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Contribution to the control of a tracker solar using hybrid controller and artificial intelligence systems

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***Abstract*— the main objective of this research is to use a control algorithm and computer capabilities developed in the field of Sun tracking to improve the effectiveness of its monitoring. This method installed on an approach in the aim of ordering of the tracking solar of a solar concentering using (FLC) and artificial intelligence systems such as neural networks Controller (NNC) to minimize tracking error and increase the performance of Solar Concentrator. The solar tracking system proposed in this paper uses two position sensors based on a detecting element for determining the position of the sun.**

The principle of FLC used in this work is to determine the position of the sun based of sun sensor and contribute to the tracker check the Fuzzy Logic Controller mechanism intended to align the mirror frame (azimuth and elevation) in the optimal direction.

The results of simulation and signal processing shown in this paper are reliable for sun tracking and the control of solar concentrators.

***Keywords*— Sun tracking, sun sensor, Fuzzy Logic Controller, artificial intelligence systems, neural networks, tracking error.**

I. Introduction

Solar energy is an important renewable energy getting more popular in many countries day by day [1]. The performance of solar power depends strongly on the solar field efficiency which is related to the tracker design, the field layout, the tracking system and control system. Controllers forms an important part for many solar energy systems, particularly for solar thermal generators, Solar trackers are usually divided in those with a unique axis and those with two axes. Single-axis trackers are simple and can be used in trough-style systems which require only single-axis tracking. Two-axis solar trackers allow to obtain an optimal tracking of the sun's path since they keep the orientation of the collectors perpendicular to the solar radiation at any time in any season [2]. For example in solar power tower, the field of heliostats is used to reflect and concentrate sunlight towards the target receiver in the upper part of the tower. The concentrated radiation is absorbed and then transformed into heat energy to generate electricity. Hence, the study of solar power technologies is the attention of several researches to improve the various processes for producing electricity. The heliostat is an optical device that follows the sun and the solar radiation concentrated on the stationary target. Each heliostat has its own guidance system, consisting of a manipulator robot with two degrees of freedom, comprising two rotary joints [3]; the trajectories of the heliostat are generated by the two articulations (joints) controlled by two motors [4]. DC motors have been popular in the control industry area for a long time, because they have many good characteristics. In addition, high reliability, flexibility and low cost of DC motors lead to use them in different applications such as robot manipulators, tracking systems and home appliances… etc.

Currently, sun-tracking algorithms which are widely adopted to follow the sun's path are classified into three major groups; open loop, closed loop and a hybrid tracking system [5]. The open loop system is based on astronomic formulae relating the sun's position to the system geometry. This system is reliable-low cost and it is recommended for larger solar field because the heliostat is under computer control. On the other hand, the closed loop system uses a sensor to track the sun. This system is more accurate and very useful for small heliostat fields. . However, this system suffers from lower performance during cloudy period. Some researchers have developed hybrid solar tracking systems that include both open loop and monitoring closed-loop systems for reasons of high tracking accuracy [6-8].

The rest of this article is organized as follows: Section 2 gives a Hybrid control system description of tracker solar. Section 3 Methodology and introduces types of controller intelligence such as fuzzy logic and PI controller as well as the proposed control methods F-PI. Section 4 shows the simulation results of both approaches. The last section is devoted to the conclusion.

II. HYBRID CONTROL SYSTEM

The systems in hybrid loop control mode are used to control the dynamic behavior of a solar system, using a combination of both open loop and closed loop control strategies. The control system can be driven by discrete signals, continuous signals, while some of these signals can be time-controlled, or event. An optical light detection device is used in this type of installation such as those used in the control system in closed loop.

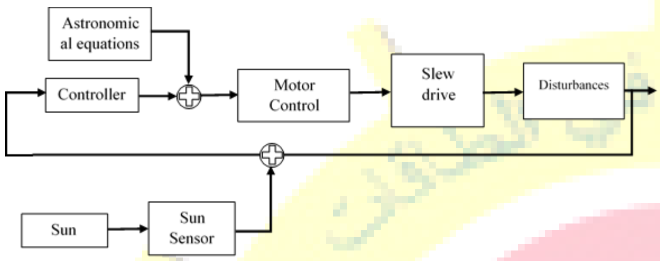

Fig. 1. Operational principles of hybrid (open-loop/closed-loop) motion control

The hybrid control approach follows the sun's path with an astronomical algorithm, while simultaneously using sensors to monitor and improve the solar tracking accuracy score. The hybrid loop control mode has the advantage compared to open loop systems and closed loop in that the positioning of the solar sensor remains in the immediate vicinity of the real-time position of the sun.

