TWO AXES SUN TRACKER USING FUZZY CONTROLLER via PIC16F877A

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ABSTRACT:

This paper presents sun tracking generating power system designed and implemented in real time. A tracking mechanism composed of photovoltaic module, stepper motor, sensors, input/output interface and expert FLC implemented on PIC, that to track the sun and keep the solar cells always face the sun in most of the day time. The proposed sun tracking controller is tested using Matlab/Simulink program, the results show that the controller have a good response

KEYWORDS:
Fuzzy Logic Control, Sun Tracking, Photovoltaic System, PIC16F877A.

I. INTRODUCTION

Renewable energy sources play an important role in electric power generation. There are various renewable sources which used for electric power generation, such as solar energy, wind energy, geothermal etc [1]. Solar Energy is a good choice for electric power generation, since the solar energy is directly converted into electrical energy by solar photovoltaic modules [2]. These modules are made up of silicon cells [3]. Many such cells are connected in series to get a solar PV module. The current rating of the modules increases when the area of the individual cells is increased, and vice versa. When many such PV modules are connected in series and parallel combinations we get solar PV arrays, that suitable for obtaining higher power output.
The applications for solar energy in recent years are increased rapidly, and that need to improve the materials and methods used to harness this power source [4]. Main factors that affect the efficiency of the collection process are solar cell efficiency, intensity of source radiation and storage techniques. The efficiency of a solar cell is limited by materials used in solar cell manufacturing. It is particularly difficult to make considerable improvements in the performance of the cell, and hence restricts the efficiency of the overall collection process. Therefore, the increase of the intensity of radiation received from the sun is the most attainable method of improving the performance of solar power. There are three major approaches for maximizing power extraction in solar systems. They are sun tracking, maximum power point (MPP) tracking or both [5]. These methods need intelligent controllers such as fuzzy logic controller or conventional controller such as PID controller.
The advantage of the fuzzy logic control is that it does not strictly need any mathematical model of the plant. It is based on plant operator experience, and it is very easy to apply. Hence, many complex systems can be controlled without knowing the exact mathematical model of the plant [6]. In addition, fuzzy logic simplifies dealing with nonlinearities in systems [7]. The good of fuzzy logic control is that the linguistic system definition becomes the control algorithm. The FLC may implement on PIC and used to moves a motor attached to the solar panel to keep it toward the sun all the day.

Then we must choose the kind of the motor as appropriate with the controlled system. Many applications related to positioning systems are being implemented with stepper motors. It has some applications in Robotics, Computer peripherals, Industrial servo quality drivers and so on. One of the main advantages of stepper motors is the strong relation between electrical pulses and rotation discrete angle steps [8].

A. Sun Tracker

Solar tracking system uses two stepper motors as the drive source to rotate the solar panel as shown in Figure 1. The position of the sun is determined by using a tracking sensor, the sensor reading is converted from analog to digital signal, and then it passed to a fuzzy logic controller implemented on PIC. The controller output is connected to the driver of the stepper motor to rotate PV panel in one axis until it faces the sun.

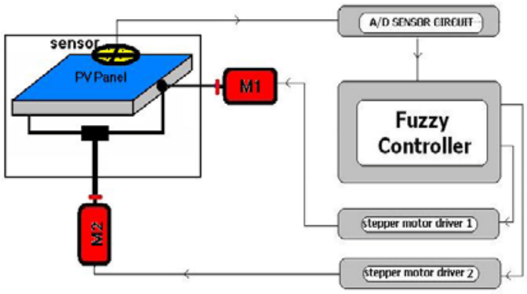

Figure (1): Block Diagram for the Sun Tracker System

II. SENSORS

There are two sensors used in the sun tracking system: photo sensor, and position sensor.

A. Photo Sensor

Light dependent resistor (LDR) is used to construct the sensor, because it is the most reliable sensor that can be used for light sensing. LDR is basically a resistor whose resistance varies with intensity of light, so more intensity gives less resistance. Different LDR sensors available in the market are, the biggest size is used to construct the sensor because the more area of the sensor mean more its sensitivity or less time taken for output to change when input changes.

Tracking Sensor Design

The tracking sensor is composed of four similar LDR sensors, which are located at the east, west, south, and north to detect the light source intensity. The LDR sensor forms a 45° angle with the light source. At the LDR sensor positions, brackets isolate the light from other orientations to achieve a wide-angle search and quickly determine the sun's position as shown in Figure 2.

