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Maximum Power Point Tracking Performance Evaluation of PV micro-inverter under Static and Dynamic Conditions

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Abstract

In this paper, Maximum Power Point Tracking (MPPT) evaluation results of commercial PV micro-inverters under static and dynamic irradiance conditions are presented. In Korea, MPPT performance of PV inverter is only evaluated under several static irradiance conditions because the dynamic MPPT performance requirement is not included in the Korean MPPT performance evaluation standard yet. In order to show the importance of the dynamic performance evaluation, this paper presents both static and dynamic MPPT performances by using two commercial PV micro-inverters. Both PV micro-inverters show high static MPPT performances by Korean standard, but one of them shows very low dynamic MPPT performance by EN 50530 testing standard. According to this result, dynamic MPPT performance should be considered well in the research and performance evaluation level.

Keywords - Photovoltaic generation, PV micro-inverter, Maximum Power Point Tracking, Grid-connected inverter, PV performance evaluation.

I. INTRODUCTION

The MPPT performance of a PV inverter is determined by the ability to follow the maximum power characteristics of a solar module that varies with solar radiation and temperature [1-3]. In Korean performance evaluation standard of the PV inverter, the MPPT performance is only evaluated for 5 cases of the static irradiation condition, which are 100%, 75%, 50%, 25%, and 12.5% of the rated irradiance 1000W/m^2 [4]. In other words, only static MPPT performances under the fixed irradiation condition are evaluated. However, in recent years, dynamic MPPT performance is becoming an issue when the solar radiation amount is changed at a high speed and a low speed in Europe [5-8].

Currently, IEC Technical Standardization Group (Working Group 6), which is an international technical standard, is preparing to establish the related IEC standard in the near future dealing with both static and dynamic MPPT performance. Therefore, the technical level of the domestic manufacturers should be improved in order to meet the national and international technical standards. In this paper, both static and dynamic MPPT performances by using two commercial PV micro-inverters for the sake of suggesting the dynamic MPPT evaluation requirement are presented.

This paper consists of three parts. Firstly, PV modeling and the conventional MPPT methods are described and performance degradation under rapidly changing irradiance environmental conditions are analyzed. Then, the static and dynamic MPPT experimental results of two commercial PV micro-inverters. Finally, the summary of the experimental results is discussed.

II. SYNOPSIS OF MPPT CONTORL METHOD

II.1 PV MODELING

The output of PV module has a nonlinear characteristic with maximum output varying according to solar radiation and temperature, as shown in Figure 1.

The characteristics of PV module are generally represented by the equivalent circuit shown in the Figure 2 and can be expressed by the following formula.

$$I_{PV} = I_{ph} - I_o \left\{ e^{\frac{q}{nkT}(V_{PV}+I_{PV}R_S)} - 1 \right\} - \frac{V_{PV}+I_{PV}R_S}{R_{sh}} \quad (1)$$

where G is the irradiance, I_{PV} is PV module output current, V_{PV} is PV module output voltage, I_{ph} is photo generated current, R_s is cell series resistance, R_{sh} is cell shunt resistance, I_d is diode current, k is Boltzmann's constant, $1.380658*10^{-23}$ [J/K], T is absolute temperature, q is electronic charge, $1.60*10^{-19}$[C], n is diode quality factor, and I_0 : diode saturation current.

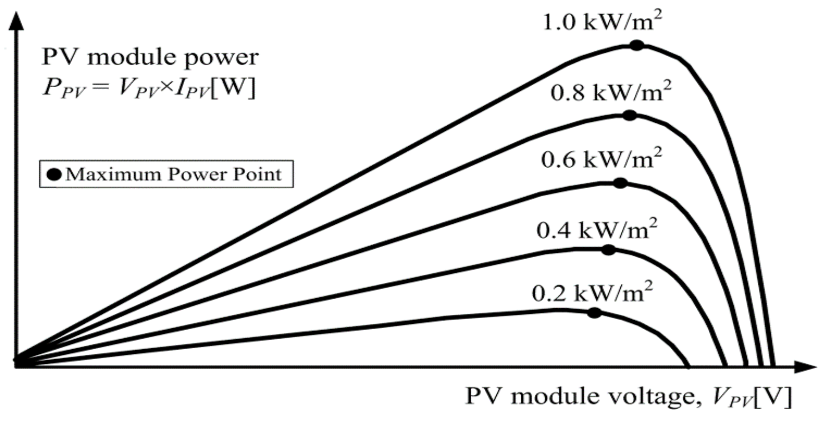

Figure 1. PV module electrical characteristics.