Figure 2 shows the flowchart that analyzes the process of determining the coordinate of the tracker solar by the hybrid control system. If the sun is not detected by the sensors due to the cloud for example, the system will send a signal to motors based on the calculation of a predefined astronomical formulas. This will continuous until the sun sensor. When the sun is detected, the system will then analyse the position of the sun using the fuzzy logic controller. This is applied for both motors. The reflector of the tracker is positioned by the pointing mechanism of the sun so that the normal to its surface is the bisector; it is the angle between the incident solar rays and a line from the central reflector the heliostat to the target at the top of tower; it is the case of a heliostat field of solar power tower plant. For other systems of solar concentration, solar tracker system is oriented opposite the sun.

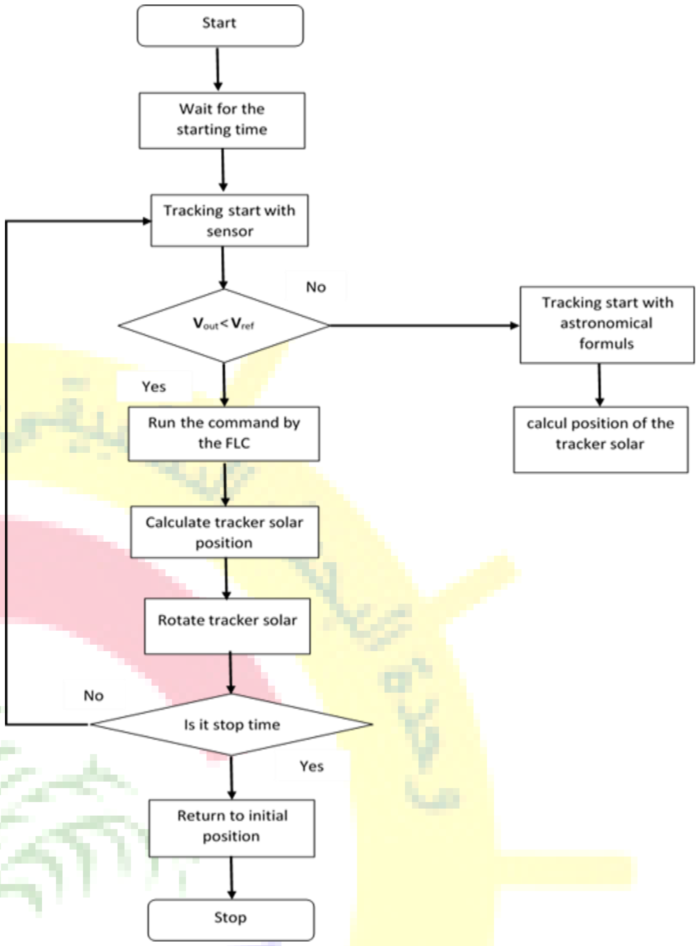

Fig. 2. Flowchart of the hybrid algorithm of tracker control.

III. METHODOLOGY

The solar tracking system proposed in this section uses two position sensors based on a detecting element for determining the position of the sun in a continuous or discrete manner.

The potential difference between the two photoelectric sensors (error) considered to set the refresh time of the position of the heliostat [9], in this case the tracker changes automatically and without any calculation. Therefore, for a system of the tracker solar very precisely the potential difference between the photoelectric sensors is very small.

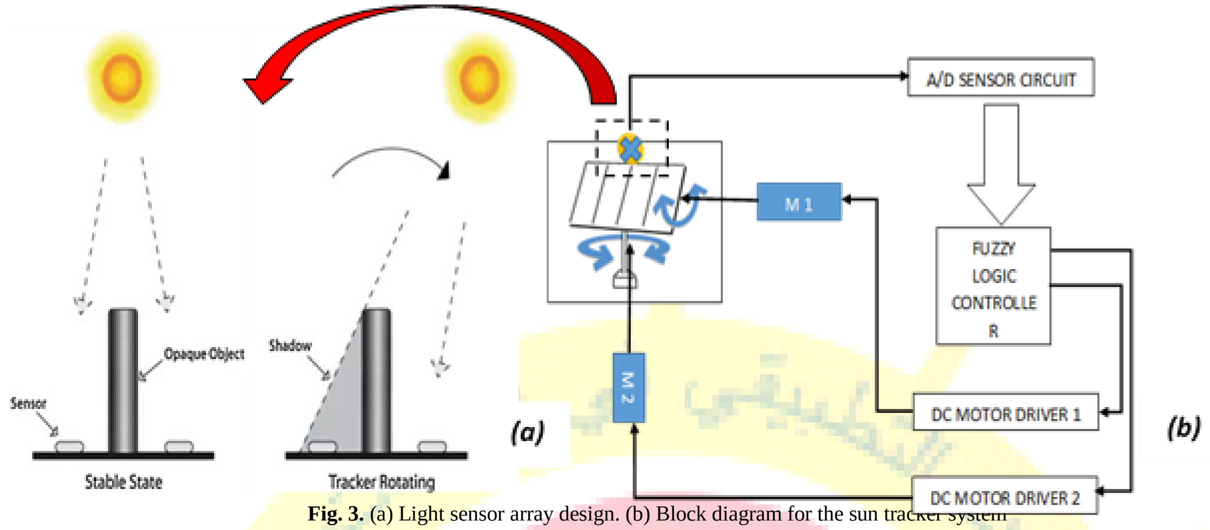

Fig. 3. (a) Light sensor array design. (b) Block diagram for the sun tracker system

Typically, one pair of sensors (figure 3) is used for one-axis tracking to control a single motor and two pairs are required for the full-tracking mode [10].