Figure (2): Tracking Sensor Internal Design

To sense the position of sun in one axe say east/west, two LDR sensors are mounted on the solar panel and placed in an enclosure. It has a response which is similar to the human eye. The east and west LDR sensors compare the intensity of received light in the east and west. When sun's position shifts, here the light source intensity received by the sensors is different; the system obtains signals from the sensors' output voltage in the two orientations. The system then determines which sensor received more intensive light based on the sensor output voltage value interpreted by voltage type A/D converter. The system drives the step motor towards the orientation of this sensor. If the output values of the two sensors are equal, the output difference is zero and the motor's drive voltage is zero, which means the system has tracked the current position of the sun.

B. Position Sensor

Position sensor used to determine the location of the PV panel to prevent the panel from the impact when it reaches the edges, and to get the PV panel to the starting point at the night. This sensor used a variable resistor (potentiometer) located on the rotor of the motor and rotate with it, and the value of the resistor (R) varies with the rotation as shown in Figure 3. When the position sensor reaches the values at the PV at the edges, the controller stopped the motor and immune it from rotating in that direction. At the night the LDRs sensors are very dark light and their values are very big, in this situation the controller go to night subroutine to rotate the PV panel until the position sensor has the starting point value.

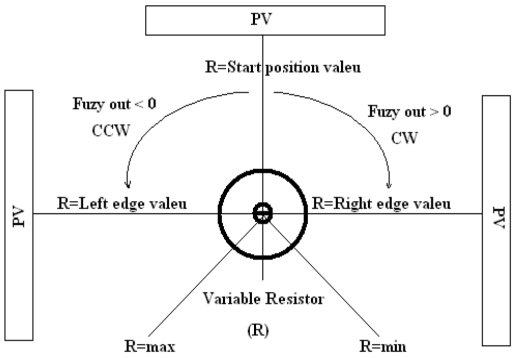

Figure (3): Position Sensor

Figure 4 shows the algorithm of extracting the motor control signals depending on sensors reading and the output of the controller. R is the value of the position sensor, and En is the enable signal to rotate the motor.

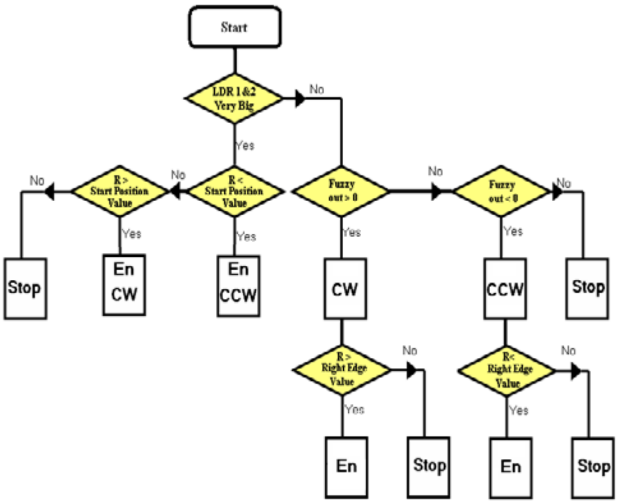

Figure (4): Motor Control Signals Algorithm

III. FUZZY LOGIC CONTROLLER

FLC has been constructed and the block diagram in Figure 5 shows the FLC for the sun tracker system.

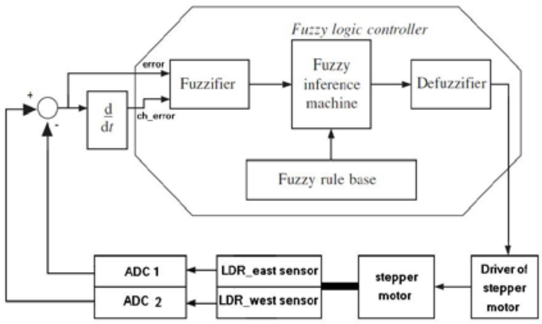

Figure (5): FLC Controller for the Sun Tracker System

A. FLC Design

FLC has two inputs which are: error and the change in error, and one output feeding to the stepper motor driver. There are two widely used approaches in FLC implementation: Mamdani and Sugeno. In this paper, Mamdani approach has been used to implement FLC for the sun tracker. FLC contains three basic parts: Fuzzification, Base rule, and Defuzzification.

