Development of Microcontroller-Based Solar Tracking System Using LDR Sensor

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***Abstract*—This paper presents the design of solar tracking controller used in the photovoltaic (PV) generation system. A low cost and simple single axis tracker is constructed using the Programmable Interface Controller (PIC). The control goal for the controller is to ensure the position of the solar PV cell is continuously adjusted according to the sun's position. In this regard, tracking mechanism ensures that the surface of the PV cell is always perpendicular to the solar radiation allowing an optimum power extraction from the sun. The controller utilizes two Light Dependent Resistor (LDR) sensors as the input sensor that sense the light intensity. The difference in resistance data of LDRs is used by the stepper motor to rotate clockwise or counter clockwise to move the solar PV cell toward the side of higher intensity. From the experimental test results, the developed prototype system is able to function properly, in which the motor is able to rotate according to the input light source.**

***Index Terms*—Photovoltaic Energy; Solar Tracker; PIC Microcontroller; LDR Sensor.**

I. INTRODUCTION

The installed capacity of solar PV in Malaysia is recently reported to achieve about 260 MW in total which is equivalent to 70% of the total renewable energy generation capacity considered in Feed in Tariff (FiT) Program in Malaysia [1]. A growing number of the solar PV installation can be seen throughout the country, particularly in the urban residential areas. The government incentive for the solar PV investment has attracted many residential customers to install the solar PV at their rooftop and participate in FiT program. This mechanism will promote more penetration of renewable energy sources to the electricity grid, particularly the solar energy and also contribute in reducing the use of conventional fuels as the source of energy.

Despite the benefits in terms of clean energy, solar PV suffers from the low energy yield, poor conversion efficiency, and in some situations, the uncontrolled generation may cause many problems to the utility in terms of access generation, power fluctuation or other power quality problems. The low efficiency of the solar PV is an ongoing challenge to the researchers and many efforts have been carried out to improve its efficiency so as to reduce the installation and maintenance costs [2].

One possible way of improving the output of the solar PV cell is to choose the location of installation at the area that receives maximum sunlight throughout the year [3]. The example of such viable locations are horizontal ground, near the shoreline and building rooftops. Other than the location, solar PV output is subjected to the seasonal and weather conditions. For example, location that receives a lot of rains and high cloud intensity will not be suitable for solar PV installation because such conditions will affect the total output and stability of solar PV. From the literature, there are many research works that have been carried out to study the optimal solar PV placement, considering the geographical locations and weather conditions as constraints [4-6].

The efficiency and output of the solar PV also can be increased by using high efficiency solar cell materials. The example of the types of materials that are currently in use are crystalline silicon, thin film or multi-junction cells. However, the high efficiency materials of solar panels currently in the market are relatively expensive [7]. There are still ongoing researches of low cost high efficient materials currently been done throughout the world.

Some researchers are focusing on the power conversion systems. For example, the high efficiency solar PV charge controllers that employs dc-to-dc converter used for charging the battery storage. Such mechanism is normally found in solar PV applications for powering the telecommunication system or supplying the energy to remote areas or islands [8]. Similar studies are also carried out for solar PV inverters. This is another important part of the solar PV power conversion system that focuses on dc-to-ac conversion. Normally, it is found in the application of grid-connected system or solar PV applications in supplying the ac loads [9]. The researches on power conversion system are quite challenging as they deal with power electronic and switching devices that need some knowledge of control system. Furthermore, many aspects need to be considered when studying about solar PV connected to the grid as it involves the problem of power quality. Consequently, in such study, the hardware implementation is not easy and most of the hardware components are relatively high cost.

Other than the aforementioned methods of improving the solar PV system output and efficiency, a similar goal can be achieved by using the solar tracking system. The tracking system is essential in many applications, such as thermal energy storage system that is mostly used in electricity generation or solar PV generations [10]. The solar tracking system is a mechanism that utilizes the sensors, motor and controller in order to capture maximum sunlight over the day. In this case, a low cost and high performance microcontrollers such as PIC microcontroller or Arduino can be used. This paper presents a low-cost design and prototype development of solar tracking controller for solar PV application. The system consists of two LDR sensors that are used as input for the PIC microcontroller to control a stepper motor in order to track the sun light. A prototype system has been developed and testing has been carried out to validate the proposed system.