To sense the position of the sun on an axis says east / west, two LDR sensors are mounted on the solar panel. The response of this approach is similar to that of a human eye. LDR probes in directions east and west compare the intensity of the received light. Based on changes in the sunlight.

The sun change creates a potential difference between the two sensors; this value from the fuzzy logic controller can generate a control voltage to the DC motor drive card (figure 4) to change the solar tracker position by keeping the optimum position.

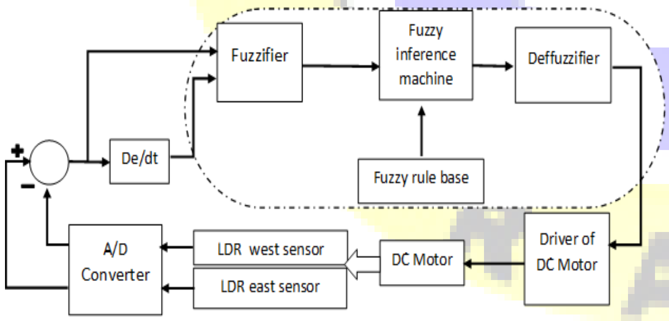

Fig. 4. FLC controller for the sun tracker system.

A. *Design of FLC for Sun Tracking system*

To design the fuzzy controller, two different approaches are taken into account (FLCa and FLCb), and two rules with different sets were defined to show that these controllers can be done in several ways that may be better than others. The two inputs to the FLCa are error and the change in error. Only one output is used which feed the DC motor driver. In this works Mamdani based model is used to construct the fuzzy controller. The FLC contains three basic parts: Fuzzification, Base rule, and Defuzzification [11].

1) First approach

The following linguistic variables are
• Error inputs

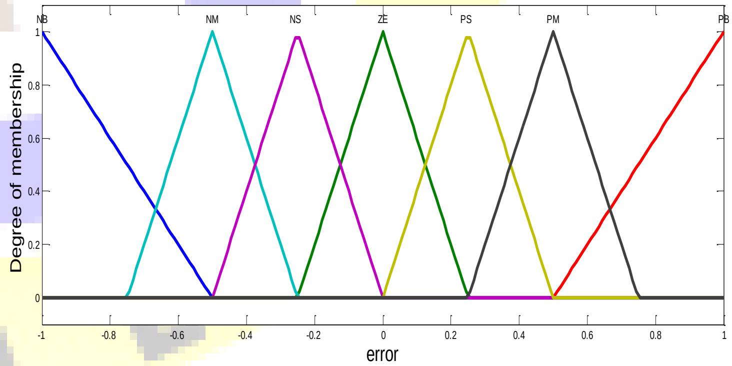

Fig. 5. Error fuzzy set of FLC

• Variation of error

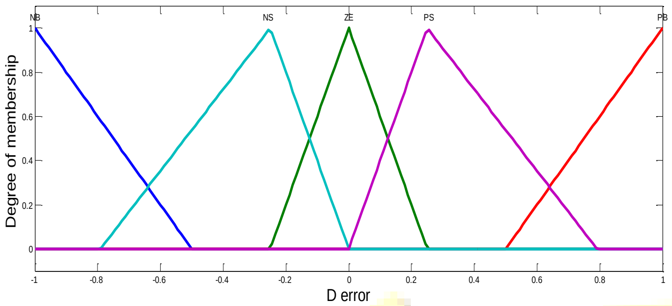

Fig. 6. Change in error fuzzy set of FLC_a

• Output

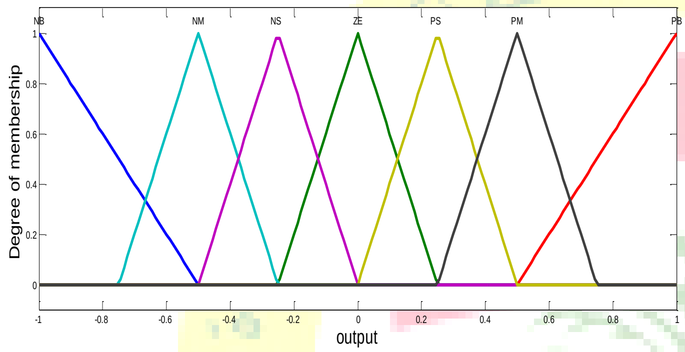

Fig. 7. Fuzzy set of FLC_a output entering to DC motor driver

Figure 5 illustrates the fuzzy set of the Error input which contains seven Triangular memberships.