1) Fuzzification

Figure 6 illustrates the fuzzy set of the Error input which contains 7 Triangular memberships

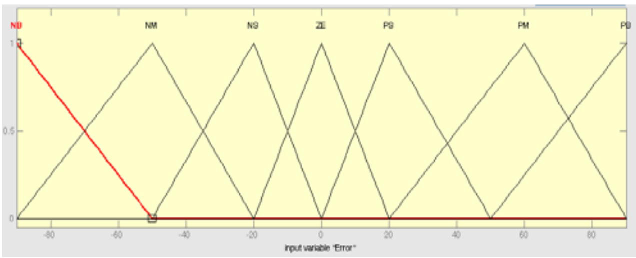

Figure (6): Error Fuzzy Set of FLC.

Figure 7 illustrates the fuzzy set of the Change of Error input which contains 7 Triangular memberships.

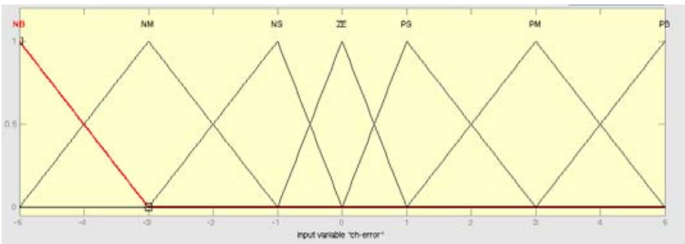

Figure (7): Change in Error Fuzzy Set of FLC.

Figure 8 illustrates the fuzzy set of the output which contains 7 Triangular memberships.

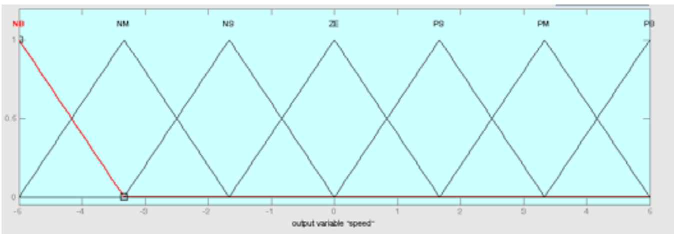

Figure (8): Fuzzy Set of FLC Output Entering to Stepper Motor Driver.

2) Control Rule Base

The knowledge base is defined by the rules for the desired relationship between the input and output variables in terms of the membership functions illustrated in Table1. The control rules are evaluated by an inference mechanism, and represented as a set of:

IF Error is ... and Change of Error is ... THEN the output will ….

For example: Rule1: IF Error is NS and Change of Error is ZE THEN the output is NS.
The linguistic variables used are:
NB: Negative Big.
NM: Negative Medium.
NS: Negative Small.
ZE: Zero.
PS: Positive Small.
PM: Positive Medium.
PB: Positive Big.

Table (1): Control Rule Base for Fuzzy Controller

Er \ CE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Figure 9 shows the surface of the base rules using in FLC which is the representation for the inputs and output values of the controller in three dimensions.

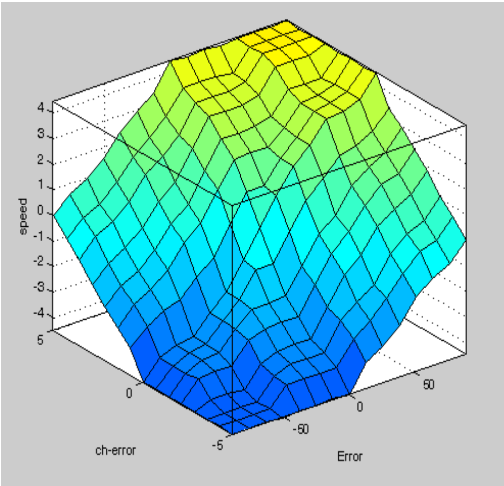

Figure (9): Rule Surface of FLC

3) Defuzzification

The centre of gravity method is widely used in Mamdani approach which has been selected in this paper to compute the output of the FLC, which is the motor speed as:

$$
Speed = \frac{\sum_{i=1}^{n} S_i * \mu(S_i)}{\sum_{i=1}^{n} \mu(S_i)} \tag{1}
$$

IV. Fuzzy Logic Controller Simulation on Matlab/Simulink

Figure 10 illustrates the Simulink block diagram for the Fuzzy controller for sun tracker system.