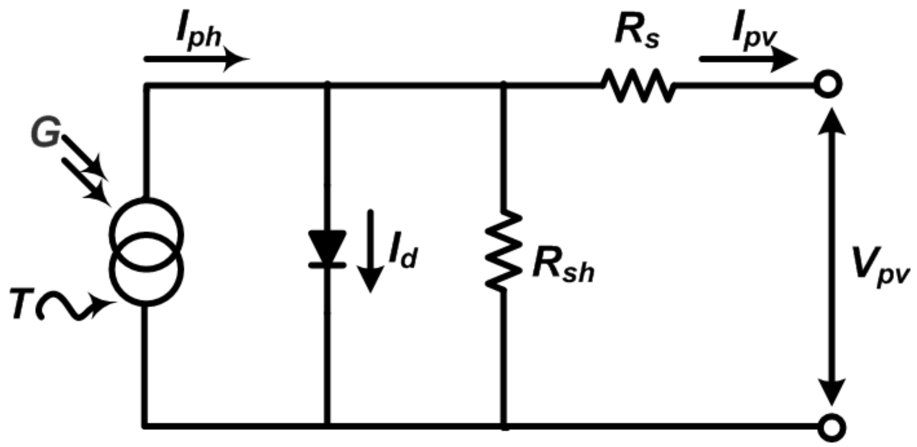

Figure 2. PV module electrical equivalent circuit.

II.2 THE TYPICAL MPPT METHOD

The output of PV module shows a nonlinear characteristic curve according to the environment such as solar radiation amount, surface temperature, etc., as shown in the Figure 1. When the operating point of the voltage-current on the characteristic curve is determined, the amount of output power of PV module is determined. In the stand-alone PV system, the operating point of the output power is determined by the capacity of the load. However, in the grid-connected PV system, the system load can be viewed as an infinitely variable load. Therefore, MPPT technique capable of maximizing the generated power is necessary in the grid-connected PV system. The research on MPPT techniques has been carried out in terms of system complexity, sensor presence, convergence speed, cost aspect, and hardware implementation. As one of the most popular MPPT method, P&O (Perturbation and Observation) method is described to analyze the performance degradation under rapidly changing environmental conditions in the following section.

The P&O method applies a disturbance to the duty ratio of the power converter to induce a change in the voltage or current of PV module, and compares the power between the previous control period and the current control period. Finally, the control command moves its operating point to the Maximum Power Point (MPP). Figure 3 shows the operational principle of the conventional P&O method. For example, when operating in the area to the left of the MPP, increasing the voltage will increase the power, and decreasing the voltage will reduce the power. Similarly, when operating in the area to the right of the MPP, increasing the voltage will reduce the power, and decreasing the voltage will increase the power. Therefore, P & O technique controls the disturbance to occur in the same direction so that the following disturbance can reach at the MPP.

