Dual Axis Solar Tracking System Using PLC

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Abstract

The photovoltaic panels have a limited efficiency and have to be increased. To increase the photovoltaic panel efficiency a dual axis solar tracking system is designed and used to track the sun position. The Siemens S7-1214 DC/DC/DC PLC is used to control the dual axis solar tracking system rotation. Four LDRs are used to detect the sun position in the sky so that the tracking system follows it to make the solar radiation perpendicular on photovoltaic panel surface. The proposed approach is compared to a fixed panel system. The results show that the proposed solar tracking system enlarges the output power of the photovoltaic panel by 39.27%.

Keywords: axis solar tracking system, Siemens PLC S7-1214, Photovoltaic panels.

I. Introduction

The energy from the sun can be used to overcome the energy crisis generated by the scarcity of Fossil fuel resources. Solar energy is free and everywhere. Due to the decreasing of solar photovoltaic energy cost, it's superior in the renewable energy sources and widely utilized in many countries.

Before solar energy can be used as an alternative source of energy for the world's ever increasing requirements, the efficiency of solar cells must be increased. In order to supply enough power to operate larger devices, larger photovoltaic arrays are required. These are typically too large, and therefore unfeasible, for the application.

Instead of increasing the size of the array, it is more beneficial to increase the performance of the solar cell. The overall performance of solar cells can be attributed to couple of factors: efficiency of the cell and intensity of the source radiation on the cell.

The materials used in the manufacture of solar cells are the biggest factors that limit the cell efficiency. This makes it difficult to improve the efficiency of the cell, and hence restricts the overall performance of the cell. However, it is an easier process to increase the amount of source radiation that is received at the cell.

In 2001, **Ghassoul** [3] presented a directional tracking system controlled by Siemens micro PLC S216. The system had never been implemented or had published testing parameters.

In 2008 **Sungur** [5] proposed the dual axis tracking system using formulas to calculate the azimuth and solar altitude angles of the sun for a period of one year. The PLC controlled dual axis tracking system had been designed and implemented. 42.6% more energy was obtained in the two axes sun tracking system. The energy consumed in the system was unremarkable.

In 2012, **YOUSIF** [7] presented a mechatronic tracking system to follow the sun position depending on four sensors were mounted on the solar panel frame. A microcontroller ATmega16L was used to control the system. The output power gain for the two axes solar tracking panel was 31.5% more than the fixed solar panel.

In 2013, **Wang** and **Lu** [9] presented a simple control implementation of a Sun tracker that employed a single dual-axis AC motor to follow the Sun and used as a stand-alone PV inverter to power the entire system. Four LDR sensor and electronic circuits were used. The total power gain of the system was 28.31%.

In 2013 **Sadyrbayev** et. al. [12] proposed a dual-axis sun tracking based on LM324N microcontroller with four photo resistors. The results showed that the dual-axis tracking system produced 31.3% more power. The energy consumed in the system is missing.

In 2013 **Armendariz** et. al. [14] presented a dual-axis solar tracking controller based on fuzzy rules constructed by means of the solar records. This scheme automatically adjusts the tilt and azimuth angles, taking into consideration the day of the year and clock time without needs any sensor.

II. Theory of the proposed system

There are two major solar tracking system mechanisms for the PV panels to follow the sun in the sky over the day time from sun-rise to sun-set.

The first mechanism is by calculating the solar altitude (α), the azimuth angle (Ψ), rotate the panel to calculate solar altitude and azimuth by using motors and actuators. The second mechanism is by using solar detector like light dependent resistors LDR to find sun's position in the sky and rotate the PV panel toward the sun using motors and actuators. The second option has been chosen for this research work due to its accuracy and cost effective.

The proposed block diagram of the research work is shown in figure 1, in which all electrical, mechanical and control parts are shown.

Four LDRs (light dependant resistors) are used to detect the light difference between all four directions. Two LDRs are used to detect the light intension difference between

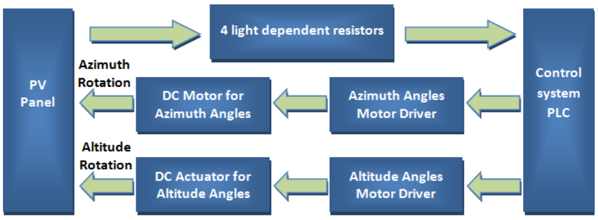

Figure 1. System block diagram

east and west and the other two LDRs are used to detect the light intension difference between north and south. The four LDRs are mounted on the solar tracking system frame. Positions of LDRs are shown in figure 2.

