Article

MIMO Fuzzy Logic Controller for Accurate Sustainable Indoor-Lighting Design Using Simultaneous Dual Control to Adjust LEDs Lighting System and Roller Blinds' Opening to Control the Daylight

Muhammad M.A.S. Mahmoud

Electrical Engineering Consultation (DFEEC)- Cairo-Egypt.
Yessenov University, Aktua-Kazakhistan
Correspondence: mmanar@yahoo.com

Abstract: This paper is an extension to previous work that introduced successful classical-control for indoor lighting system that simultaneously control LED system and roller curtain to achieve accurate light intensity for indoor lighting applications. In this paper, Multi Input Multi Output Fuzzy Logic Controller (MIMO FLC) is proposed to replace the classical-controller. Detailed method is provided to illustrate the steps to design the required MIMO FLC that has two fuzzy input, two fuzzy output and forty-five fuzzy rules with mamdani fuzzy engine. The proposed MIMO FLC is simulated in Matlab using Simulink tools. The results are illustrated, analyzed and compared with the classical-control. The response showed very close performance to the classical-controller. The maximum average error and the maximum error with respect to "Desired Lux" inside the room is -6% and -10% respectively.

Keywords: Fuzzy logic controller; Lighting control; Smart lighting control; Green buildings; Building automation; Daylight harvesting

1: Introduction

Classical-control, before fuzzy logic theory, needs either theoretical or numerical precise equations to specify relationship between inputs and outputs to design controller for the system. Now, fuzzy logic simplifies the description of the relationship between inputs and outputs by using a group of if/then statements based on human knowledge and experience. Many manufacturers for PLC and DCS have integrated the fuzzy logic control (FLC) in their products since late last century. This encouraged many control-engineers and researchers to use fuzzy logic in their designs and articles [1].

Energy building management are one of the applications that fuzzy logic finds wide appreciation to be used in. [2,3]. Baniyounes et al. used FLC controlling system to guess indoor and outdoor illuminance combination rule in order to save energy inside a commercial building. The model quantifies the outdoor and the indoor illuminance to execute a photometric analysis in order to control the dimming of artificial electric lighting [4]. Authors in [5] presented the design and implementation process of a fuzzy energy system several residential conditions. The system has the capability to learns generates rules and chose the most important linguistic variables. The data variables collected in the dataset consist of equipment and lighting energy consumption, temperature and humidity values of different areas. In [6], the paper presents a fuzzy integrated controller for temperature, lighting and fire detection in emergency conditions.

Usually, lighting control plays very important role for energy saving in both indoor and outdoor lighting application [7, 8]. FLC has used in many indoor applications using different design philosophies. In [9], the paper provided Multi-Input-Single-Output (MISO) FLC for indoor LEDs lighting system using fuzzy control. This MISO controller used two inputs obtained from Light Dependent Resistors (LDR) transducers to sense the indoor and outdoor lighting. The output of the FLC is Pulse Width Modulator (PWM) signal that control the LED lighting drive to adjust the indoor lighting. But in [10], the paper used simple FLC that adjust the indoor light intensity based on the different between desired lux and state of the light intensity in the room. However, the paper did not discuss the case if the curtain is opened and the desired lux is less than the light intensity inside the room. Therefore, in any precise indoor lighting design, indoor efficient daylight harvesting control is required.

Applications of FLC in interior daylight harvesting are discussed in many articles. The use of fuzzy logic for the estimation of average daylight factor has been discussed in [11], where the Average daylight factor is the arithmetic average of the daylight factors obtained throughout a space. In this paper, the input fuzzy set is categorized into three categories, "Reflectance", "Room Geometry" and "Window Opening" and the output of the fuzzy system is the estimated "Average Daylight Factor". In [12], comparative study is carried out between the classical model and fuzzy model to estimate the daylight factor. The fuzzy model input parameters were taken: hour, azimuth and altitude angle., and the output is the direct solar radiation on horizontal and vertical surfaces. However, in both papers the case of the rooms with daylight-diffusing glass windows are not discussed. In [13], the paper proposed an approach using MISO FLC to adjust the curtain opening in order to control the daylight harvesting inside the room. For fuzzy inputs "desired illumination value" and "the difference between the inside illuminance and the desired illumination values were taken," and the "roller blind position " was taken as output. However, the paper did not give any hardware description or schematic diagram for the proposed method. The paper took in the consideration relatively high lux value for the desired illumination, between 700 and 1500 in summer. Also, the proposed method did not solve the glare problem.
Combination of using simultaneously the daylight harvesting and artificial light in indoor lighting control has very good result in minimizing the operating cost of any building. FLCs are considered in many articles to design integrated controllers that consider the daylight entering the room in the dimming control system of the artificial light. In [14, 15], the paper introduced FLC to control the light intensity based on zoning method that relay on the installation of light intensity sensors in each zone to detect the shaded and the non-shaded areas and then control the artificial light accordingly. This method can cause unconformable glare as the lights are not illuminated uniformly across the room, and the daylight entering the room is not controlled in effective method.

From the above literature review we can recognize that although many research works were done in the daylight harvesting subject using fuzzy logic, but none of these work introduced FLC design that provide precise and comfortable control for indoor lighting without glare problems.

In my previous work [16], accurate approach for the integrated design of indoor lighting system, utilizing the daylight harvesting, LED lighting system and daylight diffuser window, is introduced to achieve precise utilization of the daylight entering the room without glare. Smart classical-controller is designed to adjust the position of the roller blind stepper motor, and hence, adjust the roller blind opening, based on the preset light intensity, to achieve precise utilization of the daylight entering the room. If the desired Lux is not achieved for any reason, the smart controller adjusts the LED circuit current to boost the light intensity to achieve precisely the desired Lux. Comprehensive test cases using MATLAB-Simulink is carried out to verify the performance of the proposed smart controller.

In this Article, extension research-work for [16] is provided to use FLC instead of classical-control. In Section 2, the procedures of the FLC design is illustrated. The response of FLC is provided in Section 3. Comparison between the

