반도체디스플레이기술학회지 제18권 제1호(2019년 3월)
Journal of the Semiconductor & Display Technology, Vol. 18, No. 1. March 2019.

Development of Tracking Algorithm for Floating Photovoltaic System

Byung-Moon So* **and Ik-Tae Im**^**†^

*Department of IT Applied System Engineering, College of Eng., Chonbuk National Univ.,
**† Mechanical Design Eng., College of Eng., Chonbuk National Univ.

ABSTRACT

Since floating facility with mooring system can be moved and rotated by wind or other environmental variables, the error in azimuthal angle must be compensated using a GPS receiver and geo-magnetic sensor. Accordingly, when an existing photovoltaic tracking algorithm is applied to a floating photovoltaic system, it is difficult to do the optimal solar tracking. In this paper, an effective azimuthal angle algorithm is develop for the photovoltaic tracking in floating condition. In order to verify the developed algorithm, the prototype of the floating photovoltaic system is manufactured and the developed algorithm is applied to the system. The algorithm shows a good tracking feasibility on the prototype.

Key Words : Floating Photovoltaic System, Azimuthal Angle, Solar Tracking Algorithm

1. Introduction

A photovoltaic (PV) system is divided into the fixed-type where the angle of PV module is fixed at a certain angle, and the tracking-type where the azimuth and altitude of the sun are tracked to receive the sunlight perpendicular to the surface of the PV module. The tracking-type PV is a high-efficiency power generation system that produces a greater amount of electricity by adding real-time sun-tracking function to the PV module. In general, it is known that on the ground, the power generation of a dual-axis tracking-type is 30% greater than a fixed-type.

Tracking-type PV system is designed to improve the efficiency of PV by tracking the sun with solar sensors, and automatically track the sun with precision using a program even when it is cloudy or rainy [1]. For this, a separate mechanical device is used to rotate a PV module. However, the number of units of PV modules that can be rotated at once is limited and there are frequent malfunctions in the units. It requires a great deal of efforts in maintenance of the units.

The tracking-type system installed on the ground has some limitations as to PV modules below 3 kW that can be operated through a single tracker and its utilization is also limited due to frequent malfunctions [2]. Because of these, the structure of the system must be designed with cantilever at a single rotation point. The cost of the structure rises as the unit module capacity increases because the cantilever length is limited due to its weight or external force.

Floating solar generate more electricity than ground-mount and rooftop (solar) systems because of the cooling effect of water. It also reduces reservoir evaporation and algae growth by shading the water [3]. In floating PV, the external force and self-weight of the structure are transferred to water through the buoyancy of which direction is the opposite to the gravitational force, so the length of the structure that can resist the gravitational force can be designed with relatively easily [4-6]. Also, as it floats on the water, it can rotate with a small amount of energy even if the unit rotation capacity is large (over 20 kW). If the tracking-type can be applicable to floating PV systems, the structure can be made simpler than the ground tracking-type, thus reducing malfunction risk and increasing efficiency [7-8]. Design of a high performance floating PV plants is still a topic of importance and a lot of interests [9].

Increasing efficiency of photovoltaic power generation

---

† E-mail: itim@jbnu.ac.kr

systems is one of the most important research interests in recent years [10, 11]. The aim of this paper is to examine the selected types of model tracking-type systems for development of a tracking algorithm for maximum power generation in floating condition and to test the developed algorithm through the models. The developed algorithm is also suggested for an actual 100 kW tracking type floating photovoltaic system based on the model verification.

2. Tracking Algorithm for Floating PV System

2.1 Concept of tracking algorithms

Tracking location of the sun on the ground includes the methods of using optical sensors (passive), by astronomical calculations (active), and the method combining the two.

The sun tracking device using optical sensor involves operation of an actuator to operate the sun tracking system using the difference of the radiation intensity detected through a photo sensor. The sun tracking method using astronomical calculations involve using information of longitude and latitude of the tracking system installation location and performs calculation or computation by time so that it is in the optimal angle and direction with the sun at all times. The sun tracker using an optical sensor is operated by the sensor response characteristics, and thus has the weakness of not being able to make an accurate sun detection in an environment with diffusion such as under cloudy weather, and thus tracking accurate location with astronomical calculations is used to supplement. By the astronomical calculation method, it can track the sun even when it does not appear for a long period of time as the sun location information is acquired by an astronomical method. The malfunction by external substances can also be limited within a certain range. It is advantageous of reducing errors in the sun tracking by astronomical calculation but there is still a weakness that the system initial position must be very accurate.

