Development of MPPT Algorithm for a Digital Controlled PV Inverter

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ABSTRACT

The characteristic of a Photovoltaic (PV) depends on fluctuations of the array temperature and irradiation. The Maximum Power Point Tracking (MPPT) is installed in a PV inverter to obtain maximum power from a PV array despite of those fluctuations. This paper is intended to develop a MPPT algorithm for a digital controlled inverter, output of which is about 100W, because an algorithm of a digital controlled system can be reconstituted more easily than an analog controlled system. The proposed MPPT program consists of two portions, one of them which calculates Maximum Power Point (P_{MAX}) voltage by Incremental Conductance[1][2] (IncCond) algorithm is named "calculating optimum voltage loop", and the other one the "adjusting k loop" adjusts the output AC current by parameter k. The experiment for the basic response and MPPT performance has been carried out by use of PV array I-V curve simulator. The availability of the program has been demonstrated by experimental results.

Keywords: MPPT Algorithm, Constant Voltage control, parameter k, current control type inverter

1. Introduction

Recently, grid-connected PV power generation systems have been spreading in residential area. The MPPT function is installed in a PV inverter to obtain maximum power from PV array in spite of the temperature and irradiation fluctuation. Therefore, the MPPT function is important in the performance of the PV system. If a system is not an analog controlled but a digital controlled, there is an advantage that renewal of a program or an algorithm is easier than the analog controlled system. The advantage shows that if the high-performance program or the algorithm is developed, it can be easily installed in the PV inverter, and it enables the PV system to improve the performance. Consequently, this paper is intended to develop the MPPT algorithm for a digital controlled inverter of which output is about 100W.

2. Proposed MPPT Program

The inputs of the proposed MPPT program are respectively average values of PV array voltage V_{DC} and current I_{DC}. The program can calculate the P_{MAX} voltage which gives P_{MAX} by using V_{DC} and I_{DC}. The output of the program is a parameter k that can control the output AC current of the inverter. Inverter's output AC current i_{AC} is given by the following equation (1):

$$i_{AC}=I_{ACMAX}\cdot k \qquad (1)$$

where k is the parameter k ($0 \leq k \leq 1$), and I_{ACMAX} is the rms value of the rated output AC current of an inverter. From the equation (1), adjusting parameter k changes the i_{AC}, therefore V_{DC} and I_{DC} are controlled by adjusting the parameter k.

The flow chart of proposed MPPT program is shown in Fig. 1[3]. This program consists of two portions. One of them which calculates P_{MAX} point voltage by Incremental Conductance[1][2] (IncCond) algorithm is named "calculating optimum voltage loop", and the other one the "adjusting k loop" adjusts output AC current by parameter k. The program calculates average values of V_{DC} and I_{DC} that are obtained from the inverter every 20ms. On the condition that V_{DC} is smaller than the V_1 (about 14V in our case), the Constant Voltage (CV) operation is chosen as a stable control. While the CV loop is not chosen, the deviation of the aim voltage (V_{ref}) and V_{DC} is calculated. If the deviation is larger than E (ex. 0.05V), "adjusting k loop" is chosen in order to decrease the deviation by adjusting parameter k. When the deviation is smaller than E, the program calculates the optimum voltage (aim voltage) at "calculating optimum voltage loop". The IncCond algorithm gives P_{MAX} point voltage with the following equation (2):[1]