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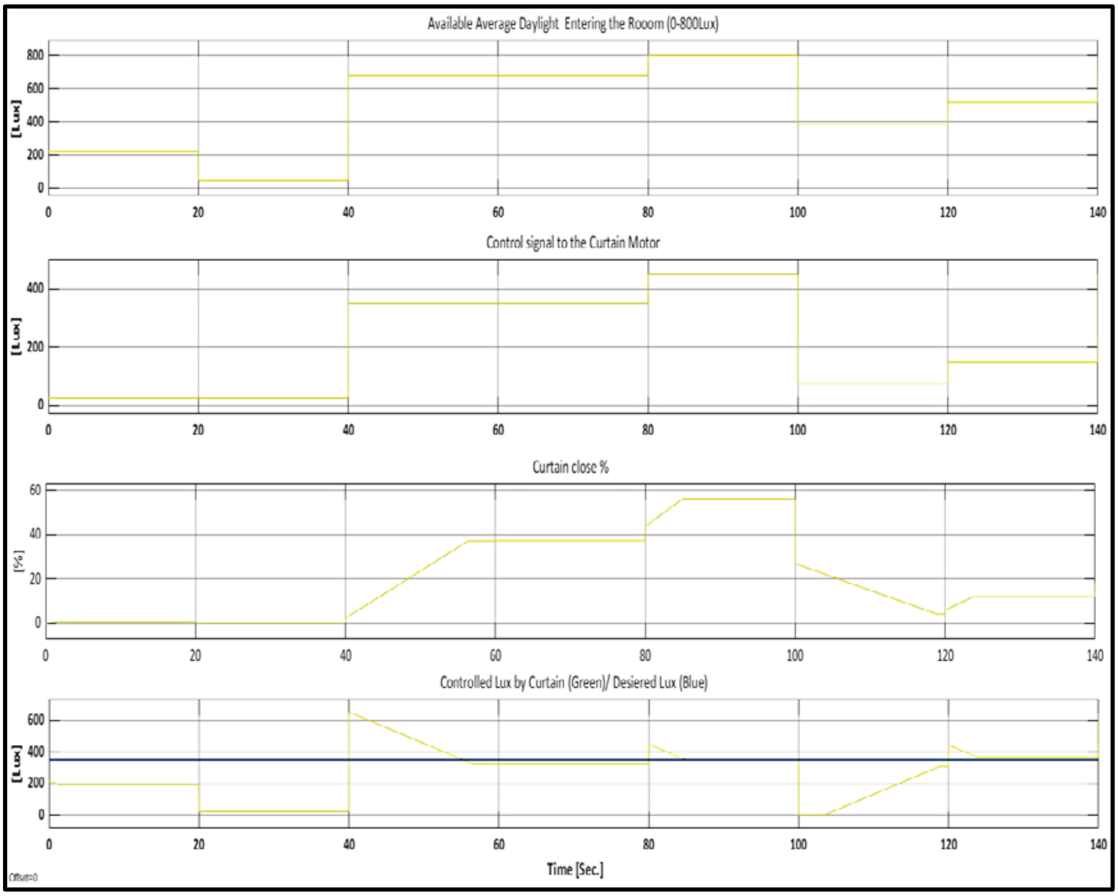
response of classical-controller and FLC is discussed in Section 4. Finally, in Section 5 summary and conclusion is given.

2: FLC design procedures:

Regardless nature of the system that need to be controlled using fuzzy logic, there are mainly three basic steps that are required for all FLCs: the russification of the controller inputs/outputs, generation of the FLC rules of and the defuzzification of the output to a crisp value for implementation. These steps will be explained in succeeding paragraphs.

In order to generate the knowledge and data that are required to build the Multi Input Multi Output (MIMO) FLC, the Simulink classical-control schematic that is presented in article [16] is used, but with different combination values of "Desired Lux" (DL) and "Available Average Daylight Entering the Room" (ADER), and record the corresponding Stepper-Motor Control Signals(SMCS) and "LED Control Signals" (LCS). The proposed design of the FLC takes in consideration the required minimum lux in offices which may varies from 200 to 750 Lux. For the range of available average daylight entering the office from the diffuser-window, the values between (0 to 800 Lux) are considered. However, the range of light intensity in the room that the LED system can provide is from 0 to 700 Lux. Figure 1 to Figure 4 illustrate the response of the classical-controller to four different cases. As a matter of fact, it is worth to highlight in this stage that in case the light intensity can change in the office maximum +/- 30 % without disturbance of the human eye [19].



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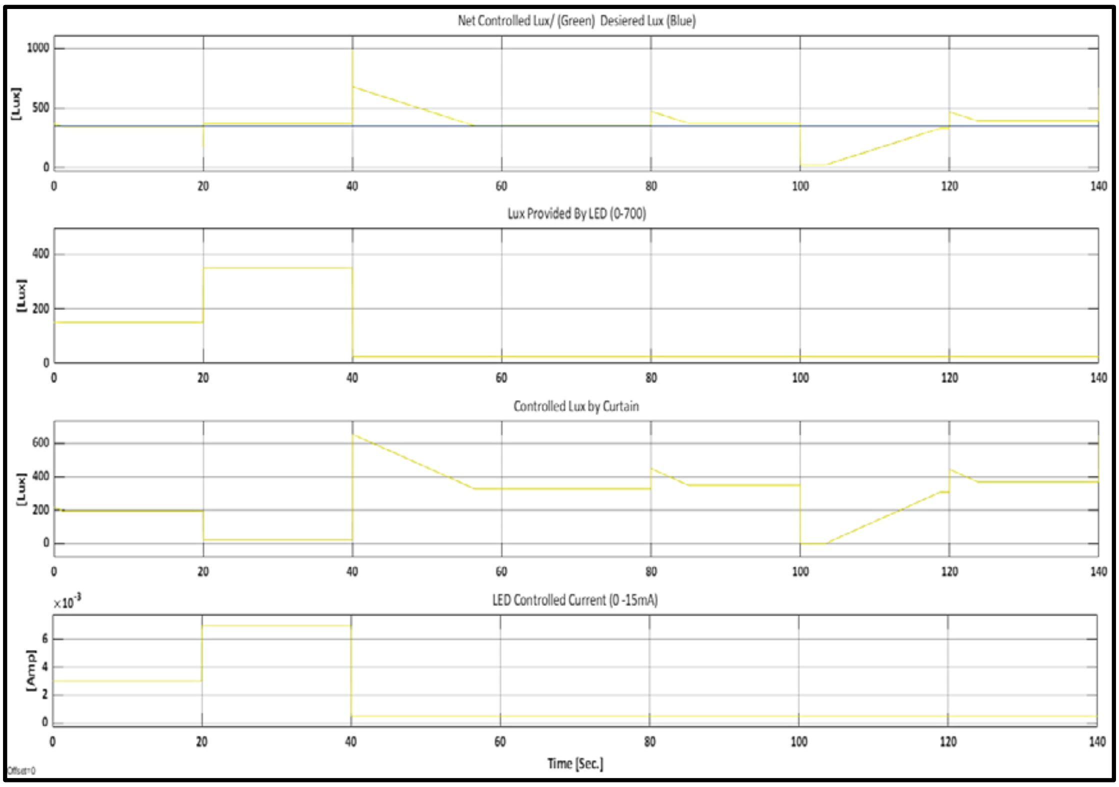
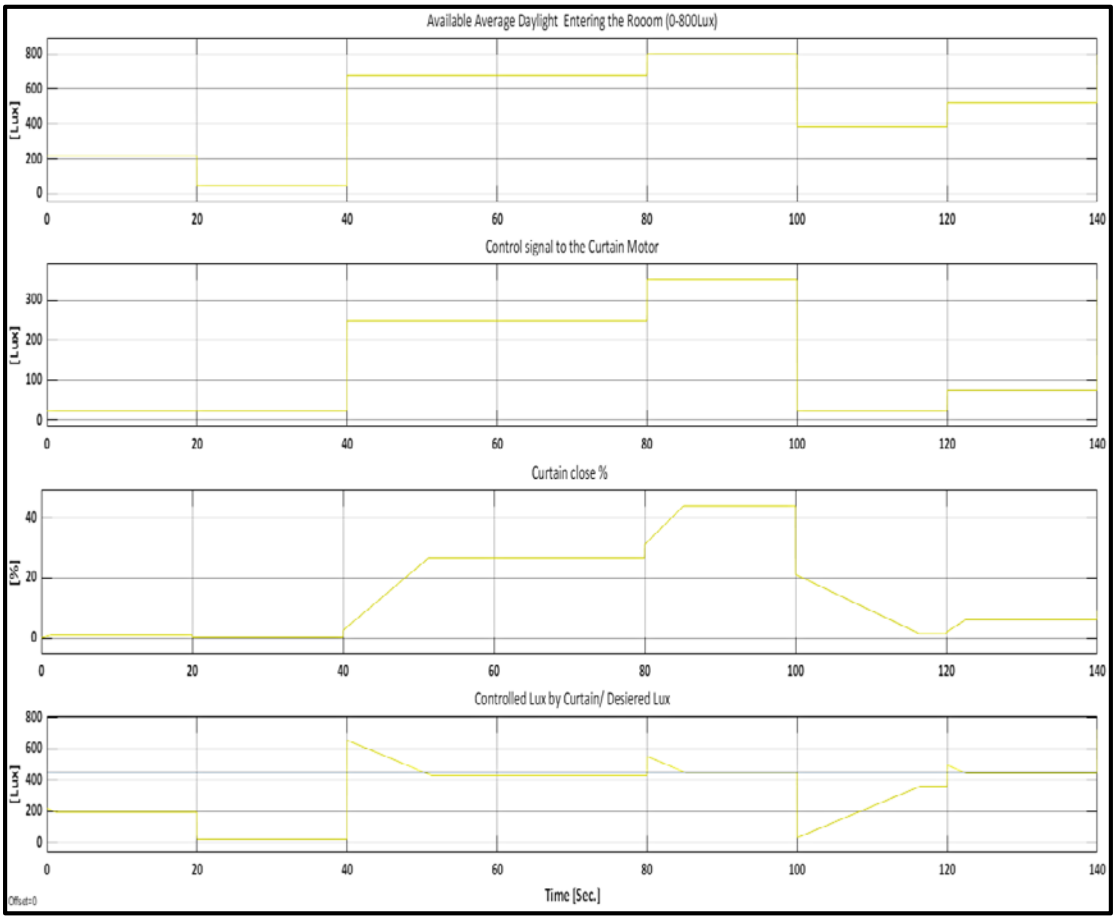


