Article

ANN Controller Design and Comparison with Other Equivalent Controllers for Low Cost Sustainable and Precise Indoor-Lighting Design Using Simultaneous Dual Control to Adjust Artificial Lighting and Daylight Harvesting

Muhammad M.A.S. Mahmoud

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

Abstract: This article is a continuity of prevouse two reserch in daylight harvastion control that were deigned using classical control apoproach and then fuzzy logic technique, In this article ANN controller is designed and its response is compared with the performance of the other two controllers. Detailed compression for the different error type is illustrated, however, the results show that the three controller operate with satisfactory accuracy.

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

1. Introduction

Lighting systems, either indoor or outdoor, consumes considerable amount of power day and night. Replacing the any other lighting type by LED become proven approach to achieve illumination very similar to daylight and reduce the operational cost of any lighting system either indoor or outdoor [1]. In outdoor, many research articles provide different economic solutions using Artificial Intelligent (AT) techniques for the street lighting operation control at night, as the daylight harvesting is not applicable [2-5]. However, daylight harvesting and its control becomes very important for sustainable solutions of indoor lighting to provide the required illumination at minimum possible cost. In [6-8], the authors provided comprehensive literature review to discuss the effect of controlled daylight harvesting on the indoor lighting and temperature of office building. The papers highlighted that different intelligent techniques such as Fuzzy logic, Artificial Neural Network (ANN), Genetic Algorithm, and PWM control, are used to control the dimming of LEDs in order to achieve the required interior illumination utilizing daylight harvesting.

ANN is used with different methodologies concentrating on the prediction of the daylight Autonomy (DA) level in order to control the daylight harvesting, either to limit the indoor temperature rise or to minimize the lighting system power consumption, during the day. In [9], the paper investigated the capability of using ANN technique to predict DA using the climate information and different window design variable. The ANN structure used in that research has five input neurons, one hidden layer with three neurons and on neuron for output layer. However, in [10] the authors used more complecated ANN with thirteen input presenting detailed information for climatic condition, design factors and timeing, and one hidden layers with six neurons and one neuron for daylight value output. For a building with specific location and orientation, these methods are complecated and takes long time to collect the climatic information for implementationto predict the DA, however, the result can be satisfactory as input to implement daylight harvesting different techniques. However, in [11] the authors have completely different

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 September 2022 doi:10.20944/preprints202209.0269.v1

opinion tells that the daylight prediction is mainly based on very few building design parameters such as window glazing type. The paper discussed for different levels of window glazing transmittances, curtain reflectance values and weather conditions, the daylighting metrics are pridicted using the compination of three machine learning algorithms, principal component analysis (PCA), ANN, and support vector machine (SVM). The results show that the ANN with PCA gives bestresult to predict the usful daylight illumination and ANN alone gives gaccpetable results for the the prediction of energy consumption.

Another indoor lighting research works have been carried out also used ANN, but concentrated only on artificial lighting system control. In [12], two-layer feedforward ANN is used to map between relate 28 individually dimmable lamps and 17 task tables. This method does not consider the contribution of daylight that enters the room in case the curtains are opened, and glaring that can be present in case the lamps give quite different illumination. Also, the method is not validated for different rooms' configurations. In closed plant production system (CPPS) application, the authors in [13] proposed an ANN that is built for CPPS with LED lighting system to estimate the energy consumption using light intensity, red light component, blue light component, green light component, white light component, pulse frequency and duty cycle of input variables. This proposed ANN can be integrated in the plant monitoring system to prioritize the energy efficiency. In [14], control of Flou/LED system using ANN method supported by mathematical method comparison using DAILux for lighting optimization process based on preference illumination is proposed. The proposed ANN model is designed to represent the complex relationship between the coefficient of variation of luminaires and illumination with 63 input variables, 6 output variables and one hidden layers with 10 neurons.

The integrated approach to use daylight harvesting control along with indoor artificial lighting control to achieve efficient indoor lighting design was implemented in using ANN with different techniques. In [15], the paper proposes daylight-adaptive and energy-efficient smart indoor lighting control technique to adjust dimmer devices using ANN. The proposed ANN controller consists of three main blocks Initiator, Preprocessor, and Decision-maker. Initiator automatically detects system elements. The target outputs of photodetectors are calculated by linear optimization at the preprocessor unit. Then, the target illuminances initiated by preprocessor block, and finally, decision-maker unit determines the required dimming levels of the lights. This proposed system took in consideration the daylight contribution as uncontrollable input that considered a major limitation in the design to achieve indoor lighting system with controlled daylight harvesting in order to minimize the lighting system consumption. Moreover, by considering the daylight harvesting as uncontrollable variable, glare problem is overlooked. In [16], the authors proposed effective ANN model that uses same number of lights and task table to train the network. The inverse model of the trained ANN is used for controller design. The roller bind is used as accessory to be either fully open and provide daylight contribution, or fully closed to avoid the glare. Standard feed-forward ANN consists of one input layer, one hidden layer, output layer and Bayesian Regularization back propagation algorithm for training are used. However, this method did not consider economic solution in case of over-illumination due to daylight harvesting, when it may cause glare, and the controller fully closes the blind, which will force the artificial light to consume more power to achieve the required illumination and compensate the loss in the daylight contribution.