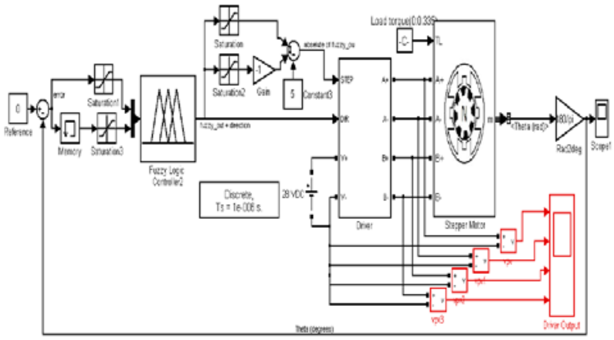

Figure (10): Testing the FLC in the Sun Tracker System Using Matlab/Simulink

The controller has been tested using Simulink motor module in MATLAB, by applying the step input and initial degree of the rotor is -10 degree. The output step response is shown in Figure 11. The range from -10 to 0 degree takes 5 steps since each step in our motor is 1.8 degree, so (10/1.8)= 5 steps.

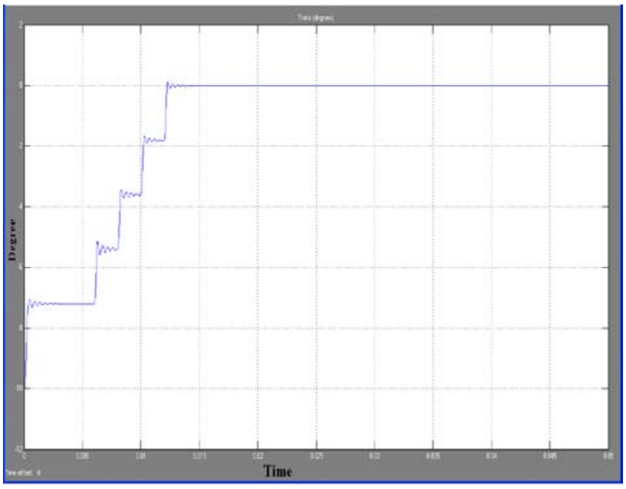

Figure (11): Output Degree

V. Implementing Fuzzy Controller on PIC 16F877A Microcontroller:

Figure 12 is a hardware printed circuit board (PCB) for the sun tracker system. It is designed on Proteus PCB Design program. The main parts of PCB are:

a) PIC 16F877A Microcontroller.
b) Two stepper motor drivers.
c) LCD display.
d) PIC programmer.

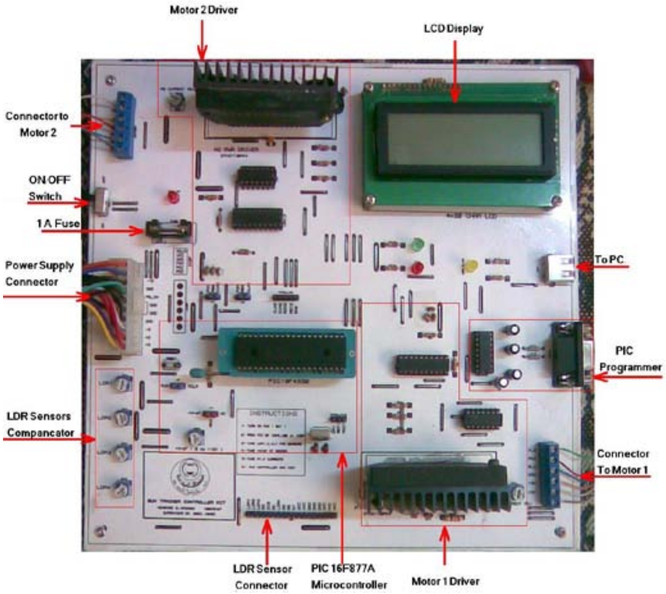

Figure (12): Sun Tracker Printed Circuit Board.

a) PIC 16F877A MICROCONTROLLER:

The fuzzy logic controller is implemented on PIC 16F877A Microcontroller (Figure 13) programmed by C language using MikroC program. The PIC reads the LDR sensors values (east and west), and converts these values from analog to digital, then gets the difference between east and west sensor reading to obtain the Error signal. From Error signal the Change in Error signal is extracted by getting the difference between instant error and last error. These two signals (Error and Change in Error) are the inputs to the FLC as shown in Figure 5. The output of FLC represents the speed of the motor to arrive at the desired degree, the FLC output value converted to a clock signal have a frequency appropriate with this value, this clock inputs to the stepper motor driver, then the stepper motor speed increase when the clock frequency increase and vice versa. The motor will rotate in clockwise direction if the output of the controller is negative, and rotate in the other direction if the output of the controller is positive.