Fig. 1: Results for Desired Lux = 350



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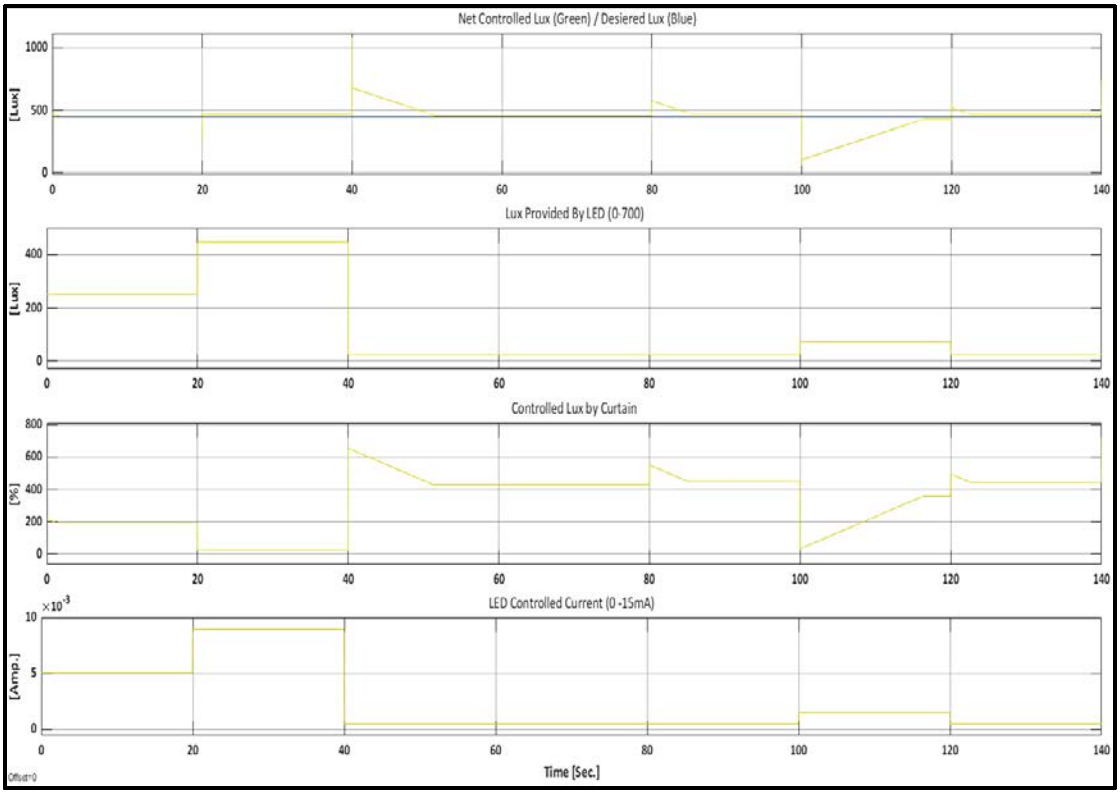
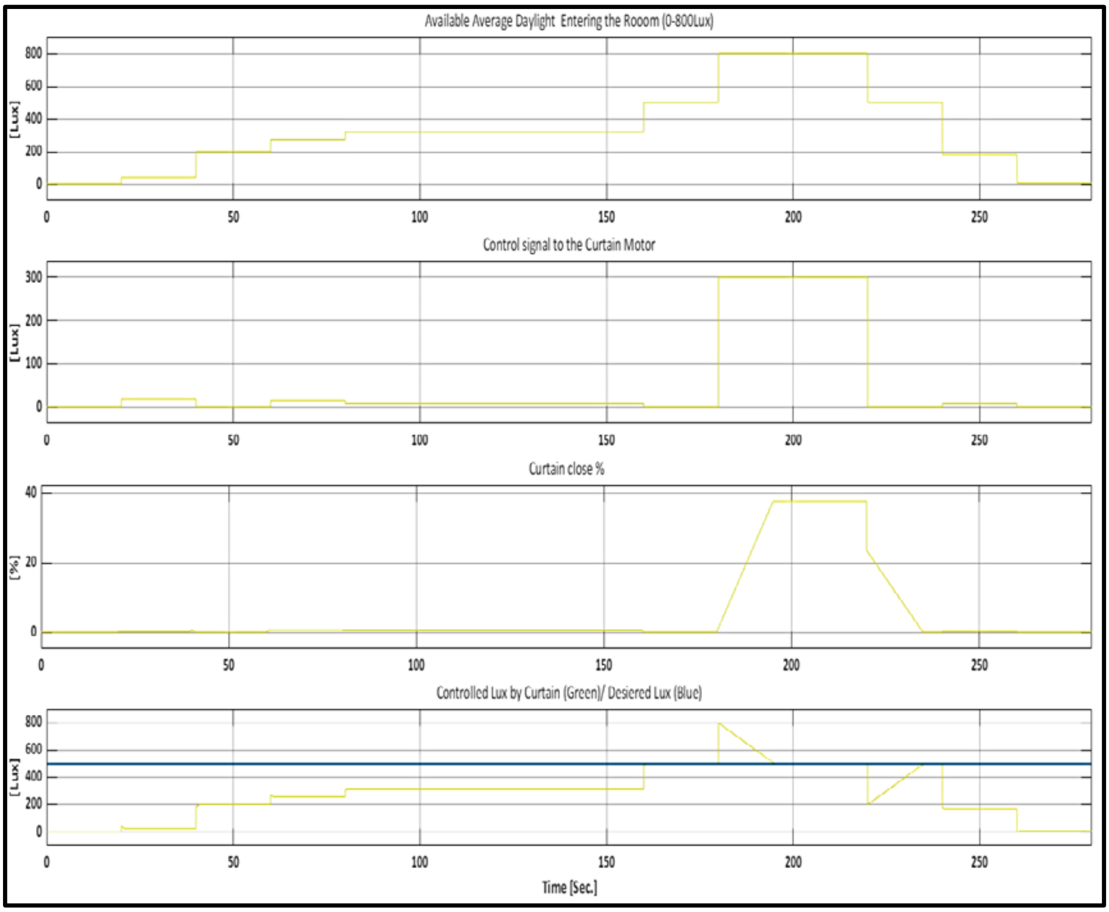