As it is noticed from the lecture review, none of the research work used the daylight harvesting control to provided low cost integrated precise indoor lighting control using ANN without glare and/or over-illumination.

In previous research work [17], the paper presented accurate classical control technique to provide integrated design for indoor lighting system that considers both the daylight harvesting and LED lighting system as controllable variables to solve the over-illumination problem, and utilizing the advantage of windows that have daylight diffusing-glazing to achieve even distribution for the daylight entering the room and to solve glare

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 September 2022 doi:10.20944/preprints202209.0269.v1

problem. This approach was reintroduced using Fuzzy MIMO technique instead of classical technique in [18].

In this Article, the author provides a further research work to develop ANN Lighting controller (ANNLC) instead of the classical and fuzzy logic controller (FLC) that were introduced in [17] and [18] respectively. The results that will be obtained from the ANN approach, will be compared with the results that were obtained from using the classical controller and the FLC. In Section 2, the procedures of the ANNLC design is given. The response of ANNLC is illustrated in Section 3. Comparison between the response of classical-controller, FLC and ANNLC is discussed in Section 4. Finally, Section 5 presents the summary and conclusion .

2. ANNLC design procedures:

There are three steps required when ANN is used to develop a controller for any system:

- Identification of the system that is required to be controlled in order to create the required database for neural network modelling and training process.
- ANNLC Design in which the created database is use to construct and train the ANN
- Test the ANNLC

2.1. System identification and Database

For the required system identification and database creating, the classical controller illustrated in [17] is used. Figure 1, retrieves the Simulink schematic diagram that uses the classical control [19].

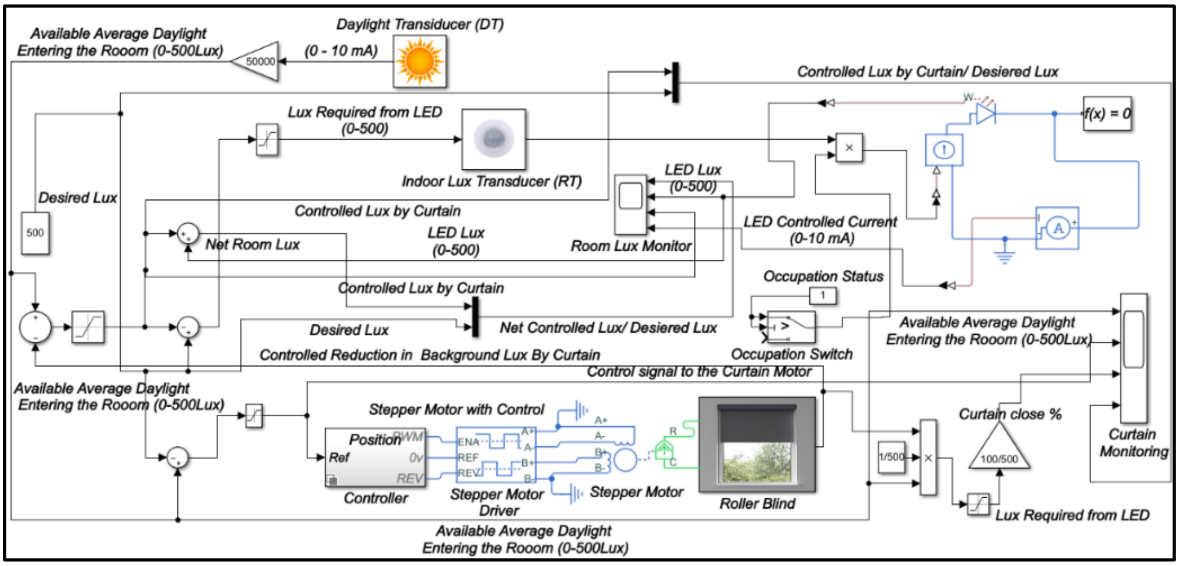

Figure 1: ISLSC Simulink circuit

Twenty-eight test cases, that their input and output are illustrated in Figure 2 and Figure 3 respectively, are carried out to cover the following ranges:

- Average Daylight Entering Room (ADER): 47– 935 Lux
- Desired Lux (DL) in offices [20]: 105 – 707 Lux
- These ranges of input variables produce output control signals with the following ranges:
- Stepper Motor Control Signal (SMCS): 0 – 574 Lux
- LED Control Signal (LCS): 0=13.2 mA

 doi:10.20944/preprints202209.0269.v1

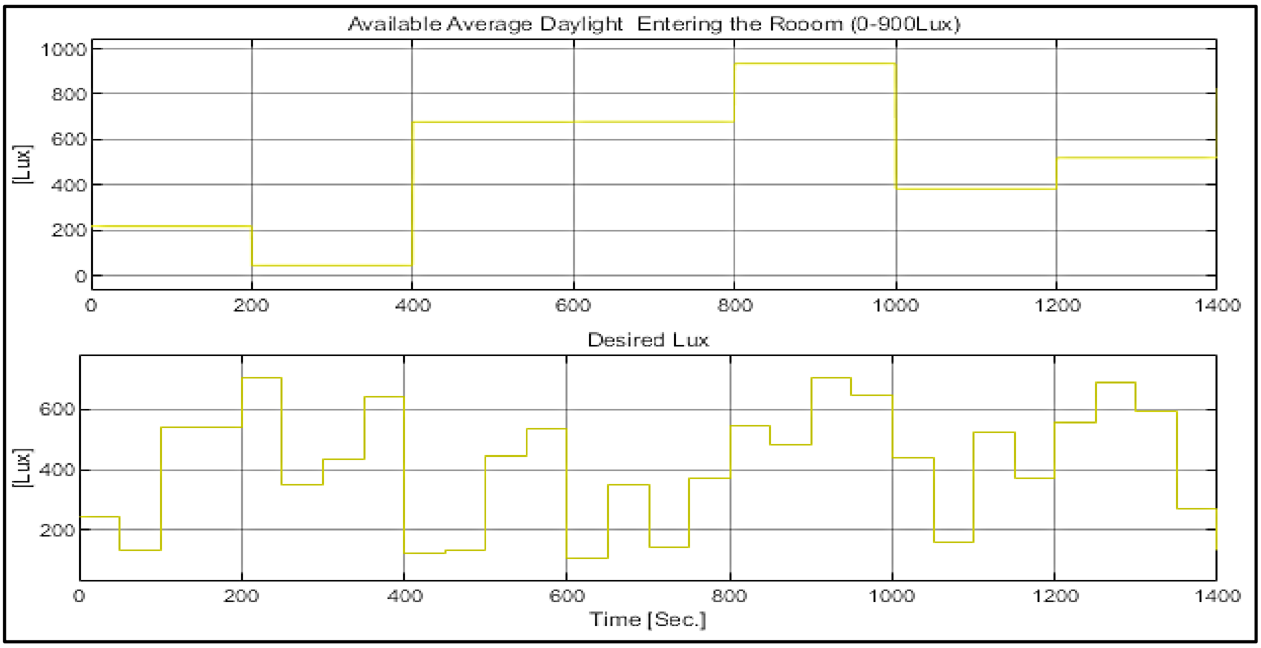

Figure 2: Input for ANN training

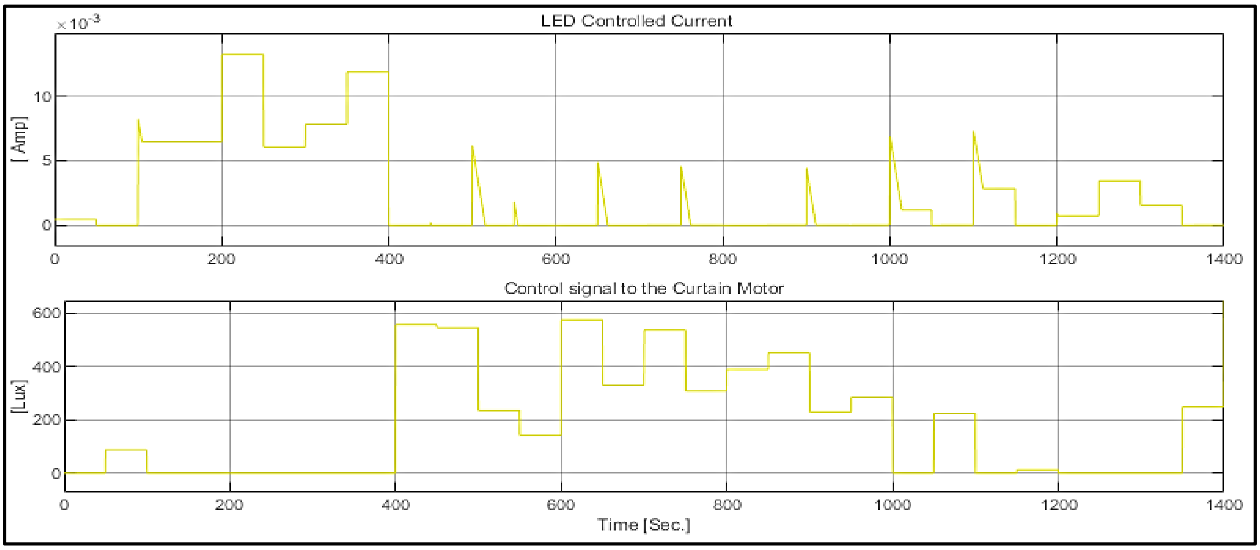

Figure 3: Output Signals ANN training

Table 1 illustrate the input and output variables that are created from 28 study-cases and it will be used to train the required ANNLC.