The LDRs used in voltage divider circuit to detect the light. The analogue input voltage for PLC card is between 0 and 10 Volts. For that the output of the voltage divider which is the input voltage for PLC analogue input card to be less than 10V. To make the voltage

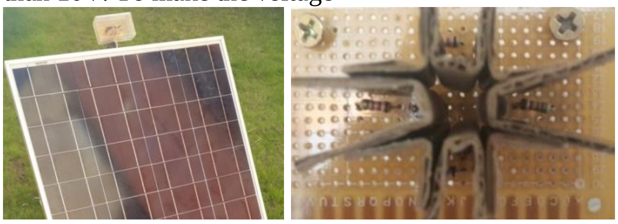

Figure 2. LDR's positions on the system

divider output less than 10V DC a 12V DC power supply is used. When it's dark the output voltage is about zero and when the light intensity increases the output voltage increases till its maximum value about 9.5 volts. The output voltage is connected to PLC analogue input card so that the PLC makes comparison with other output terminals.

Two strong mechanical structures were built, one for fixed photovoltaic panel and the other for dual axis solar tracking system using PLC. The fixed mechanical structure has a flexible arm to set the tilt angle for fixed photovoltaic panel**.** The tracking system mechanical structure made from two parts; upper and lower parts. Both parts connected by four bolts and nuts. The mechanical structure of dual axis solar tracking system is shown in figure 3.

The function of upper part is to rotate the photovoltaic panel to follow altitude angle of the sun between 0º to 90º by using a DC actuator. The lower part used to rotate the photovoltaic panel toward east and west to follow the sun's azimuth angle for 360 degrees using a DC motor. Three ball bearings were used to smooth the rotation of the structure.

24 inches, 36V DC actuator fed with 12V DC to slow down its rotation speed to make rotations softer. The DC actuator used to rotate the PV panel to follow altitude angle of the sun between 0º to 90º.

A 12V high torque DC motor is used to rotate the mechanical structure toward east and west to follow the sun's azimuth angle. The proposed for the prototype work is shown in figure 4.

To have accurate angle a low speed rotation is needed, for that two solutions applied:

Figure 3. Mechanical structure

i) Using lower voltage to reduce its speed. Where the DC motor fed with 3V DC.
ii) Using two driven gears, (9/106) teeth ratio, to decrease the rotation speed from 8 RPM to about 0.7 RPM as shown in equation (1):

$$newspeed = \frac{9}{106} oldspeed \qquad (1)$$

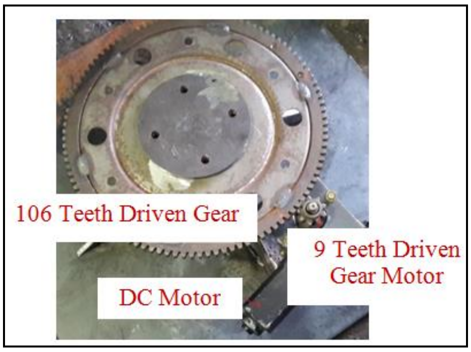

Figure 4. DC motor

A DC motor is used to rotate the mechanical structure toward east and west to follow the sun's azimuth angle because actuators can only follow the sun azimuth angle only between 90º to 270º while DC motors can rotate 360 degrees from 0º to 360º.

An accurate control system had been used to control the rotation of dual axis solar tracking system depends on the LDR sensors input. The control system used is PLC based control system. Figure 5, shows the top view of the prototype work control system.

The major components for the control system are PLC CPU, Input/output modules, relays, and power supplies. PLC CPU used in the proposed work is Siemens S7-1214 DC/DC/DC which is part of S7-1200 family has following features:

- The CPU integrated with PROFINET.
- Signal modules for expansion of controllers by input/output channels
- 24 VDC Supply type, 14 discrete inputs 24 VDC and 10 discrete outputs 24 VDC.

Figure 5. PLC based control system

The used Analogue input is Siemens SM-1223 DC/DC with 8 DC analogue inputs.

Simatic TIA Portal is used for Programmable Logic Controller of the SIMATIC S7.

The wiring diagram of PLC input and output connection are shown in figure 6.

