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Development of High-efficient, Low-concentration Photovoltaic System

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Abstract

More attention is paid to renewable energy worldwide due to the recent Japanese nuclear power plant accident, fossil energy depletion, and global warming. Studies to enhance power generation system efficiency using solar energy are currently carried out actively. Although efficiency can be enhanced using high solar concentration photovoltaic (PV) module through lens or reflectors, the high solar concentrator prices are expensive, and thus some economic difficulty arises in system configuration.

This paper has researched a method to enhance low solar concentrator system efficiency using general photovoltaic (PV) module whose price is low. This paper has used a reflective type optical device to raise low solar concentrator system efficiency and lower its price, and has developed a solar tracking system combining an image recognition type and a program type using the difference of brightness. The developed solar tracking system was installed in Asan, Korea in order to check its performance, and generated power amount was measured, according to time. As a result of comparing with a fixed power generation system, this paper found a 28% power generation efficiency improvement on average.

Keywords: *Solar concentrator, solar concentration type, difference of brightness, image recognition, photovoltaic power generation*

1. Introduction

Korea, whose energy consumption increase rate ranks No. 1 among OECD countries, implements the active development, diffusion, and expansion policy of renewable energy to solve greenhouse gas (GHG) emission reduction obligation and energy market instability. Among others, many studies to develop highly efficient technology of photovoltaic (PV) system producing electricity by converting solar energy are carried out. Meanwhile, solar concentration system development using lens or reflectors is actively performed to improve the PV module's power production efficiency as regards the PV module. As for solar concentrator, lens is generally used, or high solar concentration is pursued by designing the device as a solar tracking type using high solar concentration optical device [1].

The core technology of PV system is the accuracy of the solar tracking system. Meanwhile, low solar concentrator type solar tracking system requires a highly meticulous and sophisticated accuracy. The existing solar tracking system can be divided into a photo sensor type, a program type, and an image recognition tracking system, which uses the difference of brightness [2-4].

The photo sensor type can be categorized into the U.S. type and German type, according to the number and placement method of the sensors used. The U.S. type using the needle's eye is meant to track the degree of light that comes through a narrow opening and shifts the sensor. The type is built robustly without the part exposed to the outside.

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However, it is rated as a product focusing on diffusion, rather than on accuracy, due to a relatively big error range [5]. The German type is used for the control of rotation and altitude by placing two sensors. Although its accuracy is high, its sensitivity is also high, and therefore, a problem of malfunction is caused.

A computer is built in the program type. Although waste is pointed out because 24-hour power supply is essential, the type has a lot of merits such as small error and not much allowance for breakdown. To some degree, a compromised version is also used to check operation conditions and operate with a calculation mode using a photo sensor. However, its use rate is low because a cost increase incurred by double installation of the operating system is pointed out as a demerit, rather than a merit, to solve each type's weaknesses [6].

This paper has developed an image recognition tracking system using the difference of brightness applicable to a low solar concentrator type power generation system. Its main technology has improved solar tracking by combining the image recognition device and program calculation type; in particular, the solar tracking system has been developed for solar tracking accuracy to be within ±0.1°. This paper analyzed the solar concentration rate of the reflective type optical device by angle through simulation, and the angle generating maximum efficiency was decided as 70° in this paper.

This paper configured the system, combining it with 117W PV module, and comparatively analyzed the difference of generated power amount with a general 117W PV module.

This paper consists of Chapter One: Introduction, Chapter Two: Explanation of Low Solar Concentrator Type Solar Tracking System, Chapter Three: Development of Low Solar Concentrator Type PV Module, Chapter Four: Experimental Results, and Chapter Five: Conclusion.

2. Solar Tracking System

Existing solar position tracking method can be divided into a photo sensor type and a program type. However, the sensor type has such demerits as weakness to change in the weather, and frequent malfunction by foreign substances, while the program type has such weaknesses as 24-hour power supply for PC for management (calculation), and variables setting, according to place to install and operate the system. In this regard, this study proposes an image recognition type solar tracking system using the difference of brightness that can solve such demerits [7-9].

