

Self Tunned Fuzzy-PID controller for LED in Daylight Harvesting Environment for Smart Buildings

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of*

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Power Systems

Submitted By
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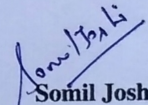
Electrical & Instrumentation Engineering Department
Thapar University, Patiala
July 2017

DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled, “ **Self Tunned Fuzzy-PID Controller for LED in Daylight Harvesting Environment for Smart Buildings**” in the partial fulfilment of the requirement for the award of the Degree of **Master of Engineering in Power Systems**, submitted to **Electrical & Instrumentation Engineering Department of Thapar University, Patiala**, is an authentic record of my own work carried under the supervision of **Dr. Mukesh Singh**. It refers others researcher’s work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

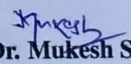
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TABLE OF CONTENTS

ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF FIGURES	iv
LIST OF TABLES	v
ABBREVIATIONS	vii
ABSTRACT	viii
1 INTRODUCTION	1
1.1 Overview	1
1.2 Literature Survey	2
1.3 Motivation of Work	4
1.4 Lacunae Identified	5
1.5 Contribution to the Work	5
1.6 Organization of the Dissertation	6
2 BACKGROUND WORK	7
2.1 Background	7
2.2 Smart Buildings	7
2.3 Need for Smart Buildings	8
2.4 Research areas of Smart Buildings	9
2.4.1 Questions to be addressed	9
2.4.2 Research Objectives	10
2.5 Components of Smart Buildings	10
2.6 Features of Smart Buildings	11
2.7 Daylight Harvesting	12
2.8 LED	14
2.8.1 Dimming of LED	15

3	PROBLEM FORMULATION	17
3.1	System Overview	17
3.2	Description of photosensor & comparator unit	18
3.3	Lumens to current conversion unit	18
3.4	Basis of Fuzzy-PID controller for PWM generation	19
3.5	Description of LED	20
3.6	Problem Formulation	20
3.6.1	TSP caluclations for different WP's	20
3.6.2	Space to height calculation for LED placement	21
3.6.3	Controller for Integrating DH with LED	23
3.6.4	Description of DC-DC buck converter	25
3.6.5	Rule Base	26
4	RESULTS & DISCUSSION	28
4.1	Introduction	28
4.2	Description of Daylight Inputs	28
4.3	Case-I: Results of WP_1 with variable inputs.	29
4.4	Case-II: Results of WP_2 with variable inputs.	31
4.5	Case-III: Results of WP_3 with variable inputs.	34
4.6	Case-IV: Results of WP_4 with variable inputs.	36
5	CONCLUSION AND FUTURE WORK	39
5.1	Conclusions	39
5.2	Scope of Future Work	40
	BIBLIOGRAPHY	41
	LIST OF PUBLICATIONS	45
	CURRICULUM VITAE OF AUTHOR	46

LIST OF FIGURES

2.1	Pillars of Smart Building (SB)	11
2.2	Classification of adaptability in Smart Buildings	12
2.3	Day Light harvesting process.	12
2.4	Heliostats guiding entire daylight to the central receiver	13
2.5	Light Transport Process	14
2.6	Diffusers for distribution	14
3.1	Diagram showing system framework.	17
3.2	Space to height ratio adjustments	21
3.3	Location of LED at WP's with space to height adjustments.	22
3.4	Block diagram showing operation of controller for artificial lighting control.	25
3.5	DC-DC buck converter driving LED	25
4.1	Controller response for WP_1 with input set D_{11}	30
4.2	Controller response for WP_1 with input set D_{12}	30
4.3	Controller response for WP_1 with input set D_{13}	31
4.4	Controller response for WP_2 with input set D_{11}	32
4.5	Controller response for WP_2 with input set D_{12}	33
4.6	Controller response for WP_2 with input set D_{13}	33
4.7	Controller response for WP_3 with input set D_{11}	34
4.8	Controller response for WP_3 with input set D_{12}	35
4.9	Controller response for WP_3 with input set D_{13}	35
4.10	Controller response for WP_4 with input set D_{11}	37
4.11	Controller response for WP_4 with input set D_{12}	37
4.12	Controller response for WP_4 with input set D_{13}	38

LIST OF TABLES

3.1	Converter parameters used for simulation	26
3.2	Description of Antecedents & Consequents	26
3.3	Table for rule base	27
4.1	Daylight variation pattern for WP_1	29
4.2	Daylight variation pattern for WP_2	32
4.3	Daylight variation pattern for WP_3	34
4.4	Daylight variation pattern for WP_4	36

ABBREVIATIONS

DH	Daylight Harvesting
SBs	Smart Buildings
LED	Light Emitting Diode
K_P	Proportional gain
K_I	Integral gain
K_D	Differential gain
TSP	Target Setpoint Illumination
WP_i	Work place for i^{th} application
WP_{si}	Standard illumination for particular WP.
LTC	Lumens to Current Conversion unit
I_{TC}	Target current corresponding to D_2 Lumens
I_{inst}	Instantaneous current from converter output
$D_1(t)$	Nonlinear, Timely Varying Daylight Input
D_2	Artificial lumens, obtained after subtracting daylight input from TSP illumination at particular WP .
D_{11}	Daylight inputs, when the variation is normal and linear.
D_{12}	Daylight inputs, during unavailability of daylight due to weather sensitivity factors.
D_{13}	Daylight inputs, with nonlinear and abrupt variation.
e	Error obtained between timely varying I_{TC} with natural daylight and instantaneous converter current I_{inst}
Δe	Change in error obtained between $(n)^{th}$ and $(n - 1)^{th}$ time instant
HVAC	Heating, Ventilation and Air Conditioning
SHR	Space to height Ratio
T_{amb}	Ambient temperature during real time operation of LED.
T_0	Reference temperature of LED.
I_0	Reference current at reference temperature T_0 .
ϕ_{i0}	Reference lumens at reference current I_0 .
A_{WP_i}	Area of i^{th} WP .

ABSTRACT

An aggregate of 19% energy is manifested in urban buildings worldwide, due to lighting. Daylight harvesting (DH) is an innovative technique which promises to reduce energy consumption by 20-60% in smart buildings (SBs). Since variations in daylight are nonlinear and weather sensitive, hence there is an urgent need of a control strategy which adapts to these variations swiftly and provides stable operation. This dissertation work presents efficient DH technique, incorporating optimum target setpoint (TSP) illumination calculations for different applications in SB. Optimum TSP calculations form basis of adaptive Fuzzy-PID controller. The controller promises self tuning of LEDs with nonlinearly varying daylight pattern. The Fuzzy controller tracks daylight changes and performs continuous tuning of control parameters K_p , K_i & K_d . Takagi-Sugeno Fuzzy inference system is incorporated to tune nonlinearly varying daylight with linear PID controllers. The PID controller receives its inputs from fuzzy system and drives optimum PWM pulses to DC-DC buck converter to regulate the output current. Output current from the converter is driven into LED to achieve TSP illumination. The simulation are performed in MATLAB-Simulink environment.

Keywords: Adaptive Control, Daylight Harvesting (DH), Fuzzy logic controller, LED, PID, Smart Buildings (SBs), self-tuning.

Chapter 1

INTRODUCTION

1.1 Overview

Urban buildings are predominantly responsible for increased carbon footprints around the globe. Almost 19% of the total generated electrical energy is manifested in lighting [1]. The Australian institute for commercialisation (AIC) projections, claim that global energy consumptions due in lighting application will increase in upcoming years [2]. U.S. Energy Information Administration, reports surge in energy consumed by lighting fixtures from 1.3% to 7% during recent years in California [3]. The above projections demand for a promising lighting control strategy to curtail energy manifested in lighting applications. Occupancy detection, lighting control systems, solid state lighting devices and daylight harvesting (DH) are some energy saving strategies associated with lighting [4–6]. Moreover the lighting loads are easy to control to a larger extent through fine dimming, which is not in case with other electrical systems like HVAC.

The daylight is surplus during daytime, it can be utilized widely in curtailing energy consumptions due to full artificial lighting during its availability. Efficient daylight harvesting systems (DHS) promise considerable energy savings. Niko *et al.* [7] emphasizes on addressing commissioning related issues of DHS, that includes robustness and architectural feasibility. But the literature lacks attention on any particular technique to be implemented for efficient DH. Parise and Martirano [8] gave relation for predicting the daylight availability and its impact on annual energy savings. This technique maximises energy saving by dividing room into three zones according to available daylight. The lighting fixtures are dimmed individually in each zone to achieve more affine energy saving. However individual dimming of each area present disadvantage by increasing system complexity as separate control strategy is formulated.

1.2 Literature Survey

In present context, effective DH requires efficient algorithms, in this regard [9] aims at eliminating problems associated with DH. Problems incorporating inappropriate sensor placement, inaccurate measurements due to blind position and daylight change are addressed. Radiosity theory and Data fusion algorithms with machine learning abilities, are implemented to calculate total illumination. Moreover, for well organized control of lighting fixtures involving DH, exact daylight pattern predictions are required. In this regard, SunCast [10] is proposed by Jiakang. The SunCast predicts natural lighting level and also reduces glare caused due to over illumination. Basu *et al.* [11] presents a wireless sensor network (WSN). This proposed network consist of a light sensor located remotely for daylight sensing. The onboard storing of daylight data is done on Hamamatsu photodiode. The stored data is transmitted to base station via IEEE protocol and control actions are taken for controlling artificial luminaries. However, the data transfer in this model takes time, consequently delaying the control process.

Multivariable controller by Boscarino [12], providing desired illumination at user defined set point is presented. This controller is basically multi input multi output (MIMO) type. This self tuning process reduces the performance index, which inturn reduces error between user defined set points and instantaneous illumination levels. However, the presented work gives a general idea for controller design. The attention on any specific application to achieve target illumination is missing from presented work. Afsari and Mishra [13] developed light transport model with group of lighting fixture, the model tracks desired set point and updates input light intensity control vector to achieve target illumination and energy saving with variable daylight pattern. The literature on DH shows considerable stress given by researchers. But existing work still lacks, a productive control strategy which integrates the DH phenomena with LED lighting. The area of intelligent and robust control for artificial lighting applications are yet to be explored to achieve unbounded control with fast response and energy efficient operation.

LED has outperformed incandescents luminaries in the area of controllable lighting due to high luminous efficacy, compact size and operational flexibility [14]. Biber [15] gives the dependence equation of LED output luminous flux on ambient temperature and forward current. The equation showed LED output flux increases with rise in forward current. Raypah *et al.* [16] confirms the claims made by Biber. The LED output luminous flux increases proportionally with increase in forward current. However, large increase in the forward current is responsible for the rise in junction temperature which consequently degrades output lumens. Similarly, reduction in output flux of LED at higher junction

temperature was verified with photoelectrothermal theory (PET) proposed [17] through a dynamic model. The output flux of multichip LED suffers less from the problem of output flux degradation, when compared with single chip LED design with rise in junction temperature. Qin and Hui [18] demonstrated that multichip LED designs maintain higher output flux and low junction temperature rise when subjected to instantaneous switching during controlled lighting applications involving DH.

Due to nonlinearity in daylight variation LED are subjected to inherent switching for controllable lighting. However, this causes degradation of output flux of LED. The degradation can be prevented by adopting suitable driver technology. The drivers are current sources which drive input current into LED for its stable operation and illumination. LED drivers majorly work on two control techniques namely, analog dimming and pulse width modulation dimming (PWM). However, the former suffers from colour shifts and nonlinearity with changes in the forward current. Different PWM controlled DC-DC topologies are suggested [19], [20]. But the discussed literature, lacks significant emphasis on particular design related application. Wang *et al.* [21], presents a flicker-free PWM dimming technique for DC-DC buck LED drivers. Here buck converter in current controlled discontinuous conduction mode (DCM) is implemented without feedback connection. The pulses are averaged through entire dimming period. Hence, need of output DC capacitor to maintain stable output voltage is eliminated, promising flicker free response by LED. Lin *et al.* [22] gives dual mode dimming control LED drivers with current balancing designs for backlight application of LED. This method includes a differential mode transformer which avoids shortcomings of complex circuitry, increased cost and high transient by implementing this particular driver scheme.