Table 1: ANNLC Input / Output

Input		Output	
ADER	**DL**	**SMCS**	**LCS**
218.9592	242.3235	**0.0000**	0.4673
218.9593	130.5790	88.0000	0.0000
218.9594	541.2620	0.0000	6.4460
218.9595	541.5430	0.0000	6.4520
47.0446	**707.5500**	0.0000	**13.2100**

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 September 2022 doi:10.20944/preprints202209.0269.v1

47.0446	349.2760	0.0000	6.0450
47.0446	437.6200	0.0000	7.8120
47.0446	640.1280	0.0000	11.8620
678.8650	122.4720	556.0000	0.0000
678.8660	134.7500	544.0000	0.0000
678.8670	444.3050	236.0000	0.0000
678.8680	536.2470	143.0000	0.0000
679.2960	**105.0000**	**574.0000**	0.0000
679.2960	349.2200	330.0000	0.0000
679.2960	143.4470	536.0000	0.0030
679.2960	371.3660	308.0000	0.0014
934.6930	546.4000	388.0000	0.0000
934.6930	482.8350	452.0000	0.0028
934.6930	704.784	230.0000	0.0018
934.6930	650.006	285.0000	0.0063
383.5000	442.5040	0.0000	1.1800
383.5000	159.7770	224.0000	0.0055
383.5000	525.0470	0.0000	2.8310
383.5000	370.4000	13.0000	0.0000
519.4160	555.7740	0.0000	0.7272
519.4160	691.7070	0.0000	3.4460
519.4160	595.4290	0.0000	1.5200
519.4160	270.5900	249.0000	0.0036

2.2. ANNLC Design:

The database listed in Table 1 are used to design and train the proposed ANNLC with standard feed-forward ANN consists of input layer of with two variables, out layer with two variables and one hidden layer with 20 neurons. Bayesian Regularization back propagation algorithm is used for the training process.

2.3. ANN training and testing

For training process, 80% of the data are used. The remaining 20% are used to test the performance of ANN. After the training of ANN is complete, its performance is tested and the result is illustrated in Figure 4 that shows the training regression. From this results, it is clear that the ANN is trained satisfactory and ready for to be used as ANNLC for the lighting.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 September 2022 doi:10.20944/preprints202209.0269.v1

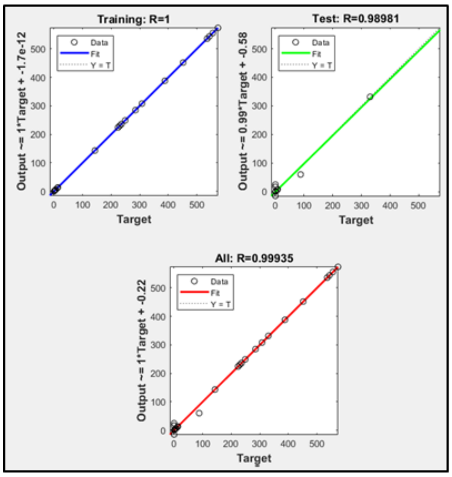

Figure 4: Training regression results

Figure 5, illustrate the Simulink model for the lighting system connected to the proposed ANNLC. In this model ANNLC is connected in such a way to replace exactly the classical controller.

