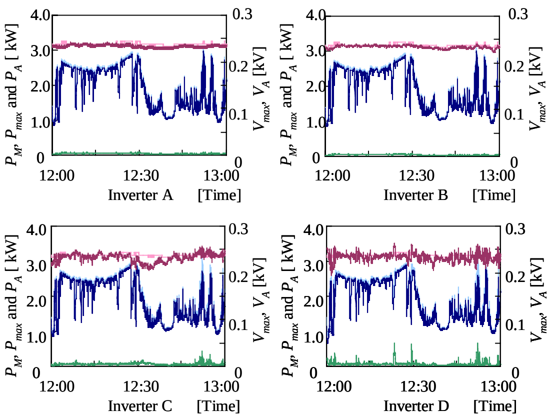


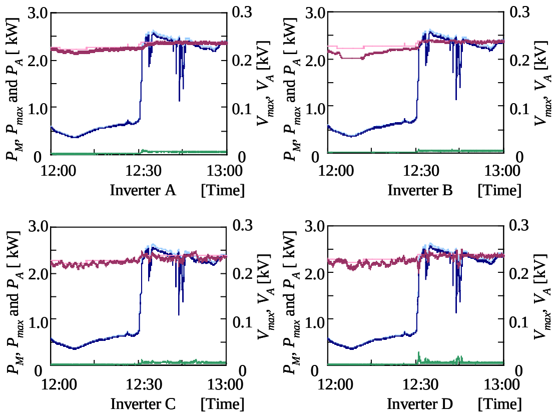
(a) Default data Clear



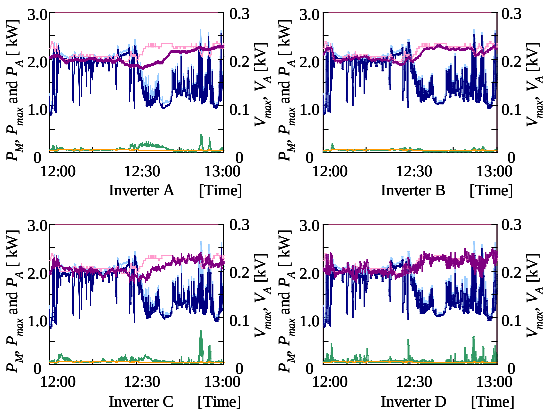
(b) Default data Vary-1



(c) Default data Vary-2



(d) Default data Vary-3



(e) Default data Vary-2 (Temp.)

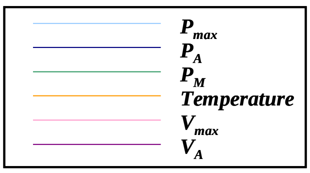


Fig.5: Tested inverter's output power P_{max}, voltage V_{pmax} at calculated PMAX point, the measured output power P_A , voltage V_A of PV array simulator, and mismatch P_M between P_{max} and P_A as functions of time using default irradiance patterns: (a) Clear, (b) Vary-1, (c) Vary-2, (d) Vary-3, and (e) Vary-2 with temperature variation.