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Control of a Novel PV Tracking System Considering the Shadow Influence

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Abstract – This paper proposes a novel control strategy of a PV tracking system considering the shadow influence. If distance of between PV arrays is not enough, shadow can be occurred to PV module. In PV system, if shadow is occurred to PV modules then PV modules operates reverses bias, and will eventually cause hot-spot and loss. To reduce loss by shadow influence, this paper proposes shadow compensation algorithm using distance between arrays and shadow length of array. The distance between arrays is calculated by using azimuth of solar, and length of array shadow is calculated using by altitude of solar. The shadow compensation algorithm proposed in this paper compares distance between arrays and length of array shadow. When the shadow length is longer than the distance between arrays, the algorithm adjusts altitude of array to avoid the shadow effects. The control algorithm proposed in this paper proves validity through compared with conventional algorithm and proposes experiment result.

Keywords: Tracker system, Photovoltaic, Shadow influence, Azimuth, Altitude

1. Introduction

Recently, interest in alternative energy has been increasing due to rise of oil price by limit of fossil fuels and environment pollution caused by indiscriminate use of fossil fuels. Compare to traditional energy sources, the solar energy is limitless and does not generate any pollution emission. The photovoltaic(PV) system is a generating system using the photoelectric effect which changes the light energy into electric energy. And the performance of PV system is depended on radiation and temperature. The methods for improvement of PV system are solar tracking method, MPPT control, improvement of solar cell performance, and power conversion system [1, 2].

The PV system is composed of program method, sensor method and hybrid method. The program method is to track sun's trace by using variable of the time with the latitude and longitude of geographical locations. And sensor method using photo sensors is tracked through difference in amount of light. Hybrid method is using both program and sensor method [3-5].

In PV system, if shadow is occurred to PV modules then PV modules operates reverses bias, and will eventually cause hot-spot [6]. The shadow influence of PV system can be solved by large PV system installation area. However, this method causes an increasing installation price. Also, an inclination angle of the tracking PV system is changed by altitude angle of sun. Consequently, a length of shadow is changed by variation of the inclination angle.

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Therefore, this paper proposes back-tracking method which can be minimized effect of shadow and installation area. The proposed tracking method in this paper compares with conventional method and proves validity of this paper.

2. Modeling of PV Tracking System

2.1 Modeling of solar cell

Fig. 1 is presented equivalent of solar cell and short current I_{sc} is equal to photo current, ideally. Open voltage of solar cell is decided diode saturation current I_o and equal to following equation [7].

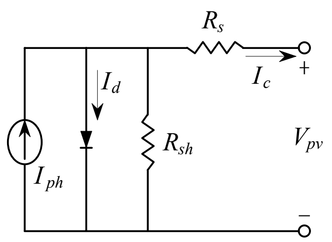

Fig. 1. Equivalent circuit of solar cell

$$I_{sc} = I_o \left[e^{\left(\frac{qV_{oc}}{kT}\right)} \right] \tag{1}$$

Where, V_{oc} is open voltage, k is Boltzmann constant, q is electric charge, I_o is saturation current and T is operating temperature $[K]$. And following equation is related function short current to open voltage with variation of temperature.

$$I_{sc} = I_o \left[e^{\left(\frac{qV_{oc}}{kT}\right)} \right] \tag{2}$$

PV module is composed a large number of solar cell connected with series and parallel. Following equation is presented to get current-voltage characteristic curve of solar cell.

$$I_{ph} = I_{sc} S_N + I_t (T_c - T_r) \tag{3}$$

$$I_d = I_o \left[e^{\frac{q(V_{pv} + I_c R_s)}{AkT}} - 1 \right] \tag{4}$$

$$I_o = I_{or} \left[\frac{T_c}{T_r} \right]^3 e^{\frac{qE_g}{Bk}\left(\frac{1}{T_r} - \frac{1}{T_c}\right)} \tag{5}$$

$$I_c = I_{ph} - I_d - \frac{V_{pv} + I_c R_s}{R_{sh}} \tag{6}$$

where, I_{ph} is photo current, S_N is the unit radiation, I_t is short current temperature constant $[A/K]$, I_d is diode current, R_s is series resistance, R_{sh} is shunt resistance, T_c is temperature of solar cell, T_r is command temperature of solar cell $[K]$, A, B are production constants, I_{or} is reverse saturation current and E_g is energy band gap.