PWM based LED drivers are capable of producing good response characteristics. But at higher switching frequencies, PWM suffers from stability related issues. Researchers in this regard developed several advanced methods for producing excellent response at high switching frequency. Primarily in this context Li *et al.* [23] proposed CMOS based synchronous buck LED driver working at higher switching frequencies. The technology is compatible with both analog and PWM dimming techniques. An intelligent estimation circuit for regulating exact current into LED based on CMOS technology is presented [24]. The results give efficient power saving and high output current regulation. Malcovati *et al.* [25] presents CMOS based buck-boost DC-DC converter operating at considerably high frequency and providing excellent line regulation. The circuit promises stable operation under system emergencies. Field programmable gate array (FPGA) technology [26] is implemented for LED drivers. This proposed technology promises to give less total harmonic distortion (THD) and high PF. The driver proposed in this scheme does not include capac-

itor and inductor in main power circuit. Hence a less bulky circuit is designed providing stable operation. Zhang *et al.* [27] suggests flyback topology for low power LED drivers. The proposed control strategy include TRIAC for dimming which shows resistance like characteristics and achieves high power factor for this class of LED drivers.

The literature reports several other works on LED driver technology. An uncontrolled offline LED driver with 93.6 percent efficiency is designed [28]. The driver promises high energy efficiency and long life time of LED and can be easily installed with road lighting control for effective operation. Hu and Zane [29] presents LED driver circuit for series connected converter cells. These cells operates with common duty cycle. Moreover, the supply for their harmonized operation is performed through dc bus. The cells operating have several flexibility, they can be operated in continuous conduction mode. Through this scheme automatic sharing of line voltage can be done. However the scheme reviewed explicitly focuses on LED driver technology and laid, no emphasis on integrating the driver technology with DH phenomena. Ripple free driver topology is presented by Fang *et al* [30]. The paper demonstrates an efficient method for nullifying the ripple voltage with twice the line frequency. A nonisolated single loop LED driver in continuous conduction mode is suggested by Lin *et al.* [31]. Taylor series model for the equivalent circuits for the LED drivers are demonstrated. Similarly, a class E resonant driver with buck boost topology is presented by Wang [32]. Considerable work is represented in literature regarding LED driver technology. However, the concerned literature lacks the integration of DH with advanced driver technology. This dissertation makes presents scheme of integrating DH with driver technology.

1.3 Motivation of Work

Despite the fact that controllable electrical lighting with DH is necessity in modern context. Its wide implementation is still missing in practical applications. According to U.S. Department of Energy reports [33], 70% of commercial buildings still lack efficient lighting control arrangement. This can be due to unavailability of reasonable technology in lighting control accounting DH. Moreover, [7] highlights only commissioning related issues. The literature clearly lacks any control scheme. Though the researchers in [11], [12] proposed some good control strategies incorporating DH, but they didn't suggest any control scheme for integrating DH phenomena with LED technology. Moreover [11] there is problem of storing the daylight pattern data and transfer of information from remote place to controller, this will introduce a time delay in overall control process. However the work reported in [21]- [27] explicitly addresses the issues with LED driver technology.

The literature laid no emphasis on controllable lighting involving DH phenomena. Therefore, through this dissertation a control scheme is presented which address the above mentioned issues. The system integrates nonlinearly varying daylight pattern with LED technology. The control scheme involves determination of target setpoint (TSP) illumination according to the application and dimensions. Moreover, calculation of LED placement and workplace length determination is also done. The self-tuned fuzzy-PID controller, automatically updates the control parameters according to the rule base. The updation of control law generates, optimum PWM pulses.

Thus accurate current are driven into the LED. Inherently this current produce optimum lumens to achieve TSP illumination for each WP's. This adaptive controller ensures linear control of nonlinearly varying daylight pattern, fast response, optimum illumination at TSP and energy saving. Hence, it is well concluded fact that, utilization of daylight with artificial lighting leads to reduction in current. This, saves the power consumption leading to less consumption of natural resources and CO_2 emissions. Moreover, through implementation of increased artificial lighting a UV radiation free environment is created.

1.4 Lacunae Identified

The following are the lacunae identified from literature surveyed above:

- Adaptive controller design for artificial lighting control is not found in literature.
- Innovative natural daylight penetration methods and target set point illumination (TSP) calculations are least considered.
- The area of room modeling, type of sensor and implementation for optimum lumen tracking are missing from previous works.
- Integration of LED driver technology with DH is not found in literature.

1.5 Contribution to the Work

The contributions made in this dissertation work are listed as below:

- Determining Target Setpoint Illumination (*TSP*) for different applications based on dimensions in smart buildings.
- Integrating DH technique with artificial lighting, for optimum illumination and energy saving.

- Development of a self-tuned fuzzy-PID controller, to achieve unbounded control of nonlinearly varying daylight pattern with energy saving.

1.6 Organization of the Dissertation

The dissertation work done is divided into 5 chapters. Chapter 1 gives a brief overview, literature review, motivation and contribution towards the control problem. Chapter 2 outlines the basics of smart buildings, daylight harvesting and LED. Chapter 3 foregrounds the system description and proposed scheme. Chapter 4 emphasizes on results and detailed discussion on obtained results. Chapter 5 concludes the dissertation work with by highlighting the scope of future work.

Chapter 2

BACKGROUND WORK

2.1 Background

This section focuses on highlighting the important aspects associated with smart buildings, daylight harvesting and LED. Since, these area are to be explored therefore strong basis are required before exploring them to the fullest of their extent. This section of dissertation is formulated to touch the different corners of this budding technology. In subsequent section a need is created which underlines technological importance, advantages and detailed discussion of surrounding areas associated with SB.

2.2 Smart Buildings

In modern context, the buildings which exercises locally available solutions to manage its energy demands are entitled as smart buildings (SBs). The utilization of locally available solution leads to energy saving, ensuring user comfort level and highly congenial environment. Moreover, these buildings produces an automated response for changing conditions rather than manual operations. SBs utilizes daylight harvesting (DH) to achieve a desired illumination, borehole thermal energy storage systems (BTESS) for heating purpose. In this system enormous amount of solar heat during summer is stored and utilized during winter for HVAC. The SBs assimilates use of modern communication systems like wireless communication, Internet of Things (IoT), smart sensors and techniques for making logical decisions to minimize energy consumption due to lighting and HVAC applications.

The clause of SB evoke the images of luxurious building structures having state of art facilities. Moreover, these building structure amalgamates all energy saving strategies and alarms for curtailing energy cost which persist in old building structures. The SB ag-

gravates a comfortable, hospitable and energy efficient environment which is completely missing from old buildings. The concept of SB when included with green buildings generates a high revenue to boost the business by infrastructure agencies. However, before the wide implementation of SB it is necessary to examine the advantages and disadvantage of this budding technology.

2.3 Need for Smart Buildings

The advent of 21st century has globally effected demand of energy. The energy demands has witnessed a surge in past decade exponentially. The penetration of technology in human life, is due to increased utilization of HVAC and lighting system. Therefore the electrical lighting and HVAC constitutes a major part of electrical load in a building. To curtail consumptions development of a self-reliant, energy efficient and fault tolerant SB is a vital necessity. The adaptive lighting control of smart building in this context gives an appropriate solution to increased energy demands. The adaptive control of lighting system involves maximized use of natural day-light which provides healthy environment and UV radiation free lighting.

The other factors which aggravates the need of SB is explicit dependence on different heating and lighting systems. In conventional buildings communication is established between operating devices. This shortcoming is overcome in SBs thus cost-effectiveness of building is not compromised. With introduction of SB in modern context, building efficiency can be greatly improved. Synchronizing all the systems together minimizes the excess consumption of energy and increases safety during system contingencies. The other advantages which encourages the necessity of SB includes increased productivity of operating staff, enhanced building operations and improved decision making across the organisation.

The following are the factors which necessitates the need of smart buildings (SBs):

- This most prime advantage associated with a SB is low operating cost. The initial cost associated with these buildings are higher. However, the pay back periods for the buildings are very less.
- The security features associated with these buildings makes detection of any fire, hazard and smoke instantaneously so that buildings can be protected from damage.
- The SB utilizes locally available solutions for buildings HVAC and lighting systems. Thus saving lots of energy and cost expenditure incorporated in electricity bills.

- Moreover, advanced features including parking management systems and waste water management systems makes them suitable candidates for future smart cities.

2.4 Research areas of Smart Buildings

The surge in energy demands and previous surveyed literature highlights that following improvements are to be done in smart buildings. Thus promising efficient operation and reduced burden on electrical grid.

- Innovative natural daylight penetration methods have to be incorporated which is still not explored by researchers.
- Proper, operating strategies must be formulated for various loads operating in smart buildings.
- Efficient, techniques for storing the seasonal energy must be explored so that they can be utilized during unavailability.
- The area of room modeling, type of sensor implemented for optimum lumen tracking is to be witnessed at their full stretch.
- Adaptive techniques for lighting related issues must be dealt with prime importance.
- Area of robust communication is to be witnessed so that the agents operating in SB must act in harmony in any contingency condition.

2.4.1 Questions to be addressed

The questions addressed to make the smart building self reliant and energy efficient are:

- Innovative techniques employed for maximum penetration of natural day lighting into the building are to be investigated.
- Methods of storing the locally available energy and utilizing it during its unavailability.
- Optimum adjustments for location of artificial lighting fixtures and their modeling for low power consumption and maximum illumination.
- Different techniques for adaptive control of lighting systems and HVAC systems for energy savings.

- Establishing a robust communication system for smart communication between various entities.
- Area of sensor and topologies for their optimal placing must be addressed for optimal measurements.

2.4.2 Research Objectives

The research objectives are to be met in area of smart buildings:

- Development of innovative techniques for maximum penetration of natural daylight in building with architectural constraints.
- Deployment of sensors and lighting system at optimum places for maximum lumen tracking and optimized illumination.
- Designing an adaptive controller for lighting and HVAC related applications for energy saving in smart building.
- Developing a robust communication system for fault tolerant operation under various systems contingencies for different equipment operating in the building..

2.5 Components of Smart Buildings

- **Hardware:** Initially a SB should be able acknowledge the environmental changes. This includes the changes occurring within the building premises and outside the buildings. The positioning of sensor for optimum tracking and metering devices at exact places should be done. Before, making any control actions the occupancy detection, light intensity measurements, temperature levels, CO_2 and noise levels must be configured. Hence installation of proper hardware should be done at optimal locations.
- **Software:** After, instantaneous tracking of changing environmental conditions by hardware installed. A proper control mechanism is required to take control action accordingly. Artificial intelligence and machine learning techniques can be integrated with controllers. Thus an efficient system can be obtained which can optimize itself and learn from past events.
- **Network:** In order to integrate two entities hardware and software a network is required. The modern communication systems like internet of things (IoT) and cloud

systems connects and stabilize different systems entities through various topologies. These topologies include person to person (PTP), person to machine (PTM) and machine to machine (MTM). Moreover, a flexibility of is also included such as using wireless and wired communication between the various systems operating within and outside the building.

2.6 Features of Smart Buildings

There are several features associated with smart building. Building adapting within an operating range and integrates all the aspects associated within the buildings separates a SB from other buildings. Hence the buildings should be able to predict and adapt to its operation from the various ongoing events. Adaptability in terms of an SB can be accounted due to the following events:

- It must take account of people perception and their comfort, which changes throughout the day and with different time in year.
- The buildings occupancy should be relatively accessed.
- The external and internal changes in weather and environment should be tracked and dealt effectively.

Fig 2.1 shows the pillars of the SB.