2.1. The Proposed Solar Tracking System

Figure 1 shows the basic sequence of the solar tracking system, and the process is as follows: Solar position data are collected through the image recognition system by brightness difference mode after automatic inspection of the solar tracking devices and surrounding environmental status. Based on the collected data, the sun is tracked by operating an actuator. Afterwards, feedback of the operation status is conducted, and operation error is minimized. The most important thing in the solar tracking system is to make solar tracking suitability within ±0.1°. The accuracy of the solar tracking system can be elevated by correcting the solar tracking system program in consideration of operation error in each actuator section.

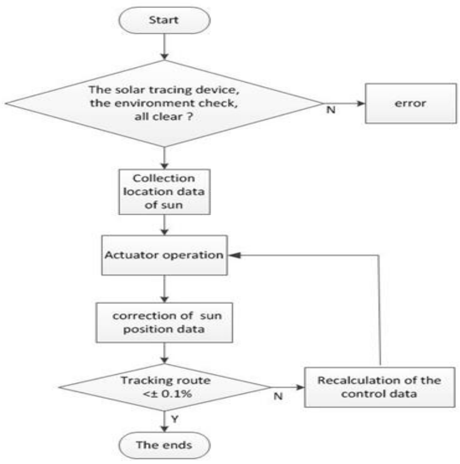

Figure 1. Basic Operation Flow Chart of Solar Tracking System

2.2. Image Recognition and Methods of the Brightness Differentiation

Figure 2 shows solar tracking results by the difference of brightness. Figure 2(a) shows the image data obtained from CCD camera module, and each pixel of the CCD camera plays a role of a sensor presenting brightness with 256 levels. The brightness changes according to the distance of light emitted from the source of light.

Using this, when brightness is divided into 16 levels by simplifying the light brightness using the histogram of the brightness of light emitted from the source of light, the following distribution is presented as shown in Figure 2(b).

As shown in Figure 2 (c), solar position can be tracked using a principle that the center of circles matches the center of the source of light when circles are formed by connecting the boundaries.

If the sun is covered behind an intervening objet or clouds, distortion is caused by the scattering of sunlight, and therefore, the formation of circles based on calculated area becomes difficult. In this regard, an error of finding many inappropriate circles is caused. In this case, the crossing, where all the rays of light gather, must be found by inversely tracking the rays of light captured on the bases of a light's linear attribute [2].

The source of light is located on the crossing. Likewise, the solar position can be tracked, while the error range is minimized even in the case of clouds, abnormal meteorological phenomena, or physical intervention since the solar position is tracked using the light's linear attribute.

Figure 2(d) shows the solar tracking results in the inappropriate environment.

(a) (b) (a) (d)

Figure 2. The Image Data Obtained From The Module Of CCD Camera

2.3. Correction Method of the Actuator Operation Error

For the solar tracking system, an actuator is used to operate PV module with tracked angle and direction. However, operation error is caused, according to the characteristics of the actuator used for the solar tracking system. To minimize such an error, the error can be corrected by measuring the angle, according to actuator's length. Figure 3 shows the graph where the angle is measured according to actuator's length. As shown in the figure, errors are caused, according to actuator's angle, and a process to correct the actuator's length is necessary to solve the problem. The equation for correction is as follows:

Stroke – Angle = Ax4 - Bx3 + Cx2 + Dx + E (1)
Angle – Stroke = Ax4 - Bx3 - Cx2 + Dx – E (2)

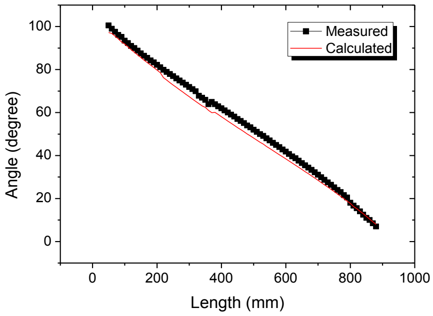

Figure 3. Angle of the Actuator Length

Each parameter can be calculated by the trial and error method. Table 1 shows each parameter's value.

Table 1. Correction Parameter of The Actuator Operation Error

Parameter	Stroke – Angle	Angle – Stroke
A	5.1563e – 011	1.483e – 007
B	2.3713e – 008	0.00012855
C	1.806e – 005	0.002995
D	0.10979	8.9779
E	0.04565	0.028754

2.4. PV Module

A simple method to enhance a PV cell's power generation efficiency is to concentrate solar energy. Reflectors or lens are generally used to enhance a PV cell's solar concentration rate. However, using lens makes production unit price higher, and the use of reflectors makes price go up, while the structure becomes complex in the case of high solar concentrator type design.