On water surface, unlike on ground surface, the entire structure moves and rotates by wind or other environmental variables even if the mooring system is installed, so an error may occur to the azimuth angle [1, 4]. In order to compensate this error, a GPS receiver and a terrestrial magnetism sensor have to be used to compensate for the twisted angle. The algorithm minimizing the error from external disturbance on water surface has also to be applied. Tracking performance on water must be improved by the hybrid type that integrates the optical sensor method and the astronomical method. In this paper, the sun tracking method for a floating photovoltaic power system which can detect any variations in the direction of structure by wind and surface flow using sensor and correct such variations is developed and applied to a model floating PV system. Program tracking that is an astronomical calculation is selected as an auxiliary method to prevent dead operation in absence of the sun.

2.2 Design of algorithm

As explained in the previous section, tracking location of the sun on the ground includes the method of using optical sensor (passive), the method by astronomical calculations (active), and the method combining the two. The last hybrid-type combining the two methods tracks the sun intelligently based on the weather information such as amount of the radiation, wind speed, and temperature for increasing the PV's efficiency. Therefore, it is applied as the sun tracking method to the floating PV system.

On water surface, however, unlike on the ground surface, the entire structure moves and rotates by wind or other environmental variables even if the mooring device is installed. An error in the sun tracking may occur to the azimuthal angle because of the movement. In order to track the sun precisely, a GPS receiver and a terrestrial magnetism sensor are used to compensate for the twisted angle and the algorithm minimizing the error from external disturbance on water surface is applied. The error compensation by an external disturbance is reported in the reference [12] and explained in the following Fig. 1.

Manual tracking algorithm is a method for tracking position of the sun using photovoltaic sensors, as shown in Fig. 1(a). It is a method that detects position of the sun for tracking. The sensor stops operating when the west limit switch is turned on (sunset) and moves to the position of the east limit for operation on the next day (sunrise). Active tracking algorithm is an algorithm that tracks position of the sun by computing hourly azimuth angle based on the astronomical position, as shown in Fig. 1(b). It is operated so that current azimuthal angle is the same as the pre-entered astronomical azimuth.

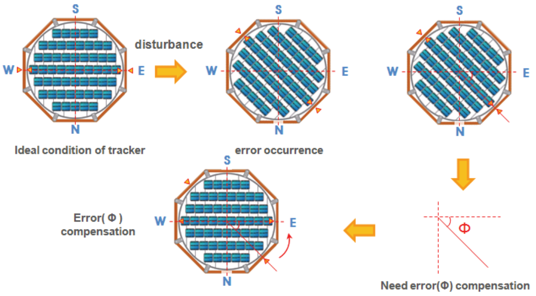

Fig. 1. Compensation of the azimuthal angle disturbed by an external force.

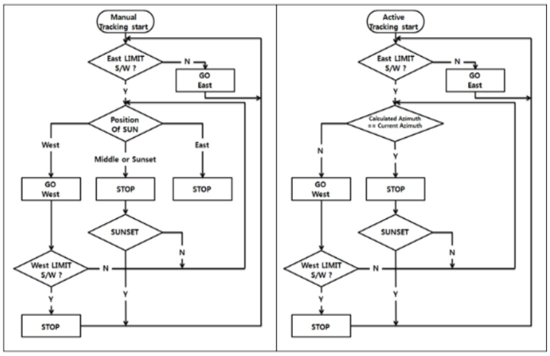

Fig. 2. Flow chart to the tracking algorithms, (a) Manual Tracking Algorithm, and (b) Active Tracking Algorithm.

3. Algorithm Application Experiment

3.1 Model for experiment

For tests of the tracking algorithm, a scaled model similar to an actual structure is manufactured and launched on a water tank to test with forward and reverse rotations using a small motor.