Fig. 2: Results for Desired Lux = 450



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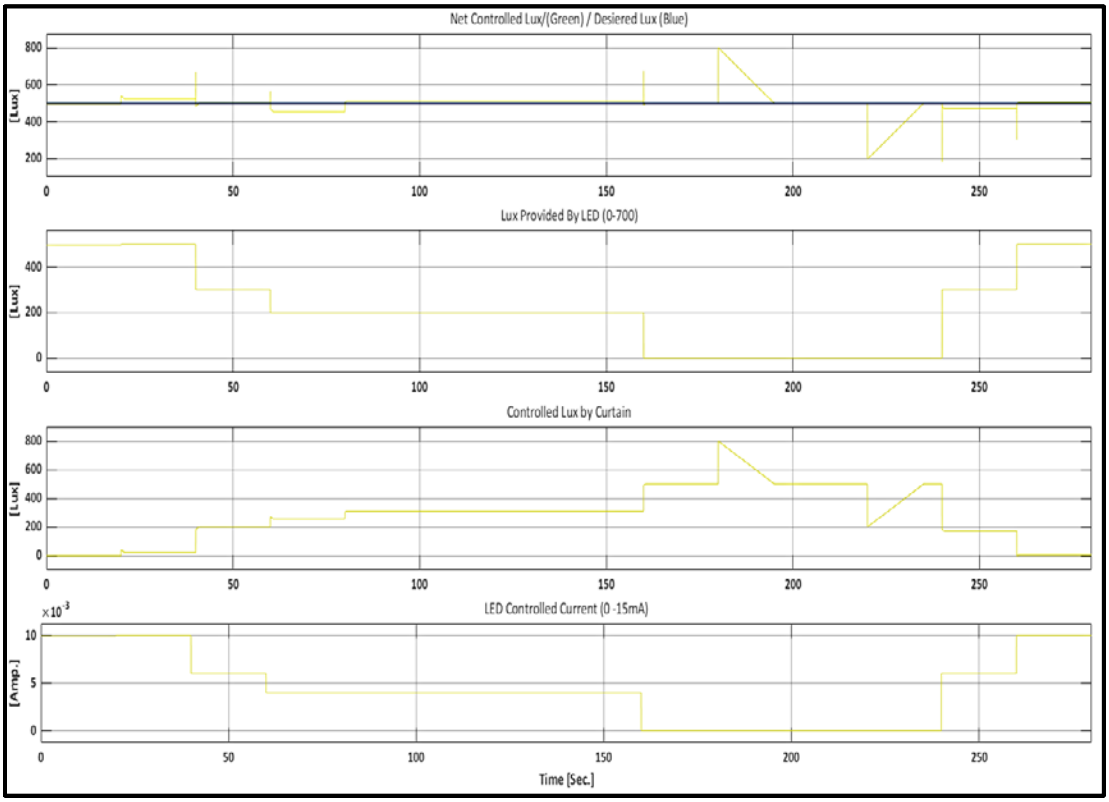
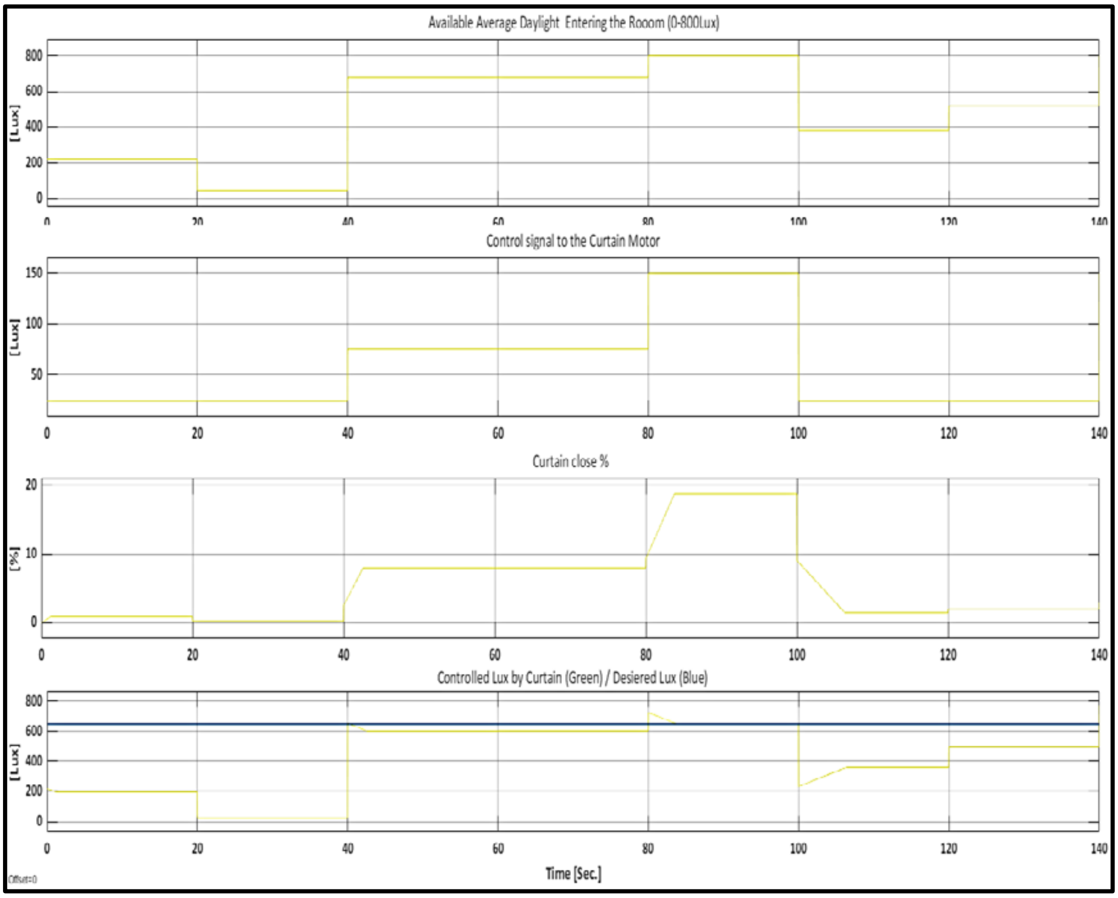