Figure 6 illustrates the fuzzy set of the Change of Error input which contains five Triangular memberships.

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

• Rules: the rules are defined as follows:

TABLE I
RULE SETS FOR FIRST APPROACH.

Error / D error	NB	NS	ZE	PS	PB
NB	PB	PM	PB	PM	ZE
NM	PB	PM	PM	PS	NS
NS	PB	PS	PS	ZE	NM
ZE	PB	ZE	ZE	NS	NB
PS	PM	NS	NS	NS	NB
PM	PS	NM	NM	NM	NB
PB	ZE	NB	NB	NB	NB

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.

The fuzzy controller Simulink diagram used in our simulation is shown in Fig. 8.

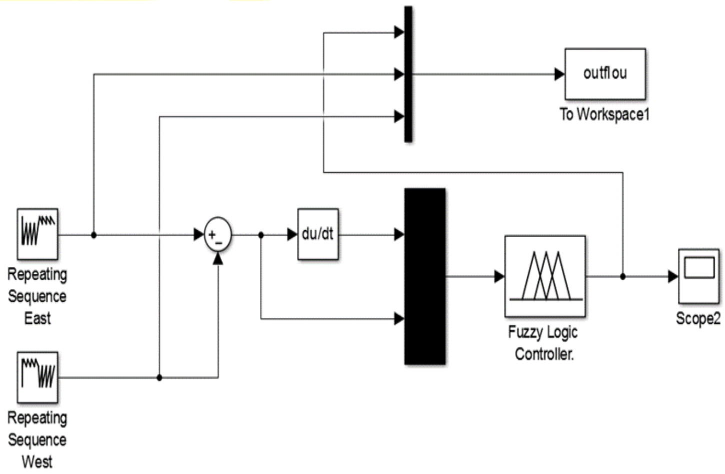

Fig. 8. One Axis Sun Tracker Using FLC_a

2) Second Approach

In the second approach, we only used the error as an input. The configurations used in FLC_b are presented as follow:

• Inputs (error) NB,NS,ZE,PS,PB.

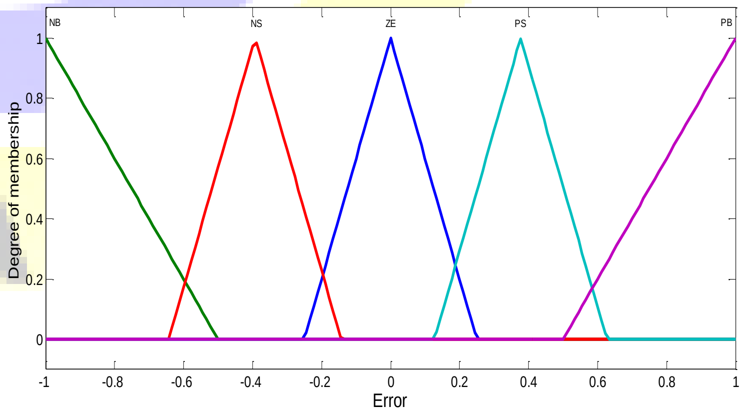

Fig. 9. Error fuzzy set of FLC_b

• Output: decrease (D), big decrease (DB), constant (CST), increase (A), small Increase (AP).

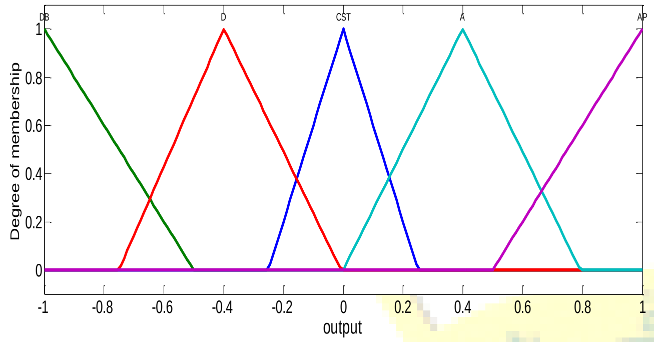

Fig. 10. Fuzzy set of FLC_b output entering to DC motor driver

• <u>Rules:</u> the rules are defined as follows:
– If the error is ZE, then control is CST.
– If the error is NB, then control is AP.
– If the error is NS, then control is A.
– If the error is PS, then control is D.
– If the error is PB, then control is DB.
In simulink, FLC_b diagram is shown in Fig. 11.