This study has designed a low solar concentrator type PV module using a reflector that can lower production unit price and enhance solar concentration rate. Figure 4 is the predicted structure chart of low solar concentrator type PV module equipped with a reflector.

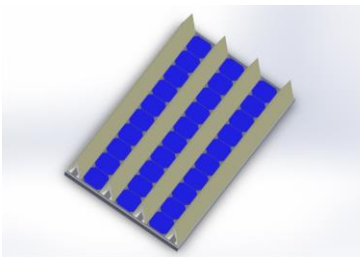

Figure 4. The Estimated Structure Diagram of Solar Concentrator Module Equipped with A Reflection Plate

3. System Implementation

3.1. Solar Tracking System

This paper proposes a solar tracking system combining the image recognition device and program type. The proposed type is to improve power generation efficiency based on solar tracking system, making solar tracking accuracy within ±0.1° error range [10]. This study has also actualized low solar concentrator type solar tracking monitoring system using light source tracking multi-control embedded system based on network. The system has been developed to verify order implementation results by using the tracking type that tracks the brightness of light emitted from the source of light and tracks the center of light source amid brightness distribution, and by collecting the data on the control method simultaneously operating many PV devices using the obtained data and on the operation results of power generation devices.

Figure 5 shows the basic structure chart of a solar tracking system. The solar tracking system consists of a solar tracker, tracker control unit (TCU) and group control unit (GCU).

The solar tracker is a device tracking the sun by collecting solar position with camera images, and the tracker can be operated through remote control. In case the sun is not captured by the camera on a cloudy day, the tracker has been designed to operate based on the programmed equations and according to latitude and longitude.

TCU, installed together with the tracker at site, is a device controlling a motor and an actuator so that sunlight can be tracked with 1 axis to 2 axes. A microprocessor is used for TCU, and pan and tilt are calculated with current time obtained through RTC chip within the TCU, while the angle that the tracker needs to reach is calculated using the pan and tilt values. TCU controls the monitor in line with the calculated angle, and tracks the sun according to image tracking values through communications with GCU

The GCU, using RS-485 serial port, is a device collecting, managing, preserving, and controlling various information and data of the TCU. GCU analyzes the solar position through two image devices, and plays a role of enhancing a tracker’s tracking accuracy.

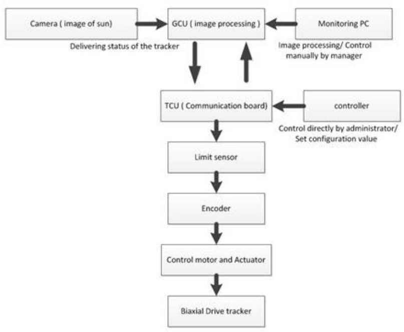

Figure 5. The Overall System Operation Environment

3.2. PV Module

This study manufactured a module without a reflector, a module equipped with a 60° reflector, and a module equipped with a 70° reflector to check the efficiency of reflector’s angle. The PV module used for measurement is a fixed type module consisting of 36 cells, with the power generation capacity being 7.2W. Figure 6 shows the image of a PV module equipped with a reflector: from left, the module without a reflector, the module with a 60° module, and the module with a 70° reflector.

Figure 6. Solar Concentrator Module 7.2W

3.3. Monitoring System

Figure 7 shows the main screen of the solar tracking device monitoring system (GCU: Group Control Unit). As revealed in the main screen, it consists of various items that a user wants to set including weather, real time direction/altitude of the sun, and status information of the tracker.

The solar tracking device monitoring system can control many TCUs. Each TCU is controlled through connection with GCU with different COM ports. Also, each TCU's total manual control and individual manual control are operated through a remote control. When a problem occurs to the image tracking screen, tracker status information, and inverter information, an abnormality sign is transmitted to the administrator, and the administrator can take a quick action. Figure 8 shows the screen of the tracker's detailed information and manual control. Figure 9 shows the image tracking screen of the solar tracking device monitoring system.