Fig. 3: Results for Desired Lux = 500



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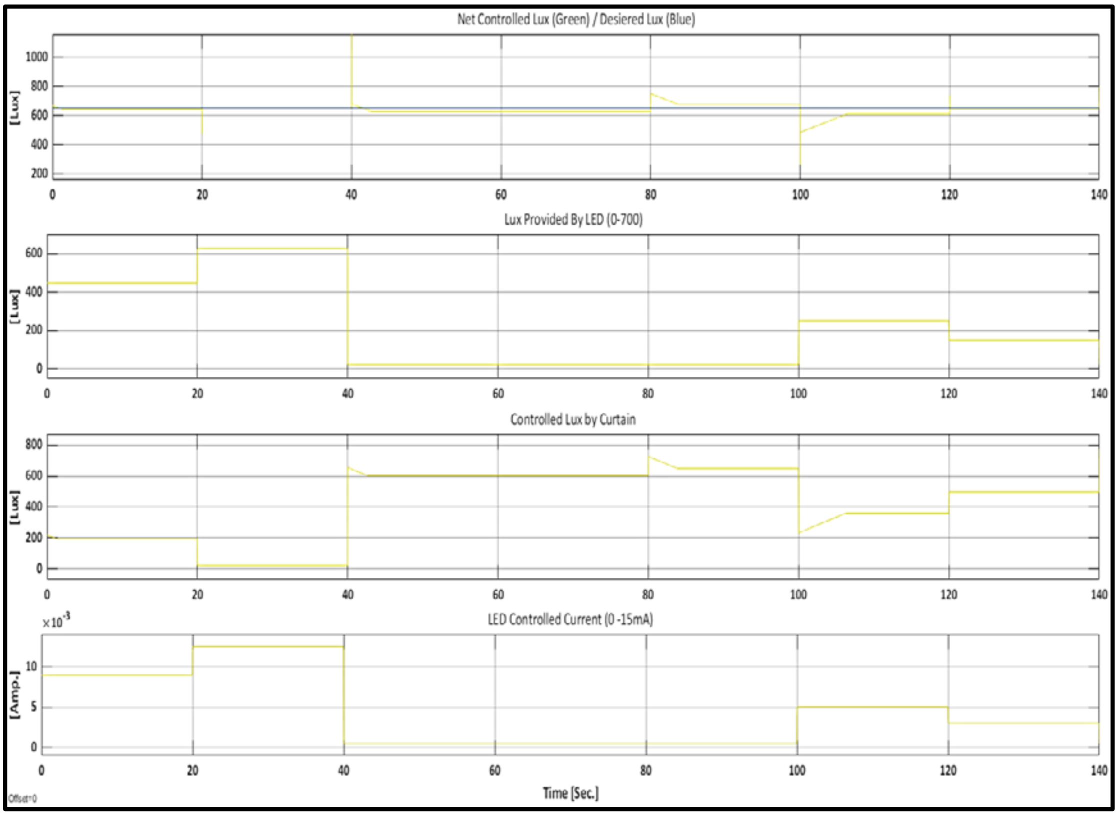

Fig. 4: Results for Desired Lux = 650

From the response of these four case, the following are extracted:

Fuzzy Input 1 (ADER):

Range (0-800)

Number of membership functions: 9

Membership function (MF): Triangle.

Membership illustrated is Figure: 5

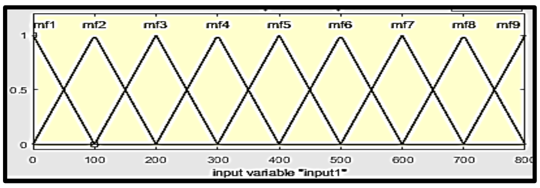

Fig 5: ADER MFs

Fuzzy Input 2 (DL):

Range (300-700)

Number of membership functions: 5

Membership function: Triangle.

MF illustrated is Figure: 6

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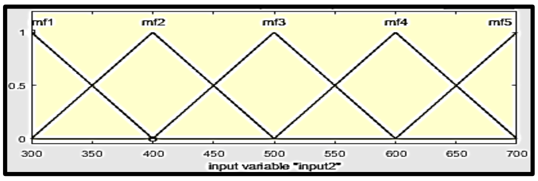

Fig 6: DL MFs

Fuzzy Output 2 (SMCS):

Range (0-600)

Number of Membership Functions: 7

Membership function (MF): Triangle.

Membership illustrated is Figure: 7

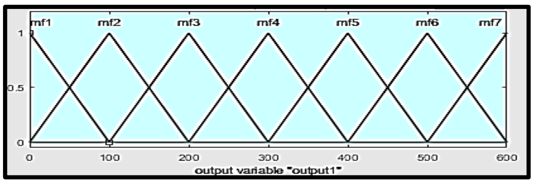

Fig 7: SMCS MFs

Fuzzy Output 1 (LCS):

Range (0-14)

Number of membership functions: 8

Membership function: Triangle.

