Optimum MPPT Control Period for Actual Insolation Condition

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Abstract**—**Solar power generation systems require maximum power point tracking (MPPT) control to get maximum power using low efficient and high cost PV modules. Most of the conventional MPPT algorithms are based on the slope-tracking concept. One of a typical slope-tracking method is Perturb and Observe (P&O) algorithm. The two factors that determine the MPPT performance of P&O algorithm are the MPPT control period and the magnitude of the perturbation voltage. When the perturbation voltage is set to large, the MPPT controller quickly moves to the new maximum power point at insolation change, while the error of output power will be huge in the steady state even when insolation is not changing. When the MPPT control period is set for short, the dynamics of the MPPT controller can be accelerated even though the perturbation voltage is set for small. However, too short MPPT control period does not contribute improvement of the MPPT performance but consumes the MPPT controller resources. Therefore, in order to determine the optimum MPPT control period and the magnitude of the perturbation voltage, it is necessary to analyze the performance of the MPPT controller for actual insolation conditions in real weather environment. This paper proposes an optimum MPPT control period that maximizes MPPT efficiency by measuring and analyzing actual insolation profiles in typical clear and cloudy weather in central Korea.

Keywords— Solar power generation, MPPT control period, MPPT efficiency, Actual insolation condition, Estimation method

I. INTRODUCTION

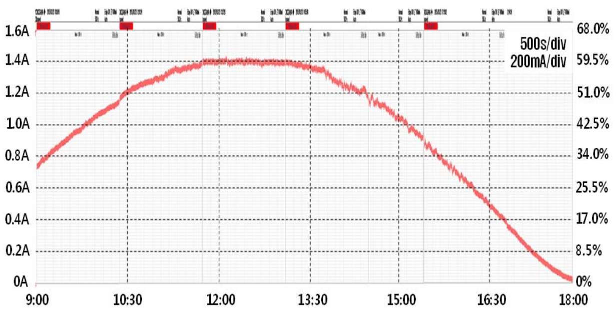
Solar power generation systems require Maximum Power Point Tracking (MPPT) control to operate the PV modules at maximum power points in order to produce maximum power with usage of high cost and low efficient equipment. Furthermore, in order to produce the maximum power in a practical environment where the insolation varies from moment to moment, the solar power generation system needs a controller that gets the MPP quickly and accurately. Most commonly used MPPT control algorithm is based on slope-tracking concept, which determines the slope of the output power throughout the change of the operating point of the PV module and searches for the maximum power operating point. Perturb and Observe (P&O) algorithm is a typical example. P&O algorithm makes PV module terminal voltage varied like subtracting or adding for a certain perturbation voltage. And it works out variable of PV module output power and finds out the next operating point of PV module terminal voltage toward the maximum output power [1][2].

The two factors that determine the performance of the MPPT controller are the control period of the MPPT controller and the magnitude of the perturbation voltage. In other words, The MPPT perturbation voltage which is set for large makes the maximum power point able to be found quickly when the insolation changes. But, in the steady state where the insolation does not change, the PV module output power unnecessarily oscillates greatly around the maximum power point and loss occurs. On the contrary, if the perturbation voltage is set to a small value, the output power of the PV module will oscillate at a small value near the maximum power point in the steady state where the insolation does not change, and the power generation amount can be stably maintained. However, if the insolation changes frequently like cloudy days with lots of clouds, the maximum power point cannot be followed up in advance and it causes a large loss in power generation [3][4]. On the other hand, the MPPT control period which is set for short makes the dynamics of the MPPT controller be accelerated even though the perturbation voltage is set to a small value. But too short MPPT control period does not contribute to the improvement of the MPPT performance and only consumes the MPPT facility cost or the controller time resources.