II. OVERVIEW OF SOLAR TRACKING SYSTEM

When the sun is observed from the earth's surface, every day it rises from east and sets in the west. In general, a solar PV cell will produce maximum output when the surface of the cell is perpendicular to the solar radiation. By keeping the surface continuously at the right angle to the sun's radiation, the daily extraction and conversion of the solar energy to electric energy is maximized [11]. This is called a solar tracking system, which commonly facilitates an optimum energy extraction by the solar thermal system as well as the photovoltaic system.

Currently, the majority of residential solar PV systems are installed at the rooftop of the buildings. Thus, the installation is of a fixed type. This mechanism results in a poor energy yield as fixed installation can only capture the most energy when the sun's shine is directly perpendicular to the cell's surface. As the sun moves during the day, the average daily output of the energy from a fixed installation is low because some of the energy are wasted. In some situations, the fixed type system requires more series connected to solar panels to increase the output at the desired level. This occupies more spaces at the rooftop and causes more investment to the solar PV panels. In most cases, the cost of PV panels overweights the cost of tracker system. A well-designed system which utilizes a simple tracker will need fewer panels due to the increased efficiency resulting in a reduction of initial implementation costs [11]. The commercially available solar tracking systems are also relatively expensive and sometimes they do not meet the user's need. Therefore, there is a need to develop a high efficient solar tracker from the low-cost materials.

III. DESIGN OF SOLAR TRACKER USING LDR SENSOR

In this research work, the low-cost components of the solar tracking controller have been selected. The main controller board consists of PIC microcontroller kit that serves as the main unit with a voltage regulator as well as an amplifier as the signal conditioning unit. The design concept of the proposed solar tracking controller is as shown in Figure 1. The controller is programmed to control the stepper motor at the output, where the stepper motor is attached to the gears that will rotate the solar PV panel. As can be seen from Figure 1, at the input side, two LDRs are used in which each of the LDR is placed at the two sides of the solar PV panel, respectively. The relative position of the LDR will ensure the difference in resistance value (bright and shaded conditions) that will be compared in order to rotate the motor in clockwise or counterclockwise directions.

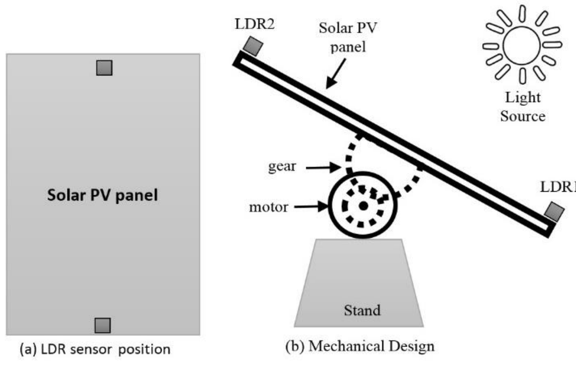

Figure 1: The design concept of the proposed solar tracker

A. LDR Sensor Properties

The properties of the LDR sensors have been studied as they serve as the essential part of the program in PIC. In general, LDRs are used to detect the light intensity. In the dark condition, the resistance of the LDR is nearly 1M ohms, and when it is illuminated with the light, the resistance value drops exponentially to several hundreds of ohms. Such property is essential in identifying the light source, for example by comparing the resistance values of the two LDRs that are placed at different positions on the solar PV panel: The surface of the solar PV can be adjusted by the motor to rotate toward the light source.

For the LDR to function, a series of connection with a resistor is required as shown in Figure 2. The circuit forms a voltage divider at the junction of the sensor and the resistor. In general, the change of light intensity causes the changes of output voltage that will be used as input to the PIC microcontroller. From figure 2, V_0 can be measured from the voltage divider rule of $V_0 = 5 \text{ volt} \times [R_{LDR} / (R_{LDR}+R_1)]$. By substituting an appropriate value of the resistance, R_1, the voltage range can be set, for example 0 volt in bright light and 5 volt in the shade situation. This analog voltage, ranging of 0 and 5 volt will be read by 10-bit ADC as 0 decimal and 1023 decimal, respectively.