$$(1/V)\cdot dP/dV = I/V + dI/dV \qquad (2)$$

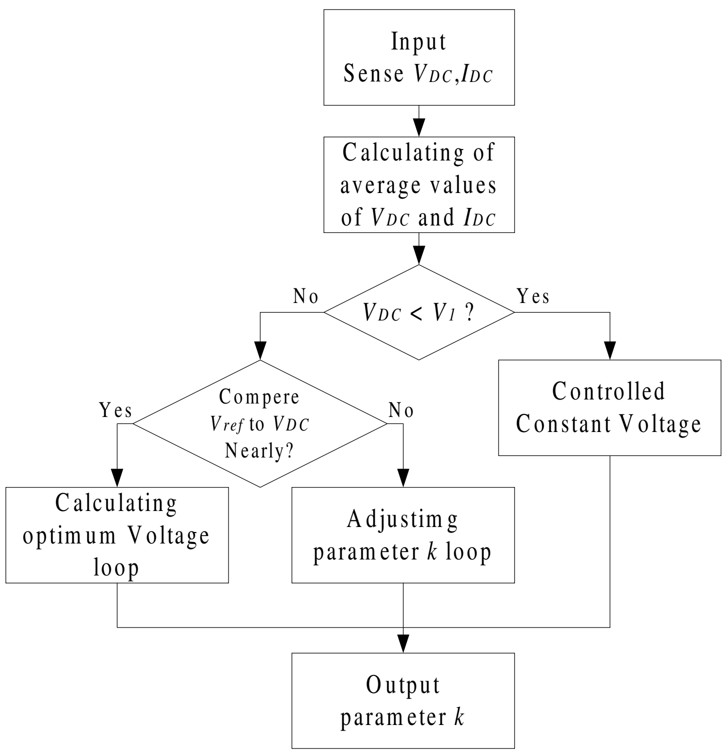


Fig. 1 Flow chart of the proposed MPPT Program.

3. Experiments with The Proposed MPPT Algorithm

3.1 The basic response and the MPPT performance

Experiments of the basic response and the MPPT performance have been carried out with the proposed MPPT program. The configuration of the experimental system is shown in Fig. 2. The experimental system was constructed using an PV array I-V curve simulator[4] as the input for the system. The output of the inverter was connected to an AC power source of single-phase $100V_{rms}$ and 50Hz. Between the inverter and the AC power source, the load resistance of 60 Ω was connected in parallel as the load for the system.

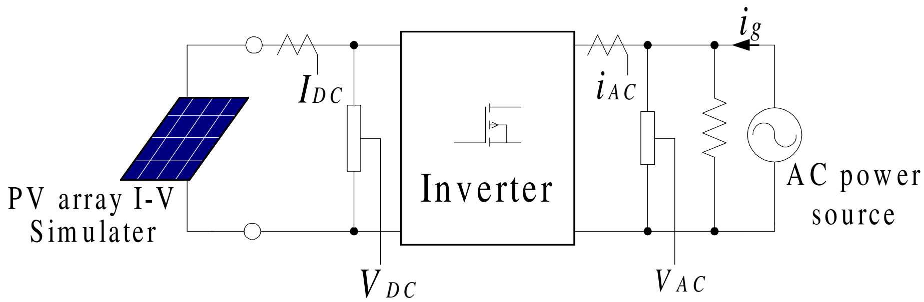


Fig. 2 Configuration of experimental system.

The observed waveforms at rapid irradiance fluctuation are shown in Fig.3. In this experiment, irradiance was stepped up and down between 1.0kW/m^2 to 0.8kW/m^2. In spite of rapid irradiance fluctuation corresponds to 20W, the program kept MPPT operation by the optimal adjusted parameter *k*. The measured response time to search for the Maximum Power Point (MPP) was 63 sec and 6 sec for stepping down and stepping up of irradiance. The results of tests confirm that the program can track the MPP at rapid irradiance fluctuation. The measured operating points on the P-V curve at the fill factor (*FF*) of 0.9, are shown in Fig. 4 and on the I-V curve are shown in Fig 5. The average values of MPPT efficiency for proposed MPPT program are summarized in Table I. As a result, the inverter can track the MPP on P-V (I-V) curve between 0.4 and 0.9 of the *FF* by proposed program. The efficiency fall in the low output range is caused by not any problem of the software but by the hardware.