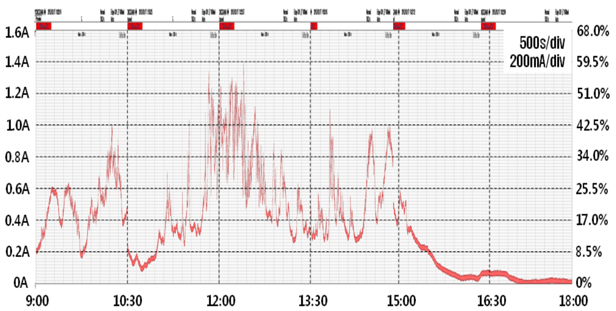
So the performance by the MPPT control period is largely affected by the actual insolation conditions at weather in the PV generation area. If the insolation is changed rapidly in the actual weather environment, the MPPT control period should be set short for fast transient response characteristics. However if the change of the insolation is smooth, there is no reason to set the MPPT control period shorter than necessary. This paper proposes an optimum MPPT control period by measuring the insolation in the actual weather environment and analyzing to construct the profile and perform the simulation to derive optimal power generation efficiency.

II. ANALYSIS OF INSOLATION OF ACTUAL WEATHER ENVIRONMENT

There are two methods of measuring the insolation, a direct measurement method to use a pyreheliometer and an indirect measurement method to estimate the change of the insolation by observing the short current (Isc) of a PV module since it is proportional to the insolation level. In this paper, indirect measurement method is adopted because of low experimental cost and simplicity. As the short circuit current of the PV module is proportional to the insolation level, the insolation percentage ($\boldsymbol{G}$) based on the weather change can be expressed as Equation (1).



(a) Clear spring day



(b) Cloudy spring day

Fig. 1. 9-hour insolation profile at Cheonan-city in central Korea

TABLE I. ELECTRICAL SPECIFICATIONS OF THE PV MODULE USED IN MEASUREMENT

Parameter	Value
Maximum power (P_{MPP})	20 [W]
MPP voltage (V_{MPP})	17.5 [V]
MPP current (I_{MPP})	1.14 [A]
Open circuit voltage (V_{OC})	21.5 [V]
Short circuit current (I_{SC})	2.36 [A]

TABLE II. ACCUMULATED INSOLATION ACCORDING TO WEATHER

Weather condition		**Insolation quantity**	
		Actual value [A.s]	***Percentage [%]***
STC condition		57,595	100
Actual	***Clear sky***	24,015	41.70
	Cloudy sky	10,332	17.94

$$G(t) = \frac{I_{SC/SEN}(t)}{I_{SC/NOM}} \times 100\ [\%] \tag{1}$$

Here, $I_{SC/SEN}$: Short current of PV module measured in actual insolation condition.

$I_{SC/NOM}$: Short current of PV module in standard test condition (STC) at 100% insolation

In this paper, PV module used in insolation measurement is polycrystalline type, and the electrical specifications are shown in Table 1. For the analysis of insolation throughout the change of weather during the day, the insolation was measured for 9 hours from 9:00 am to 6:00 pm. The sampling interval of insolation was set to 0.02 seconds

Table 2 shows the accumulated insolation for a time span of about 7.7 hours. It can be seen that the total insolation on a clear day is about 2.3 times larger than a cloudy day. If the power generation of the PV module is assumed proportional to the insolation, it can be seen that the amount of power generation on a clear day can increased about 2.3 times than the cloudy day. In Table 2, the percentage of the accumulated insolation (G_{TOT}) was calculated by the following equation (2).