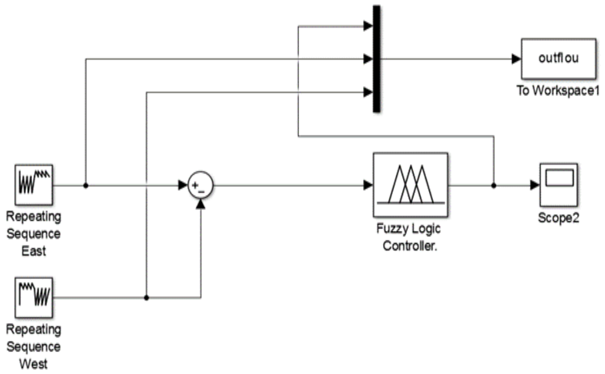

Fig. 11. One Axis Sun Tracker Using FLC_b

3) Examples of fuzzy logic controller

In this case we simulated the photoelectric sensor output signals to validate the operation of fuzzy controller.

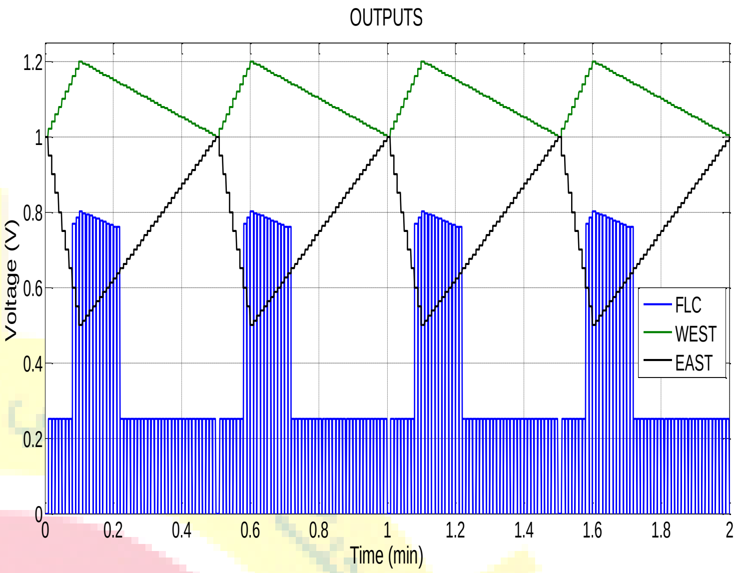

Fig. 12. Comparison between the three signals East West and FLC_a

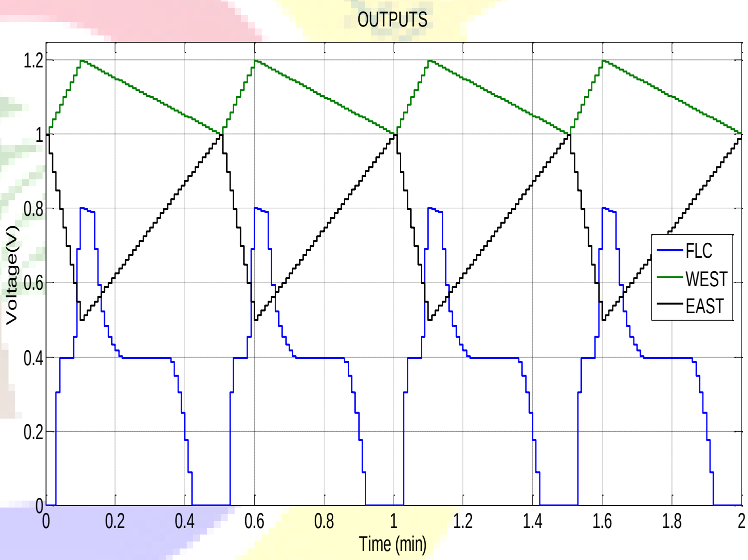

Fig. 13. Comparison between the three signals East West and FLC_b

In the general case, it is best to work with discrete signals to gain energy [12]. Our FLC output signal is used to control both solar tracker movements (azimuth, elevation) for optimal position relative to the incident solar ray and maximum efficiency.

The results presented in Figures 12 and figure 13 confirm the proper functioning of fuzzy controller with both configuration FLC_a and FLC_b.

Figure 12 shows the change of the voltage at LDR terminal east west with the time, when the sun moves the voltage is reduced by LDR east against the west LDR voltage will increase and the intensity of the fuzzy controller output changes depending on the difference between the two voltages. If the difference is more significant, the amplitude of the FLC output is high.

Both configurations FLCa and FLCb gives good results except the second configuration gives very precise pulses.

The following figure (fig 14, fig 15) shows exceeding of the tracker because of engine fault or if solar noon for elevation.