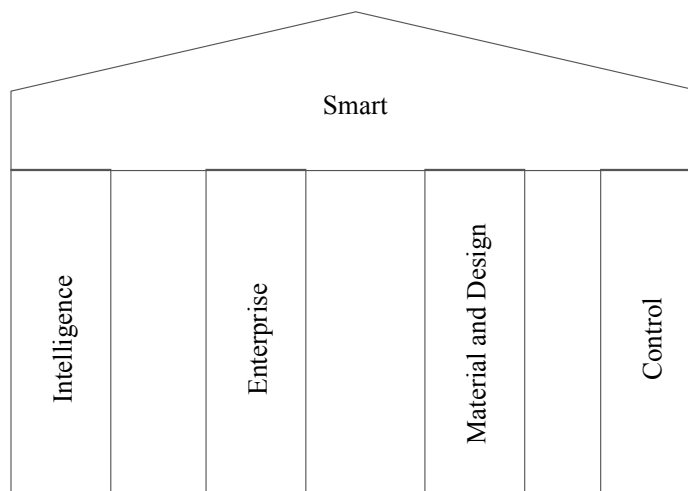


Figure 2.1: Pillars of Smart Building (SB)

However, the most distinctive feature of smart building is adaptability and reduced payoff periods. The adaptability is furthermore classified into three different subcategories which includes:

- Small duration adaptability
- Medium duration adaptability
- Large duration adaptability

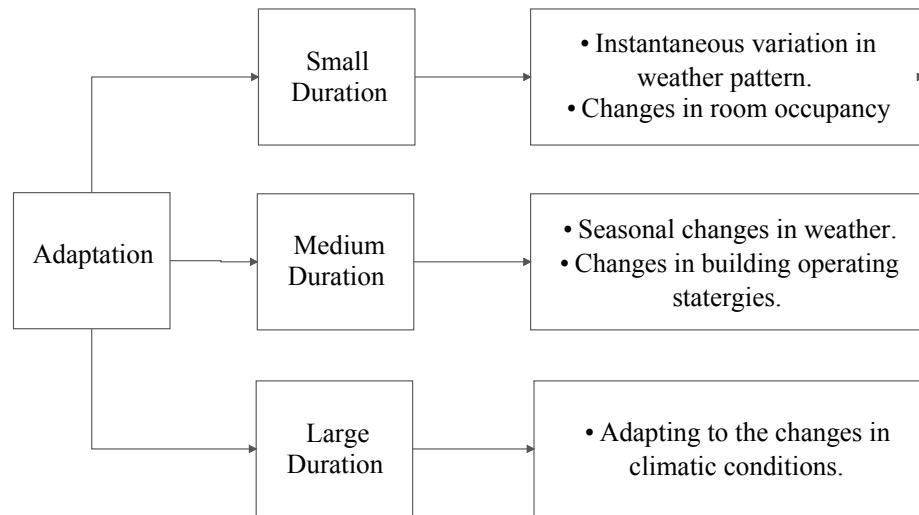


Figure 2.2: Classification of adaptability in Smart Buildings

2.7 Daylight Harvesting

The daylight harvesting (DH) is technique associated with collection of natural daylight. The DH is utilized as innovative technique for curtailing energy manifested in lighting applications. The artificial lighting is synchronized with incoming daylight to attain target setpoint (TSP) illumination levels. However, efficient penetration of daylight harvested majorly depends on architectural constraints of WP. A typical daylight harvesting process is shown through blockdiagram in Fig. 2.3.

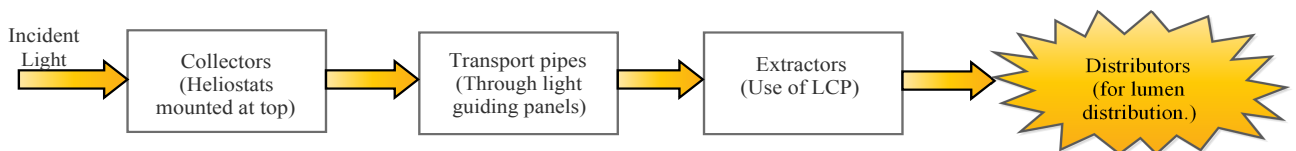


Figure 2.3: Day Light harvesting process.

In above figure, the collectors performs prime function of collecting daylight. Generally, for this purpose heliostats are integrated on roof tops. They collect the incoming sunlight and concentrates the entire daylight to a central receiver. The Fig 2.4 shows the

working of roof mounted heliostats. These heliostats are basically computer controlled mirrors, they perform the task of concentrating daylight to particular with alteration in sun azimuth.

Normally, a H1 heliostat delivers 1300 watts of heat and approximately 150,000 lu-

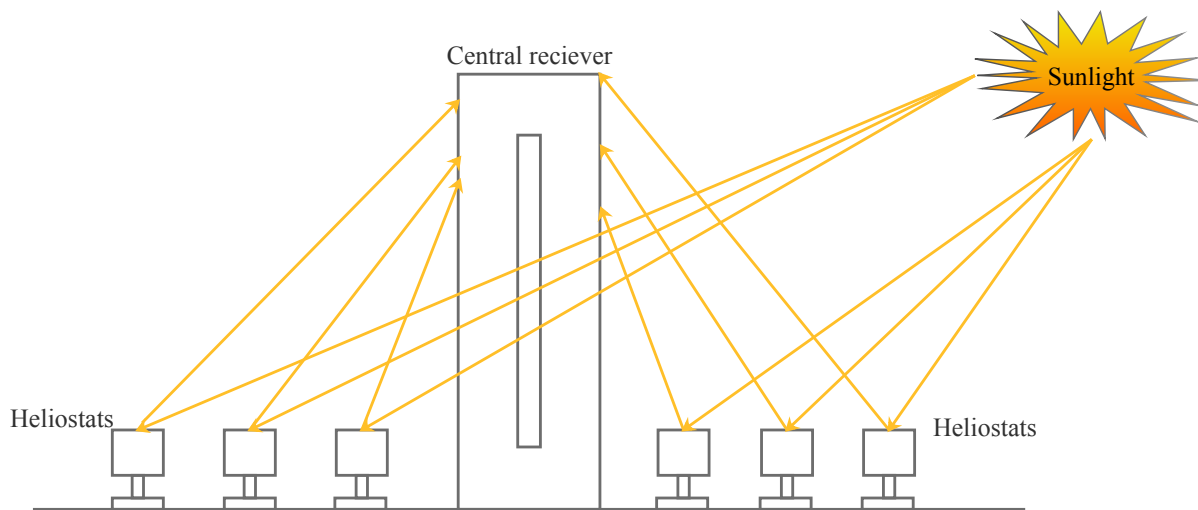


Figure 2.4: Heliostats guiding entire daylight to the central receiver

mens. Their combined operation provides tremendous daylight and heat for both commercial and residential purpose. The inherent advantages heliostats include low operational power, reduced maintenance, integrated wifi networking, easy control, robust designs and fast switching at user defined points. They are also implemented in industries in eliminating fossil fuel requirement for heating purpose. Other applications include reduction in moisture content of crops, sterilization of medical equipment and large scale industrial cooking.

Now, these heliostats concentrate daylight to central receiver. They are also called solar energy concentrators. They transfer normally 80-85 percent of collected energy for further process. Through central receiver the daylight is transported to the different WP. For this purpose the light transport pipes are integrated within the buildings. These light transport pipes are implemented in building to transfer natural daylight effectively to different area of buildings. The light trapping and light enhancement mechanisms are involved in these light pipes. Thus required daylight is transported to the exact WP's. For more better daylight penetration the light transport pipes are equipped with light guiding panels. In Fig 2.5 the light transport process is shown for better distribution of daylight at WP's each end of the light transport pipe are equipped with extractors. The extractors are basically diffusers they consist of convex lenses that diverge the light effectively throughout the WP. The combined operation of the above mentioned components leads to effective distribution of daylight at

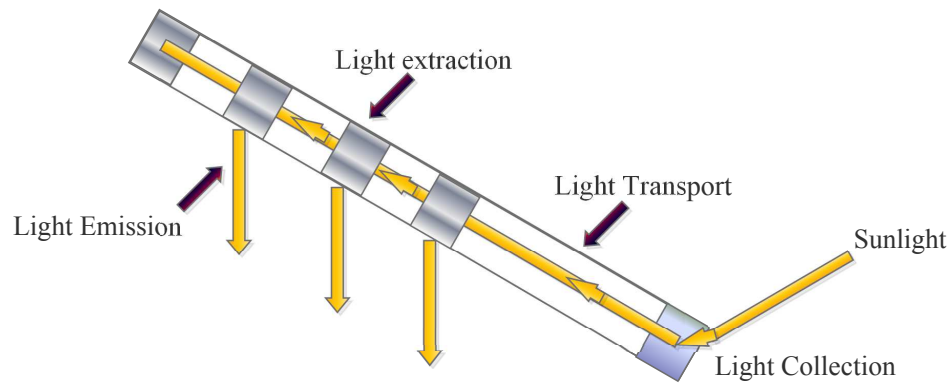


Figure 2.5: Light Transport Process

each WP. Thus, making TSP illumination possible at each WP and synchronized operation with artificial lighting. They can be placed in buildings both vertically and horizontally according to the application. However, the extraction of light can be done wherever it is required.

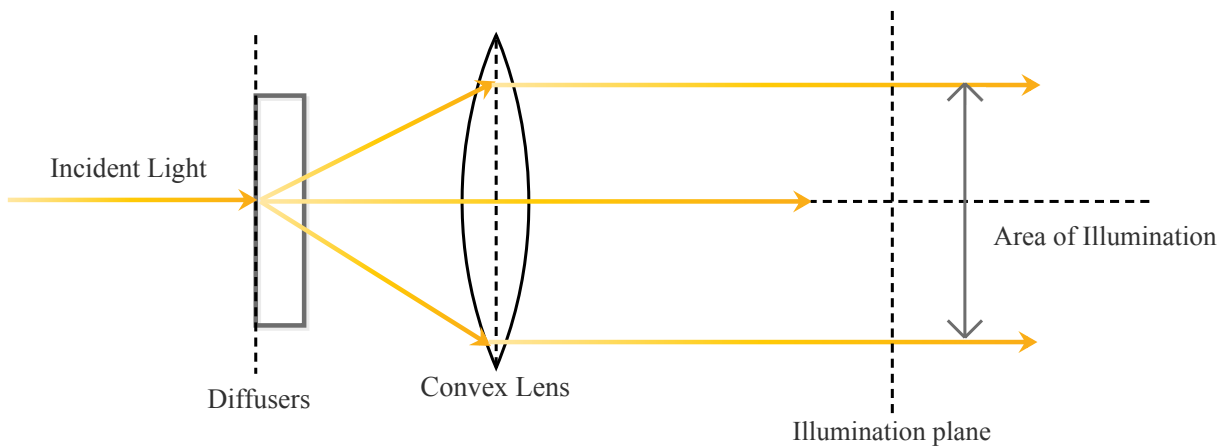


Figure 2.6: Diffusers for distribution

The Fig 2.6 shows the microscopic view of the diffusers installed at each extraction point. The diffusers diverges the light rays to every corner of WP.

2.8 LED

The rapid advancement in semiconductor technology has made LED as popular artificial light energy source. The LED has completely outperformed its other counterparts like fluorescent, halogens and incandescent lamps. The LED comes out to be superior than other sources due to several factors. These factors include high efficiency, economically affordable and environment friendly. LED are basically P-N junction diodes, emitting light of

different colours by using different semiconductor material in their active region. A class of ternary compound AlGaInP and AlGaAs generates red light, green light are generated by GaN and AlGaP whereas InGaN emits blue light. However, for generating white light through LED three different approach are followed. These are firstly all three colours of red, blue and green are used together in single bulb. In, second approach ultraviolet LED are implemented which eliminates red, blue and green phosphor. These phosphor material transforms, UV light of high energy to lower energy wavelength of green, red and blue light from LED chip. The third method incorporates utilization of blue coloured LED for illuminating yellow phosphor material.