Figure 7. Capturing of the Main Solar Tracking

Figure 8. Detail information of Tracker and Manual Control

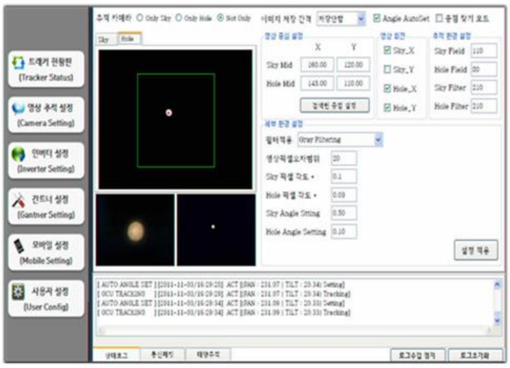

Figure 9. Capturing of the Solar Image Tracking

Table 2. 7.2W Measurement Result at 10 AM

	module without a reflector	60° reflector	70° reflector
voltage [V]	7.87	8.31	8.66
current [A]	0.7	1.03	1.22
Temp.[℃]	40	47	64
Inso. [W/m²]	1070	1101	1675
Gen. power [W]	5.509	8.559	10.565

Table 3. 7.2W Measurement Result at 3 PM

	module without a reflector	60° reflector	70° reflector
voltage [V]	8.63	8.83	9.3
current [A]	0.79	1.03	1.22
Temp.[℃]	45	52	73
Inso. [W/m²]	1135	1161	1825
Gen. power [W]	6.817	9.095	11.346

4. Experimental Result

This study measured the voltage, current, temperature, insolation, and generated power amount to check the performance of the type proposed in this study. The measurement was carried out in June 2014, and the measurement location was Asan, Korea (at 126° longitude and 37° latitude). Measurement was carried out in the morning and afternoon, and Tables 2 and 3 show the measured data.

The generated power amount in the afternoon was 6.817W in the case of the module without a reflector, and each cell's generated power amount was 0.189W (6,817W/36 cells). The generated power amount of each cell of the module with a 60° reflector and the module with a 70° reflector was 0.253W and 0.315W, respectively. As shown in the table above, the generated power amount was highest at the angle of 70° of the reflector. In addition, the module having the 70° reflector showed the biggest power generation efficiency improvement of 66.6% (=(0.315-0.189)/0.189*100%), compared with the general module.

To check the performance of the solar tracking system that applied image recognition type, this study used the general PV module with a capacity of 117W, which is used in an actual power plant. The general module with a capacity of 117W was installed as a fixed type, and the 117W module having a 70° reflector was installed to the low solar concentrator type solar tracking system. Using all this, a generated power amount test was conducted. The data measured to compare the performance of each module included voltage, current, generated power amount, and insolation. The measurement time was from noon to 15:30 when insolation was at its highest point. The measurement interval was 30 minutes.

Table 4 shows the comparative results of the generated power amount of each module. The power amount of the module proposed in this study was higher by 26.6W on average than the general module. Therefore, power generation efficiency was improved by 28% on average.

Table 4. Comparison Of Generation Capacity Of Each Module

Time (interval 30)	Test Environment (insolation, **kW/m^2**)	**General Module** power **[W]**	**Proposed Module** power **[W]**	Comparison power **[W]**	**발전효율 [%]**
12:00	0.972	117.14	143.44	+26.30	22.45
12:30	1.075	112.95	138.98	+26.03	23.05
13:00	0.937	110.24	135.75	+25.51	23.14
13:30	0.412	48.13	55.64	+7.51	15.6
14:00	0.880	104.88	138.11	+33.23	31.68
14:30	0.735	87.83	121.18	+33.35	37.97
15:00	0.736	89.23	117.01	+27.78	31.13
15:30	0.739	87.85	120.91	+33.06	37.63

5. Conclusions

This study has developed a highly efficient low solar concentrator type photovoltaic (PV) system. The sensor type tracking error problem was solved by developing the solar tracking system of an image recognition type. Also, tracking accuracy was improved by minimizing the used actuator's operation error to ±0.1° through correcting the error in a program manner. By improving the solar concentration rate of the low solar concentrator type PV module using a reflector, the module efficiency having a 117W capacity rose about 27.83%. In this regard, a low solar concentrator type PV system with high efficiency, compared with unit price, can be produced in a mass production system if the outcome of this study is used. If the efficiency improvement technology of low solar concentrator is additionally developed, the PV system with higher efficiency can be considered for development.

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