International Journal of Control and Automation
Vol. 9, No. 9 (2016), pp.319-330
http//dx.doi.org/10.14257/ijca.2016.9.9.31

Realization of 2 Axes Solar Tracking System

Hyeok Jae Woo[1], Amarnath Varma Angani[2] and Kyoo Jae Shin[3]

[1,2,3]*Department of ICT Creative Design, Graduate School, Busan University of* [1,2,3]*Foreign Studies, BUFS*

reedvil@gmail.com, Amarnath.angani@gmail.com, kyoojae@bufs.ac.kr

Abstract

In this Paper, method of converting solar energy into direct current electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon commonly studied in physics, photochemistry and electrochemistry. A photovoltaic system employs solar panels composed of a number of solar cells to supply usable solar power. Hence it is the challenge for the present generation to generate maximum electricity by using solar power although many developments were made to collect the solar energy. Hence solar tracking system has been implemented that plays a vital role in collecting the solar energy. The present invention consists of a 2 axes solar servo control tracking device that performs the remote servo control and remote monitoring of solar module assemblies without manual interference according to the solar azimuth that generates maximum electric power with single power transmission that improves the tracking accuracy, with minimum cost and can check the malfunctions to track the solar luminance. The efficiency of photo voltaic power generation can be improved by 15% to 18%.

Keywords*: solar tracking system, solar azimuth, high driving torque, Ac Induction motor, proportional integral derivative (PID), ICT VAEMS*

1. Introduction

The solar energy is a renewable energy and it is very important for providing the electricity. The most abundant energy in the universe is obtained from sun. Hence it is the challenge for the present generation to generate maximum electricity by using solar power although many developments were made to collect the solar energy, but unable to utilize the maximum power released from sun. In this paper, the 2 axes solar tracking system designed for the Information Communications and Technology Vertical Aquarium Energy Management System (ICT VAEMS). Its purpose is to set, manage, and evaluate science and technology policy, support scientific research and development, develop human resources, conduct R&D leading to the production and consumption of Atomic power, plan national informatization and information protection strategies, manage radio frequency bands, oversee the information and communications technology (ICT) industry, and operate Korea post. This is the newly introduced concept throughout the world. Due to this system, we can reduce the space, human effort and use wastage of hot water of thermal power plant.

1.1. Reason for Invention

The equipment is a solar servo control tracking device which consists of remotely controlling and monitoring a solar module assembly for smooth driven according to the solar azimuth. The solar azimuth is obtained from the following azimuth equation by using time H and declination.

ISSN: 2005-4297 IJCA

1.2. Comparison this Invention with Existing Device:

1. The existing solar tracking device utilizes DC motor and a worm gear to give a driving force to the photo conductive cell (CdS) and a solar module assembly by measuring luminance to detect rotation angle of the tracking device.

2. The light sensors like CdS are arranged at the top of the solar module assembly for detecting the solar azimuth which increases cost, and it is very difficult to detect when weather is changed. Even measured azimuth will have large error range due to the CdS.

3. DC motor is not sufficient to drive more than six module assemblies as it has less driving torque, hence conversion of AC 220V to DC power is required that increases the cost.

4. It is difficult to control the driven angle of solar module assembly as the angle is measured by counting the number of pulses generated per one revolution using the proximity sensor.

5.To maintain the fixed horizontal position of solar module assembly the artificial manipulation is required to prevent damage from natural calamities like typhoon, heavy snow fall *etc*.

6. To inspect the solar module assembly always an operator must visit the site it increases the maintenance cost, as the system is not equipped with monitoring [1].

These are the disadvantages with the existing device.

1.3. Summary of the Invention

The present invention is the remedy for the above disadvantages, which provides a remotely servo controlling and monitoring the solar module assembly according to the solar azimuth measured by single solar cell sensor and solar module assembly that consists of solar panels arranged in 4*4 matrix form to achieve high electric power generation with less cost.

The solar servo control tracking device also comprises of:

a). Integrated control device that consist single solar cell sensor unit detects the luminance of sunrays according to the solar azimuth. b). Control panel that transmits control signals remotely with respect to maximum solar azimuth calculated by comparing with sunrays incident on the solar cell sensor unit and solar azimuth measured in real time.

c). Solar tracking device that includes a solar tracking device controller remotely that receives the control signals through wireless network.

d). High torque driving unit driven by AC single phase inductor to generate high torque with respect to the control signal.

e). The operating angle of sensor unit is installed to high torque driving unit, to track the sun according to the control signal.