It is considered that third method is best of the three approach to generate white light. The option is considered superior to other two approaches since it does not include hazardous UV light. The use of hazardous UV light causes the decay of phosphor material and LED internal packaging. Moreover, the implementation of feedback circuitry is required in 3-colour LED bulb to combine and tune them exactly. The behaviour of each colour changes with time, therefore care must be taken to design the control circuit efficiently.

The other significant advantages of LED which makes them competitively superior than the other lighting devices includes high luminous efficacy per watt. The luminous efficacy is the total lumens emitted by a light source when one watt of power is applied at input of the LED. The luminous efficacy of LED is found to be highest of all i.e is 90 lumens per watt. Which is comparatively much higher when compared with incandescent bulb and CFL which are approximately 20 and 70 lumens per watt. A high luminous of LED leads to conversion of higher percentage of electrical power into light rather than to heat. Moreover, the life of LED are promised to be 50,000 hours which is significantly higher than CFL i.e 10,000 hours and incandescents 1200 hours respectively. When a comparison is made for different artificial lighting devices nearly 42 incandescent bulbs are required for operating 50,000 hours which is comparatively higher than CFL which is five. The other advantage include dimming, which is done by proportionally supplying reduced electrical current at the input of LED.

2.8.1 Dimming of LED

Dimming of LED is an intrinsic feature of evolving solid state technology. The LED dimming is majorly classified into following two categories listed below. Since input current is responsible for proportional illumination. Therefore, both the methods regulates the amount of input current driven into LED. However, one type of technique poses inherent advantage over the other.

1. Analog dimming: The analog dimming technique is generally implemented for portable equipments. This type of dimming also called as 0-10 V dimming. The analog dimming of LED poses some inherent advantages including reduced EMI and significantly high efficiency than other dimming methods. The dimming is usually achieved by directly controlling the input current. The method is significantly different from PWM where voltage control is done.
2. PWM dimming: Pulse width modulation (PWM) as name suggest is method to used to control the dimming by varying the duty cycle of applied voltage. This type of dimming is highly effective when power range is high. The EMI and noise is significantly higher in PWM method when compared with analog dimming method. The PWM dimming when compared with analog dimming is more accurate. The efficiency is lost upto 25 percent in analog dimming. Moreover, this dimming method easily produces high dimming ratios.

Chapter 3

PROBLEM FORMULATION

3.1 System Overview

The proposed system comprises two different components for maintaining target setpoint (TSP) illumination at work place (WP). These components are namely, natural daylight harvested through window and artificial lighting through LED. The entire system is depicted in Fig. 3.1.

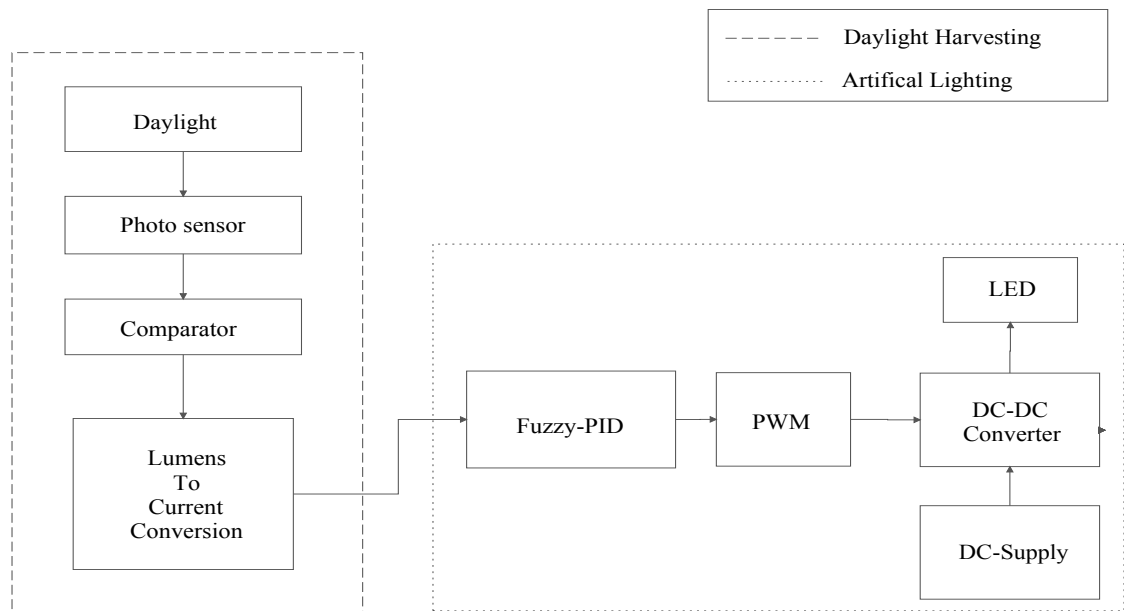


Figure 3.1: Diagram showing system framework.

3.2 Description of photosensor & comparator unit

To achieve TSP illumination, daylight inputs entering into a room through window are sensed. The photosensors are positioned at each window, from where daylight is entering into a room. This type of sensor placement and natural light measurements falls in the category of open loop sensor placement. Advantage offered by this type of sensor placement is, it mitigates the effect of false sensing. Since, these photosensors explicitly measures the natural daylight availability. Thus a pure estimation of artificial lighting supplemented by LED is calculated.

After obtaining estimation of real time daylight pattern entering into the WP, these inputs are instantaneously transferred to the comparator unit. The comparator unit performs an important task of estimating the artificial lumens. The comparator unit subtracts the estimated daylight input from TSP. Calculation of TSP for particular WP are described in latter sections. As the daylight inputs are nonlinear and time varying in nature. These variations occurs due to change in environmental conditions and weather sensitivity factors. Therefore the comparator output, also varies with variations due to incoming daylight. This amount of lumens are to be compensated by the artificial lighting to reach the required TSP illumination levels with consequent energy saving.

3.3 Lumens to current conversion unit

Now, the task of achieving TSP at each WP are performed through artificial lighting. However, effective control of LED can only be done after exact estimation of target current (TC). This TC current acts as reference to achieve TSP illumination at each WP. The lumen to current (LTC) conversion unit, gives the exact basis of this TC. The LTC unit are modelled, keeping consideration of LED specifications and ratings which are implemented for illumination at WP. These specifications includes, ambient temperature of operation during real time and reference values of current, temperature and lumens of LED. The TC, thus obtained by LTC unit is to be driven into LED at each time instant to achieve TSP illumination. This TC is dynamically updated with variation in daylight. Hence, a control strategy is required for adaptive control of this nonlinear process. For control application involving different LED we have to change characteristic of LTC unit accordingly. For higher daylight $D_1(t)$, the requirement of artificial lighting will be low hence, a low D_2 value is obtained consequently getting reduced value of target current I_{TC} . Similarly for less value of $D_1(t)$, the requirement of artificial lighting D_2 is high therefore proportion-

ally larger value of target current I_{TC} is obtained. The case involving daylight input D_{11} will generate moderate values of target current, however the daylight input D_{12} generates increased values of I_{TC} because of unavailability of daylight and the third input D_{13} will generate proportionally much lesser value of I_{TC} since daylight is adequately available in this case.

3.4 Basis of Fuzzy-PID controller for PWM generation

The variations in TC are nonlinear and timely varying due to nature of daylight. Therefore, a control strategy is required to reach the levels of nonlinear TC. To deliver the purpose, fuzzy-PID controller is manifested. This fuzzy controller tracks the nonlinear changes occurring in the TC values. For efficient tracking of this TC, the controller is modelled in terms of antecedents and consequents. In this system, error and error change are modelled as antecedents and control parameters of PID controller i.e K_P , K_I and K_D are replicated as consequents. Since, nonlinear changes in TC cannot be modelled in terms of differential equations hence Takagi-Sugeno (T-S) fuzzy inference system (FIS) is incorporated. The T-S system promises more efficient tracking and self tuning to reach TSP illumination levels. The other significant advantage of Sugeno FIS, is that the consequents are modelled as either linear or constant function of antecedents. The K_P , K_I and K_D , for this process are modelled as linear function of error e and change in error Δe . Thus, a crisp value is obtained at output irrespective of the fuzzy input.

$$K_P = f(e, \Delta e) = a_1 e + b_1 \Delta e + u_1 \quad (3.1)$$

$$K_I = g(e, \Delta e) = a_2 e + b_2 \Delta e + u_2 \quad (3.2)$$

$$K_D = h(e, \Delta e) = a_3 e + b_3 \Delta e + u_3 \quad (3.3)$$

Here f , g & h are linear functions of e & Δe .

This linear modelling of consequents, gives a crisp output which is not in case with other FIS like Mamdani. Thus tuning a nonlinear control process becomes relatively trouble-free. Hence, the integration of linear PID controller can be done to achieve optimal response during contingencies. The PID controller adapts, the dynamically varying control parameter and produces output response. The output of PID controllers is given to PWM generator which generates PWM pulses corresponding to changing TC. These pulses are fed to the gate terminal of DC-DC buck converter which regulates instantaneous output current of converter. This instantaneous current is driven into LED and compared constantly with TC. The error produced is given again to Fuzzy-PID controller. Thus entire control

process is regulated in the closed loop. Thus, achieving TSP illumination and curtailing energy manifested in lighting applications in SB.

3.5 Description of LED

The LED modelled in this system is surface mounted diode (SMD) 5730 with power consumption of 0.5 W, working voltage 2.8-3.2 V and rated current of 150mA. The output lumens varies from 55-65 lumens per component at rated current. Moreover, the ejection of lumens are entirely dependent on current magnitude driven into the LED and ambient temperature at the time of LED operation.

3.6 Problem Formulation

SB generally comprises of different components based on their application within a single buildings. The target here is to provide TSP illumination with DH and artificial lighting at different WP. The lumen density requirements for each WP varies explicitly. Generally conference halls and office buildings requires lower distribution of 250 lumens per square meter [34]. Wherein the resturants and showrooms have higher lumen density of 500 lumens per square meter when compared with former. Moreover, the lumen distribution at each WP is dependent on dimensional constraints. Therefore calculation of target set point (TSP) for each WP, optimal placement of artifical light sources with proper space to height ratios (SHR) and controller designs for each WP becomes important in the area of controllable lighting applications involving DH.

3.6.1 TSP caluclations for different WP's

The basis of control action of fuzzy-PID controller is primarily dependent on TSP illumination calculations. The TSP calculation requires estimation of WP area, where TSP illumination is to be maintained throughout the control process. Here the WP length and breadth are denoted by L_{WP} and B_{WP} respectively. Total WP area is given by A_{WP} .

$$A_{WP_i} = (L_{WP_i} \times B_{WP_i}) \text{feet}^2 \quad (3.4)$$

here WP length and breadth are represented in feets. A transformation factor of 0.093 transforms it into square-meters.

$$A_{WP_{effectivei}} = (0.093 \times A_{WP_i}) \text{m}^2 \quad (3.5)$$

This effective WP area is to be illuminated with TSP illumination. The effective area of i^{th} WP area is multiplied with standardized illumination values to get TSP for i^{th} WP.

$$TSP(WP)_i = A_{WP_{effective}} \times (WP_{si})lumens \quad (3.6)$$

Hence, TSP for each WP are obtained with above equation. This TSP illumination should be maintained each time by combined operation of time varying daylight and adaptive controller for tuning of artificial light with daylight is proposed in later sections.