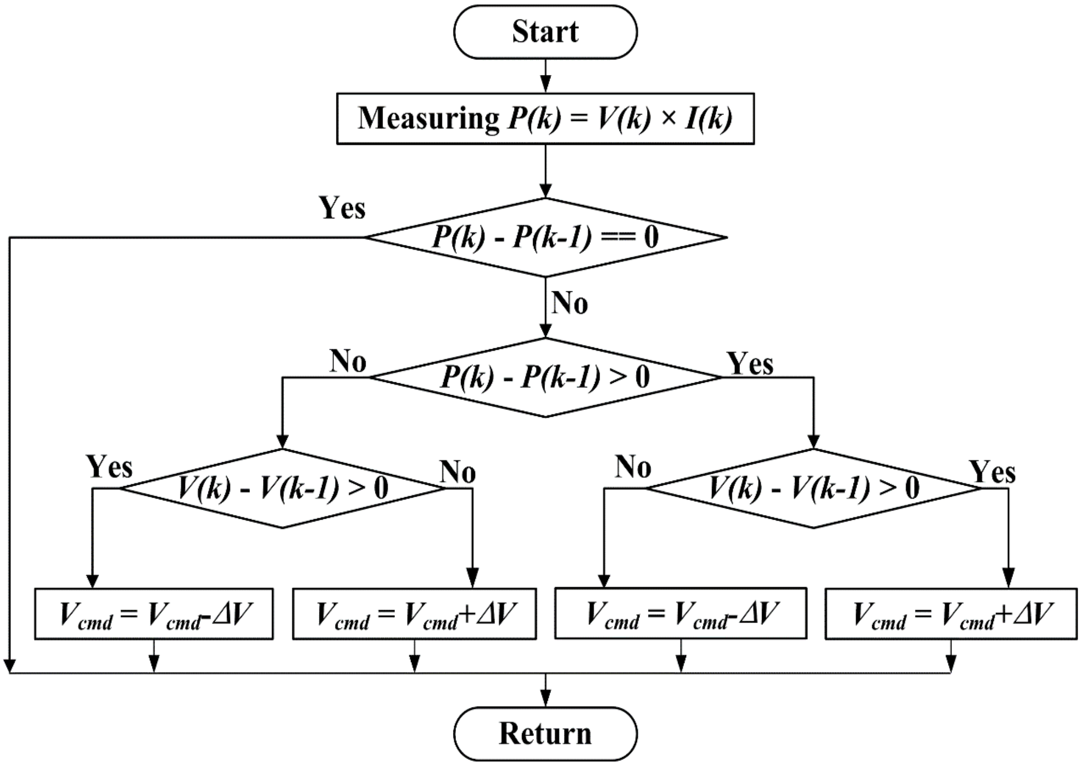

Figure 3. Flowchart of the conventional P&O method.

II.3 DISCUSSION

A typical P&O technique can produce false control commands when the solar radiation changes rapidly. The P&O concept is a structure in which a control command of the next cycle is generated in accordance with the power variation according to the duty control command. By the way, when the power fluctuation by the control command mix with the power variation by the rapidly changing solar irradiation, the correct control command could not be generated due to the wrong power variation information. For example, while the present PV voltage stays at point A and the duty command make the PV voltage to be decreased, the next MPPT duty command will be different from the irradiance condition. When the irradiance is fixed, the next control command will be decreased again because the power is increased from point A to point B, according to the P&O method, as shown in Figure 3. This is a correct operation to track the MPP in Figure 4. However, while the irradiance is decreased as shown in Figure 4, the next control command will be increased because the power is decreased from point A to point C. This is a wrong operation, which moves in the opposite direction to the MPP in Figure 4. This is the reason why it is necessary to develop the control techniques that can distinguish them and to build the evaluation procedures and facilities that can evaluate them.

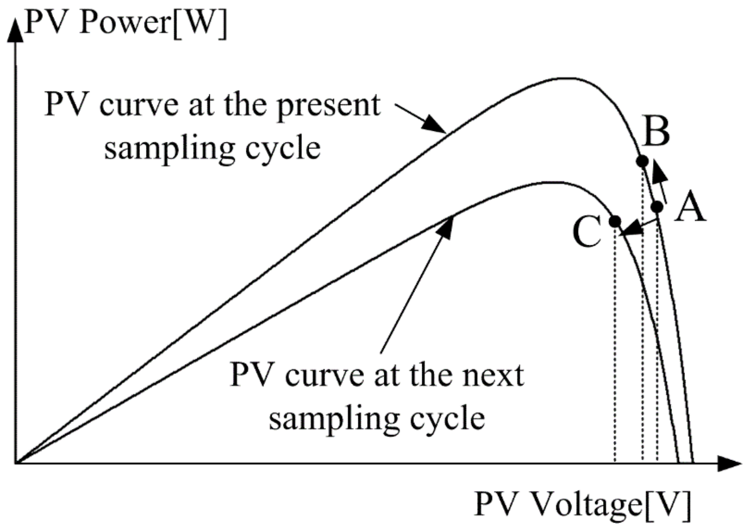

Figure 4. Power-voltage characteristics of PV module under rapidly changing irradiance environmental condition.

Table 1: Electrical specifications for PV micro-inverters

Parameter	Model A of PV micro-inverter	Model B of PV micro-inverter
Input voltage range [V]	22~46	22~45
MPPT control voltage range [V]	22~37	22~36
Output nominal power [W]	250	215

III. EXPERIMENTAL RESULTS

Both static and dynamic MPPT performance evaluation are conducted by using two commercial PV micro-inverters for the sake of suggesting the dynamic MPPT evaluation requirement. The electrical specification of two PV micro-inverters are shown in Table 1, which are named as Model A and Model B.

Firstly, the MPPT performance was evaluated only at the static condition. When the solar radiation conditions were 100%, 75%, 50%, 25%, and 12.5%, the performance was compared between Model A and Model B. As shown in Table 2, the efficiencies of Model A were slightly lower than those of Model B, but both shows high MPPT efficiency over 90%.

Table 2: Static MPPT performance efficiency of two PV micro-inverters

Irradiance / EUT	12.5%	25%	50%	75%	100%
Model A	98.82%	93.01%	99.83%	99.81%	99.59%
Model B	99.36%	99.33%	99.96%	99.93%	99.89%