Operation methods include a manual rotation with forward and reverse rotation buttons, movement along the light using an optical sensor (azimuthal sensor), and movement for given time according to the astronomical timer. Fig. 3 shows the test set of the tracking-type floating photovoltaic model. A power module is composed of four circular PV units as shown in the figure. A standing light is used instead of the sun. The PV unit rotation is accomplished by a rotor which is on when forward / reverse button is pushed and it is used for manual operation test as shown in Fig. 4.

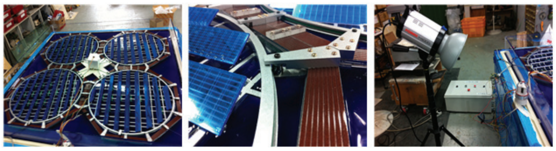

Fig. 3. Sun tracking test set of the floating photovoltaic model.

Fig. 4. Manual forward and reverse rotation control using the control panel.

3.2 Manual and active tracking algorithm test

Movement of the rotating structure along the light using an optical sensor (azimuth sensor) is tested to the scaled model. Usually, optical sensors of tracking-type floating photovoltaic power generation systems are installed on a module frame within the rotor. However, in this test, the sensor is attached outside of the structure instead of the rotor itself since the rotor of the model cannot support the weight of the optical sensor. An artificial sun using a halogen lamp having similar characteristics with sunlight is prepared and used in the tests. The lamp is moved to the left or right of the optical sensor to test the forward or reverse rotation of the rotor. Fig. 5 shows a photograph of the test.

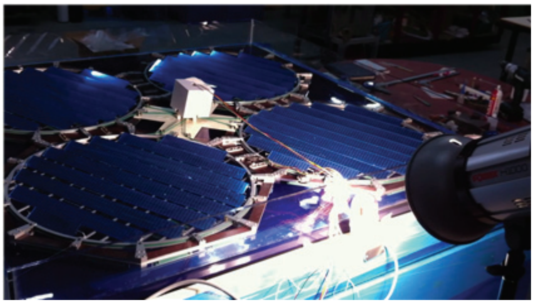

Fig. 5. A photograph of the solar tracking test using an artificial sun and an optical sensor.

The active tracking algorithm is also developed and applied to the scaled model. This algorithm is about to move PV modules for a given time according to the astronomical data using a timer and to see if it comes to a stop properly.

Time and angle of forward or reverse rotations for the small motor are calculated to rotate the modules from the east to the west during the day, and it is automatically moved to the east once it arrives at the stop sensor on the west limit.

4. Control Algorithm Considering External Disturbances

Despite application of a mooring system to floating photovoltaic systems, external environmental factors such as flows induced by wind cause movement and rotation of the overall structure within a certain range from a fixed position. Therefore, change in the angle of the PV module of an actual 100 kW tracking type floating photovoltaic system is analyzed to examine the effect of flows. Variation of the angle of the module structure was between 0.3° and 25.2° from due south for 8 months of measurement period. For each month, the angle changed between the minimum of 3.62° and the maximum of 22.7° in May, 8.7° and 21.3° in June, 3.2° and 17.8° in July, 0.3° and 9.5° in August, 1.7° and 8.9° in September, 1° and 9.8° in October, 3.9° and 17.5° in November, and 11.9° and 25.2° in December. It can be seen that effect of flows is large in winter season. This measurement clearly shows that a control algorithm has to include the consideration about the external disturbances.

Combining the astronomical tracking method and the sensor control method are used to track the actual floating photovoltaic system in order to consider flow effect. This method uses the elevation angle and azimuth of the installation area about position of the Sun based on astronomical calculation when the sun irradiation is 350 W/㎡ or below, as well as the sensor control. External disturbance data are also included to the control program. When the sun irradiation is above 350 W/㎡, the sun is tracked using an irradiation sensor. The final control algorithm in which external effect is considered is shown in Fig. 7.

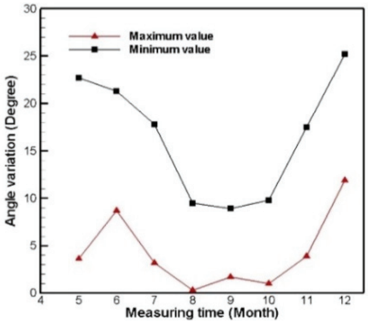

Fig. 6. PV module angle variation according to season.