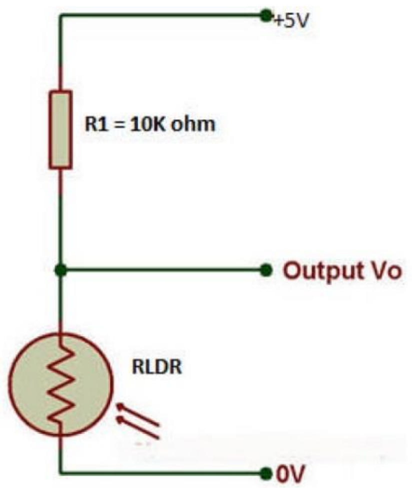

Figure 2: Circuit for measuring the output voltage of LDR sensor [12]

B. System Block Diagram and Circuit Design

Figure 3 shows the system block diagram. It consists of LDR sensors, PIC16F877A microcontroller (with built in ADC), stepper motor (with L293D driver) and a solar panel. At the input, there are two LDR sensors used to sense the light intensity and the analog data from the sensors will be converted to digital data by the ADC inside the PIC16F877A microcontroller. The digital is then used by the PIC microcontroller to determine either the stepper motor should rotate clockwise or counterclockwise. PIC stored the program for the system to function where it received input from the LDRs and sent the data signal to the stepper motor. At the output, the motor was rotated according to the input conditions so that the surface of the solar panel can be adjusted accordingly.

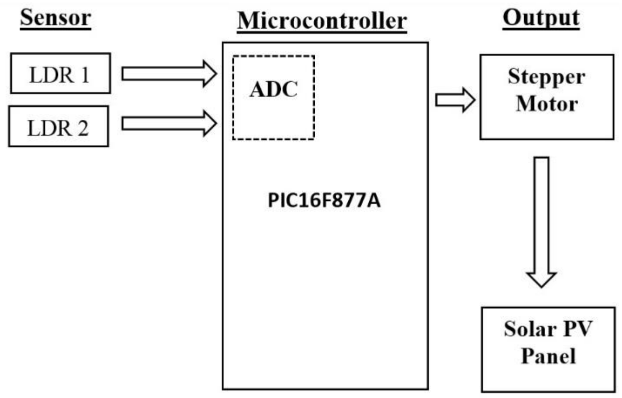

Figure 3: Solar tracking system block diagram

The circuit design of this project was carried out using Proteus 8.0. Simulation of the circuit is as shown in figure 4. Here, it is important to know if there is any error in the circuit. From Figure 4, it is known that the circuit of stepper motor and LDR sensors that are connected with the PIC16F877A microcontroller is functioning well.

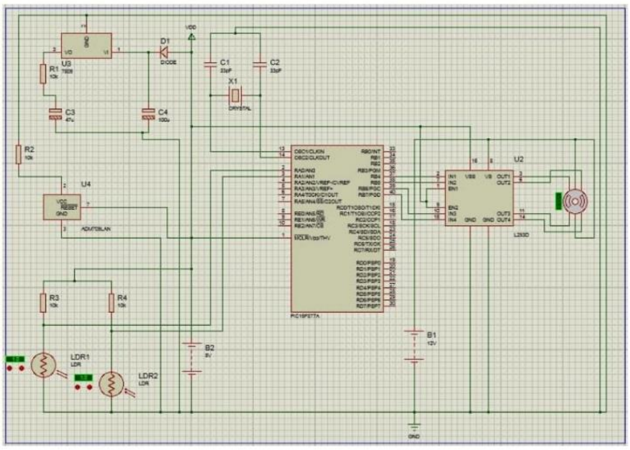

Figure 4: Solar tracking system circuit simulation

C. *Program Execution Flowchart*

The flowchart of the solar tracking system is as shown in Figure 5. From the figure, the signal from the LDRs is converted to digital form, which is then compared to the PIC16F877A so that the stepper motor rotates accordingly. In principle, the resistance of the LDR that receives brighter light decreases, which in return results in lower voltage value. On the other hand, higher voltage means the LDR is in a dark situation. As can be seen from the flowchart in Figure 5, when the two LDRs have equal value of intensity, the motor is kept idle and in static position. If LDR1 has higher intensity (lower voltage) than the LDR2, it means that the resistance of the LDR1 is smaller. This condition causes the motor to rotate the solar panel in clockwise direction. In contrast, when LDR2 has higher intensity than the LDR1, the LDR1 will have larger resistance value causing the stepper motor to be rotated in counter clockwise direction toward the brighter light source. These processes will continue over the day for 19:00 hours, in which with the time set in the PIC, the panel will be rotated back to its initial position for the following day's operation.