3.6.2 Space to height calculation for LED placement

The Fig-3.2 shows gives an arrangement of space to height adjustment for optimum illumination level at WP. The standard light intensity equation (3.7) shows that the light intensity

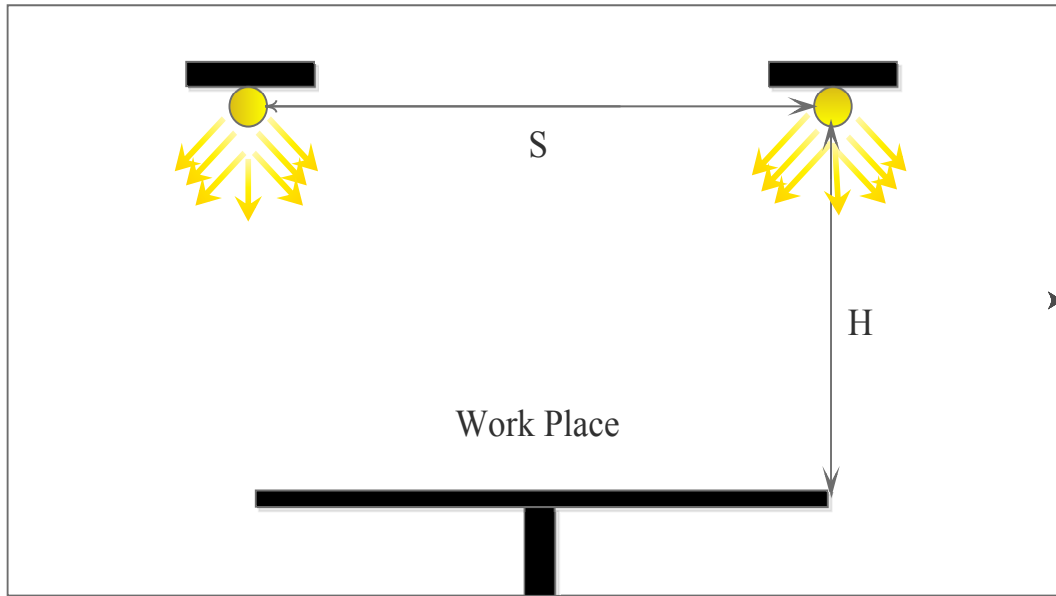


Figure 3.2: Space to height ratio adjustments

varies with distance and angle of the object to be placed in WP.

$$L = \frac{(k \sin \theta) I}{d^2} \quad (3.7)$$

To optimally illuminate the WP with TSP illumination, space to height calculations are done for each lighting fixture. The light intensity I , ejected by fixture is subjected to remain constant at each time instant. In Fig-3.3, A is a point where LED is placed and C is the farthest point where object can be placed in WP w.r.t LED.

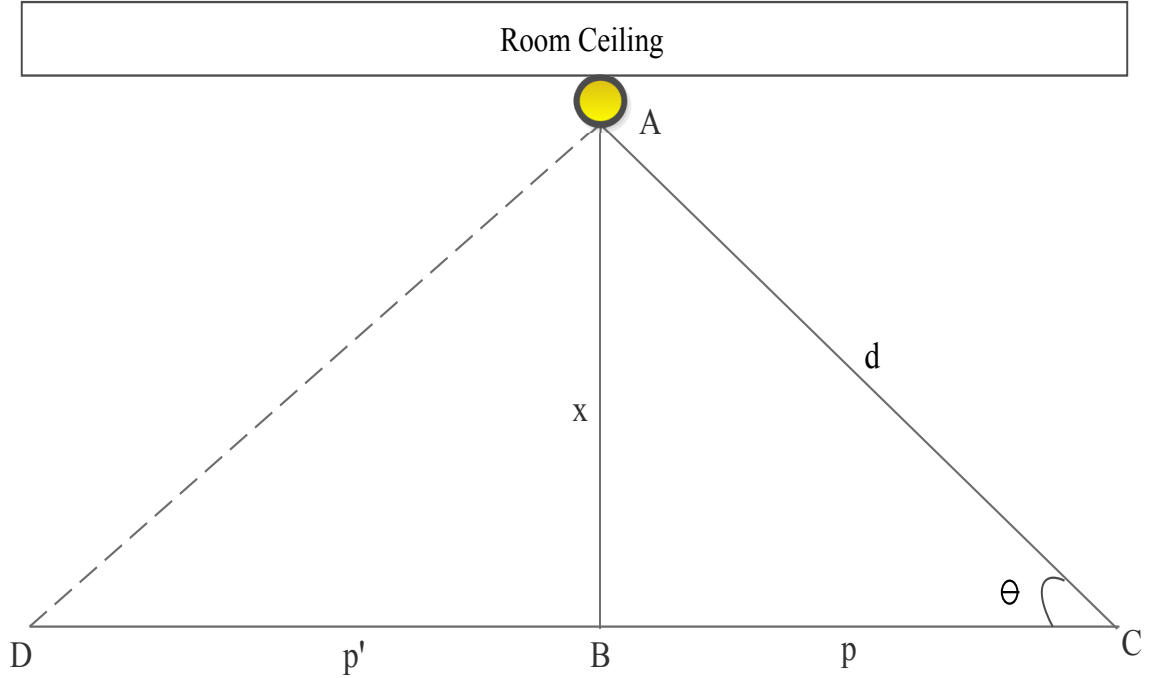


Figure 3.3: Location of LED at WP's with space to height adjustments.

Right angle triangle ABC, shown in Fig-3.2:

$$AC^2 = AB^2 + BC^2 \quad (3.8)$$

$$d^2 = x^2 + p^2 \quad (3.9)$$

$$k' = k \times I \quad (3.10)$$

$$L = \frac{k' \times \sin \theta}{d^2} \quad (3.11)$$

Converting $\sin \theta$ in terms of room dimensions.

$$\sin \theta = \frac{x}{(x^2 + p^2)^{1/2}} \quad (3.12)$$

Substituting (3.9) and (3.12) in (3.11)

$$L = \frac{k'x}{(x^2 + p^2)^{3/2}} \quad (3.13)$$

Differentiating (3.13) w.r.t to x and equating it to zero.

$$p^2 - 2x^2 = 0 \quad (3.14)$$

$$p^2 = 2x^2 \quad (3.15)$$

$$p = \sqrt{2}x \quad (3.16)$$

Therefore space should be $\sqrt{2}$ times that of height. Total length of space in which object can be placed for optimal illumination is given by pp' .

$$pp' = 2\sqrt{2}x \quad (3.17)$$

The space to height ratio (SHR), for the different WP can be given as:

$$SHR_{WP_i} = \frac{p_i}{x_i} \quad (3.18)$$

i denotes the WP for which SHR calculation is done, p_i is space stretch for i^{th} WP and x_i is height for i^{th} WP .

Therefore, LED and WP should be aligned accordingly, to make SHR ratio lying in range of 1-1.414.

3.6.3 Controller for Integrating DH with LED

Determination of TSP illumination level for particular WP and SHR calculations form basis for artificial lighting. The photosensor positioned, explicitly senses the natural daylight input denoted by $D_1(t)$. Since, the daylight inputs are nonlinear and time varying. They cannot alone maintain TSP levels at each time instant. Hence, for estimating the artificial lighting level these daylight inputs are transferred to the comparator unit. The comparator unit subtracts the dynamically varying daylight input $D_1(t)$ from TSP .

$$D_2 = (TSP) - D_1(t) \quad (3.19)$$

Here, D_2 denotes artificial lumens which are to be supplemented by LED to maintain TSP illumination. The comparator unit updates the D_2 with varying daylight. The estimation of natural daylight alone does not suffice the problem. To achieve TSP illumination a target current I_{TC} should be driven into the LED that will supplement D_2 .

For getting exact estimation of I_{TC} , the daylight inputs are continuously transferred to lumen to current conversion (LTC) unit. The LTC determines the dynamically varying current with variable daylight inputs. The updated D_2 values are substituted in equation (3.20). The equation (3.20) is obtained by manipulating the light output variation equation with input current as suggested by Biber [15]. The characteristics of this equation are similar to the LED, which is implemented for artificial lighting. This I_{TC} is updated rigorously with

update of D_2 .

$$I_{TC} = \frac{-(b_1 I_0) + \sqrt{(b_1 I_0)^2 - 4b_0 \left(b_2 - \frac{D_2}{\phi_{i0}(a_0(T_{amb} - T_0) + a_1)} \right)} (I_0)^2}{2b_0} \quad (3.20)$$

Here I_0 is the reference current of the LED at the reference temperature T_0 and ϕ_{i0} are the lumens at this reference current I_0 . This I_{TC} largely depends on specifications of the LED to be implemented for artificial lighting. T_{amb} is the ambient temperature of the LED during real time operation. b_0 , b_1 , b_2 , a_0 and a_1 are the LED internal parameters [16].

This target current I_{TC} is to be provided by DC-DC buck converter for getting D_2 lumens for the LED. The buck converter generates the instantaneous current I_{inst} which is driven into the LED. Since daylight varies nonlinearly, therefore I_{TC} is also updated with the change in daylight this lead to generation of error e , due to difference in I_{TC} and I_{inst} .

$$e = I_{TC} - I_{inst} \quad (3.21)$$

To achieve TSP illumination levels and integrating DH phenomena with artificial lighting fuzzy-PID controller is developed. The controller will track the changes in values of I_{TC} . To model this controller, the inputs are modelled in terms of antecedents and consequents. The two inputs are error e and change in error Δe . The Δe is the difference of error values between two successive time instants.

$$\Delta e = e(n) - e(n-1) \quad (3.22)$$

The error e and the change in error Δe are the antecedents in this control problem. These antecedents are modelled according to the triangular membership function with variable input range. Since the daylight variation pattern is highly nonlinear and timely varying. Hence, Takagi-Sugeno fuzzy inference (FIS) is implemented. The advantage offered by this system is the consequents i.e K_P , K_I and K_D are modelled as either linear or constant functions of antecedents. For, this control problem we have considered output membership function to be linear function of error e and change in error Δe . Thus output of this FIS are control parameters K_P , K_I and K_D which linearly adapts to changing values of I_{TC} . The updated control parameters are given to PID controller. The PID controller correspondingly generates the control signal for PWM generator. The PWM generator has higher switching frequency in order of 5 kHz. The PWM pulses trigger the gate terminal of MOSFET. Thus desired output current response I_{inst} is obtained with required TSP illumination at each WP with stable operation. Fig-3.4 shows the entire control process of the fuzzy-PID controller.

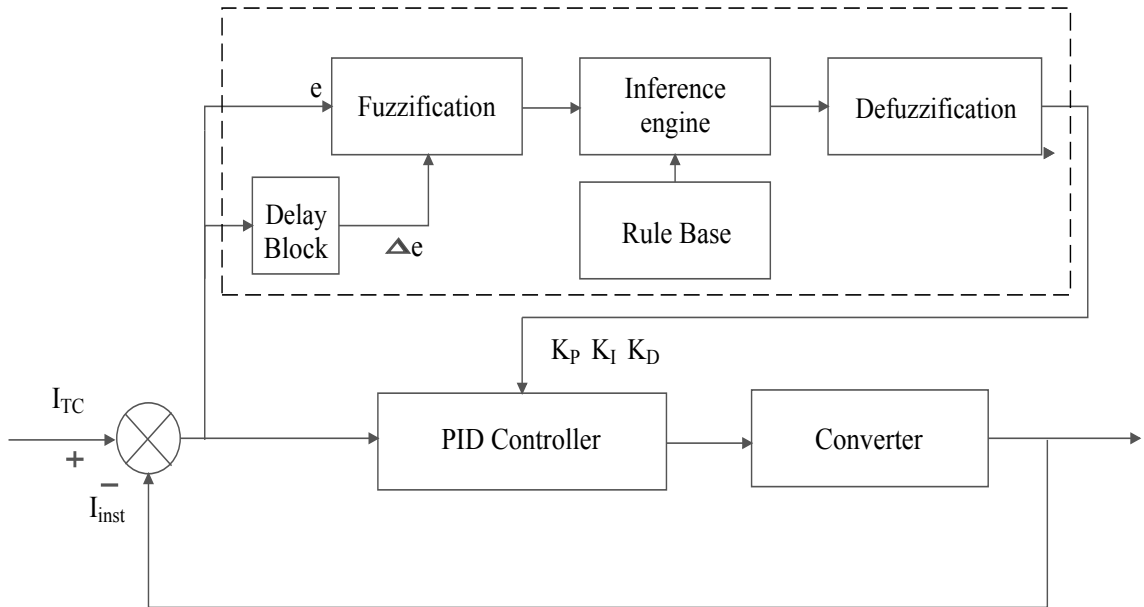


Figure 3.4: Block diagram showing operation of controller for artificial lighting control.