Fig. 2 is presented PSIM model of solar cell and Fig. 3 is presented current-voltage and power-voltage curve of solar cell.

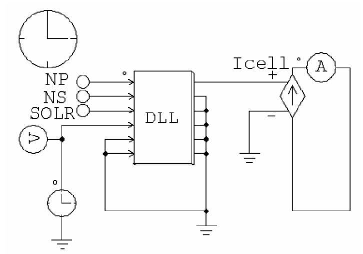

Fig. 2. PSIM model of solar cell array

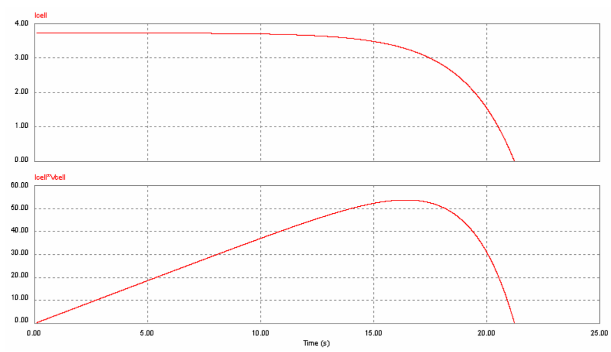

Fig. 3. I-V and P-V characteristic waveform of solar cell array

3. Algorithm for Control of Tracking Considering Shadow Effect

In PV system, if shadow in occurred to PV modules then PV modules operates reverses bias, and will eventually cause hot-spot. This phenomenon will bring about damage of PV module and it is causative of output decreasing. To prevent these problems, the bypass diode and blocking diode is used to PV system.

The hot-spot occurs by shaded PV module. It influences system output. The solar cell that is affected by shadow is operated resistance element due to reverse bias when the PV module without bypass diode appears shadow. Even when PV module has bypass diodes, if shadows cover 60% of cells or more, bypass diodes are activated and only those cell that is not influenced by shadow generate power, so power output is decreased. Also, an inclination angle of the tracking PV system is changed by altitude angle of sun. Consequently, a length of shadow is changed by variation of the inclination angle. The shadow is the longest in the sunrise and sunset and is the shortest in the afternoon. If distance between PV arrays is short because the site of photovoltaic power plant is not enough, shadow is occurred to PV array in the sunrise and sunset and then output power is decreased.

Fig. 4 shows the new control algorithm considering shadow effects. Coordinates for calculation of distance between PV arrays for different azimuth angles of the sun are presented in Fig. 5.

Fig. 6 shows distance calculation between PV arrays within 0°~ 45°azimuth angle of solar.

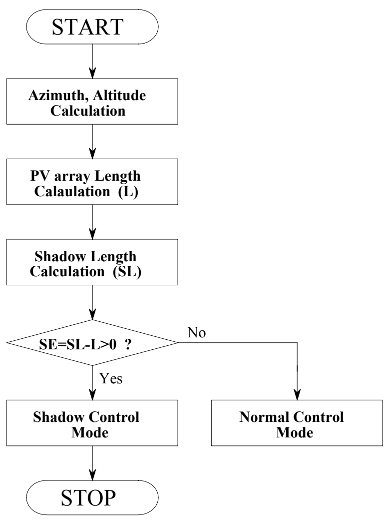

Fig. 4. Algorithm of tracking controller

By calculating current solar altitude angle, distance between PV arrays can be found. Distance between PV arrays for different azimuth angles of the sun can be calculated as shown in Eq. (7)~(22).