5. Application of the Developed Algorithm

In order to test the developed tracking algorithm to control floating PV, the tracking system using the developed algorithm was applied to the PV power generation plant at Hapcheon-gun, Korea. The azimuth of the sun was measured from 8:00 in the morning to 20:00 in the evening on September 18. The driver movement angle controlled by the developed algorithm that was based on a geomagnetic sensor, calculated angle from the control program, and the actual azimuth value which are officially authorized astronomical

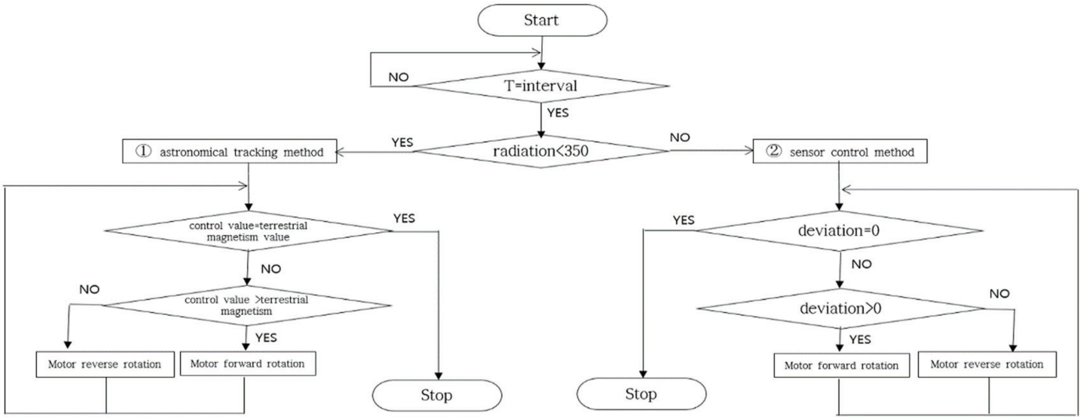

Fig. 7. Floating PV control algorithm considering external disturbance.

Table 1. Comparison of test value and real azimuth value

Time	Structure test value	Calculated azimuth	Real azimuth	Solar radiation	Difference
8:15	101	105.5	103	326	2.0
9:15	115.8	116.5	113	792	-2.8
10:15	131.2	131.7	127	718	-4.2
11:15	155.9	152	146	729	-9.9
12:15	169.8	176.5	170	864	0.2
13:15	195.5	201.7	196	681	0.5
14:15	219.7	223.2	219	410	-0.7
15:15	236.1	239.2	236	346	-0.1
16:15	249.3	251.5	249	351	-0.3
17:15	262.6	263.1	259	138	-3.6
18:15	266.4	270.3	268	18	1.6
19:15	266.4	279.3	277	0	10.6
20:15	266.5	298.7	286	0	19.5

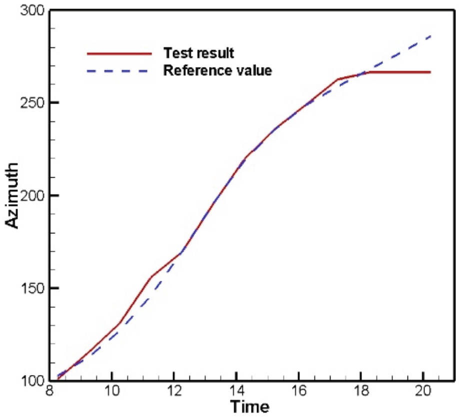

Fig. 8. Comparison of test values and the real azimuth values.

institution are listed in Table 1. Movement interval of the driver was about 1 minute, and it started at 8:11. The first measurement was at 8:15, 4 minutes after the start, in order to stabilize the geomagnetic sensor. Actual azimuth data from an officially authorized astronomical institution over time and the operation data were compared.

Fig. 8 compares the azimuth that was tracked using the floating photovoltaic algorithm, that is, test values in Table 1 and the real azimuth from the institution. Large difference after 19:15 is due to the zero solar radiation. Tracking the sun was actually stopped after this time because of sunset. Except these, test values show very good accuracy.

6. Conclusion

On water surface, the entire structure of photovoltaic power generation plants moves and rotates by wind or other external disturbances from environmental surroundings even if the mooring system is installed. This may cause errors to the azimuth angle for tracking the sun in the PV modules on water surface. In order to compensate for this error, GPS receiver and terrestrial magnetism sensor was used to measure the twisted angle and the algorithm minimizing the error from external disturbances was applied.