3.6.4 Description of DC-DC buck converter

The DC-DC buck converter is implemented to effectively control the dimming of LED. The converter is given fixed input supply of 110 V DC at input. The PWM pulses are given according to the daylight pattern. The PID controller generates optimum PWM pulses to regulate output current. The converter switching frequency is fixed to 5 kHz. Fig-3.5 shows DC-DC buck converter driving LED. Table 3.1 gives the simulation parameter taken for converter.

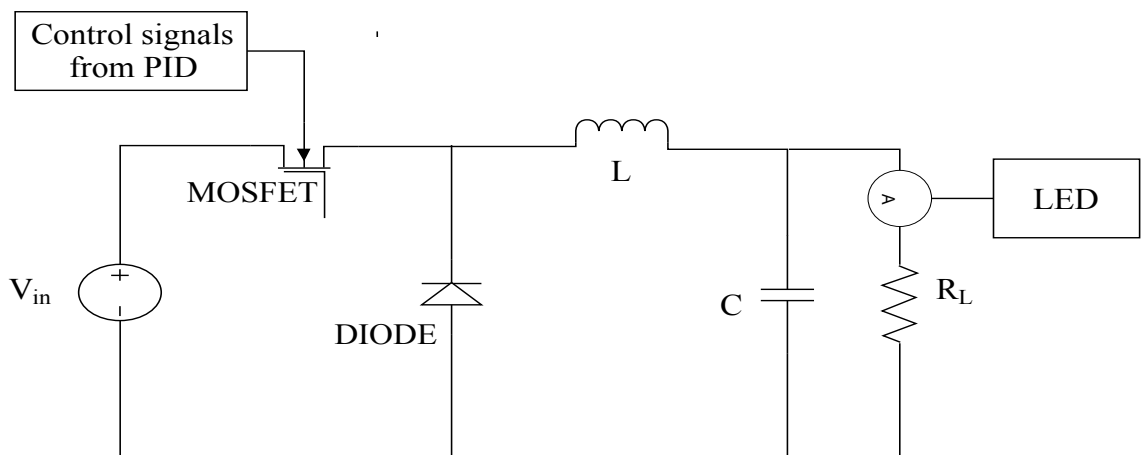


Figure 3.5: DC-DC buck converter driving LED

Table 3.1: Converter parameters used for simulation

Converter Parameters	
V_s	110 V
Inductance (L)	100mH
Capacitance (C)	120 μ F
Load resistance (R_L)	300 Ω

3.6.5 Rule Base

The Integration of DH with artificial lighting is nonlinear control process. To achieve adaptive control of the LED with changing daylight fuzzy-PID controller is implemented. Here, Takagi-Sugeno system is implemented. The advantage offered by this system is the consequents K_P , K_I and K_D are linear function of antecedents error e and change in error Δe . The IF-THEN rules are framed as under. Here, nine IF-THEN rules are framed to achieve desired response. The antecedents and consequents are modelled in Table 3.2. They are further divided into three individual membership functions.

Table 3.2: Description of Antecedents & Consequents

Description of Antecedents		
e	e_L	error Low
	e_M	error Moderate
	e_H	error High
Δe	Δe_L	change in error Low
	Δe_M	change in error Moderate
	Δe_H	change in error High
Description of Consequents		
K_P	K_{P_L}	Propotional gain Low
	K_{P_M}	Propotional gain Moderate
	K_{P_H}	Propotional gain High
K_I	K_{I_L}	Integral gain Low
	K_{I_M}	Integral gain Moderate
	K_{I_H}	Integral gain High
K_D	K_{D_L}	Differential gain Low
	K_{D_M}	Differential gain Moderate
	K_{D_H}	Differential gain High

The rule base formulation for the control process is stated as:

If error e is low e_L and change in error Δe is high than propotional gain K_P is low i.e

K_P , integral gain K_I medium K_{I_M} and differential gain K_D is high K_{D_H} .

All the rule base for control process are similarly modelled and described in Table 3.3.

Table 3.3: Table for rule base

INPUT		OUTPUT		
e	Δe	K_P	K_I	K_D
e_L	Δe_L	K_{P_L}	K_{I_L}	K_{D_L}
e_L	Δe_M	K_{P_L}	K_{I_M}	K_{D_L}
e_L	Δe_H	K_{P_M}	K_{I_H}	K_{D_M}
e_M	Δe_L	K_{P_M}	K_{I_M}	K_{D_M}
e_M	Δe_M	K_{P_M}	K_{I_M}	K_{D_M}
e_M	Δe_H	K_{P_H}	K_{I_M}	K_{D_M}
e_H	Δe_L	K_{P_H}	K_{I_L}	K_{D_M}
e_H	Δe_M	K_{P_H}	K_{I_M}	K_{D_M}
e_H	Δe_H	K_{P_H}	K_{I_H}	K_{D_H}

Chapter 4

RESULTS & DISCUSSION

4.1 Introduction

The nonlinear variations in daylight poses problem of maintaining target setpoint (TSP) illumination. The daylight residing inside the range of 100-3000 lumens falls in category of useful daylight illuminance (UDI) level [35]. The daylight inputs for this control problem are modelled keeping in track of time varying and nonlinear nature. The contingencies associated with climate and weather are considered. The effect of rain, clouds and partial shading when daylight is unavialable or reduced are included. The effect of these unbounded variations are tested with Fuzzy-PID controller. The controller are tested at different WP's where TSP illumination level varies with changing dimensions and applications.

Here, we have taken four cases for different WP which have different TSP illumination levels. Since all WP's are operating in a single SB. It is assumed that, they recieves same daylight inputs at each time instant. The time of operation of each WP is fixed between 0900 hours to 1800 hours during daylight availability hours.

4.2 Description of Daylight Inputs

The daylight inputs are denoted by D_{11} , D_{12} and D_{13} respectively. The input set D_{11} , is the normal variation of daylight. This variation takes place within the bounded range. The inputs linearly increases with time upto a certain time extent and decreases as the day progress. This input case represents daylight distribution at normal day. However, the input D_{12} incorporates the effect of weather. This input set considers the unavialabilty of the daylight due to conditions like rain, partial shading etc since daylight is unavialable during

this time.

This particular input set lays attention on accessing controller performance during daylight degraded period. The input D_{13} includes the effect of nonlinear variation in daylight. The daylight levels varies abruptly throughout the day in this input. It rises for particular hours of the day and suddenly decreases in next hours. Purpose of this daylight input is to test controller, wheather it can inherit the variations in daylight and produce exact response.

4.3 Case-I: Results of WP_1 with variable inputs.

The standard illumination WP_{si} for WP_1 is considered as 250 lumens per m^2 . The TSP for WP_1 comes out to be 2790 lumens ($A_{WP_1}=11.16 m^2$, $TSP=11.16 \times 250=2790$ lumens). The daylight input D_{11} is normal variation, the daylight input at 0900 hours is 900 lumens. This is obtained from a single daylight source i.e window located in the room. The daylight input follows a linear profile throughout the day. Since, TSP for WP_1 is 2790 lumens and D_{11} is 900 lumens, therefore 1890 lumens ($2790-900=1890$ lumens) are to be supplied through artificial lighting D_2 . The daylight input increases at 1000 hours to 1000 lumens, which reduces the requirement of artifical lighting at this point of time. Consequently, the controller draws reduced current during the time instants when availability of daylight is high.

Moreover, the linearly increasing pattern of D_{11} till 1400 hours i.e 1550 lumens inturn

Table 4.1: Daylight variation pattern for WP_1

Daylight Inputs (Lumnes)			
TIME (Hour)	D_{11}	D_{12}	D_{13}
0900	900	700	1200
1000	1000	600	1450
1100	1200	550	1300
1200	1400	400	1500
1300	1500	300	1250
1400	1550	200	1200
1500	1200	250	1100
1600	1000	200	1050
1700	800	200	900
1800	500	100	700

curtails the artificial lighting requirement to 1240 lumens ($2790-1550=1240$ lumens). The reduced lumens requirement through D_2 , at this time instant inturn reduces target current I_{TC} is to be drawn from converter. However with the progress of the day the daylight levels

reduces. Thus the need of D_2 increases after 1400 hours. At 1600 hours the D_{11} goes down to 800 lumens. Thus aggravating the demand for D_2 to 1790 lumens ($2790-1000 = 1790$ lumens). The, I_{TC} demand also escalates at the latter part of the day. Finally the D_{11} goes down to 500 lumens at 1800 hours, this increases the I_{TC} requirement to high values. The Fig. 4.1 shows the response of controller with input set D_{11} .

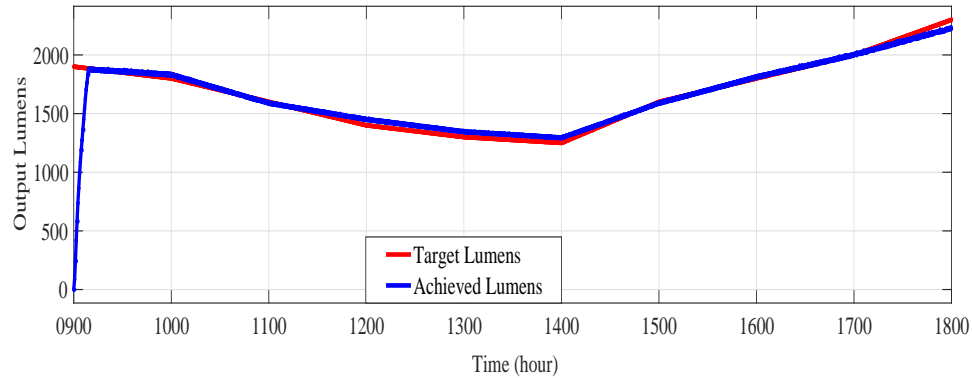


Figure 4.1: Controller response for WP_1 with input set D_{11}

The second set of daylight input D_{12} , shown in Table 4.1 includes the effect of rain, clouds and shading which reduces the daylight inputs. The D_{12} starts with 700 lumens at 0900 hours and monotonously reduces to 200 lumens at 1400 hours. A relatively flat profile is maintained till 1700 hours and then reduces to 100 lumens at 1800 hours. The target current I_{TC} values also increases due to reduced daylight input values D_{12} . Artificial lighting D_2 , requirement at 0900 hours is 2090 lumens ($2790-700 = 2090$ lumens).

Fig. 4.2 shows the response of controller at each time instants. The results shows that

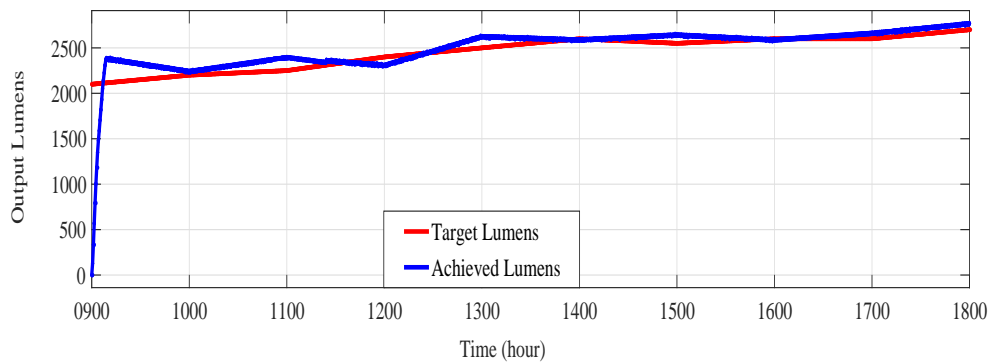


Figure 4.2: Controller response for WP_1 with input set D_{12}

controller inherently adapts to the change in artificial lumens D_2 requirement. D_2 increases

abruptly from 2090 lumens ($2790-700=2090$ lumens) at 0900 hours to 2690 lumens at 1800 hours ($2790-100=2690$ lumens). Thus, through exact and precise tuning of fuzzy-PID, controller TSP illumination of 2790 lumens ($11.16 \times 250=2790$ lumens) is maintained at each time instant. The I_{TC} magnitudes also increases due to unavailability daylight D_{12} , hence the power drawn from DC supply increases.