In this paper, 2 axes solar tracking system is designed to the power supply for ICT VAEMS.

2. Modeling of Solar Tracking System

The solar tracking system is a device for aligning the solar panel towards the sun. The solar tracking system has the assembly of remote servo control and remote monitoring. It is composed of solar illumination of the solar azimuth one solar cell sensor device detecting a value and integrated control device including the integrated control panel. The sun radiates in the form of electromagnetic energy and the amount of electromagnetic radiation that reaches the earth from the sun in referred to as solar radiation. To use the solar energy efficiently for the different applications, we need the high degree of accuracy to ensure the concentrated sunlight is directed precisely to the power device. The Modeling of solar tracking system mainly depends on the four parts as shown in the Figure 1.

There are namely

(1) Irradiance sensor

(2) Proportional Integral Derivative (PID) controller

(3) Electrical driving unit using Induction Motor

(4) 2 axes using Azimuth and elevation angle sensor unit.

2.1. Irradiation Sensor

The irradiance sensor is used for the professional photo voltaic monitoring of photovoltaic installation. Based on the measured solar radiation the expected energy yield can be determined and compared to the actual yield. The irradiance of the surface as shown in the equation (1).

$$E_e = \frac{\partial \phi_e}{\partial A} \tag{1}$$

where ϕ_e is the radiant flux and A is the area.

2.2. Proportional Integral Derivative (PID) Controller

A proportional integral derivative controller (PID controller) is a control loop feedback mechanism. A PID controller continuously calculates an error value as the difference between a measured process variable and desired set point. The controller attempts to minimize the error over time by adjustment of a control variable. The ideal equation for the PID is as shown in the equation (2).

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau) d\tau + k_d \frac{de}{dt} \tag{2}$$

where $u(t)$ is the input signal, k_p is the proportional gain, k_i is the integral gain and k_d is the derivative gain.

2.3. Electrical Driving Unit Using Induction Motor

The induction motor is a type of electric motor in which alternating current from a power source is fed through a primary winding and induces a current in a secondary winding, with the parts arranged so that the resulting magnetic field causes a movable rotor to rotate with respect to a fixed stator. The Induction motor equations are shown in the following equations. The magnetic field created in the stator rotates at a synchronous speed (N_s) [2].

$$N_s = 120X \frac{f}{P} \tag{3}$$

where the synchronous speed of the stator is, f is the supply frequency in Hertz and P is the number of poles on the stator.

$$\%slip = \frac{N_s - N_b}{N_s} X100 \tag{4}$$

where N_s is the synchronous speed in the RPM and N_b is the base speed in RPM.

The motor load system can be described by the fundamental torque equation.

$$T - T_l = J\frac{d\omega_m}{dt} + \omega_m \frac{dJ}{dt} \quad (5)$$

where T is the instantaneous value of the developed motor torque, T_l is the instantaneous value of the load torque, ω_m is the instantaneous angular velocity of the motor shaft(rad/sec) and J is the moment of inertia of the motor-load system. For drives with constant inertia $\frac{dJ}{dt} = 0$.

$$T = T_l + J\frac{d\omega}{dt} \quad (6)$$

where T_m is the motor torque, J_m is the rotor inertia, ω_m is the rotor angular velocity , B_m is the viscous friction coefficient and T_l is the load torque.

2.4.2. Axes Using Azimuth and Elevation Angle Sensor Unit

The 2 axes solar tracking unit mainly consists of two unit's namely remote total controller and tracker controller. The remote total controller consists of PID controller and 2 axes absolute angle output unit. The tracker controller has PID angle controller, 2 axes driver circuit and 2 axes tracker for AC motor. When the sun light as giving the input to the PID controller, it sends the control signal to the 2 axes absolute angle unit. The 2 axes absolute angle unit sends the absolute angle to the PID angle controller and it sends the signal to 2 axes driver circuit. The 2 axes driver circuit sends the signal and rotates the 2 axes tracker. Then, it will be fine-tuned to maximum intensity of solar radiation and give the electrical voltage as output. When any disturbance comes, the signal will be feed backed to the PID angle controller. Here, 2 axes refer azimuth angle and elevation angles.