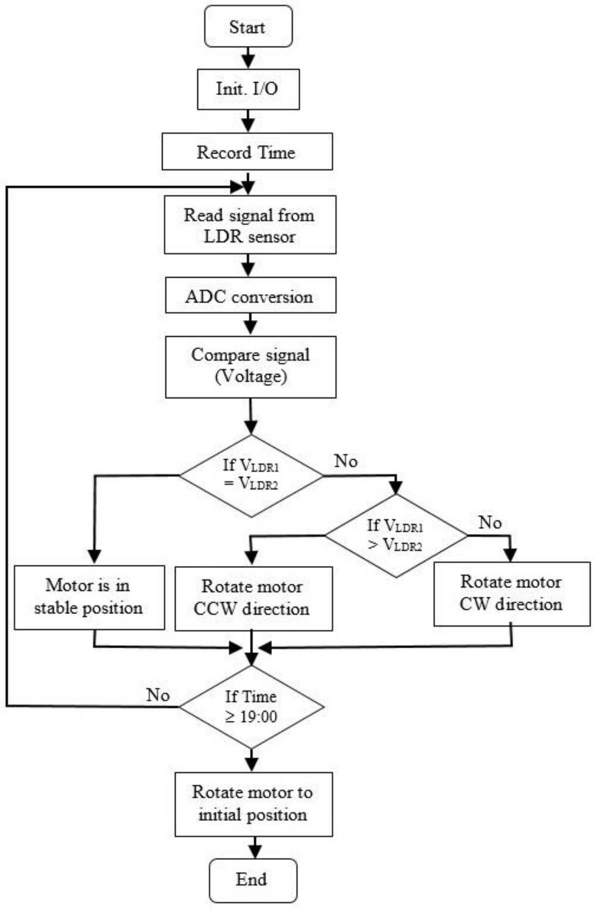

Figure 5: Program execution flowchart

The program code was written using C language in MPLAB software. The general flow of the coding is as can be seen in the flowchart shown in Figure 5. From the completed codes, the source code is compiled and downloaded into the PIC using the PICkit 2 programmer.

IV. RESULTS AND DISCUSSION

The results are divided into two categories: The results of hardware testing and the results of final hardware prototype testing.

A. *Results of Hardware Testing*

The hardware testing represents the results obtained from the experiment carried out for LDR sensor. Figure 6 shows the circuit of LDR when it is exposed to sunlight. From the whole day experiment, the light intensity and the changes in current of the LDR has been measured. Table I shows the relationship of the light intensity, resistance and the current of the LDR sensor. It is clearly shown that when the light intensity is high, the resistance is low and the flow of current is high. On the other hand, in the dark or during low light level, no extra electron is flowing, resulting in smaller current. From the values in Table I, an appropriate value of resistance R_1 has been chosen to cater for the PIC input voltage range of 0-5 volts.

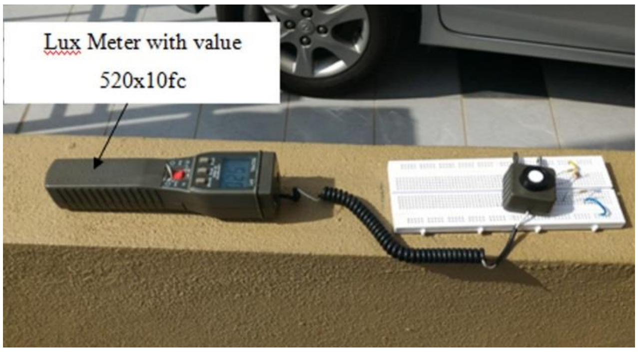

Figure 6: Lux meter used to measure the light detection of LDR

Table 1
LDR Sensor Measurements

Time (hrs)	Light Intensity (W/m^2)	Resistance (kΩ)	Current (mA)
830	41	19.2	2.54
930	156	16.4	3.16
1030	229	15.1	3.17
1130	305	14.8	3.24
1230	315	13.3	3.35
1330	321	12.5	3.51
1430	294	13.2	3.33
1530	232	17.1	3.24
1630	154	16.9	3.11

In addition to the experiment for measuring the relationship between light intensity with the resistance of the LDR, the effects of distance between two LDRs also have been studied. Figure 7 shows the changes in resistance of the LDRs with the change of the distance between LDRs and the light source. This indicates that, for a single axis rotation, the use of a minimum of two LDRs is adequate as the resistance value between two LDRs is always different and the LDR with larger distance with the light source always returns higher resistance values.