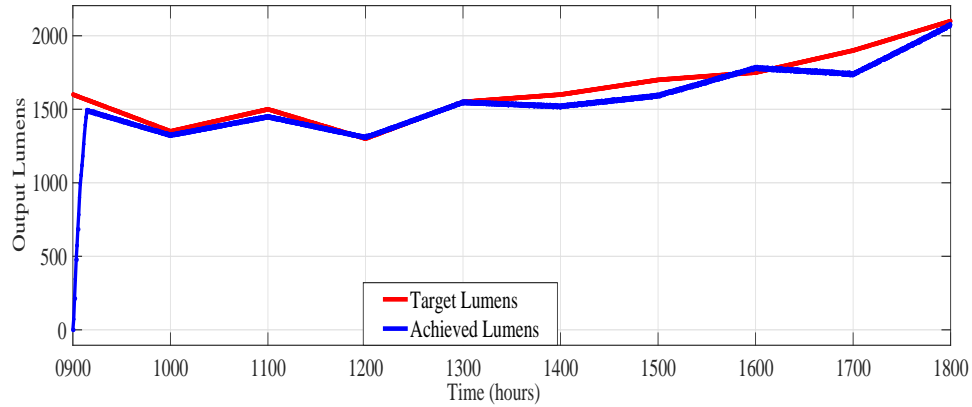


Figure 4.3: Controller response for WP_1 with input set D_{13}

The third daylight input set D_{13} incorporates the effect of nonlinearly varying daylight pattern. This input set attempts to emulate of uncertain daylight changes. The D_{13} at 0900 hours is comparatively highest of the three inputs as shown in Table 4.1. The D_{13} varies abruptly throughout the day increasing to 1450 lumens at 1000 hours and then reducing to 1300 lumens at following hour. The nonlinear changes are efficiently tracked by the controller and adaptive response is produced to achieve TSP illumination values. Fig. 4.3 shows the response of controller with D_{13} as daylight input. The target current I_{TC} magnitude are consequently lower than other two input sets. This because of the less requirement of artificial lighting D_2 i.e 1890 lumens ($2790-900=1890$ lumens) at 0900 hours to 2090 lumens ($2790-700=2090$ lumens) at 1800 hours. But, the variation in I_{TC} is nonlinear and abrupt through out the day.

4.4 Case-II: Results of WP_2 with variable inputs.

The controller effectively adapts the daylight variation changes for WP_1 with low lumen distribution. This section attempts to examine the WP 's with moderate illumination levels. However, the WP_2 have larger area due to room dimensions. Therefore, the TSP illumination for WP_2 is 6790 lumens which higher, when compared with WP_1 ($A_{WP_2}=26.784 m^2$,

$TSP=26.784 \times 250=6696$ lumens). As TSP of WP_2 is higher, therefore for healthy distribution of daylight two daylight sources i.e window are taken. Hence, magnitude of each input set described in Table 4.2 are doubled than that in Table 4.1.

Table 4.2: Daylight variation pattern for WP_2

Daylight Inputs (Lumnes)			
TIME (Hour)	D_{11}	D_{12}	D_{13}
0900	1800	1400	2400
1000	2000	1200	2900
1100	2400	1100	2600
1200	2800	800	3000
1300	3000	600	2500
1400	3100	400	2400
1500	2400	500	2200
1600	2000	400	2100
1700	1600	400	1800
1800	1000	200	1400

The response of controller, with daylight input D_{11} is shown in Fig. 4.4. The controller adapts to linear inputs instantaneously and produces desired response to maintain TSP illumination at each time instant. The artificial lumens D_2 to be supplemented at 0900 hours with input set D_{11} are 4896 lumens ($6696-2 \times 900=4896$ lumens). With progress in the day the D_{11} values increases upto a certain time instant and then achieves maxima of 3100 lumens ($1550 \times 2=3100$ lumens) at 1400 hours. The controllers tracks the trajectory

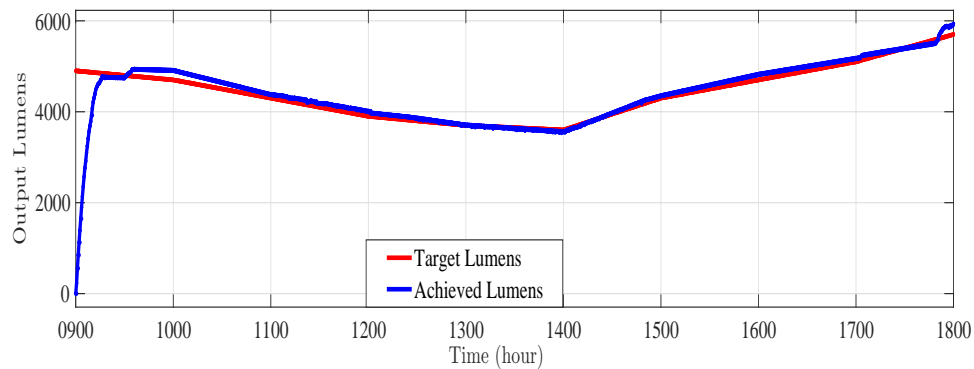


Figure 4.4: Controller response for WP_2 with input set D_{11}

of target lumens at each time instants. Moreover, the demand of D_2 increases as the day progress due to reduction in D_{11} . The target current TC values also rises, with reduction

in D_{11} . The fuzzy-PID controller, tracks the increased demand and accordingly generates PWM pulses to generate the instantaneous current I_{inst} at converter output for achieving TSP illumination.

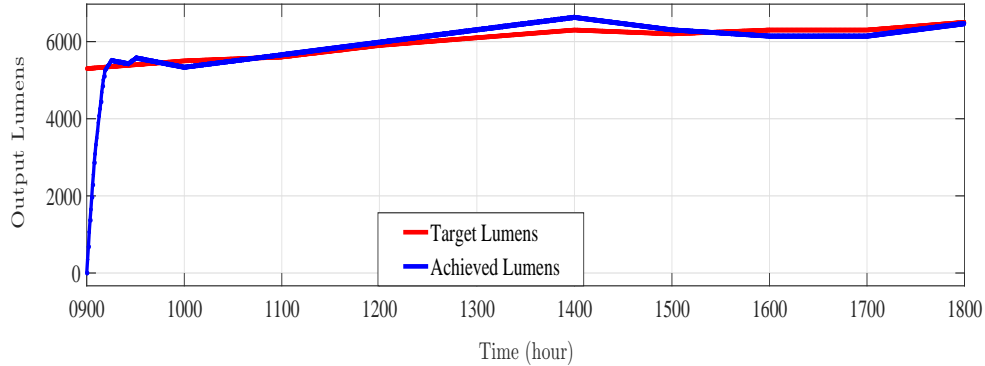


Figure 4.5: Controller response for WP_2 with input set D_{12}

The proposed fuzzy-PID controller is tested for daylight input D_{12} . The controller generates almost complementary response to the target lumens curve. The Fig. 4.5 shows the desired response. The D_{12} input set supplements reduced distribution due to consideration of weather sensitivity factors. However, the modifications done in control parameters balances the surge in demand of artificial changes. The regulated parameters alters PWM pulses to achieve target illumination even at low natural lumens availability which is 1800 hours.

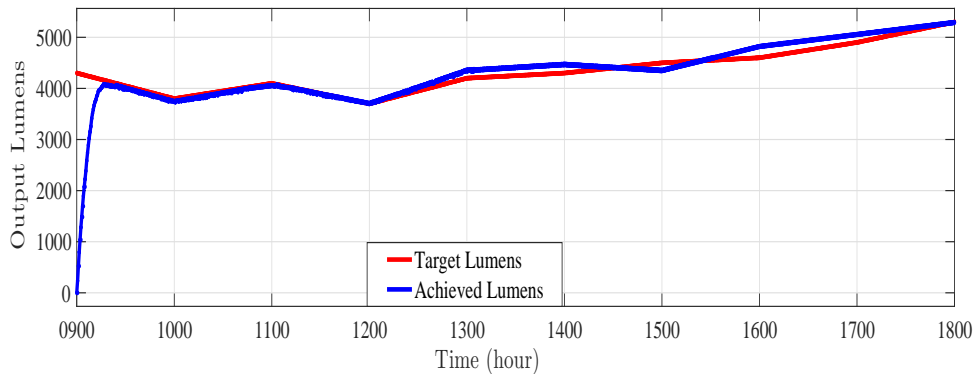


Figure 4.6: Controller response for WP_2 with input set D_{13}

However, in Fig. 4.6 the response of nonlinearly varying daylight pattern is shown. As stated earlier, the D_{13} inputs increases during particular time instant and reduces at some other time instants. The supply current drawn by converter during 1200 hours is

minimum. Since, the lumens distribution at 1200 hours is maximum i.e 3000 lumens, therefore a compensation of 3696 lumens ($6696-3000=3696$ lumens) are to be done by D_2 . Thus proportionally less current is drawn by converter. The controller produces exact response at each time instant to achieve TSP illumination levels. Thus promising desired illumination nonlinearly varying daylight and energy saving.

4.5 Case-III: Results of WP_3 with variable inputs.

The controller produces desired response for WP_1 and WP_2 , despite alterations in TSP illumination levels for both the WP 's. This case foregrounds, the controller response for

Table 4.3: Daylight variation pattern for WP_3

Daylight Inputs (Lumnes)			
TIME (Hour)	D_{11}	D_{12}	D_{13}
0900	3600	2800	4800
1000	4000	2400	5800
1100	4800	2200	5200
1200	5600	1600	6000
1300	6000	1200	5000
1400	6200	800	4800
1500	4800	1000	4400
1600	4000	800	4200
1700	3200	800	3600
1800	2000	400	2800

WP 's with high TSP illumination demands. The standard illumination WP_{si} for WP_3 is

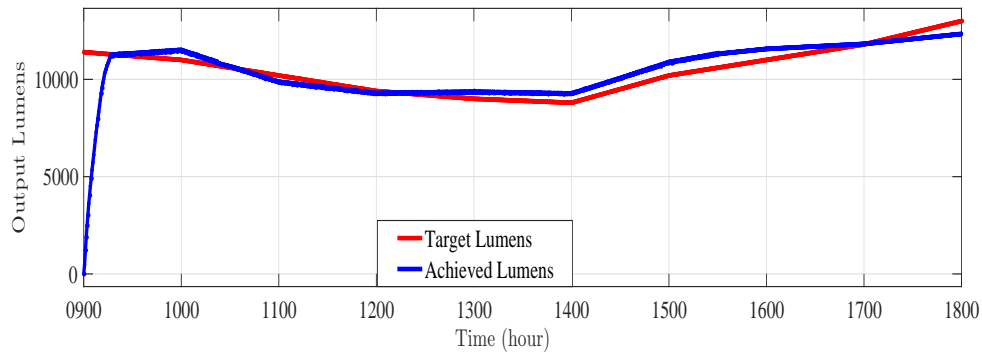


Figure 4.7: Controller response for WP_3 with input set D_{11}

considered as 500 lumens per m^2 . Thus TSP for WP_3 is 15066 lumens ($30.132 \times 500 = 15066$ lumens). Since, the WP_3 have high TSP illumination, to suffice the variable TSP demands the current application includes four daylight sources i.e window. Hence, each inputs of Table-4.1 are multiplied by factor of four so that appropriate daylight input reaches WP 's. The controller is tested with daylight input set D_{11} . At 0900 hours the artificial lumens demand to achieve TSP is 11466 lumens.