$$G_{TOT} = \int G(t) \cdot dt\,[\%] \tag{2}$$

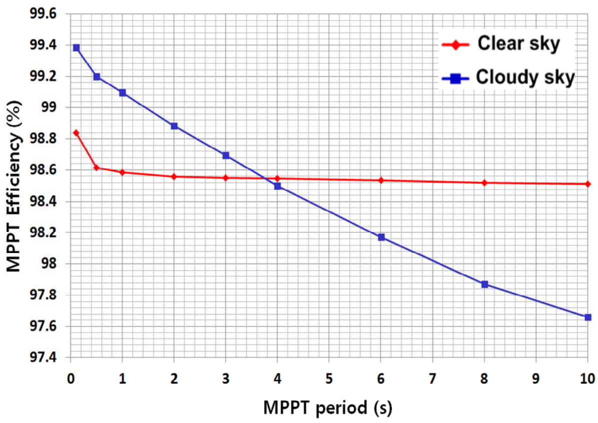
The analysis of the insolation profile shows that the size and pattern of insolation on clear and cloudy days are significantly different. On a clear day, the change in insolation is gentle, but on a cloudy day, the insolation changes very irregularly. Therefore it is important to set the control period of the MPPT controller which can guarantee the maximum power generation of the PV module in various practical weather conditions.

III. MPPT EFFICIENCY AND MPPT CONTROL PERIOD

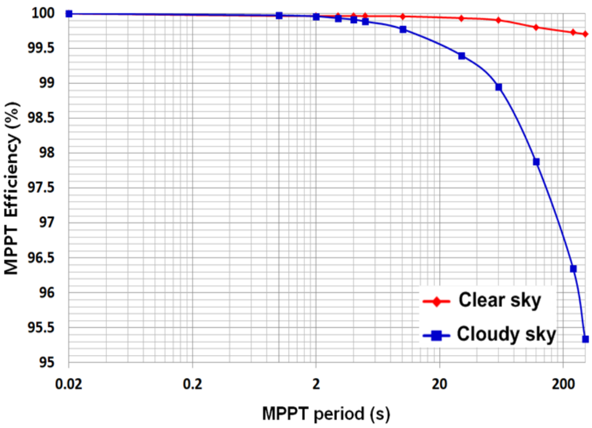
In this paper, the insolation data on the actual weather condition is acquired from clear and cloudy day, so that the power generation efficiencies of the PV module according to the MPPT control period in each weather condition can be estimated. The estimation of power generation PV module for the insolation profile is performed in two ways. The first way is to directly estimate the generated power according to the MPPT control period from the insolation profile. The second way is a more detailed estimation of the generated power according to the MPPT control period. In this method, the diode equivalent model developed by the authors is used [5]. And the I-V characteristic curve of the PV module at each MPPT period from the insolation information is simulated, where exact MPP voltage is exploited and applied to get generated power during the MPPT control period. Here, all measured/analyzed values are calculated as percentages to compare.

In the simplified estimation method, the peak value of the insolation is limited by the initial insolation level sampled at the start point of each set MPPT control period and the insolation is integrated in the corresponding MPPT control period. This method simply estimates the generating power of a PV module when the MPPT controller works properly. The MPPT efficiency by this estimation method will be referred to as peak cut MPPT efficiency ($\eta_{MPPT/PKCUT}$). Equation (3) is a formula for calculating the peak cut MPPT efficiency.

$$\eta_{MPPT/PKCUT} = \frac{\sum_{k=0}^{n} PeakCut\,(I_{SC/SEN}) \times T_{MPPT}}{(I_{SC/NOM})\int_0^t dt} \times 100[\%] \tag{3}$$



(a) Simplification method



(b) Detailed method

Fig. 2. Comparison of MPPT control period and MPPT efficiency characteristics by the two estimation methods

Here, $PeakCut(I_{SC/SEN})$: The short circuit current peak-cut by the initial measured value at the starting point of each MPPT control interval

In the detailed estimation method, PV module is simulated with a diode equivalent model so that P-V curve of PV module is extracted from insolation data obtained at each sampling moment. This method gets accurate MPP voltage in each MPPT control period.