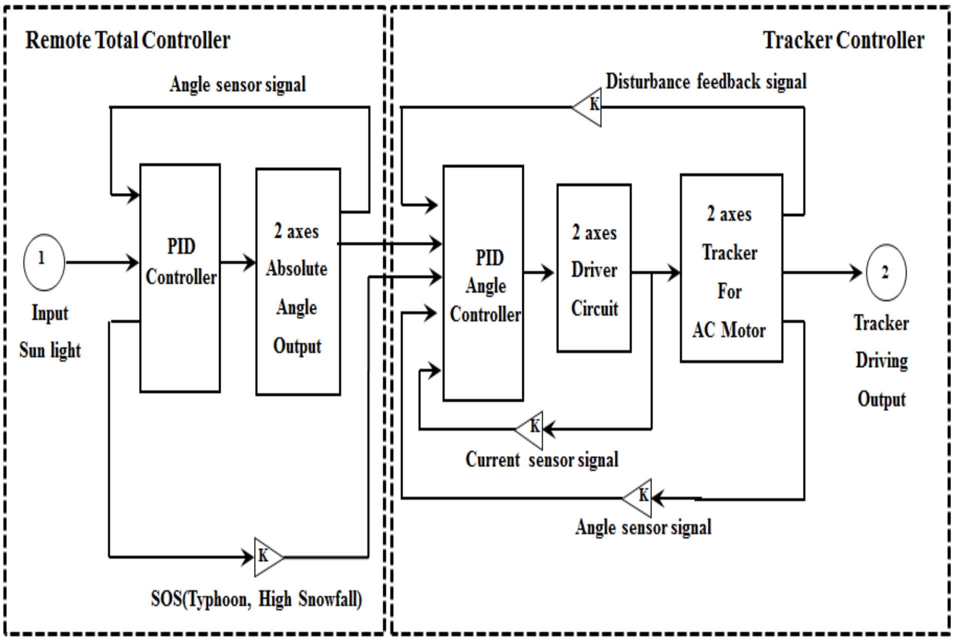


Figure 1. The Block Diagram of 2-Axes Solar Tracking Unit

2.5. Building Vertical Aquarium Using 2 Axes Solar Tracking System

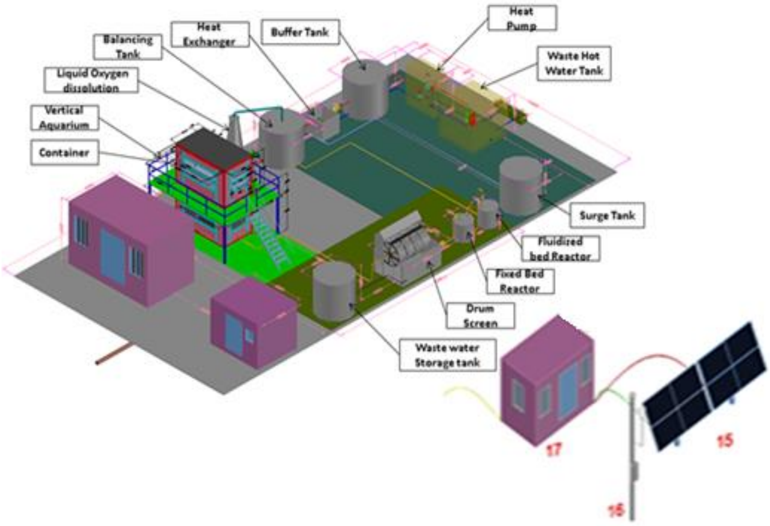


Figure 2. The Building Vertical Aquarium Using 2 Axes Solar Tracking System, (A) Vertical Building, (B) 2 Axes Solar Panels, (C) Two Axes Solar Light Tracking Device, (D) Irradiation Sensor

An azimuth is angular measurement in the spherical coordinate system. To find the azimuth angle of the sun, the azimuth angle sensor will be connected to the DC motor. The elevation angle is the angular height of the sun in the sky measured from the horizontal. The elevation is 0° at sunrise and 90° when the sun is directly overhead this happens for example at the equator on the spring and fall equinoxes.The 2 axes solar tracking system is designed for the building vertical aquarium. The solar tracking system has two axes namely azimuth angle and elevation angle. This system mainly takes the solar energy and it can be converted into the electrical energy. When the solar light fall on the 2 axes solar panel, the maximum solar radiation absorbed photovoltaic cell measured by the irradiation sensor and converts it into electrical energy. This generated power will be send to the building vertical aquarium. The Building vertical aquarium using 2 axes solar tracking system as shown in the Figure 2. The system consists of 2 axes solar panel, two axes solar tracking device, irradiation sensor and vertical aquarium building. The generated power utilizes entire vertical aquarium.