In this paper, the manual and active tracking algorithms for floating photovoltaic system were demonstrated by a model experiment. The algorithm was developed based on the model experiment of floating photovoltaic system and applied to a demonstration plant to analyze its accuracy, and the developed algorithm had excellent tracking accuracy. The tracking algorithm proposed in this paper will set the basis for future development of tracking type floating photovoltaic systems.

Tracking performance can be improved in the future by adding an algorithm that sequentially rotates more than one structure to reduce the force inflicted on 4 rotating structures during tracking of azimuthal angle and by considering time and angle of rotation during operation of an actual motor.

References

1. Young-Kwan Choi, Nam-Hyung Lee, Kern-Joong Kim, Yong Cho, “A Study on the Influence to Solar Radiation by Changing the Azimuth and Tilt of a Photovoltaic Array,” *The Transactions of the Korean Institute of Electrical Engineers*, Vol. 62, No. 5, pp. 712-716, 2013.
2. Young-Kwan Choi, Nam-Hyung Lee, Kern-Joong Kim, “Analysis of the Grounding System of Floating Photovoltaic Systems,” *ISGCE2013 ETCP-1169*, July 2013.
3. Alok Sahu, NehaYadav, K.Sudhakar, “Floating photovoltaic power plant: A review,” *Renewable and Sustainable Energy Reviews*, Vol. 66, ,pp, 815–824. 2016.
4. Young-Kwan Choi, Nam-Hyung Lee, An-Kyu Lee, Kern-Joong Kim, “A study on major design elements of tracking-type floating photovoltaic systems,” *International Journal of Smart Grid and Clean Energy*, Vol.3, No.1, pp. 70-74, January 2014.
5. An-Kyu Lee, Gang-Wook Shin, Sung-Tack Hong, Young-Kwan Choi, “A study on development of ICT convergence technology for tracking-type floating photovoltaic systems,” *International Journal of Smart Grid and Clean Energy*, Vol.3, No.1, pp.80-87, January 2014.
6. Young-Kwan Choi, Nam-Hyung Lee, Kern-Joong Kim, “Empirical Research on the efficiency of Floating PV systems compared with Overland PV Systems,” *CES-CUBE 2013, Proceedings, The 3rd International Conference on Circuits, Control, Communication, Electricity, Electronics, Energy, System, Signal and Simulation, ASTL*, Vol. 25, pp. 284-289, July 2013.
7. Young-Kwan Choi, Jong-Seok Yi, “The Technique of Installing Floating Photovoltaic Systems,” *Journal of the Korea Academia-Industrial cooperation Society*, Vol. 14, No. 9, pp. 4447-4453, 2013.
8. Young-Kwan Choi, “A Study on Power Generation Analysis of Floating PV System Considering Environmental Impact,” *International Journal of Software Engineering and Its Applications(IJSEIA)*, Vol. 8, No. 1, pp. 75-84, 2014.
9. R. Cazzaniga, M. Cicu, M. Rosa-Clot, P. Rosa-Clot, G.M. Tina, C. Ventura, “Floating photovoltaic plants: Performance analysis and design solutions,” *Renewable and Sustainable Energy Reviews*, Vol. 81, pp. 1730–1741, 2018.
10. J. G. Kim, O. Yang, “Design of DC optimizer for maximum power generation system of solar panel,” *Journal of the Semiconductor & Display Technology*, Vol. 17, No. 1, pp. 40-44, 2018.
11. H. Lim, G.-S. Joo, S.-C. Roh, J.-H. Choi, J.-D. Jung, H.-I. Seo, “Texturing of two adhered wafers for high efficiency crystalline silicon solar cells,” *Journal of the Semiconductor & Display Technology*, Vol. 13, No. 3, pp. 21-25, 2014.
12. Young-Kwan Choi, Nam-Hyung Lee, An-Kyu Lee, Kern-Joong Kim, “A study on major design elements of tracking-type floating photovoltaic systems,” *International Journal of Smart Grid and Clean Energy*, Vol. 2, No. 1, November 2013.

접수일: 2019년 2월 25일, 심사일: 2019년 3월 7일,
게재확정일: 2019년 3월 17일