III. Control Algorithm for the system

The control algorithm of the system is as follows:

1. At the start of the system, the system check the light via the photo sensor if its day the system operate the PLC and reads the LDR inputs.
2. After reading the output voltage value from LDRs circuit, the West LDR and East LDR will be compared. If West LDR is greater than East LDR by 100mV then rotate toward West until the difference will be less than 100mV or the West limit switch closed.
3. The North LDR and South LDR will be compared also. If North LDR is greater than South LDR by 100mV then rotate toward North until the difference will be less than 100mV. If North LDR smaller than South LDR by 100mV then rotate toward South until the difference will be less than 100mV.
4. For cloudy or dusty weather condition the tracking system will not rotate because the difference values between LDRs are less than 100mV.
5. If West LDR output voltage value was less than 500mV then rotate toward East until the East limit switch closed.
6. The system checks the light via the LDR's, if its night the system switches off the PLC and the LDRs power and waiting until next day lights.

The flowchart shown in figure 7 clarifies the control algorithm of the tracking system.

IV. Results and Discussions

Based on the design configuration presented, the complete operational experimental model of a dual axis solar tracking system using PLC has been designed.

Two solar photovoltaic panels with the same specifications were used to collect data. One was fixed toward the south and the other followed the sun from sunrise to sunset.

The specifications of the two solar photovoltaic panels are shown in Table (1).

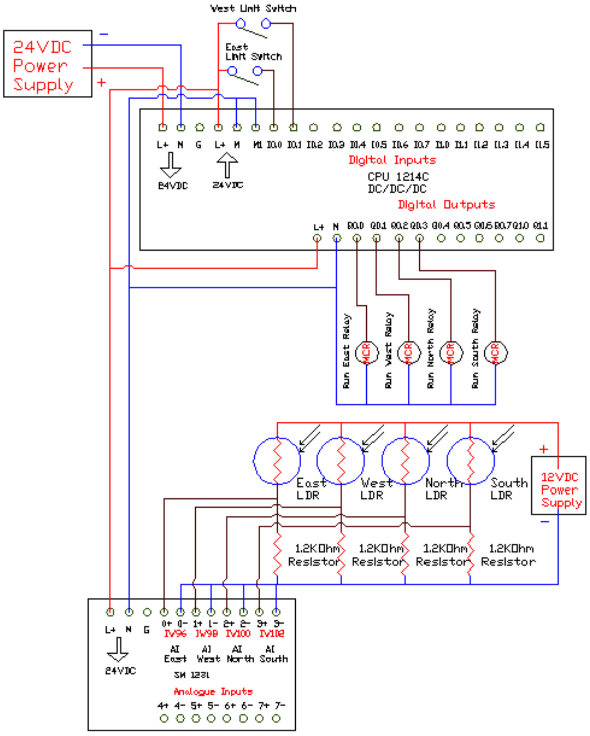

Figure 6. Wiring diagram of the system

The tests took place at Erbil; the capital of Kurdistan; Iraq. The latitude is 36.15° and the longitude is 44.05°.

On June 2nd, 2014, it was a cloudy day; the dual axis solar tracking system tested , the tracking use to stop rotating when it was cloudy, because the voltage difference between east and west and north and south LDRs was too small (less than 100mV).

Before starting the tests we have to find the maximum power point of the PV panel. This can be done by using a variable resistor as a load R_L, connecting across the PV panel outputs, then measuring both voltage and current across R_L. The circuit diagram is shown in figure 8.

To obtain maximum power point results collected on June 15th, 2014 while changing the load resistor R_L from its maximum value (170 to 0) Ω, both voltage across R_L and current through it were recorded with steps of 0.5 volts as shown in Figure (9).

As per results the maxim power point occurs at voltage of 12.2 v and current of 2.3 A. At that point the power was 28.06 w and the load resistor was 5.3 Ω.

Fixed photovoltaic panels are oriented to the south and the value of the tilt angle fixed on 36.15° which equal to latitude of test location [33, 34]. The results collected on June 26th, 2014 from sunrise at 5AM to sunset at 7:30PM. Were the weather condition are as follows: temperature between 26.6°C and 42.5°C, wind speed 100 m/hr and humidity 38%.

The results measured for voltage and current for both fixed photovoltaic panel and the panel with tracking system every 30 minutes. Figure (10) shows the output power collected for both fixed and tracked PV panels.