3. Construction of 2 Axes Solar Tracking System

The Solar tracking device unit consists of azimuth driver, tracker controller, irradiation sensor, wind sensor, total remote controller unit and elevation driver as shown in the Figure 3.

3.1. Design of 2 Axes Solar Tracking System

(1) Azimuth Driver

(a) 1st and 2nd Worm Gear: In order to transmit the rotation torque to PV (Photo Voltaic cell) modules for the Azimuth Axis, the Azimuth Driver can drive the PV modules as a high torque using the 1st and 2nd worms.

(b) Azimuth Angle Sensor: The Tracker Controller can calculate the optimal command using the angle sensor, which can measure the rotation angle of PV modules.

(c) AC Driving Motor with Reduced Gear: The motor uses the AC driving motor

(60W) with the gear, which allows having advantages such as not having a brush or a converter.

(d) Limited S/W (South/West): Tracker is protected using the limited sensor, which limits the moving range of the azimuth.

(2) Elevation Driver

(a) Ball Screw Gear: In order to transmit the rotation torque to PV modules for the elevation axis, the elevation driver can drive the PV modules as a high torque using the ball screw.

(b) Elevation Angle Sensor: The tracker controller can calculate the optimal angle using the elevation angle sensor, which measures the rotation angle of PV modules.

(c) AC Driving Motor with Reduced Gear: The motor uses the AC driving motor (60W) with the gear, which allows having advantages such as not having a brush or a converter.

(d) Limited S/W (South/West): The tracker is protected using the limited sensor, which limits the moving range of elevation.

(3) Irradiation Sensor

The illumination sensor is designed to measure the light strength in azimuth using solar cells, which has to be water proofed for the rain and snow.

Irradiation Sensor: It is used to arrange the maximum electrical power. The sensor must install the position without a shadow and must connect to tracker controller.

3.2. Design of Irradiation Sensor Unit

The azimuth angle is the projectile direction from which the sunlight is coming. At solar noon, the sun is always directly south in the northern hemisphere and directly north in the southern hemisphere. The azimuth angle varies throughout the day as shown in the Figure 4. At the equinoxes, the sun rises directly east and sets directly west regardless of the

Latitude, thus making the azimuth angles 90° at sunrise and 270° at sunset.

In general however, the azimuth angle varies with the latitude and time of year and the full equations to calculate the sun's position throughout the day [1].

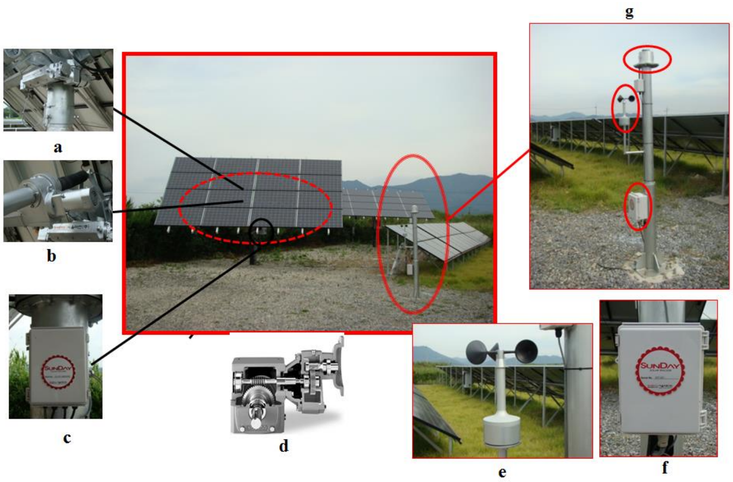
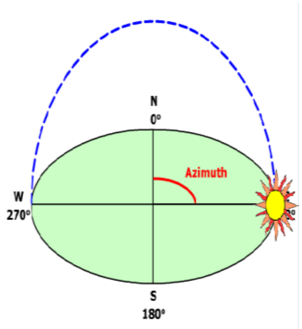
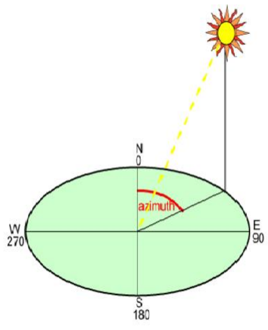