The Fig. 4.7 shows efficient tracking of the variable target values. The controller operation promises the target illumination at variable daylight distribution time zone. The controller action even achieves the values of 13066 lumens at 1800 hours. The Fig. 4.8

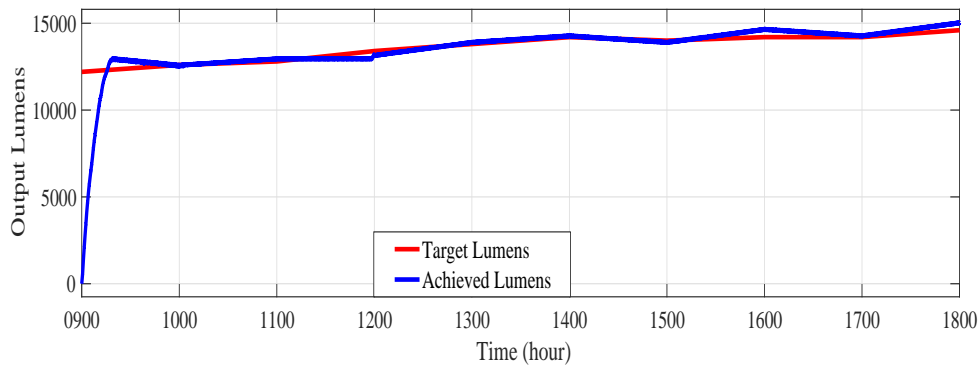


Figure 4.8: Controller response for WP_3 with input set D_{12}

shows the controller response for daylight input D_{12} at WP_3 . The unavailability of daylight

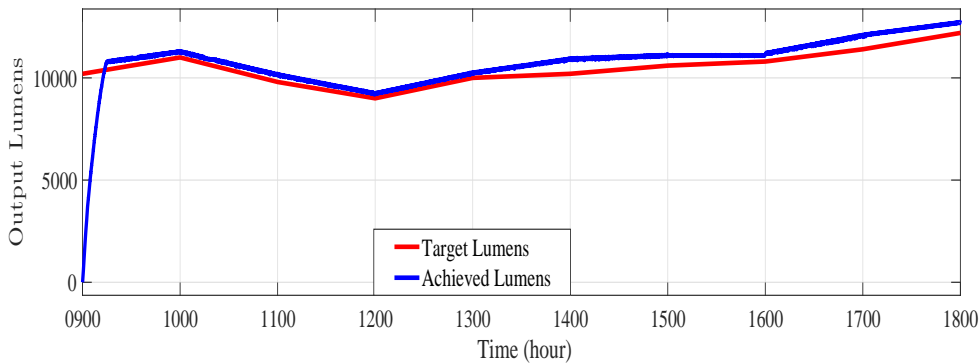


Figure 4.9: Controller response for WP_3 with input set D_{13}

is efficiently tracked. The adaptive controller accordingly generate control signals for time zones where daylight distribution is poor. The controller provides excellent response at 1300 hours, however this the starting point point where degradation in D_{12} begins. The

D_{12} levels falls from 1200 lumens at 1300 hours ($300 \times 4 = 1200$ lumens) to 400 lumens at 1800 hours ($100 \times 4 = 400$ lumens) received from four daylight sources.

Desired response by adaptive controller is shown in Fig. 4.9 for abruptly varying daylight input D_{13} . The TSP levels are productively achieved at different time instants. The availability of natural input in D_{13} is comparatively higher at 1000 hours and 1200 hours, which drops during 1100 hours and 1300 hours. The nonlinear characteristic of D_{13} is complemented by controller for WP_3 to achieve target lumens.

4.6 Case-IV: Results of WP_4 with variable inputs.

After successfully integrating different daylight inputs for the three WP 's in above sections. The present segment aims at integrating DH with WP_3 . The TSP illumination for this particular WP is increased to 18600 lumens ($A_{WP_4} = 37.20 \text{ m}^2$, $TSP = 37.20 \times 500 = 18600$ lumens). The standard illumination WP_{si} for this particular application is assumed to be 500 lumens per m^2 .

Table 4.4: Daylight variation pattern for WP_4

Daylight Inputs (Lumnes)			
TIME (Hour)	D_{11}	D_{12}	D_{13}
0900	4500	3500	6000
1000	5000	3000	7250
1100	6000	2750	6500
1200	7000	2000	7500
1300	7500	1500	6250
1400	7750	1000	6000
1500	6000	1250	5500
1600	5000	1000	5250
1700	4000	1000	4500
1800	2500	500	3500

Table 4.4 shows daylight variation inputs which are given to controller. For this application to achieve TSP illumination at each time instants the daylight inputs are increased to five times the values presented in Table 4.1. Initially, the controller response for input set D_{11} is determined. The change in natural lumens are effectively adopted by the adaptive fuzzy-PID controller. Moreover, an instantaneous response is generated by the controller during each changes. The Fig. 4.10 shows the response of controller with input set D_{11} . The controller achieves fine tuning with the linear variations in daylight changes. The daylight input increases linearly from 4500 lumens ($900 \times 5 = 4500$ lumens) at 0900 hours to 7750

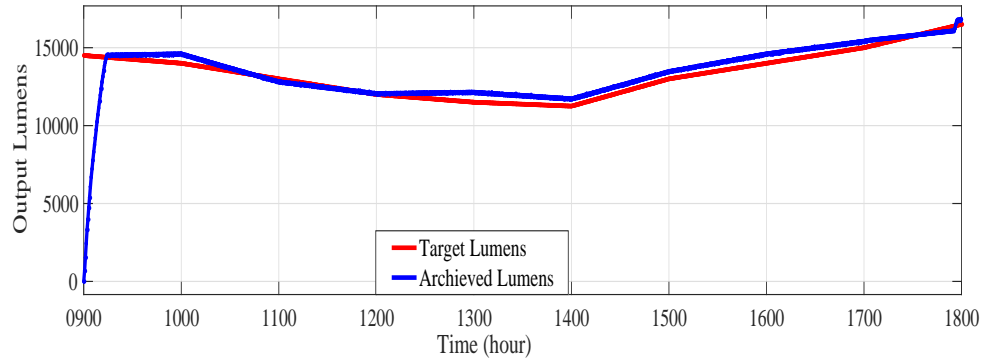


Figure 4.10: Controller response for WP_4 with input set D_{11}

lumens ($1550 \times 5 = 7750$ lumens) at 1400 hours. The linear drop in daylight input is then witnessed i.e 2500 lumens ($500 \times 5 = 2500$ lumens) at 1800 hours.

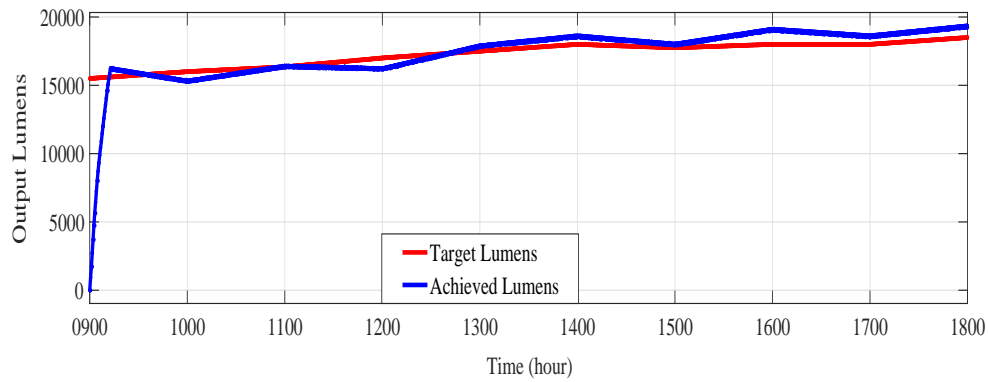


Figure 4.11: Controller response for WP_4 with input set D_{12}

The Fig. 4.11 represents the controller response with input set D_{12} . This input set incorporates the weather factors, the daylight availability is reduced at different time instants of the day. The controller responds well with the degraded availability of daylight. The D_2 reaches to the minimum region of illumination easily i.e is 1800 hours.

A similar response is seen with input set D_{13} . The controller adapts swift changes in daylight in prompt manner. The Fig. 4.12 shows the desired results by the controller for the WP_4 . The controller facilitates the desired response with variation in daylight inputs. In this input set accomodates the swift changes taking place in daylight changes. The daylight input is escalated during 1000 hours, 1200 hours and 1400 hours and subsequently falls at the preceding hours. Moreover the converter have to supply reduced I_{TC} values during when daylight availability is high. The controller response at each WP is matched evenly by the controller. The Takagi-suegeno system automatedly track the nonlinear variation

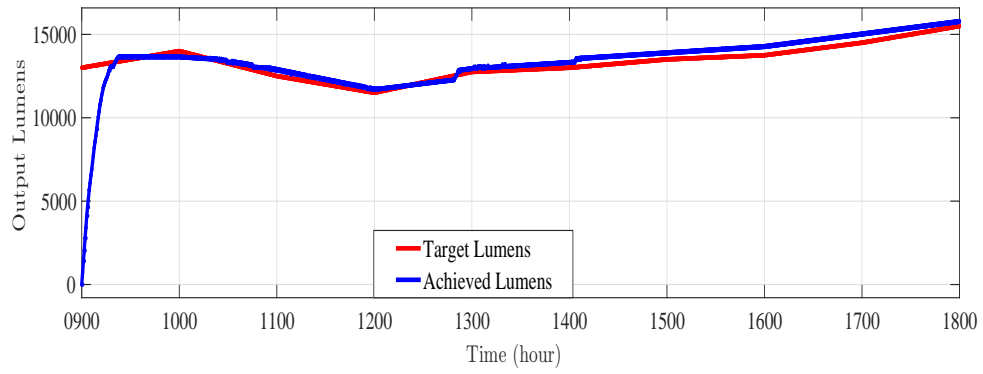


Figure 4.12: Controller response for WP_4 with input set D_{13}

and drives appropriate PWM pulses at the gate terminal of DC-DC buck converter.

Chapter 5

CONCLUSION AND FUTURE WORK

5.1 Conclusions

This dissertation work aims on integrating DH with artificial lighting. The fuzzy-PID controller is developed to tune the artificial lighting (LED) with daylight. The fuzzy controller incorporates Takagi-sugeno fuzzy inference system. The inference system makes over all control process adaptive and achieves self-tuning. The controller updates the control parameters to achieve TSP illumination level at different WP's. Moreover, self tuning of artificial lighting with DH reduces the current drawn from supply thus achieving energy saving. The results section confirms, that proposed controller effectively adapts to daylight variations. The results are verified with three different daylight input sets D_{11} , D_{12} and D_{13} incorporating various constraints i.e room dimensions and applications. Following conclusions are drawn from above work:

- The Fuzzy-PID controller developed here, combines the robust characteristics of PID to produce fast response and heuristic approach of fuzzy systems incorporating human intelligence.
- The Takagi Sugeno FIS achieves the linear tuning for abrupt daylight variation.
- The inclusion of DH phenomena with artificial lighting reduces the current drawn from supply to obtain proportional illumination.
- The inputs applied to the controller, are comfortably incorporated to achieve TSP illumination levels.

5.2 Scope of Future Work

The presented work gives one method to integrate DH with artificial lighting to achieve desired illumination. Moreover, contributions can be made for more optimum control of LED involving DH, these identified as:

- Implementing adaptive neuro fuzzy inference system (ANFIS) system for updating control parameters of PID controller.
- Moreover, the converter with different topologies can be implemented. This provides more effective control of instantaneous current drawn from converter.
- The constraints associated with different WP's can be effectively integrated in order to obtain better and realistic simulation.
- The controller can be tested for real time data obtained for any WP's, rather than testing it with defined inputs.
- Research and development of the proposed technology will lead to practical feasibility of controller.

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LIST OF PUBLICATIONS

1. S Joshi and M. Singh, “ Adaptive Control of LED in Daylight Harvesting Environment in Smart Buildings” Manuscript under prepration

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