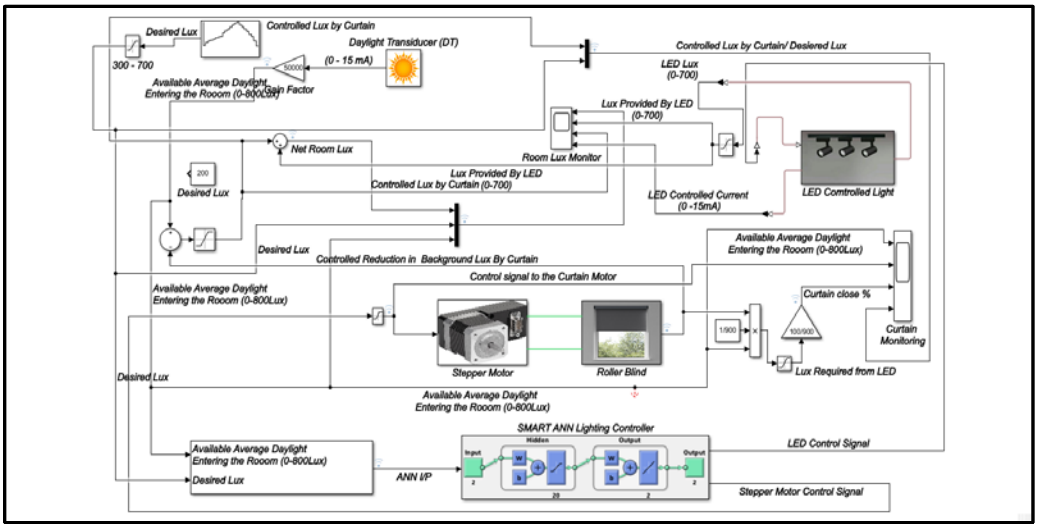

Figure 5: Lighting system connected to the proposed ANNLC.

3. ANNLC Response Results

The developed Simulink model in Section 2 is used to test the response of the ANNLC at different combination values of “Desired Lux” and “Available Average Daylight Entering the Room” to cover the full range of both input. Figure 6 illustrates the results.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 19 September 2022 doi:10.20944/preprints202209.0269.v1

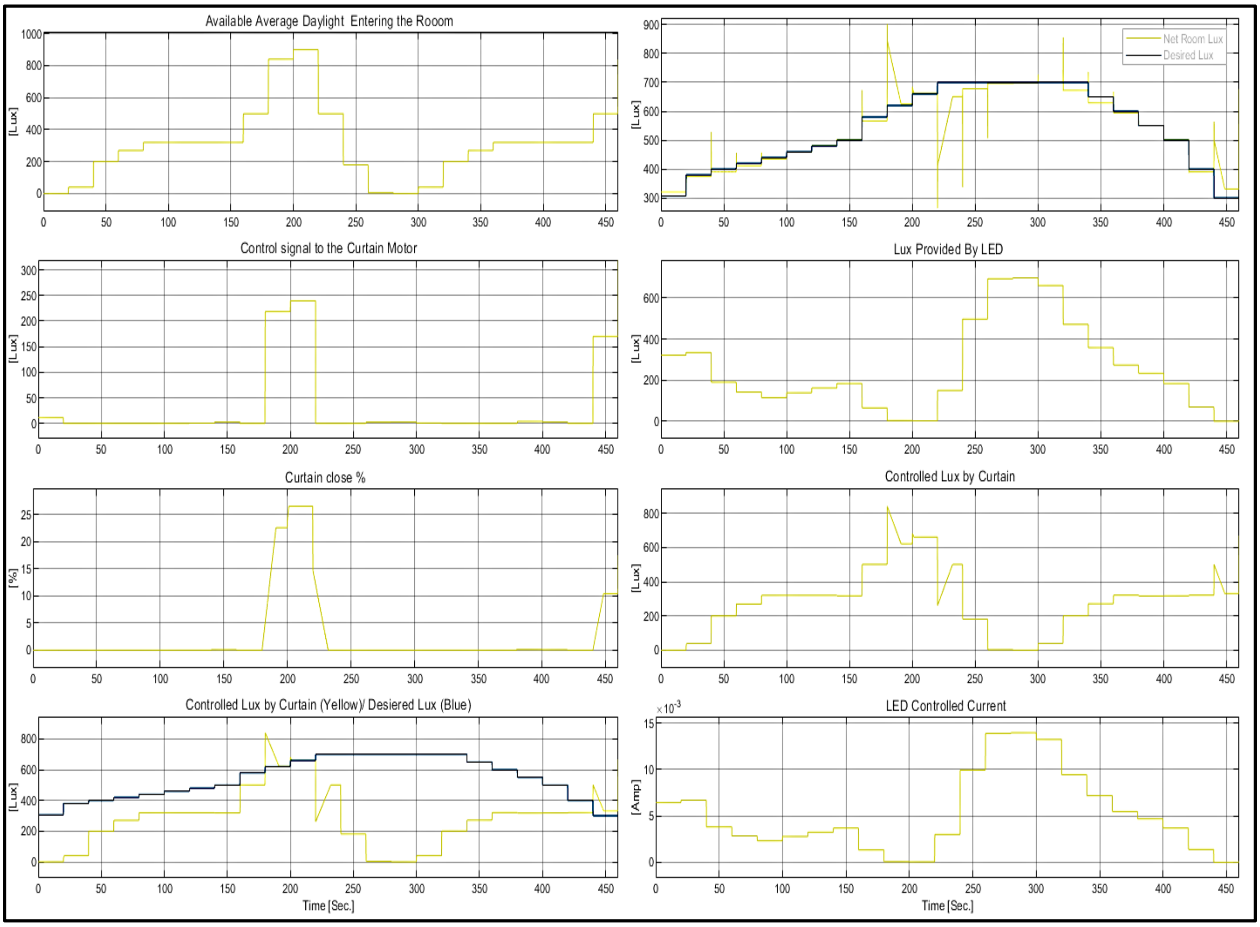

Figure 6. Response of the ANNLC.