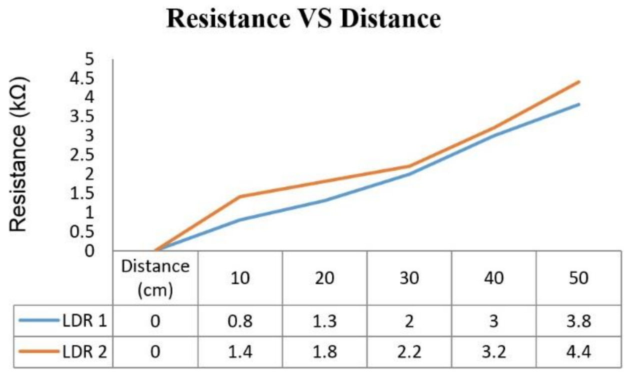

Figure 7: Relationship between resistance values of two LDRs with the distance from the light source

B. *Results of Complete Prototype Testing*

The prototype model as shown in Figure 8 is the final system that has been developed. The circuit is connected to the input power supply of 12 V and the running condition of the prototype has been observed.

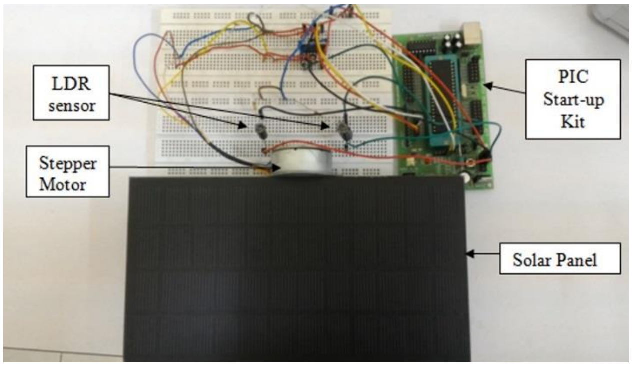

Figure 8: Hardware prototype model of a complete solar tracking system

Figure 9 shows the testing of the prototype, in which the solar panel has been replaced with a PCB board as it is much lighter; hence it is easy for the motor to rotate. The prototype has been tested in the laboratory using a torchlight as the light source.

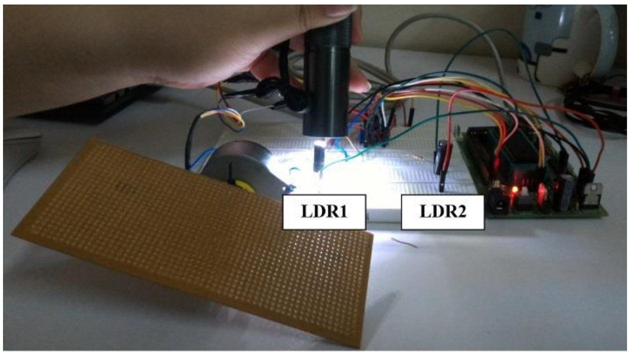

Figure 9: LDR1 brighter than LDR2 – motor rotate CW

From Figure 9, as the light is directed to the LDR1, the brighter light condition of the LDR1 will cause the motor to rotate in clockwise direction. This means that the solar PV panel will be rotated toward the light source that is located closer to LDR1 sensor. Similarly, as shown in Figure 10, when LDR1 is shaded, it returns higher voltage value of the LDR1 so that the motor is now rotated in counter clockwise direction.

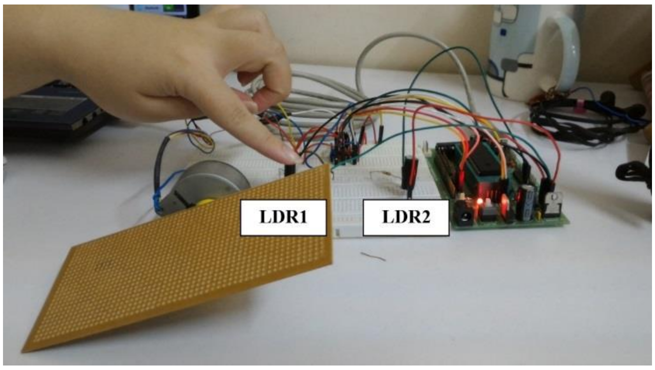

Figure 10: LDR1 shaded – motor rotate CCW

Consequently, a similar procedure of experiment has been carried out for LDR2 that results in the motor to rotate accordingly toward the light source when there are changes in the input sensors. The working conditions of the motor at the output with respect to the input condition of LDRs show that the programmed code in the PIC is working properly.