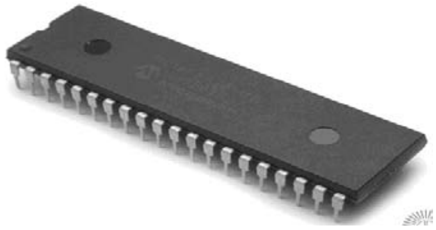

Figure (13): PIC 16F877A Microcontroller

b) STEPPER MOTOR DRIVER:

Two Unipolar Stepper Motors are used in the sun tracker system, one to rotate the PV plant around vertical axis, and the second motor to rotate it around horizontal axis. Each have a 1.8-degree for each step and six wires connects four coils or two coils divided by center connections on each coil, as shown in Figure 14. The center connections of the coils are tied together and used as the power connection.

Figure (14): Unipolar Stepper Motor.

Stepper motors require more power than other components in the circuit, so they are connected with a separate power supply. The voltage is applied to each of the coils in a sequence as shown in Table 2 to control the stepper. When the sequence is applied as steps from 1 to 4, the motor will rotate in clockwise direction, and rotate in the other direction if the steps are in reverse order.

Table (2): Unipolar Full-Step Phase Sequence

	Step	ϕ_1	ϕ_2	ϕ_3	ϕ_4
CW	1	ON	OFF	ON	OFF
↓	2	ON	OFF	OFF	ON
CCW	3	OFF	ON	OFF	ON
↑	4	OFF	ON	ON	OFF

To control the unipolar steppers, two driver circuits were used to obtain the stepping sequence as shown in Table II. Wires 5 and 6 are wired to the supply voltage. One of these drivers is shown as a block diagram in Figure 15.

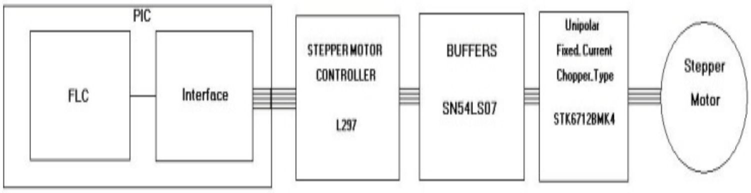

Figure (15): Unipolar Stepper Motor Driver as Block Diagram.

The main components in the driver are:

STEPPER MOTOR CONTROLLER (L297 IC):

The L297 Stepper Motor Controller IC is used to generate four phase drive signals for four phase unipolar step motor. It receive 5 control signals from the controller, these signals are:

CLOCK: An active low pulse on this input advances the motor one increment. The step occurs on the rising edge of this signal. Its frequency controls the speed of the motor. The output of the FLC is applied to an interface block subroutine in the PIC and converted to a clock wave have a frequency appropriate with its value.

CW/CCW: Clockwise/counter clockwise direction control input.

HALF/FULL: Half/full step select input. When high selects half step operation, when low selects full step operation.

RESET: An active low pulse on this input restores the translator to the home position (state 1, ABCD = 0101).

ENABLE: When low (inactive), A, B, C and D are brought low.

BUFFERS/DRIVERS (SN74LS07 IC):

This IC constructs six buffers/drivers gates (Figure 16) with high-voltage open-collector outputs to interface with high-level circuits or for driving high-current loads. They are also characterized for use as buffers.

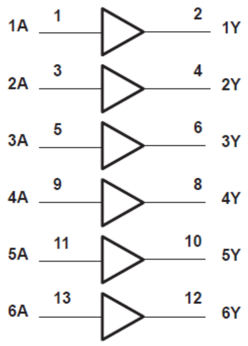

Figure (16): Buffers/drivers (SN74LS07 IC) as logic diagram.

UNIPOLAR FIXED-CURRENT CHOPPER_TYPE ,4-PHASE STEPPING MOTOR DRIVER (STK6712BMK4)IC :

This IC have self-excitation design, means chopping frequency is determined by motor L and R. since it supports chopping at 20 kHz or higher.