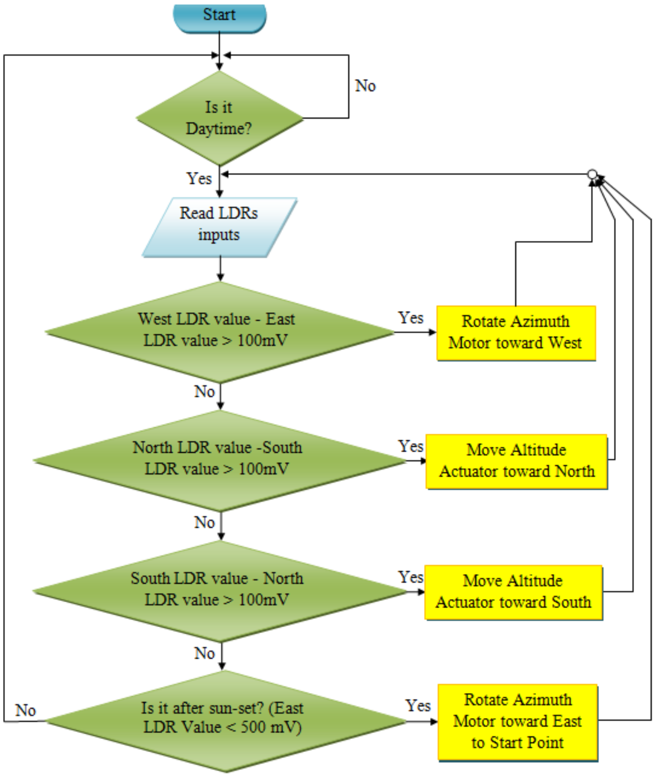

figure 7. Flowchart of the control system

Table (1) Specifications of the solar panels

Description	Unit	Value
Dimension of PV panel	mm	835x663x35
Out peak Power (Pm)	W	50
Maximum power point Voltage (Vmp)	V	17
Maximum power point Current (Vmp)	A	2.95
Open Circuit Voltage (Voc)	V	21.5
Short Circuit Current (Isc)	A	3.2

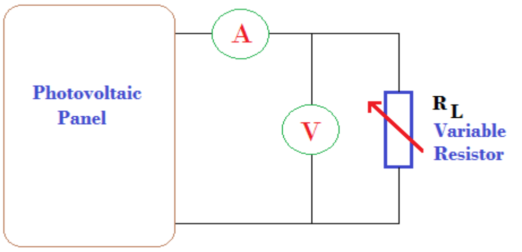

Figure 8. Maximum power point circuit

The percentage output power gain of the solar panel with two-dimensional tracking system over the fixed solar panel is shown in graph in Figure (11).

The results showing that between sunrise 5AM and 10AM the percentage of power gain is high 98% also at the evening time
between 2:30PM and sunset 7:30PM the percentage of power gain is 100%. While the percentage of power gain is about 8% during noon time between 10AM and 2:30PM which means the fixed solar panel works effectively only during noon time while the solar panel with dual axis solar tracking system is working effectively whole the day from sunrise to sunset.

To ensure that the tracking system actually produced more power than it used, measurements were taken for the power consumption of each individual component of the system.