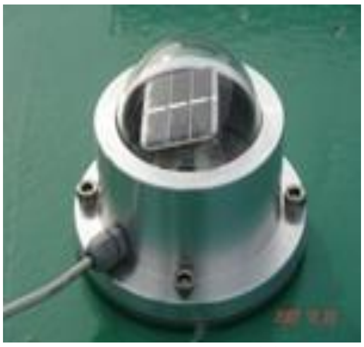
Figure 3. The Solar Tracking Device Unit (A) Azimuth Driver (B) Elevation Driver (C) Tracker Controller, (D) Azimuth Angle, E) Wind Sensor, (F) Remote Unit, (G) Total Controller



(a)



(b)



(c)

Figure 4. The Animation View of Azimuth Angle, (a) At Sunrise on the Spring and Fall Equinox, The Azimuth Angle Is 900, (B) Elevation Angle, (c) Irradiation Sensor Unit

The solar azimuth is obtained from the following azimuth equation by using time H and declination [4].

$$\tan(A) = \frac{-\cos(\delta)\cos(\pi)\sin(H)}{\sin(\delta) - \sin(\pi)\sin(a)} \tag{7}$$

where A is the azimuth angle and H is the time.

$$\sin(a) = \sin(\delta)\sin(\pi) + \cos(\delta)\cos(\pi)\cos(H) \tag{8}$$

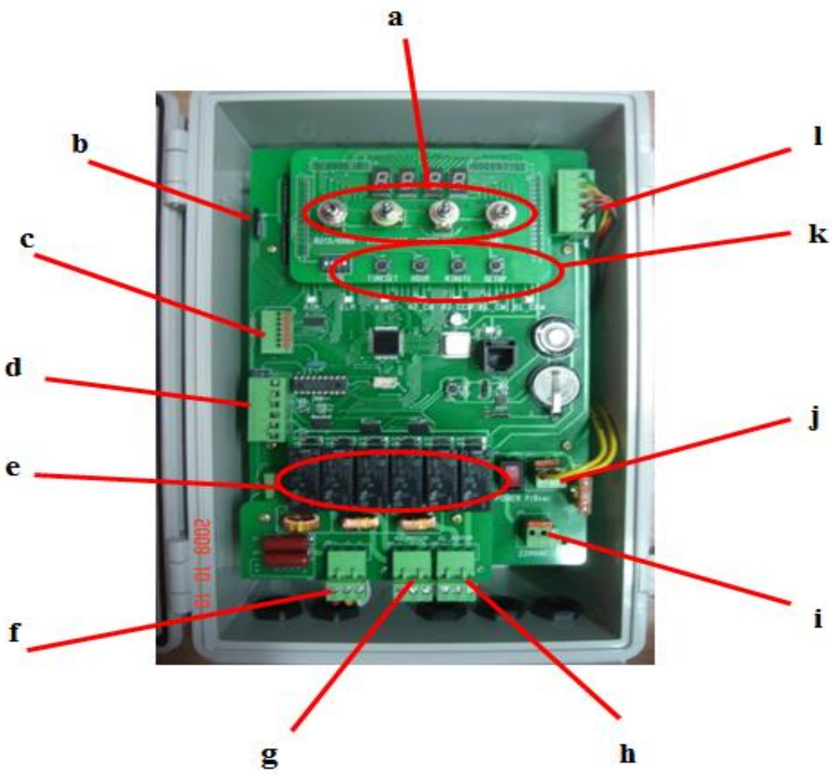
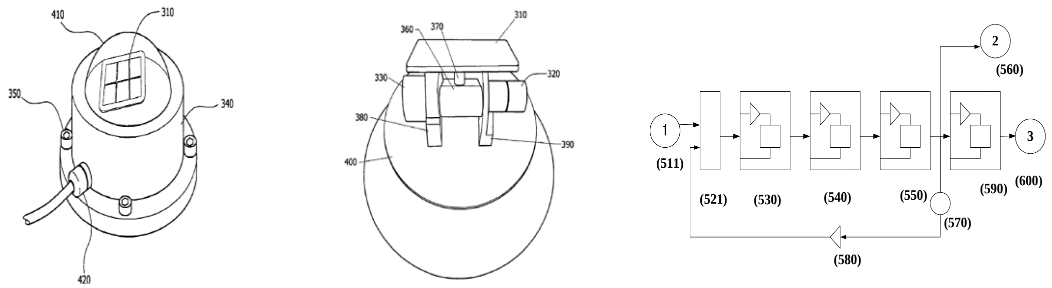