From the response of thee ANNLC illustrated in Figure 6, it can be observed that the controller performance is accurate, and the desired illumination has been achieving along the full range of the inputs with solute absolute maximum error of 8% approximately, and absolute average error of 3% approximately. This error is acceptable as the light intensity remains within the permissible margin that doesn't disturbance of the human eye (+/- 30 %) [21]. It can be also observed that during the full range of input values the control signals, that are generated by the ANNLC to control the LED, do not cause any overshoot case in the LED response.

It is worth to mention that the spikes appear in the "Net Room Lux" curves response, are due to the software calculation algorithm and it is not real values in the system response. This can be confirmed by adding the Curtain Lux to the LED Lux to obtain the Room net lux results without these spikes.

4. Comparison Between the Performance of ANNLC, FCL and Classical-control:

It is important now to compare between the performance of the classical control and FLC that are introduced in [17] and [18] with the ANNLC that is presented in this article. This comparison is required for the designers who need to decide which technology they have to select, and have some sort of hesitation.

In this compression, exactly same design criteria are considered to model the three controllers: Classical Controller, FLC and ANNLC. Then, a comprehensive study cases are carried out considering the following inputs:

- "DL" for standard illuminance level of offices (500 Lux).

- Nonlinear scenario of "ADER" to simulate the daylight interning an office from west side Window with diffuser glazing.

In Figure 7, the response of the three controllers, are illustrated.