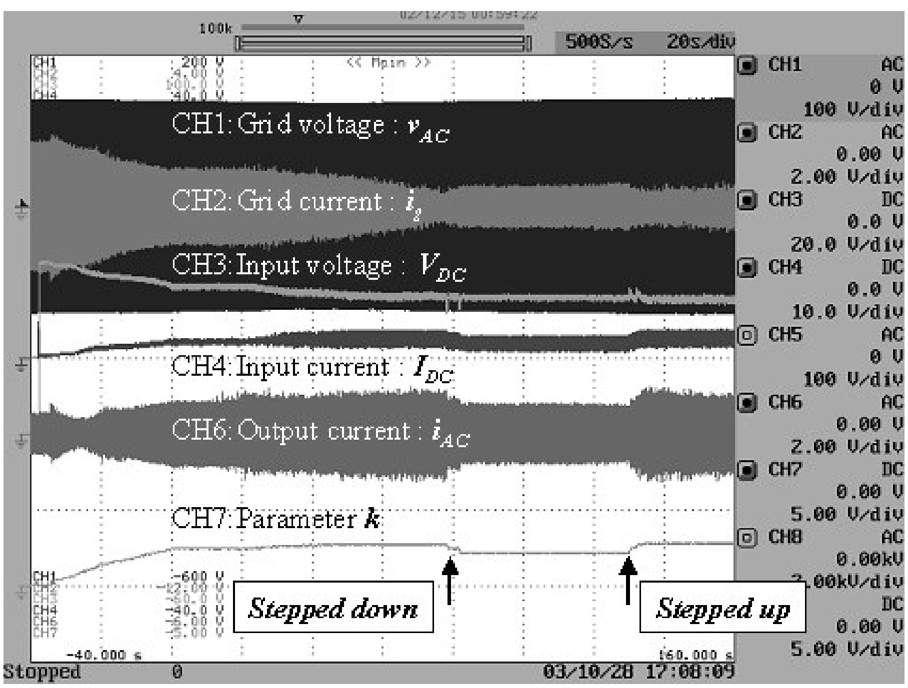
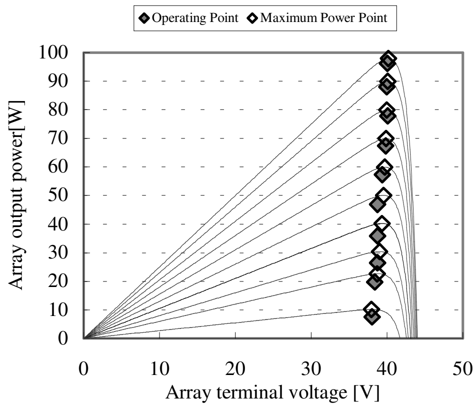


Fig. 3 Observed waveforms at rapid irradiance fluctuation.
(As regards the currents, vertical axis V/div means A/div)



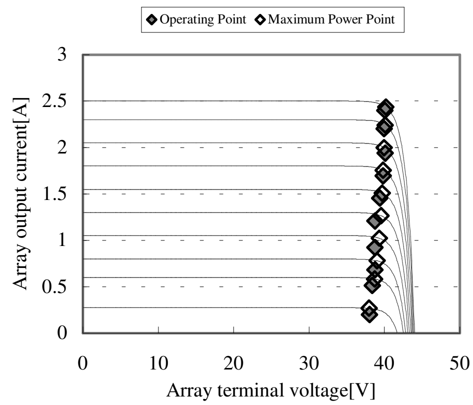


Fig. 4 Measured operating points on P-V curve at *FF* 0.9.

Fig. 5 Measured operating points on I-V curve at *FF* 0.9.

Table I: Measured MPPT efficiencies in different *FF* and P_{MAX} conditions.

		Fill Factor						
		0.4	**0.5**	**0.6**	**0.7**	**0.8**	**0.85**	**0.9**
P_{MAX}**[W]**	**10**	83%	86%	54~67%	56~75%	65~77%	60~75%	46~75%
	20	84%	85%	84%	85%	83%	70~86%	75~86%
	30	94%	92%	93%	88%	87%	88%	81%
	40	97%	95%	95%	92%	90%	88%	87%
	50	94%	95%	95%	94%	95%	93%	92%
	60	94%	95%	93%	95%	95%	95%	95%
	70	96%	96%	96%	95%	96%	96%	96%
	80	95%	96%	96%	97%	97%	96%	97%
	90	*	97%	97%	98%	97%	97%	98%
	100	*	97%	98%	98%	98%	97%	98%

(*: This condition cannot be simulated with the PV array I-V curve simulator.)

3.2 The Constant Voltage Control Function

The irradiance stepping down condition is considered about a current control type inverter for PV system. Sometimes, the I-V curve is changed by rapid decrease of irradiance. This change may occur mismatch between the inverter output power and the generation power from PV. Assuming that the operating point is at the maximum power point before the irradiance stepping down, then mismatch is caused by a stepping down, and PV array output current before the stepping down is larger than short circuit current after the stepping down. In this case, the parameter k requires the inverter to supply more output power than the maximum output power from the PV. Consequently, the operating point jumps and stagnates at the I_{sc} point. As a result the inverter stops and can not obtain gain from the PV.

In the proposed MPPT program, when such a phenomenon arises, its operation is switched to the Constant Voltage (CV) function during a fixed period, then MPPT control starts after the period. It can be achieved by the CV function that to avoid the stagnation at the I_{sc} point and to recover the P_{MAX} point. In case when such phenomena happen, the V_{DC} becomes smaller than V_I, which is detected and processed following the flow chart as shown in Fig. 1.