Figure 5. Two-Axis Solar Light Tracking Device,(a) Control Switch, (b) Remote Control Line, (c) Irradiation Sensor Line, (d) Rotation Sensor Line ,(e) Rotation Sensor Line, (f) Relay Module, (g) Relay Line, (H) Azimuth Motor Line, (H) Elevation Motor Line, (I) 220VAC Line, (J) AC Power B/D, (K) Time Set Switch, and (L) DC Power B/D

The elevation angle is the angular height of the sun in the sky measured from the horizontal [6] [7] [8]. The elevation is 0° at sunrise and 90° when the sun is directly overhead this happens for example at the equator on the spring and fall equinoxes. It depends on the latitude of a particular location and day of the year. The design of photovoltaic systems is the maximum elevation angle, that is, the maximum height of the sun in the sky at a particular time of year. This maximum elevation angle occurs at solar noon and depends on the latitude and declinationangle. The solar radiation sensor measures global radiation, the sum at the point of measurement of both the direct and diffuse components of solar irradiance [9]. The transducer of the sensor, which converts incident radiation to electrical current, is a photodiode with wide spectral response. From the sensor's output voltage, the console calculates and displays solar irradiance. It also integrates the irradiance values and displays total incident energy over a set period of time. An irradiation sensor as shown in the Figure 4(c).

The 2 axes solar tracking device as shown in the Figure 5. The solar cell sensor unit 300, as illustrated in Figures 6(a) and 6(b), includes a stepping motor 320, a solar cell rotation shaft 360, a rotation angle sensor 330, a solar cell 310, a base plate400 having supports 380 and 390, a case 340, a transparent semi-spherical body 410, and a Water-proof connector 420.The stepping motor



(a) (b) (c)

Figure 6. Solar Cell Sensor Unit According to Present Invention,(a) Illustrating an Actual Appearance of Solar Cell Sensor Unit (B) Illustrating an Actual Structure of Solar Cell Sensor Unit, (C) Schematic Diagram of Measurement of Solar Azimuth by Integrated Control Panel

320 provides rotary power in order to measure an incident angle of sunrays entering at a maximum luminance such that the solar cell 310 can scan luminance of 30 degrees to 150 degrees. The solar cell rotation shaft 360 transmits the rotary power of the stepping motor 320. The rotation angle sensor 330 measures an azimuth with respect to the luminance of the sunrays. The solar cell 310 is installed to the solar cell rotation shaft 360 to measure the luminance of the sunrays. On the base plate 400, a left support 380 and a right support 390 to which the stepping motor 320, the solar cell rotation shaft 360, and the rotation angle sensor 330 are installed. The case 340 is installed on the base plate 400 to enclose and protect the stepping motor 320, the solar cell 310, the solar cell rotation shaft 360, and the rotation angle sensor 330. The transparent semi-spherical body 410 is installed on the top of the case 340 to protect the components in the case from entering water and from moisture. The water-proof 420 is install the case 340 to connect an electric wire providing electric power, and wires to input the control signal from the integrated control panel 500 to the stepping motor 320 and to output a signal from the rotation angle sensor 330. A reference numeral 350 indicates a bolt fixture attaching the case 340 to the base plate 400. The Figure 6(c) shows the solar cell sensor unit 300 measures luminance of sunrays at a solar azimuth to detect a maximal solar azimuth of the sunrays entering at a maximal incident angle. A solar cell rotation control signal 511 of 30 degrees to 150 degrees is periodically input to the solar cell sensor unit 300. A rotation

angle calculator 521 compares a rotation angle signal 580 detected and amplified by a rotation angle sensor 570 with the solar cell rotation angle control signal 511.

An error of the solar cell rotation angle is compensated by a proportional-integral-derivative (PID) servo controller 530 and is applied to a stepping motor driver 540.The stepping motor driver 540 drives the stepping motor 550 and in this case the rotation angle 560 is detected by the rotation angle sensor 570 to be fed back to the rotation angle calculator 521. A rotation angle of a solar cell 590 fixed to the stepping motor 550 is controlled by the stepping motor 550 and continuously scans luminance 600 every rotation angle of the solar cell 590 so that maximal luminance of the sunrays with respect to the rotation angle can be detected.