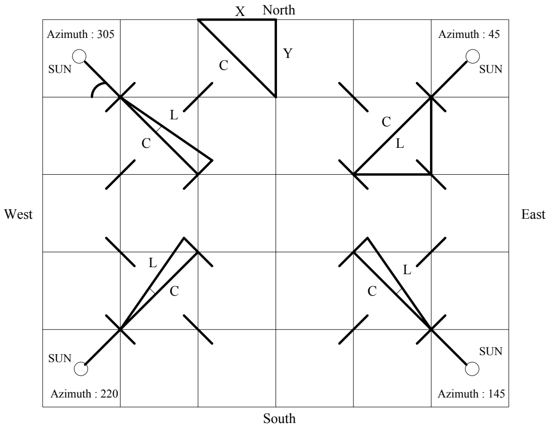

Fig. 5. Computation between PV array lengths by azimuth of solar

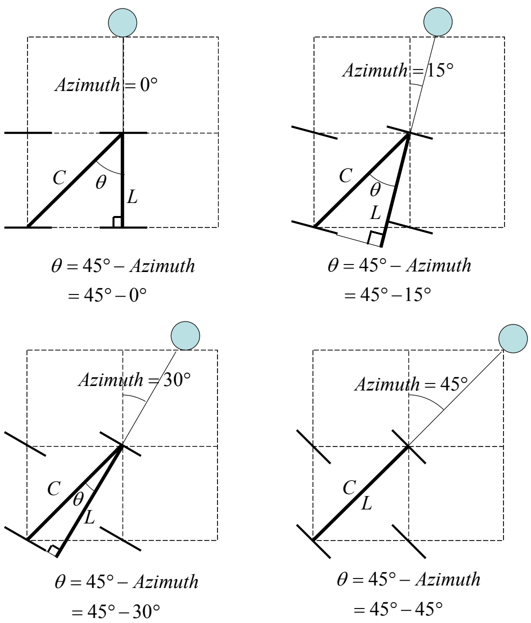

Fig. 6. Distance calculation between PV arrays within 0°~ 45° azimuth angle of solar (Case 1)

Case 1)
$\text{Azimuth}(0^\circ) < \text{Azimuth}(\theta) \le \text{Azimuth}(45^\circ)$

$$\theta = 45^\circ - Azimuth(\theta) \tag{7}$$

$$L = C \times \cos(\theta) \tag{8}$$

Case 2)
$\text{Azimuth}(45^\circ) < \text{Azimuth}(\theta) \le \text{Azimuth}(90^\circ)$

$$\theta = Azimuth(\theta) - 45^\circ \tag{9}$$

$$L = C \times \cos(\theta) \tag{10}$$

Case 3)
$\text{Azimuth}(90^\circ) < \text{Azimuth}(\theta) \le \text{Azimuth}(135^\circ)$

$$\theta = 135^\circ - Azimuth(\theta) \tag{11}$$

$$L = C \times \cos(\theta) \tag{12}$$

Case 4)
$\text{Azimuth}(135^\circ) < \text{Azimuth}(\theta) \le \text{Azimuth}(180^\circ)$

$$\theta = Azimuth(\theta) - 135^\circ \tag{13}$$

$$L = C \times \cos(\theta) \tag{14}$$

Case 5)
$\text{Azimuth}(180^\circ) < \text{Azimuth}(\theta) \le \text{Azimuth}(225^\circ)$

$$\theta = 225^\circ - Azimuth(\theta) \tag{15}$$

$$L = C \times \cos(\theta) \tag{16}$$

Case 6)
$\text{Azimuth}(225^\circ) < \text{Azimuth}(\theta) \le \text{Azimuth}(270^\circ)$

$$\theta = Azimuth(\theta) - 225^\circ \tag{17}$$

$$L = C \times \cos(\theta) \tag{18}$$

Case 7)
$\text{Azimuth}(270^\circ) < \text{Azimuth}(\theta) \le \text{Azimuth}(315^\circ)$

$$\theta = 315^\circ - Azimuth(\theta) \tag{19}$$

$$L = C \times \cos(\theta) \tag{20}$$

Case 8)
$\text{Azimuth}(315^\circ) < \text{Azimuth}(\theta) \le \text{Azimuth}(360^\circ)$

$$\theta = Azimuth(\theta) - 315^\circ \tag{21}$$

$$L = C \times \cos(\theta) \tag{22}$$

Where, X, Y, C are fixed values, and distances between PV arrays, and Fig. 7 shows the actual arrangement of PV arrays using the algorithm in this paper.