Experiments for checking the effectiveness of CV function have been carried out by using the proposed CV function program. The configuration of the experimental system is shown in Fig. 2. The experiments have been carried out with two kinds of programs one of them in which the proposed CV function is installed (named Type A), and the other one is not (named Type B). The aim voltage of CV function (V_{refcv}) is given by the following equation (3):

$$V_{refcv}=V_{oc}\cdot k_{cv} \qquad (3)$$

where V_{oc} is the open circuit voltage, and k_{cv} is a parameter which determines the ratio of V_{oc} and V_{refcv}.The range of k_{cv} is 0 to 1. In our case, k_{cv} was set to 0.88. First, the experiment against stepping down of irradiance was carried out. The measured PV output power of Type A and Type B are shown in Fig. 6. The theoretical output power means the indicated P_{MAX} of PV array I-V curve simulator. Figure 6 shows Type A is more stable than from Type B. The total amount of the output power and the normalized one by the theoretical output power are summarized in Table II. The results show that the electric power of Type A is larger than that of Type B.

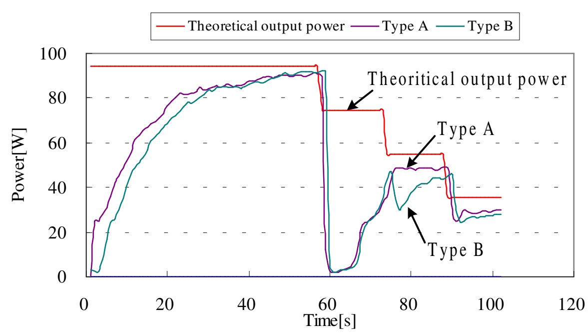


Fig. 6 The measured output powers of PV array I-V curve simulator with Type A and Type B.

Table II: The total amount of output power and the normalized output power by the theoretical output power.

	Theoretical output power	Type A	Type B
Total output power [Wh]	7898	5648	5309
Normalized output power	1.00	0.72	0.67

Next, the experiment about the continuation of the operating point jumps and stagnates at the I_{sc} point was carried out. The measured PV output values of Type A are shown in Fig. 7. The measured PV output values of Type B are shown in Fig. 8. From Fig. 7, when the term of CV control ends, the operating point occurs stagnation at the I_{sc} point. Comparing Fig. 7 with Fig. 8, it is confirmed that the operating point stagnation is more difficult to occur in Type A than Type B. The total amount of output power and the normalized one by theoretical output power are summarized in Table III. The results show that the electric power of Type A is larger than that of Type B.

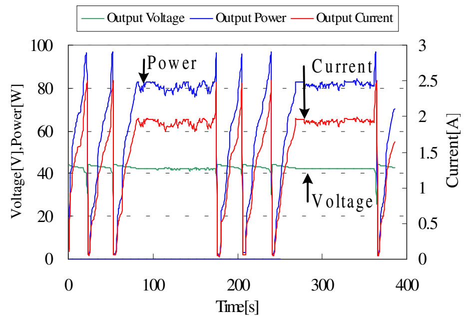


Fig.7 The measured output values
PV array I-V curve simulator with Type A.

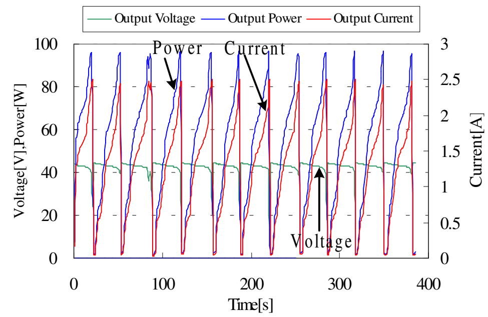


Fig. 8 The measured output values
PV array I-V curve simulator with Type B.

Table III: The total amount of output power and the normalized output power by the theoretical output power.

	Theoretical output power	Type A	Type B
Total output power [Wh]	37697	25041	19621
Normalized output power	1.00	0.67	0.52

4. Conclusion

An MPPT algorithm for a digital controlled inverter has been proposed in this paper. The series of experimental results confirm that the program can be applied to the MPPT operation at static characteristic and at rapid irradiance fluctuation. The program is able to seek P_{MAX} point, in the range of fill factor from 0.4 to 0.9. The Constant Voltage function program was proposed for the operating point occurs stagnation at the I_{sc} point, and the effectiveness of this function has been demonstrated by experimental results. The availability of the program has been confirmed by experimental results.

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