Fig. 2 is a graph comparing the relations between MPPT control period and the estimated MPPT efficiency by the two estimation methods proposed in this paper. The estimated MPPT efficiency from the sunny conditions on a clear day is almost unchanged when the MPPT period is longer than 1 second, whereas the estimated MPPT efficiency from the cloudy day is linearly decreased with nearly constant slope against MPPT period. The estimated MPPT efficiency of the cloudy day is always higher than that of the clear day in a smaller MPPT period, but the decreasing slope of the estimated MPPT efficiency with a longer MPPT period in the cloudy day is larger compared with the clear day. This is consistent with the physical meaning of the insolation profile in Fig. 1. That is, since the insolation on the cloudy day changes with a sharp slope on the time axis, the shorter the MPPT control period, the more accurate the MPPT control corresponding to the change of the insolation. In this paper, critical MPPT period is defined when the estimated MPPT efficiency is equal on both clear and cloudy day. In Fig. 2a), the critical MPPT period of the peak cut estimation method is about 4 seconds.

Fig. 2b) graphically illustrates the relationship between the MPPT control period and the estimated MPPT efficiency by the detailed method on clear and cloudy day. The critical MPPT period appears at about 2 seconds. This is about half compared to the critical MPPT period of 4 seconds obtained from the simplification method. However, it can be seen that the inflection point where the MPPT efficiency starts to differ greatly on clear and cloudy day is the time point when the MPPT control period exceeds about 4 seconds. Above this MPPT control period, the estimated MPPT efficiency on the cloudy day becomes sharply lower than on the clear day. Therefore, the optimal MPPT control period, in which the estimated MPPT efficiency begins to drop sharply on cloudy days compared to clear days, is almost identical to the critical MPPT period of 4 seconds that was analyzed by the peak cut simplification method.

Here, the estimated MPPT efficiency is about 99.98% at the optimal MPPT period analyzed by the detailed method, while the estimated MPPT efficiency by the peak cut simplification method was about 98.55%. It can be interpreted that the peak cut simplification method estimates the amount of power generation to the lowest insolation when the insolation monotonically increases in the MPPT control section, thereby estimating the generation power relatively smaller than the detailed method. In conclusion, we can easily estimate the optimum MPPT control period and the MPPT efficiency with an error of about 1.5% for the peak cut simplification method.

IV. CONCLUSION

In In this paper, to determine the appropriate MPPT control period to maximize the MPPT efficiency in various actual weather conditions, the insolation was measured in typical weather of clear and cloudy days in the central part of Korea. Based on the measured insolation data, the MPPT efficiency was analyzed by simulating the power generation according to various MPPT control periods. As a result, it is confirmed that the optimal MPPT control period which has the highest MPPT efficiency with minimum MPPT control resource in all weather conditions is about 4 seconds regardless of a clear day and a cloudy day. Compared with the detailed estimation by the PV model, the peak cut simplification method can estimate the optimal MPPT control period almost equally with small difference of the MPPT efficiency with an error of about 1.5%. The proposed theory can be used to predict the power generation of a projected area where photovoltaic power plant is to be installed based on annual meteorological data, or to determine the appropriate MPPT control period of the power conditioning system (PCS) for photovoltaic power generation.

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REFERENCES

[1] M. A. Elgendy, B. Zahawi, D. J. Atkinson, “Evaluation of perturb and observe MPPT algorithm implementation techniques,” IET International Conference on Power Electronics, Machines and Drives, March 2012.

[2] R. John, S. S. Mohammed, R. Zachariah, “Variable Step Size Perturb and Observe MPPT Algorithm for Standalone Solar Photovoltaic System,” IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing, March 2017.

[3] B. Subudhi, R. Pradhan, “A comparative study on maximum power point tracking techniques for photovoltaic power systems,” IEEE Transactions on Sustainable Energy, vol. 4, pp. 89-98, July 2013.

[4] Q. Fu, N. Tong, “Research on MPPT Technique in Photovoltaic Power Generation System,” International Conference on Computer Science and Electronics Engineering, vol. 3, pp. 394-398, March 2012.

[5] H. Park, Y. J. Kim, H. Kim, “PV Cell Model by Single-diode Electrical Equivalent Circuit,” JEET, vol. 11, pp. 1323-1331, May 2016.