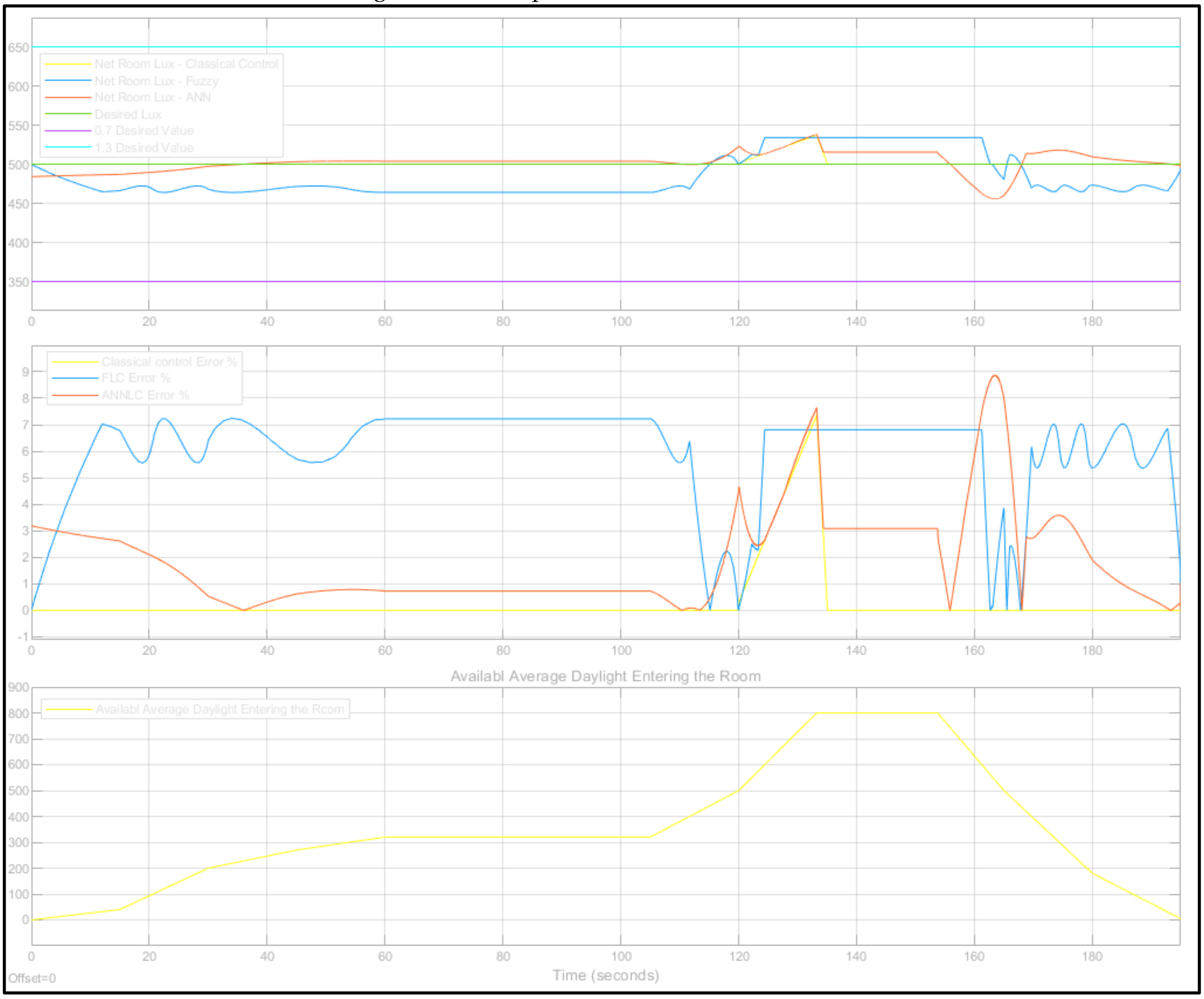

Figure 7. Comparison between the response of Classical Controller, FLC and ANNLC.

The following Table 2 summarizes the statistics of the absolute error, with respect to the desired illuminance value, for the responses of the three controllers:

Table 2. Result Statistics.

Statistics	Classical Control	FLC	ANNLC
Minimum Absolute error %	0	$1.137*10^{-14}$	$1.137*10^{-14}$
Maximum Absolute Error %	7.373	7.245	8.83
Maximum Absolute Transient Error %	7.373	7.245	8.83
Minimum Absolute Transient Error %	0.2	$1.137*10^{-14}$	$1.137*10^{-14}$
Maximum Absolute Steady State Error %	0	7.225	3.084
Minimum Absolute Steady State Error %	0	6.813	0.73
Average Absolute Error %	1.542	5.026	3.957

From Figure 7 and Table 1, it can be noticed the following:

- The response of all three controllers are within the acceptable margin +/- 30%, so the human eye will not recognize the fluctuation of the illuminance inside the office.
- Based on average absolute error, the highest accuracy is obtained by the classical controller (1.542%), and the least accurate controller is FLC (5.026). ANNLC is in between with average absolute error of 3.957%.
- Economically in this particular design, for continuous operation, FLC is the most economical as from Figure 7 it shows that the achieved illuminance is acceptable. Also in the same time, most of the time when the (ADER) is less than (DL), the illuminance level is the least compared with other controllers, and hence the power consumption using the FLC is the least. However, in any other different design, the economic comparison need to be done based on the response of the actual design.
- For the three controllers, the individual maximum absolute transient error is always higher than the maximum absolute steady state error.
- It is worth to highlight that for maximum absolute Transient error values, FLC error (7.245) is slightly less than Classical Controller error (7.373) and much less the ANNLC error (8.83).

5. Conclussion

The paper started with literature review for the previous researches that are carried out to design different controllers for daylight and/or artificial light that can be installed indoor using ANN for economic power consumption, customer satisfaction or both. Then the paper gave detailed procedures to design ANN controller with two input and two output to control simultaneously LED system and roller blind. The performance of the proposed controller is compared with equivalent two controllers were designed in previous worm using but using classical control and fuzzy control. The result shows that the three controllers are accurate. However, there response have slight different performance-based with different errors.

References:

[1] M. M. A. S. Mahmoud, "Economic Model for Calculating the Global Saving Norm of Replacement High-Intensity Discharge Lamps with LED Lamp in Oil and Gas Plant," *2020 IEEE 61th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON)*, 2020, pp. 1-5, doi: 10.1109/RTUCON51174.2020.9316481.

[2] Antonio del Corte-Valiente, José Luis Castillo-Sequera, Ana Castillo-Martinez, José Manuel Gómez-Pulido and Jose-Maria Gutierrez-Martinez, "Article An Artificial Neural Network for Analyzing Overall Uniformity in Outdoor Lighting Systems" *Energies,* vol.10 , 175, *2017,* doi:10.3390/en10020175.

[3] Prabu Mohandas Jerline Sheebha Anni Xiao-Zhi Gao, "Artificial Neural Network based Smart and Energy Efficient Street Lighting System: A Case Study for Residential area in Hosur", *Sustainable cities and society,* .2019, https://doi.org/doi:10.1016/j.scs.2019.101499

[4] Mahmoud M.A.S.M , Leyla Muradkhanli, "Safer Design and Less Cost Operation for Low-Traffic Long-Roads Illumination Using Control System Based on Pattern Recognition Technique", *Journal of Intelligent Control and Automation, scientific research publishing*, 2020.