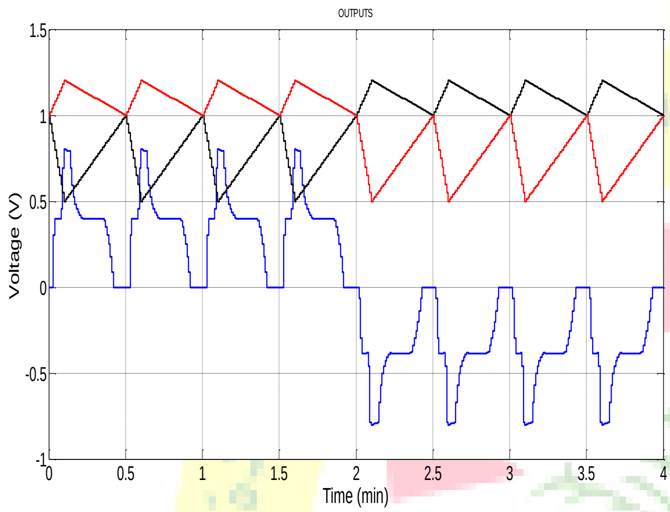

Fig. 14. Comparison between the three signals East West and FLC_a in exceptional cases

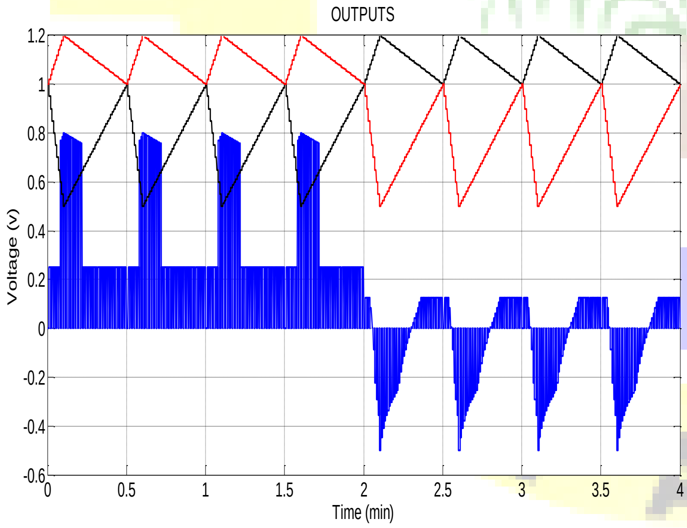

Fig. 15. Comparison between the three signals East West and FLC_b in exceptional cases

Figure 14 and figure 15 of this particular show a case the output signals of the sensor will reverse in the case of an error due to a large tracker orientation or the case of solar noon to rise because as the sun changes its top run down.

Because of that the sense of reverse motor direction to keep the tracker in the effectively position relative to the sun; So even with a noise or mechanical error caused by the tracker, the system directs the frame to the optimal position.

B. Fuzzy, F-PI and Neural Controller description and design

In this section, we will present a description, conception and configurations used in the simulation part for fuzzy, F-PI and neural controllers.

We use the control system by the neural network, proposed in [13]. And the fuzzy controller in [14]. In addition, a third PID auto-adjusting (F-PI) presented in [15]. These controls are compared to a work that was presented in [16]. The figures 16-18 illustrate the diagram Simulink/Matlab used in this study.