V. Conclusion

In this paper, a study on the development and implementation of a single axis solar tracking system based on two LDR sensors has been presented. The circuit design has been developed at a minimum cost and has been integrated onto a single board for simple assembly. A simple mechanical structure of the controller board hopefully can fit within the base platform of the solar tracking system. The software control for the PIC microcontroller was written in MPLAB software, which was simple and easy to understand. From the results of software testing by the simulation as well as hardware prototype testing, it is shown that the program that has been coded in the PIC works well according to the proposed concept of solar tracker. The movement of the motor was controlled according to the changes in the light intensity between the two sensors meaning that the surface of the solar PV panel is kept perpendicular to the sun's radiation. This mechanism ensures maximum extraction of solar energy by the solar PV cells.

Future Work

This paper only presents the concept and implementation of the proposed solar tracking system in PIC. Successful implementation of the hardware and its working condition has been presented and discussed. However, to improve the reliability of the proposed method, the following points are of interest and will be the subject of our future work.

- The LDR sensor has been chosen as input because of its wide availability and relatively low cost. In improving the sensing conditions of the sensors, analysis of different types of sensors will be carried out with the consideration of increasing the number of sensors used as input.
- Another important point to be discussed in future work is further analysis of the results in terms of comparison with existing solution of solar tracking system. Comparison criteria include the performance, reliability, cost of system or materials used and suitability to be used in Malaysia.

Acknowledgment

The authors would like to acknowledge Universiti Malaysia Terengganu Malaysia and Ministry of Higher Education Malaysia (MOHE) for the financial support of this research. This research is supported by MOHE under the Fundamental Research Grant Scheme (FRGS), Vot No. 59418 (Ref: FRGS/1/2015/TK10/UMT/02/1)

References

[1]. Sustainable Energy Development Authority (SEDA) Malaysia. Available: http://seda.gov.my. Accesed:[05 June,2016].

[2]. G. K. Singh, "Solar power generation by PV (photovoltaic) technology: A review," Energy, vol. 53, pp. 1-13, 2013.

[3]. S. Kucuksari, A. M. Khaleghi, M. Hamidi, Y. Zhang, F. Szidarovszky, G. Bayraksan, and Y.-J. Son, "An Integrated GIS, optimization and simulation framework for optimal PV size and location in campus area environments," Applied Energy, vol. 113, pp. 1601-1613, 2014.

[4]. R. Al Abri, E. F. El-Saadany, and Y. M. Atwa, "Optimal placement and sizing method to improve the voltage stability margin in a distribution system using distributed generation," IEEE Transactions on power systems, vol. 28, pp. 326-334, 2013.

[5]. B. Vonk, M. Gibescu, E. Veldman and J. Sloothweg, "Automatic PV productions profile generation using geographic and historical weather data", in 19th International Universities Power Engineering Conference (UPEC), 2014, pp. 1-6

[6]. I. H. Rowlands, B. P. Kemery, and I. Beausoleil-Morrison, "Managing solar-PV variability with geographical dispersion: an Ontario (Canada) case-study," Renewable Energy, vol. 68, pp. 171-180, 2014.

[7]. S. Sharma, K. Kumar Jain, A. Sharma, "Solar cells: In research and Applications – A review", Materials Science and Applications, vol. 6, pp. 1145-1155, 2015

[8]. O. Ellabban, H. Abu-Rub, and F. Blaabjerg, "Renewable energy resources: Current status, future prospects and their enabling technology," Renewable and Sustainable Energy Reviews, vol. 39, pp. 748-764, 2014.

[9]. E. Romero-Cadaval, G. Spagnuolo, L. G. Franquelo, C. A. Ramos-Paja, T. Suntio, and W. M. Xiao, "Grid-connected photovoltaic generation plants: Components and operation," IEEE Industrial Electronics Magazine, vol. 7, pp. 6-20, 2013.

[10]. R. G. Vieira, F. K. O. M. V. Guerra, M. R. B. G. Vale, M. M. Araujo, " Comparative performance analysis between static solar panels and single-axis tracking system on a hot climate region near to the equator", Renewable and Sustainable Energy Rerviews, vol. 64(2016), pp. 672-681, 2016

[11]. R. Kansal, "PIC based automatic solar radiation tracker," Asian Journal of Chemistry, pp. 21-28, 2009.

[12]. R. A. Ferdaus, M. A. Mohammed, S. Rahman, S. Salehin, and M. A. Mannan, "Energy efficient hybrid dual axis solar tracking system," Journal of Renewable Energy, vol. , 2014