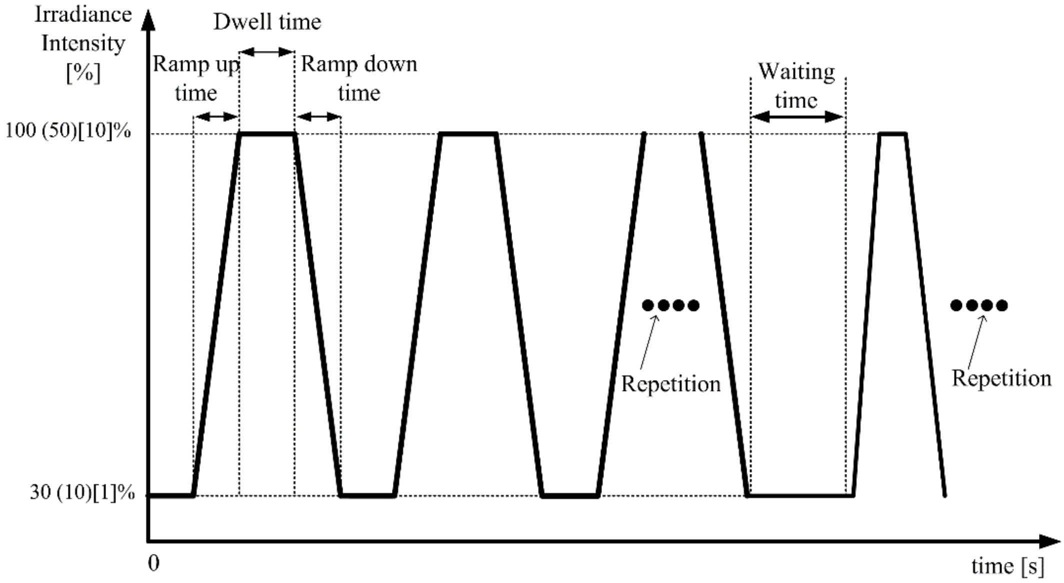

Figure 5. Irradiance variation profile for EN 50530.

Secondly, the dynamic MPPT performance was evaluated by EN 50530 standard, as shown in Fig. 5 [9]. This is because there is no standard procedure to measure the dynamic performance of MPPT in both Korean standard and IEC 61683 [4,10]. They have only static MPPT performance evaluation procedure in the standards. It is expected that IEC 61683 includes the dynamic performance evaluation. In EN 50530, there are three irradiance variation cases to measure dynamic MPPT performance, as shown in Table 3, 4, and 5.

Table 3: Dynamic MPPT efficiency of both Model A and Model B under the varying irradiance from 30% to 100%.

	Repetitions	Waiting time[s]	Ramp up [s]	Dwell time [s]	Ramp down [s]	Efficiency [%]	
						Model A	Model B
1	10	300	70	10	70	99.16	99.91
2	10	300	50	10	50	99.52	99.91
3	10	300	35	10	35	99.05	99.91
4	10	300	23	10	23	97.15	99.91
5	10	300	14	10	14	97.58	99.90
6	10	300	7	10	7	98.89	99.89

Table 4: Dynamic MPPT efficiency of Model A under the varying irradiance from 10% to 50%.

	Repetitions	Waiting time[s]	Ramp up [s]	Dwell time [s]	Ramp down [s]	Efficiency [%]	
						Model A	Model B
1	2	300	800	10	800	99.58	99.82
2	2	300	400	10	400	99.64	99.82
3	3	300	200	10	200	99.43	99.82
4	4	300	133	10	133	99.39	99.83
5	6	300	80	10	80	98.87	99.82
6	8	300	57	10	57	98.90	99.83
7	10	300	40	10	40	98.82	99.82
8	10	300	29	10	29	97.10	99.82
9	10	300	20	10	20	96.84	99.79
10	10	300	13	10	13	85.68	99.76
11	10	300	8	10	8	68.30	99.59

Table 5: Dynamic MPPT efficiency of Model A under the varying irradiance from 1% to 10%.

	Repetitions	Waiting time[s]	Ramp up [s]	Dwell time [s]	Ramp down [s]	Efficiency [%]	
						Model A	Model B
1	1	300	980	30	980	97.19	99.17

For model A, when the solar radiation changes from 10% to 50%, the measured dynamic MPPT efficiency is 68.3%, which is very low. This performance is an important performance indicator that is not considered in the Korean standard, and it should be reflected in the future development of the product. On the other hand, in the case of Model B, excellent dynamic performance is shown with about 99% in all the solar radiation variation conditions, which means that it is possible to implement a good dynamic MPPT performance. According to these results, it can be said that the dynamic MPPT performance should be considered well in the product development and performance evaluation level.

IV. CONCLUSION

In the present evaluation standard of PV micro-inverter, only the static MPPT is fixed is evaluated while the irradiation amount is fixed, and the dynamic MPPT performance is not considered. This paper presents both static and dynamic MPPT performances by using two commercial PV micro-inverters. Both PV micro-inverters meet the static performance requirement by Korean standard, but one of them shows low dynamic MPPT performance. According to this result, dynamic MPPT performance should be considered well in the research and performance evaluation level.

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