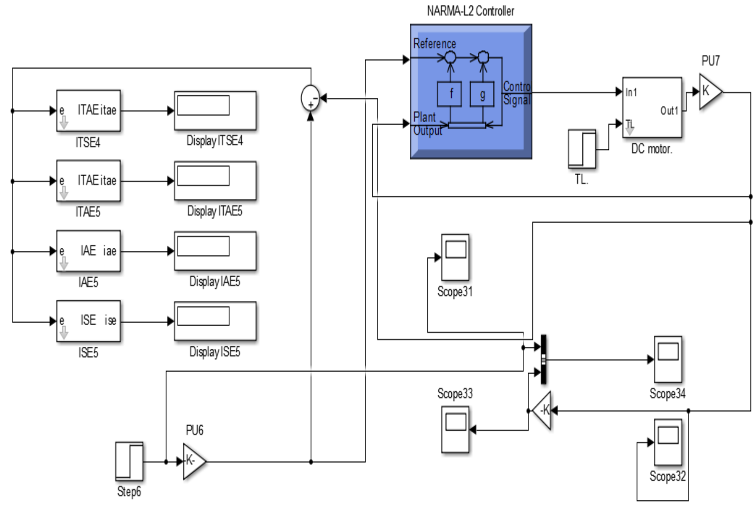

Fig. 16. Closed loop system using Neural Network Controller

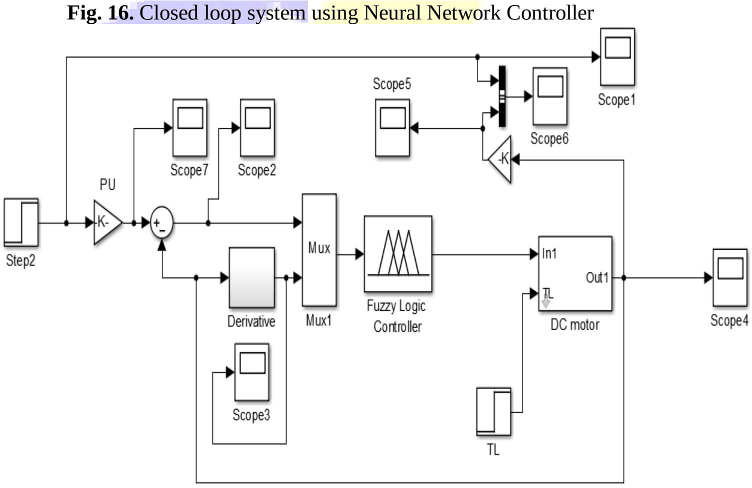

Fig. 17. Closed loop system using Fuzzy logic Controller (FLCA, FLCB, FLCC) [17]

IV. RESULT

In this part, we are interested to demonstrate the results through the design and simulation of a Neural, fuzzy logic and F-PI Controller in order to learn a little more about the design of controllers and determine the main characteristics of intelligent control.