Fig. 7. PV array composition

Arrangement of PV arrays is made up using Eq. (7)~(22). And altitude of solar which changes shadow length has to be considered. Fig. 8 shows calculation of length of shadow for different altitude angles.

Length of shadow(SL) can be obtained as follows.

$$SL = AL \div \cos(\theta) \tag{23}$$

The method for compensation of shadow influence controls as follows.

First, the distance between PV arrays(L) calculate using

Eq. (7)~(22).

Second, the shadow length of PV array(SL) calculates using Eq. (23).

Third, L and SL compare length. And difference of these converts to angle.

Finally, altitude of PV array is controlled using this angle.

Method to compensation of shadow is the control to altitude angle in regard to length of shadow effect conversely.

The length of difference of L and SL is can be expressed as follow.

$$SE = SL - L \tag{24}$$

The compensation angle is as follows.

$$M\theta = \cos^{-1}\left(\frac{L}{SL}\right) \tag{25}$$

The altitude of PV array considered a shadow influence can be expressed as follows.

$$\mathrm{M}\alpha_{\mathrm{S}}\ (\text{Modify Altitude}) = \alpha_{\mathrm{S}}(\text{Altitude}) + \mathrm{M}\theta \tag{26}$$

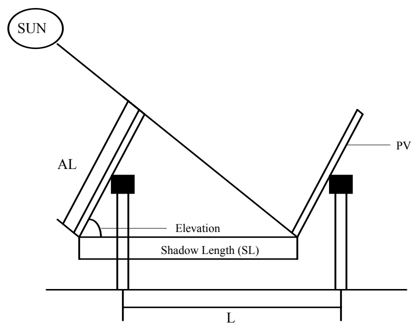

Fig. 8. Shadow length computation of PV array by altitude

Fig. 9 shows the flow chart of the algorithm for calculation of distance between PV arrays.

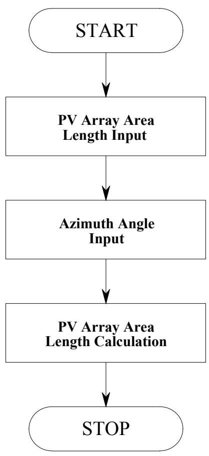

Fig. 9. Algorithm for calculation of distance between PV arrays

Fig. 10 shows the algorithm for calculation of shadow length using the length of PV array and altitude angle of solar.

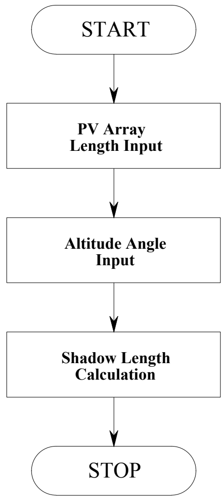

Fig. 10. Shadow length calculation algorithm of PV array

Table 1 is result value calculating the shadow compensation angle by azimuth and altitude of solar.

Table 1. Shadow compensation angle by azimuth and altitude of solar.

Time	Azimuth	Altitude	Array distance	Array declination	Shadow Length	SE	Compensation Angle	Control Altitude
(hour)	(°)	(°)	(mm)	(°)	(mm)	(mm)	(°)	(°)
7	103.22	4.23	8041	85.77	64127	56085	82.8	87.03
8	112.50	15.94	8740	74.06	17220	8480	59.5	75.44
9	123.47	24.75	9269	63.25	10509	1240	28.1	54.86
10	137.00	34.15	9454	53.85	8018	−1436	0.0	34.15
11	154.01	43.13	8944	44.87	6918	−2026	0.0	43.13
12	174.45	44.48	7304	43.52	6523	−782	0.0	44.48
13	195.85	45.37	8262	44.63	6647	−1615	0.0	45.37
14	214.74	40.07	9309	49.93	7348	−1960	0.0	40.07
15	230.05	31.75	9423	58.25	8989	−435	0.0	31.75
16	242.08	21.55	9043	68.45	12877	3835	45.4	64.94
17	252.07	10.24	8424	79.76	26603	18179	71.5	81.78
X axis Length	(mm)	6689.23	C axis Length	(mm)	9460			
Y axis Length	(mm)	6689.23	Array Length	(mm)	4730			

4. Experiment and Result

Table 2 shows specification of PV module. And Table 3 shows specification of PV inverter.