Figure17 show the schematic diagram for the connecting of the stepper motor driver component while designing PCB using *Proteus* program.

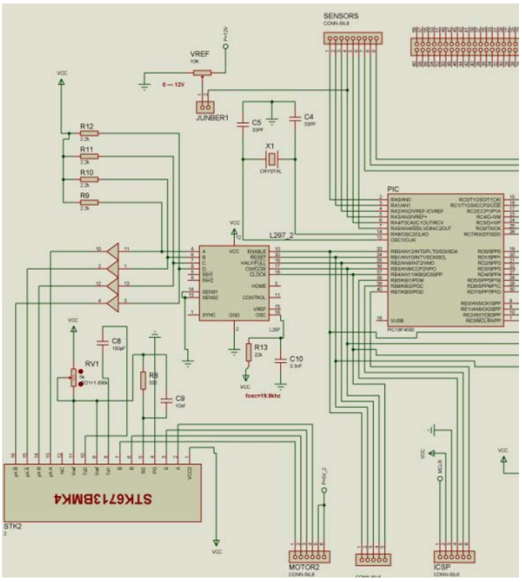

Figure (17): Schematic Diagram Stepper Motor Driver Component PCB Design using Proteus Program.

c) LCD DISPLAY:

LCD is used in our system to display the vertical and horizontal degrees. Four data lines are required only to be connected to the four port pins of PIC and three control signals to control the data flow and display. Figure 18 show LCD Pin Diagram.

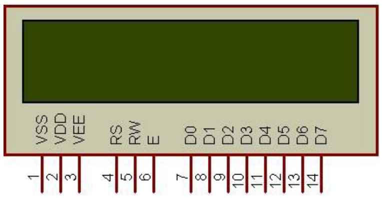

Figure 18: LCD Pin Diagram

d) PIC PROGRAMMER:

This circuit is used for programming the PIC without removing it from the board, and for reading any data from the PIC on the PC using hyper terminal program by connecting the serial cable between the board and PC. The (Max232) IC Is used to transfer data between PIC and serial connector as shown in Figure 19.

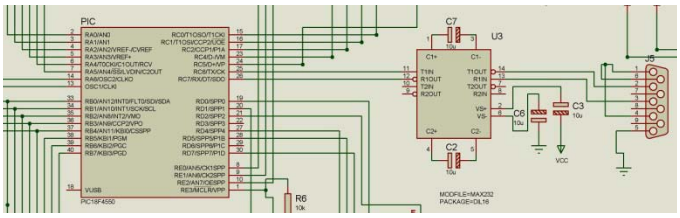

Figure 19: Schematic Diagram for PIC Programmer Connection using Proteus Program.

VI. MECHANICAL CONSTRUCTION AND COMPONENTS

System prototype consists of a mechanical mechanism of 2 degrees of freedom (D.O.F) designed to support and direct a PV solar cell attached to it. Mechanism has the ability to rotate the PV cell about 2_axes, x or z.

Electro- mechanical drive system of x- axis consists of a stepper motor with a1.5 cm radius pulley attached to its shaft and is driving a 2.5 cm radius pulley attached to main driving shaft through a belt. Belt mechanism realizes a speed reduction of 40%, and a torque increase of 40% in order to with stand demand load.

Main driving shaft is attached to the main frame and supported with two bearings. Also, this shaft is provided by an electro-mechanical clutch in order to prevent axis rotation when driving motor is disabled and to assure to keep the PV panel at the same end position. Main driving shaft transmits rotation to the second shaft through two identical meshing gears with the same angular speed. Second shaft is supported by the main frame by two ball bearings. PV panel is attached to the second shaft and its angular position is measured with a potentiometer attached to the second shaft end.

VII. CONCLUSION

In this paper, fuzzy logic controllers are fabricated on PIC 16F877A Microcontroller to increase the energy generation efficiency of tracking controller received from solar cells. By implementing a sun tracker controlled using fuzzy logic controller to keep the PV panel pointing toward the sun by using a stepper motor. The use of stepper motor enables accurate tracking of the sun. LDR resistors are used to determine the solar light intensity. Sun tracking generating power system is designed and implemented in real time. The proposed sun tracking controller and the proposed controller for grid-connected photovoltaic system are tested using Matlab/Simulink program, the results show that the controller have a good responses. The proposed solar tracking power generation fuzzy controller is able to track the sun light automatically. It is an efficient system for solar energy collection.

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