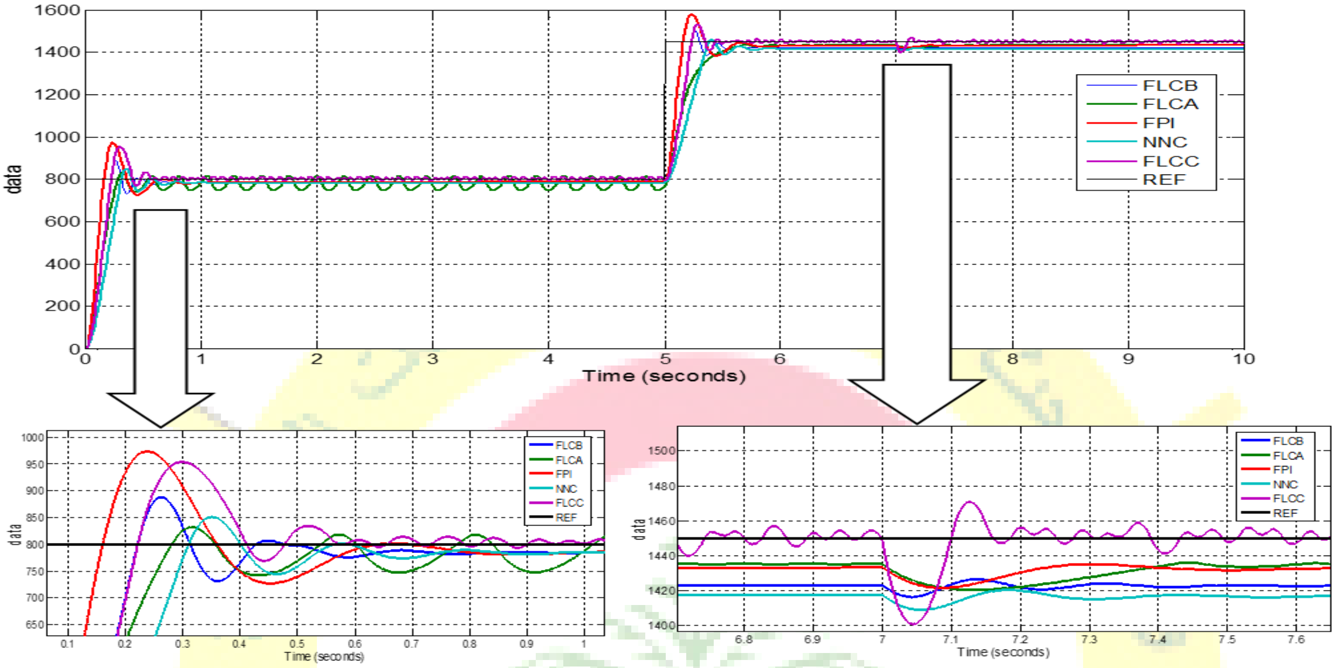

Fig. 19. Comparison between regulators Neural, fuzzy logic and F-PI Controller

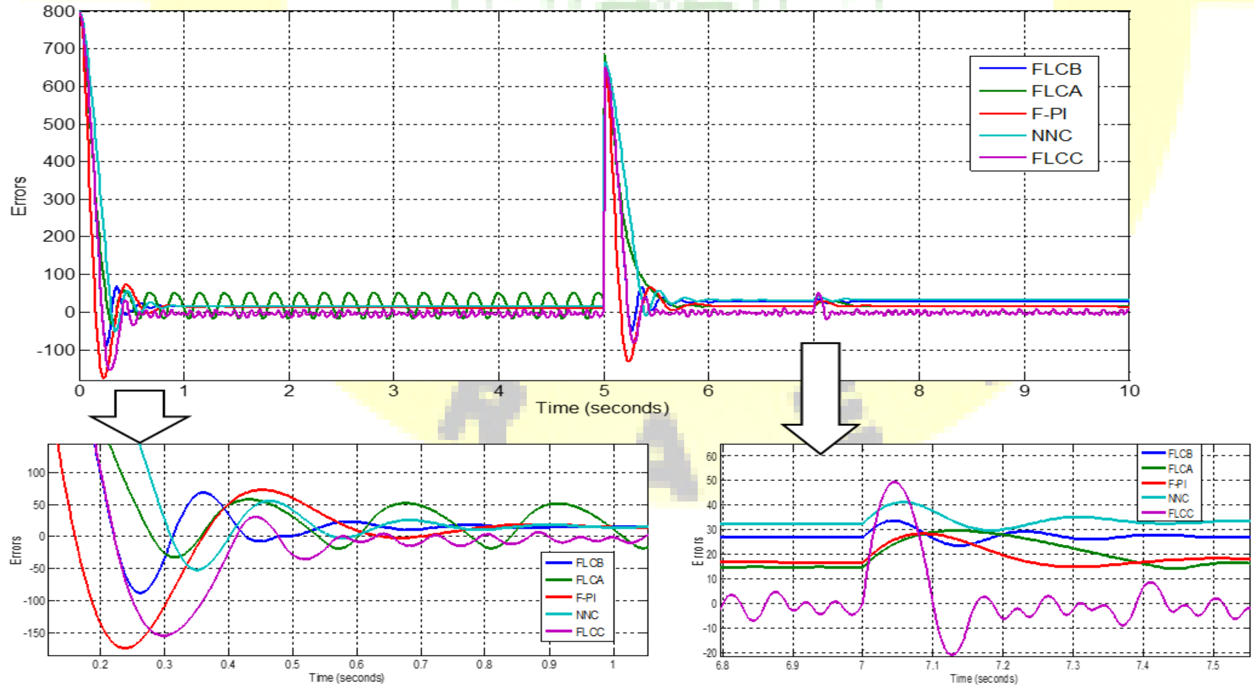

Fig. 20. Errors of three controllers

The error, e, presented in Figure 20, which calculate the difference between reference and actual value, it is commonly characterized into several quantities [17].

TABLE 2.
PERFORMANCE INDEXES OF FLC, NNC, AND F-PI CONTROLLERS.

	NNC	F-PI	FLA	FLCB	FLCC
ITSE	0.10	**0.079**	0.11	0.12	0.17
ITAE	**0.048**	0.07	1.10	1.04	1.40
IAE	**0.17**	0.21	0.27	0.29	0.34
ISE	0.050	**0.037**	0.051	0.054	0.070

The results of the analysis with a comparison of the five controllers are presented in figure 19 and figure 20 with details. Figure 20 shows the comparison result between the five controllers for a given scenario and figure 20 shows the error between the reference and simulated data.

From these figures, we can note that NNC gives the best results compared to other methods. From this figure, it is clearly shown that NC and F-PI give good results. However, NC presents some fluctuations that can be harmful for the DC motor. But, we can see that FLC and F-PI give results without fluctuations.

Similarly, Table 1 shows the performance indexes of fuzzy, F-PI and neural controllers. The calculated values of the IAE, ISE, ITAE and ITSE shown in Table 1 confirm the simulation results and values of the figures 19 and 20.

V. CONCLUSION

This work shows an example of application and simulation of artificial intelligence control device based on models of fuzzy logic of the sun sensor for controlling a sun tracking. The first part of this work confirms the real possibility of using a fuzzy system to control a DC motor.

The second part of this paper is a study of a sample application of artificial intelligence controller based on the neural networks, F-PI and fuzzy logic models. In the design of intelligent controllers, it is more important to know how the system works as it is evident in the dynamic case, a set of rules can be created in the case of fuzzy logic controller and learning neural network model to achieve the desired results. At first stage, simulation of different configurations of neural and fuzzy controllers has been tested. At the second stage, a comparative phase is needed in order to get the appropriate model.

Comparing the three controllers fuzzy and F-PI with neural. We can note that the NNC, it shows better response to step changes and very close to zero (Table 1 and figures 20-21). The neural controller is better, according to the ISE and ITSE parameter. Even the auto-adjustable (F-PI) controller gives the best results (ISE, ITSE) for controlling the DC motor and guide the solar tracker.

The results presented in this study are very encouraging because from the configuration model of neural network and combination of a classic control system PI and fuzzy logic it will be possible to further increase system performance.

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