Fig. 11 shows experiment equipment proposes in this paper. The experiment equipment is grid-connected PV tracking system.

It includes a PV array and tracking sensor. Tracking control board is controlled by proposed algorithm using sensor signal and PC. PV Inverter is composed two groups to compare case of shadow compensation and non-compensation and output power is monitored through PC. Also, generated power is connected grid through wattmeter.

Table 2. Specification of solar cell module

Maximum power(P_{max})	[W]	210
Max .power voltage(V_{mp})	[V]	41.3
Max .power current(I_{mp})	[A]	5.09
Open circuit voltage(V_{oc})	[A]	50.9
Short circuit current(I_{sc})	[A]	5.57
Warranted minimum power(P_{min})	[W]	199.5
Output tolerance	[%]	+10/-5
Maximum system voltage	[V]	600
Temperature coefficient of P_{max}	[%/°C]	-0.3
Temperature coefficient of V_{oc}	[V/°C]	-0.127
Temperature coefficient of I_{sc}	[mA/°C]	1.67

Standard Test Conditions : Air mass 1.5
Irradiance= 1000W/m^2 , Cell temperature= 25°C

Table 3. Specification of PV inverter

Term	Standard
Recommended power supply	28-42 kWp
MPP voltage range	210-420 V
Max. input voltage (at 1000W/m^2/–10°C in an open circuit)	530 V
Max. input current	164 A
Nominal output power(P_{max})	32 kW
Max. output power	32 kW
Nominal mains voltage	3NPE × 400V, +10/ − 15 %
Nominal output current	3 × 46.4 A
Nominal frequency	60 ± 0.2 Hz
Maximum efficiency	94.3 %
Overnight internal consumption	9 W
Internal consumption operation	66 W

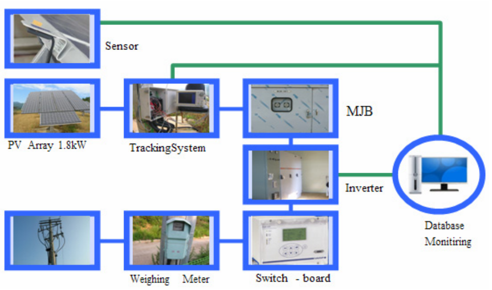

Fig. 11. Configuration of experiment device in proposed paper

Fig. 12 shows the air temperature and surface temperature with variable radiation. Rapidly change of radiation causes variation of surface temperature of module. Fig. 13 shows the AC power changing with shadow compensation. Generation of tracking system with shadow compensation is 20.1[kWh] but, generation of tracking without shadow compensation is 15.34[kWh] at the AM 8:20. Therefore, the generating of shadow compensation system is 4.76[kWh] higher than the other system.