Membership illustrated is Figure: 8

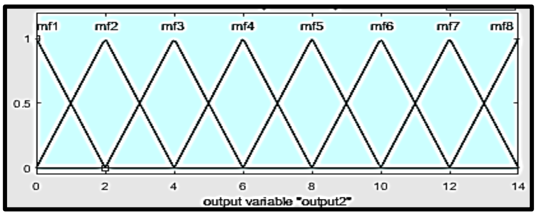

Fig 8: LCS MFs

Fuzzy Engine:

Fuzzy Controller: Mamdani

And Method: Min

Aggregation: Max

Defuzzification: Centroid

Fuzzy Rules:

Table 1 illustrate the fuzzy rules using 45 different rules that govern the fuzzy output based on the Fuzzy input. From these rules it can be noticed that as the minimum desire lux in office is 300Lux (Input2, MF1), so at maximum ADER of 800Lux (Input 1, MF9), the (Output 1, MF6) is fired to provide approximately 86% closing of the window, while LED are switched off (Output 2, MF1), and therefore the membership function (Output 1, MF7) is not fired at any rule.

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Table 1: Fuzzy Rules

Serial No.	Rule	Input 1 MF No.	Input Connection	Input 2 MF No.	Result	Output 1 MF No.	Output Connection	Output 2 MF No.
1	IF	1	AND	1	THEN	1	AND	4
2	IF	1	AND	2	THEN	1	THEN	5
3	IF	1	AND	3	THEN	1	THEN	6
4	IF	1	AND	4	THEN	1	THEN	7
5	IF	1	AND	5	THEN	1	THEN	8
6	IF	2	AND	1	THEN	1	THEN	3
7	IF	2	AND	2	THEN	1	THEN	4
8	IF	2	AND	3	THEN	1	THEN	5
9	IF	2	AND	4	THEN	1	THEN	6
10	IF	2	AND	5	THEN	1	THEN	7
11	IF	3	AND	1	THEN	1	THEN	2
12	IF	3	AND	2	THEN	1	THEN	3
13	IF	3	AND	3	THEN	1	THEN	4
14	IF	3	AND	4	THEN	1	THEN	5
15	IF	3	AND	5	THEN	1	THEN	6
16	IF	4	AND	1	THEN	1	THEN	1
17	IF	4	AND	2	THEN	1	THEN	2
18	IF	4	AND	3	THEN	1	THEN	3
19	IF	4	AND	4	THEN	1	THEN	4
20	IF	4	AND	5	THEN	1	THEN	5
21	IF	5	AND	1	THEN	2	THEN	1
22	IF	5	AND	2	THEN	1	THEN	1
23	IF	5	AND	3	THEN	1	THEN	2
24	IF	5	AND	4	THEN	1	THEN	3
25	IF	5	AND	5	THEN	1	THEN	4
26	IF	6	AND	1	THEN	3	THEN	1
27	IF	6	AND	2	THEN	2	THEN	1
28	IF	6	AND	3	THEN	1	THEN	1
29	IF	6	AND	4	THEN	1	THEN	2
30	IF	6	AND	5	THEN	4	THEN	3
31	IF	7	AND	1	THEN	3	THEN	1
32	IF	7	AND	2	THEN	3	THEN	1
33	IF	7	AND	3	THEN	2	THEN	1
34	IF	7	AND	4	THEN	1	THEN	1
35	IF	7	AND	5	THEN	1	THEN	2
36	IF	8	AND	1	THEN	5	THEN	1
37	IF	8	AND	2	THEN	4	THEN	1

38	IF	8	AND	3	THEN	3	THEN	1
39	IF	8	AND	4	THEN	2	THEN	1
40	IF	8	AND	5	THEN	1	THEN	1
41	**IF**	**9**	**AND**	**1**	**THEN**	**6**	**THEN**	**1**
42	IF	9	AND	2	THEN	5	THEN	1
43	IF	9	AND	3	THEN	4	THEN	1
44	IF	9	AND	4	THEN	3	THEN	1
45	IF	9	AND	5	THEN	2	THEN	1

MATLAB Simulink Modeling:

The developed above fuzzy system is used to model the required MIMO FLC in Simulink. Figure 9 illustrate the schematic diagram of the proposed system.

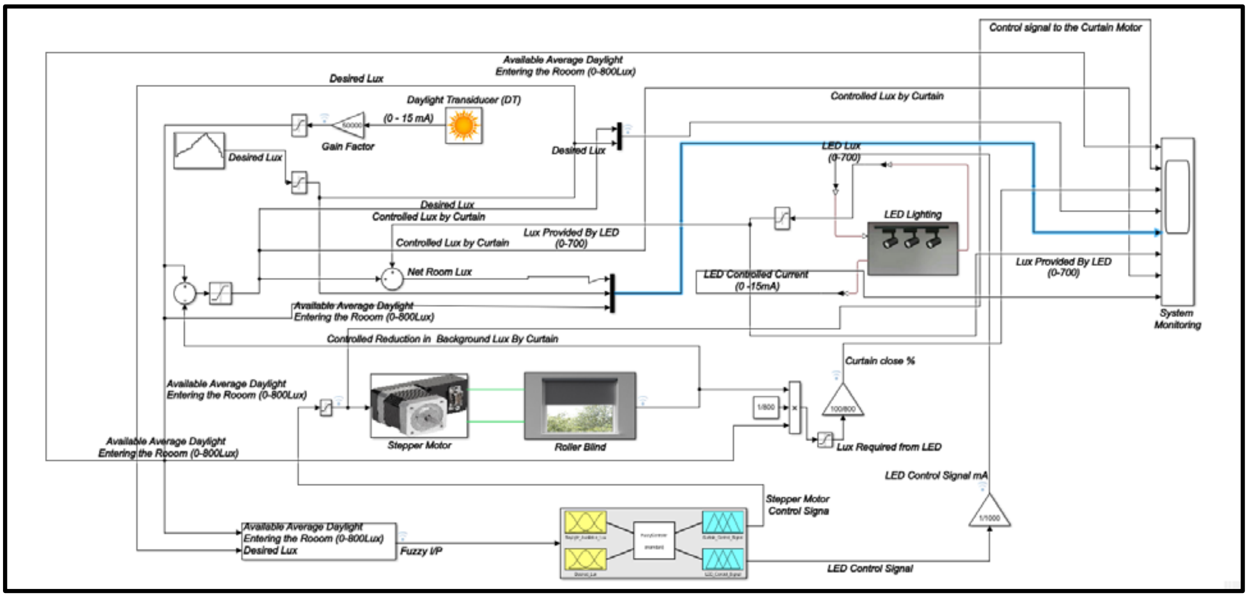

Fig 9: Indoor Lighting System with MIMO FLC

3: MIMO FLC Response Results

The developed model in Section 2 is used to test the response of the MIMO FLC at different combination values of "Desired Lux" and "Available Average Daylight Entering the Room" to cover the full range of both input. Figure 10 illustrates the results