[5] S. Smys, Abul Basar, Haoxiang Wang, "Artificial Neural Network Based Power Management for Smart Street Lighting Systems", *Journal of Artificial Intelligence and Capsule Networks*, Vol.02/ No. 01(2020) Pages: 42-52 http://irojournals.com/aicn/
DOI: https://doi.org/10.36548/jaicn.2020.1.005 42 ISSN: 2582-2012

[6] Muhammad M.A.S. Mahmoud,"Sustainable and Precise Indoor-Lighting System Design Using Simultaneous Control for LEDs Lighting Intensity and Roller Blinds' Opening to Achieve Economic Energy Consumption", *Jordan Journal of Electrical Engineering*, 2022.

[7] Odiyur Vathanam, G.S.; Kalyanasundaram, K.; Elavarasan, R.M.; Hussain Khahro, S.; Subramaniam, U.; Pugazhendhi, R.; Ramesh, M.; Gopalakrishnan, R.M. "A Review on Effective Use of Daylight Harvesting Using Intelligent Lighting Control Systems for Sustainable Office Buildings in India." *Sustainability* 2021, 13, 4973. https://doi.org/10.3390/ su13094973

[8] Mahmoud M.A.S.M,"Automated Smart Utilization of Background Lights and Daylight for Green Building Efficient and Economic Indoor Lighting Intensity Control", *Journal of Intelligent Control and Automation, scientific research publishing*, 12, 1-15, 2021.

[9] Clara-Larissa Lorenz, Michael Packianather, A. Benjamin Spaeth and Clarice Bleil De Souza,"Artificial Neural Network-Based Modelling for Daylight Evaluations", Symposium on Simulation for Architecture & Urban Design, 05-07 June 2018, pp 11-18.

[10] Tugˇçe Kazanasmaz, Murat Gu¨naydin, Selcen Binol, "Artificial neural networks to predict daylight illuminance in office buildings", *Building and Environment* vol. 44 (2009) 1751–1757.

[11] Sixuan Zhou, Dong Liu," Prediction of Daylighting and Energy Performance Using Artificial Neural Network and Support Vector Machine", *American Journal of Civil Engineering and Architecture*, 2015, Vol. 3, No. 3A, 1-8 , http://pubs.sciepub.com/ajcea/3/3A/1 .

[12] Marek Dudzik, Mirosław Dechnik, Marcin Furtak, "Application of neural networks to lighting systems, *MATEC Web of Conferences 282*, 02069, 2019.

[13] Olvera-Gonzalez, E., Rivera, M.M., Escalante-Garcia, N.; Flores-Gallegos,"E. Modeling Energy LED Light Consumption Based on an Artificial Intelligent Method Applied to Closed Plant Production System", *Applied. Sciences*, 2021, 11, 2735.
https:// doi.org/10.3390/app11062735.

[14] Merimé SOUFFO TAGUEU and Benoît NDZANA "Lighting Optimization Control of Fluo/LED System Using Neural Network and Mathematical model", *International Journal of Electrical Engineering & Technology (IJEET)*, Volume 10, Issue 4, July -August 2019, pp. 47-59, Article ID: IJEET_10_04_006
http://www.iaeme.com/IJEET/issues.asp?JType=IJEET&VType=10&IType=4

[15] Atefesadat Seyedolhosseini, Nasser Masoumi, Mehdi Modarressi, Noushin Karimian, "Daylight adaptive smart indoor lighting control method using artificial neural networks", Journal of Building Engineering, 29. pp. 101141, 2019. ISSN 2352-7102.
DOI: https://doi.org/10.1016/j.jobe.2019.101141

[16] Nandha Kumar Kandasamya , Giridharan Karunagaranb , Costas Spanosb , King Jet Tsengc , Boon-Hee Soong, "Smart lighting system using ANN-IMC for personalized lighting control and daylight harvesting", *Building and Environment*, vol. 139, pp. 70-180, 2018, https://doi.org/10.1016/j.buildenv.2018.05.005

[17] Muhammad M.A.S. Mahmoud,"Sustainable and Precise Indoor-Lighting System Design Using Simultaneous Control for LEDs Lighting Intensity and Roller Blinds' Opening to Achieve Economic Energy Consumption", *Jordan Journal of Electrical Engineering*, 2022.

[18] Muhammad M.A.S. Mahmoud," MIMO Fuzzy Logic Controller for Sustainable and Precise Indoor-Lighting Design Using Simultaneous Dual Control to Adjust Artificial Lighting and Daylight Harvesting", *Jordan Journal of Electrical Engineering*, 2022.

[19] The MathWorks, "Simulink" *MATLAB 2019Ra*, 2019.

 doi:10.20944/preprints202209.0269.v1

[20] Rea, E. *The IESNA Lighting Handbook*.2013.

[21] LED Life for General Lighting,"Recommendations for the Deffinition and Specification if Useful Life for Light-emitted Diods Light Source", *ASSIST,* vol, 1, Isuuw 7, 2006.