3.3. Total Remote Controller

(1) Wire Schematic

If the motor and sensor lines are not connected correctly, the tracker can operate incorrectly. Therefore the installer has to work by the schematics.

(2) Control Switch (Operating Mode):

Auto Mode: It is the mode that automatically controls the rotation sensor of the PV modules, which is controlled by the solar azimuth angle command.

Manual Mode: It is the mode that manually controls the manual switch.

(3) East/West Switch: In the manual mode, the tracker controls the west or east direction using the control switch, only in the state of maintenance and installation.

(4) North/South Switch:

In the manual mode, tracker controls the north or south direction using the control switch, only in the state of maintenance and installation.

(5) SOS Setting Switch:

Rotation Angle Setting Switch: It sets the initial angle condition after the installation of the tracker.

Time Setting Switch: It sets the initial time after the installation of the tracker, which can measure the data and actual time.

(6) Time Display:

Time Setting Switch: It sets the initial time. The installer must set the actual time correctly, because the tracker is controlled by the actual time and the Irradiation Sensor.

(7) Relay Module:

Resetting Switch: This switch resets it to the initial operating.

It is the module that switches power for the directional control of the AC driving motor. If the module has any complications, you can exchange the Relay Module.

(8) AC Power Connector:

It is the connector of the AC power line, which is for 100~220VAC, 50/60Hz, and 2Φ.

(9) Motor Connector:

It is the connector of the motor power line, which is for the following; 100~220VAC, 50/60Hz, 2Φ, 60W, 10A.

(10) Rotation Angle Sensor Line

It is the power and signal line of the Rotation Angle Sensor, which supplies a +5Vdc power voltage and outputs 0 to +5Vdc signal voltage.

(11) AC Power Line Cap.

It is the cap of the AC power line, which is for 100~220VAC, 50/60Hz, and 2Φ.

(12) Motor Power Line Cap:

It is the cap of the motor power line, which is for the following; 100~220VAC, 50/60Hz, 2Φ, 60W, 10A.

(13) Rotation Angle Sensor Line Cap.

It is the cap for the Rotation Angle Sensor.

3.4. Wind Sensor

At the initial installation of the wind sensor, the fixed base must be installed correctly to the true south.

3.5. Remote Unit

1) Remote Unit

The remote unit transmits the rotation angle command to the tracker controller and receives the rotation angle output and the motor current signals.

2) Antenna

The Patch antenna is used to transmit and receive data between the total remote controller and the tracker controller. The distance of wireless communication is when there is no obstacle within 1Km.

4. Design of Mechanical Driving Unit

Each solar module assemblies consists of 4*4 matrix array solar panel, number of solar modules are 6(1,2,3,4,5,6). These modules weight is 20% more than the existing modules to increase the photovoltaic power generation by high driving torque unit to track the sunrays. The high driving torque is installed in between third and fourth solar module assemblies and fixed to the adjusting shaft, to drive the six module assemblies at once. The operating angles of solar module assemblies and operation states of AC single phase inductor are remotely monitored. The 1 to 6 solar module assemblies can be driven with operating angle range of 30 degrees to 150 degrees with tracking device controller; the angles are detected by operating angle sensors are fixed to the driving torque [3][4]. The driving torque unit consists of cooling fans attached to the AC single phase inductor which are driven through the servo control that can be done by tracking device controllers that receives the control signal from the control panel (500).

(a) (b)

Figure 7. Operating Angle Sensor Driver Unit (A) Azimuth Driver (B) Elevation Driver

The driving force of the pinion of third worm reducer is transmitted to worm wheel at a gear ratio of 55:1; worm wheel is meshed with power transmission rotary shaft. The mechanism for servo control of rotation angle of solar module assemblies are as follows, as sensor pinion wheel meshed with pinion of third reducer that transmits the gear ratio to the sensor wheel, the operating angle sensor used to detect 360 degrees is installed on a rotation shaft on the sensor worm wheel to detect absolute rotation angle as shown in the Figure 7.

5. Experimental Results

1. The remote control and remote monitoring done between integrated control panel and tracking device controller, the former measures the luminance of sun rays according to the operating angle detected by operating sensor unit, while the later measures the AC single inductor's voltage to send the control signals to solar module assemblies.

2. The characteristic curve of solar cell unit as shown in the Figure 8(a). However

from the characteristic curve of luminance the solar azimuth is obtained in the range of 24.3 degrees to 153 degrees is observed.