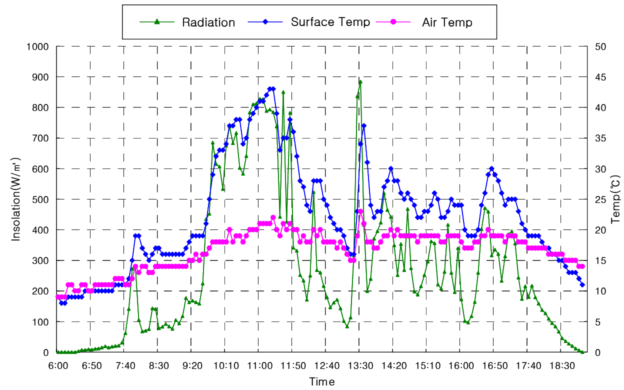

Fig. 12. Temperature change by radiation variation

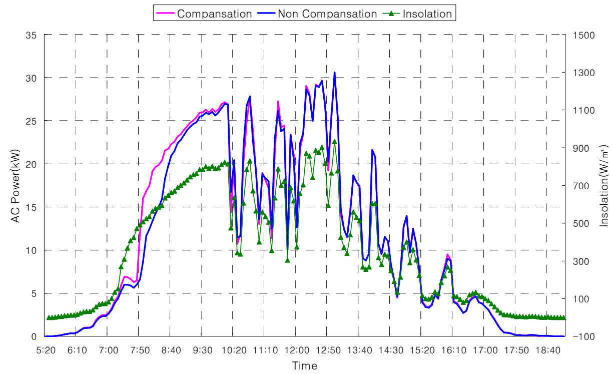

Fig. 13. Change of AC power by shadow compensation

Fig. 14 shows radiation and cumulative generating. Generation with proposed shadow compensation algorithm is 6.86[kW] higher than non-compensation algorithm.

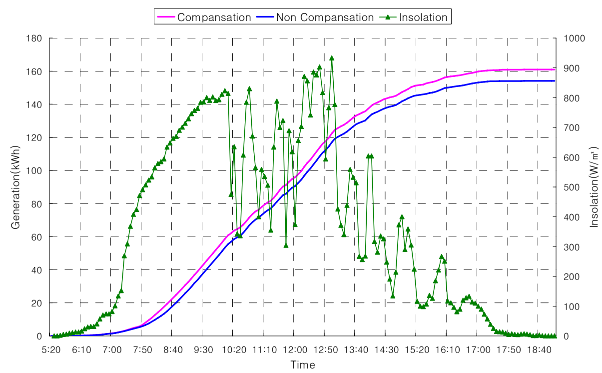

Fig. 14. Comparison with power by shadow compensation

Fig. 15 shows generation for a month with proposed shadow compensation algorithm. Generation of tracking with shadow compensation is 5,208[kWh] but, generation of tracking with shadow non-compensation is 5,084[kWh]. Therefore, the generation of the proposed system is 123[kWh] higher than the other. Accordingly, proposed algorithm is proved the validity and efficiency through the compare to conventional algorithm.

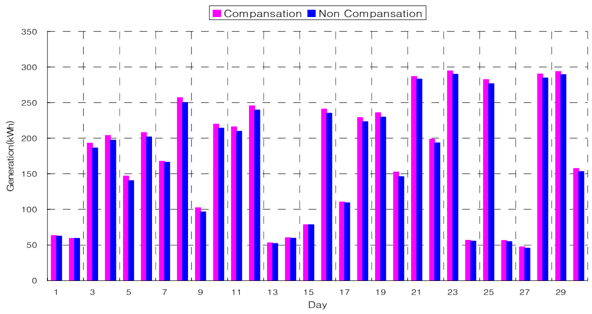

Fig. 15. Comparison with power by shadow compensation (a month)

5. Conclusions

This paper proposes a tracking system considering a shadow influence in order to improve the efficiency of PV system. If distance of between PV arrays is not enough, shadow can be occurred to PV module. The influence of this shadow is decreased efficiency and generating of PV system. Distance of between PV arrays and length of shadow is changed according to position of solar.

Therefore, this paper proposes the back-tracking method which is not shaded to a PV module using azimuth and altitude of solar. The proposed method calculates distance of between PV arrays using azimuth of solar, and calculates shadow length of PV array using altitude of solar. The proposed method calculates distance of between PV arrays using azimuth of solar, and calculates shadow length of PV array using altitude of solar and then compares with the distance of between PV arrays and the shadow length. When the shadow length is longer than the distance between arrays, the algorithm adjusts altitude of array to avoid the shadow influence.

Tracking system applying the proposed method in this paper is compared with conventional tracking system about AC power and generating in radiation changing condition. The proposed system is higher power generation (6.86[kW] a day and 123[kW] a month) than conventional system. Therefore, the validity of the shadow compensation algorithm proposed in the paper was verified.

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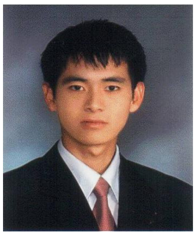

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