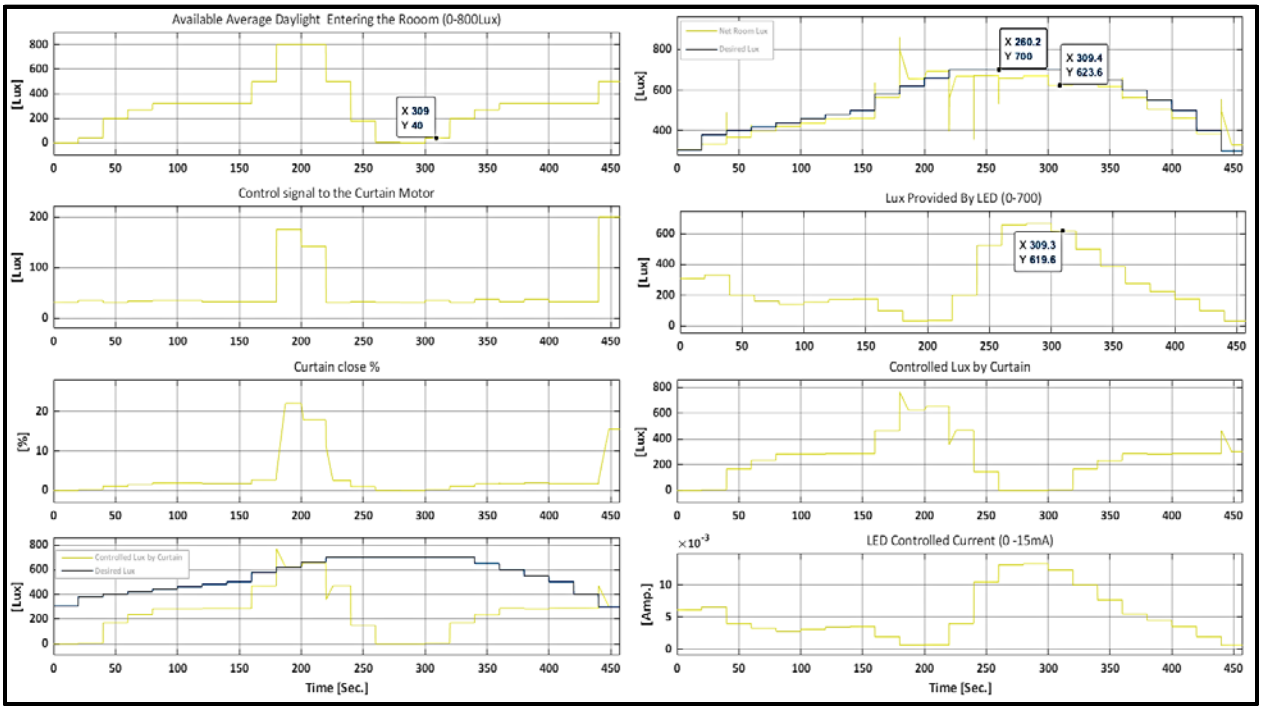

Fig. 10. Response of the MIMO FLC

From Figure 10, the response MIMO FLC shows accurate performance to achieve the desired Lux with absoluted average error less than 6%. The maximum error of approximately -10% occurs when the desired Lux is 700 and the Room Net Lux is 624. This error is within the acceptable value as the light intensity remains within the permissible margin that doesn't disturbance of the human eye (+/- 30 %).

4: Comparison Between the Performance of Classical-control Model and MIMO FLC Model

In order to validate the performance of the FLC as a controller for the proposed system, the classical-control response is taken as reference. Figure 11 illustrated the comparison between the two controllers.

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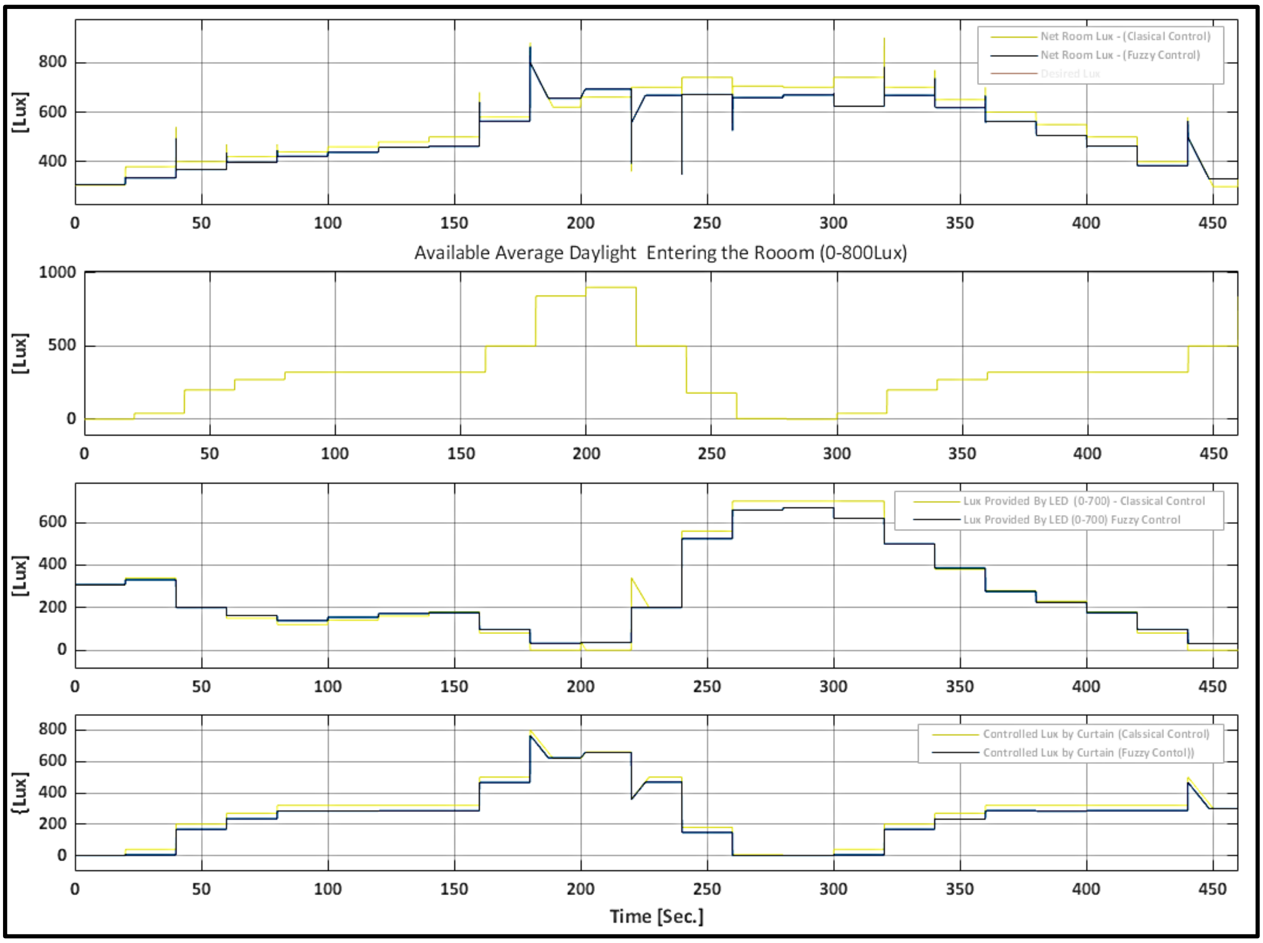

Fig. 11. Comparison between Classical-control and MIMO FLC Response

From the Figure 11, it is clearly that MIMO FLC response almost equal with the classical-controller response with negligible difference between them. The LED light and the curtain (Roller-Blid) are controlled almost identically to big extent by both controllers. However, the LED system response using MIMO FLC looks more smooth, without overshoots, compared with the classical-controller. Figure 12 illustrates two overshoots in the classical-controller that are not in the FLC. This actually minor problem and even needn't to be solved because these overshoots, either in FLC or in classical-controller, will not be recognized by the human eyes, and will not cause actual disturbance to the people inside the room.