3. As the initial position of 30 degrees to 90 degrees was applied to the solar module assemblies the time response operation characteristics is observed.

4. The manual/automatic mode selectors are installed in the mode selector. The mode selector is switched to the manual mode so that driving signals are supplied to the AC single phase inductor to drive the inductor and to control the operation angles of solar module assemblies.

5. Able to check the malfunctioning of solar module assemblies and can take emergency measures to track the solar luminance. The time response operation characteristics of solar module as shown in the Figure 8(b). The experimental analysis of the 2 axes solar tracking system efficiency has been improved 15% to 18%.

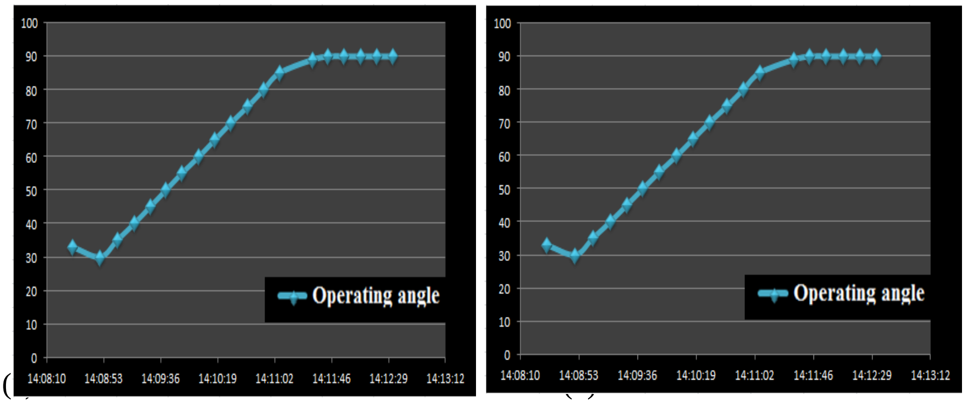


Figure 8. (A) Characteristics of Solar Cell Sensor Unit (X-Axis Represents a Solar Azimuth and Y-Axis Represents Luminance), (B) Time Response Operation Characteristics of Solar Module Assembly (X-Axis Represents Time and Y-Axis Represents Driving Angle of Solar Module Assembly)

6. Conclusion

In this paper, the 2 axes solar tracking system is designed for the ICT VAEMS. From the result it can be concluded that the precise operating angle servo-control is implemented by using operating angle sensor unit. The each of the tracking device controllers receives optimal signal from the integrated control panel to perform the precise operating angle servo-control, hence the efficiency of photo voltaic power generation can be improved by 15% to 18%. Hence, the system has been satisfied for the ICT VAEMS.

Acknowledgment

This work supports the KOREA Ministry of Trade, Industry and Energy. We are established the project which is industrial verification and design of ICT VAEMS practical models. Also, this work granted to “Busan University of Foreign Studies”.

References

[1] K. H. Choi, I. C. Lim, H. W. Kim, H. J. Woo, K. Shin, “Solar servo control tracking device”, United States Patent No: US 8, no. 042, vol. 534 B2, **(2011)**.
[2] R. Parekh, “AC Induction Motor Fundamentals”, Microchip, AN887.
[3] L. Miloudiet, “Solar tracking with Photovoltaic Panel”,Science Direct, Energy procedia, vol. 42, **(2013)**, pp.103-112.
[4] P.papageorgas,”Smart solar panels: In-situ monitoring of photovoltaic panels based on wired and wireless sensor networks”,Science Direct, Energy Procedia, vol 36, no.01, **(2013)**, pp.535-545.
[5] http://www.pveducation.org/pvcdrom/properties-of-sunlight/azimuth-angle.
[6] K. Shin, “Realization of solar servo tracking system using the 2 axes solar sensor module”, vol 38, no.01, **(2015)**, pp.1508-1511.
[7] B. Hanus ,”Solar Dachanlagen”,Franzis Energie technik, **(2009)**.
[8] V. Sundara, Siva Kumar and S Suryanarayana, “Automatic Dual Axis Sun Tracking System using LDR Sensor”, International Journal of Current Engineering and Technology, vol.4, no.5, **(2014)**.
[9] Md.T. A. Khan, S.M.Shahrear Tanzil, R. Rahman and S M Shanfiul Alam, “Design and Construction of an Automatic Solar Tracking System”, ICECE, **(2010)**.