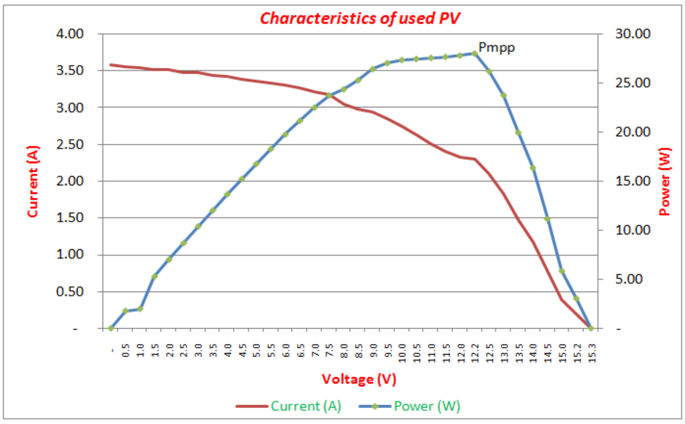

Figure 9. Maximum power point measured characteristics

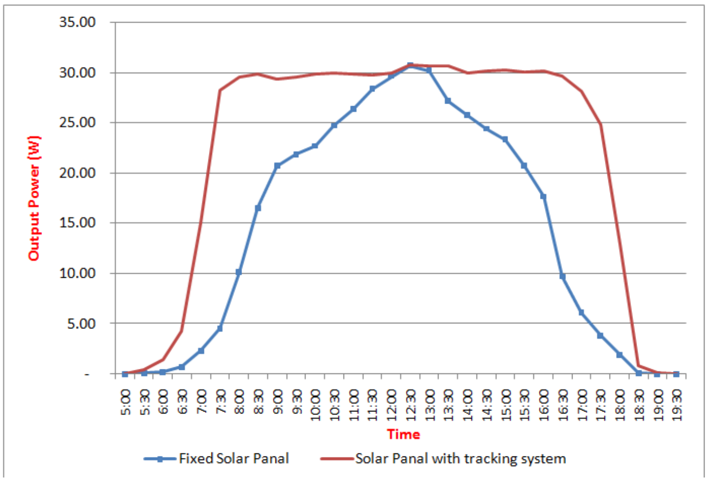

Figure 10. Output power for both fixed and tracked PV Panels

Several measurements were taken to find the individual current draws to each section of the system and its working time. The main sections are control system, the east-west DC motor and north-south DC actuator.

Table (2) shows the breakdown of power consumption, measured voltage and current with its time for each section.

Total energy consumption by the system = 87,696 + 12,528 + 300 + 423 + 321 = **101,268 J/day**

To find net output power gain we have to calculate the output power received from both systems over the day. The sum of all individual measured power multiplied by its duration.

Energy from fixed solar system = 775,402 J/day

Energy from solar tracking system=1,181,174 J/day

Net Energy obtained from solar tracking system=1,181,174J/day-101,268J/day = 1,079,906 J/day

Net Output Energy Gain = (1,079,906 J/day - 775,402 J/day) / 775,402 J/day = 39.27%

The net output energy gain using dual axis solar tracking system is **39.27%.**

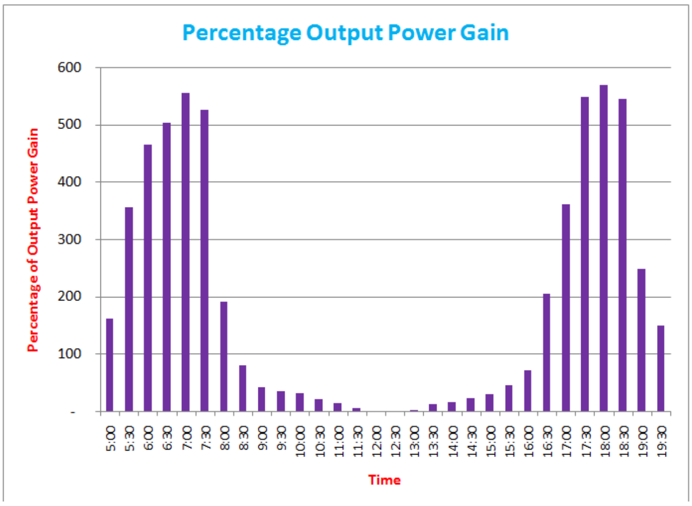

Figure 11. Percentage of Output power gain between both systems

Table (2) Power consumption for all sections of the system

Section	Control system PLC	Sensors	East-West Motor	North-South Actuator	Motor Return to start
Working time (seconds)	14.5 hrs x 3600 sec	14.5 hrs x 3600 sec	1 sec every 10min for 14.5hrs	1.5 sec every 10min for 14.5hrs	93 sec Once a day
Voltage (V)	24	12	3	12	3
Current (A)	0.07	0.02	1.15	0.27	1.15
Power (W)	1.68	0.24	3.45	3.24	3.45
Energy consumed (J/day) =power x time	**87,696 J/day**	**12,528 J/day**	**300 J/day**	**423 J/day**	**321 J/day**

V. Conclusions

The design, fabrication and implementation of the dual axis solar tracking system using PLC, the fixed panel and the dual axis solar tracking system using PLC systems were tested, the practical results collected and analyzed, the following were concluded:

1. The net output energy gain using the dual axis solar tracking system using PLC was 39.27% over fixed panel output energy.
2. The analysis of the results showed that the percentage of power gain was 98% during morning and during evening time the percentage of power gain was 100%. While the percentage of power gain was about 8% during noon time.
3. That means the fixed solar panel works effectively only during noon time while the solar panel with dual axis solar tracking system using PLC was working effectively the whole day from sunrise to sunset.
4. To reduce power consumption at the cloudy day; the dual axis solar tracking system was not rotating when it was cloudy that was due to a small value of the voltage difference between east and west also the voltage difference between north and south LDRs (less than 100mV).
5. Using PLC as control system was very effective because the parameters of the control system and the condition statements can be change online during the operation of the tracking system to obtain best results.

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