It is worth to mention that the spikes, which appear in the “Net Room Lux” curves, for the response of both the Fuzzy Controller and the Classical-controller, are due to the software calculation algorithm and it is not real values in the system response. This can be confirmed by adding the LED Lux to the Curtain Lux to obtain the Room net lux without these spikes.

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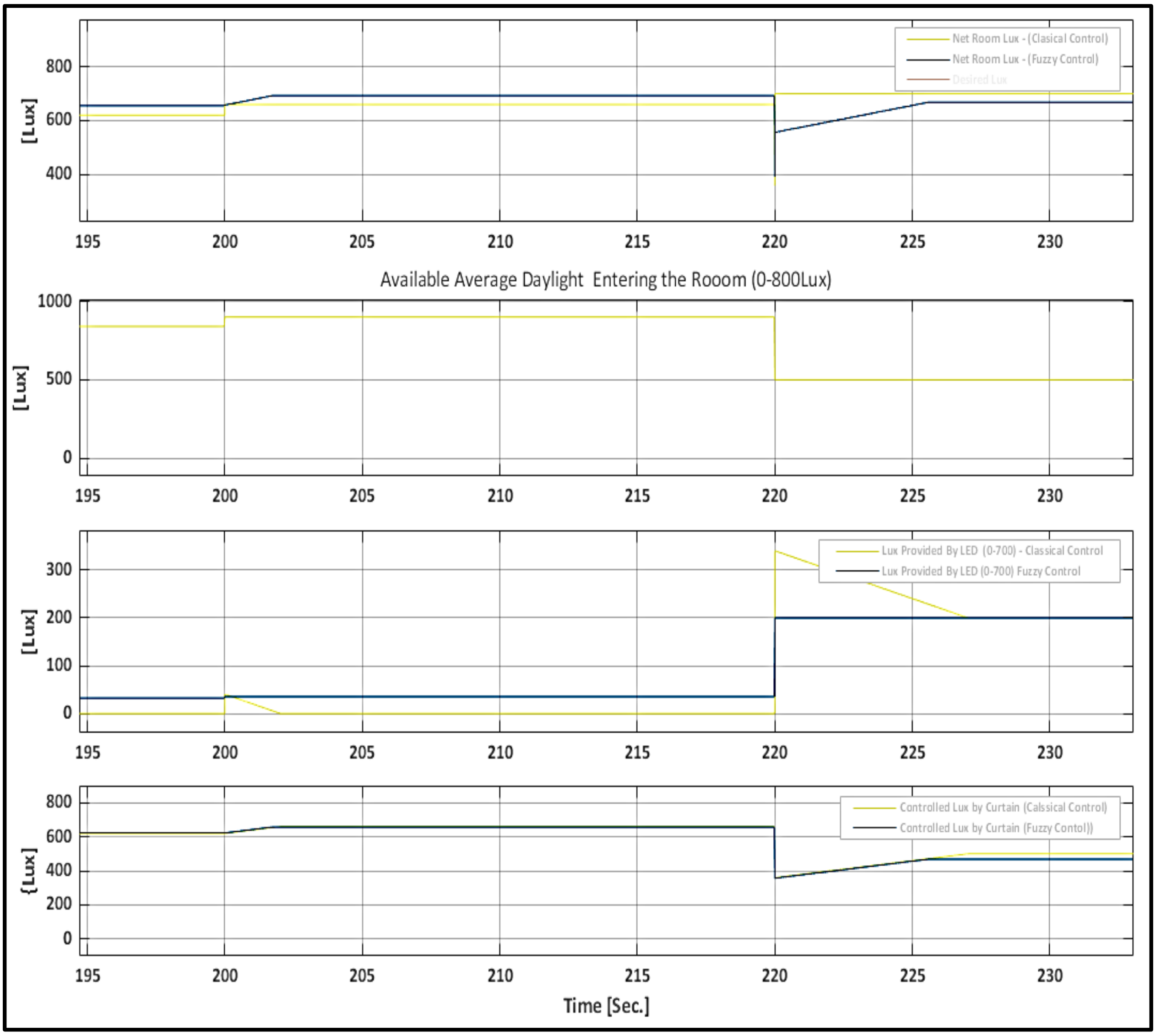

4: Conclusion

First, comprehensive literature review was carried out to analys the previous research works in day harvesting using fuzzy logic. It was noticed that none of the previous works present precise control for the indoor lighting without deficiency either in the accuracy or in the performance such as glare problems, and/or in the cost. This paper is an extension of the only previous work that presented the classical-design of sustainable and precise indoor-lighting system using simultaneous control for LEDs Lighting intensity and curtain's opening, without glare problems, to achieve economic energy consumption.

The new in this paper that FLC is used to replace the classical control. The paper illustrated the method of the design MIMO FLC that are used to simultaneously to control the drives of LED lighting system and the stepper motor, that drive the curtain. The proposed design is simulated and tested using in Simulink. The response of the MIMO FLC is illustrate, discussed and compared with the classical-control model. The results show that the response of the MIMO FLC is very close to the classical-controller response. The response of MIMO showed that the average error is less than

-6% and the maximum error -10% with respect to the "Desired Lux" inside the room. For the future work, Artificial Neural Network (ANN) method may be used to control the LED and the curtain drives, and the results can be compared with the results of classical-control and MIMO FLC.

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Muhammad M.A.S. Mahmoud, Egyptian, Received the B.S. degree in Engineering from Cairo University and the M.Sc. degree from Kuwait University. First Ph.D. degree from Transilvania University of Brasov, Romania in IT and Computer. Second PhD Degree in Electrical Power system and Machine, Cairo Univ. Egypt. He received a position of "Professor" on 2018. His current research interests in Fuzzy and Artificial Neural Network Techniques application include power delivery, protection reliability, control, safety, building automation and energy management. Prof. Dr. Muhammad is of IEEE Member in 1999, IEEE Senior Member (SM) since 2001 and TFS –IEEE Reviewer 2016.