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Artificial Intelligent Technique for Power Management Lighting Based on FPGA

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K E Y W O R D S

Artificial neural network, LED (Light Emitting Diode), Pulse Width Modulation signal, FPGA (Field Programmable Gate Array), Dimming, Power Saving

A B S T R A C T

The modern technological advances gave rise to new intelligent ways of performance and management in various fields of our lives. The employment of the artificial intelligent techniques proved influential in enhancing the technological developments and in meeting the demands for new, more efficient, more reliable and faster ways of performing activities and tasks. Lighting systems are an important part of human life. For this reason, it is important to reduce and manage energy consumption properly. Light dimming paves the way for massive energy saving in lighting applications. The options include simply reducing the output during the night and achieve maximum saving with variable dimming. Advantage can be taken of off-peak times (no light needed) to reduce energy consumption significantly. Pulse Width Modulation (PWM) technique is used as dimming method. The proposed system offers intelligent management of lighting to reduce power consumption, extend lamp life and reduce maintenance. In this work, we will be using multiple sensors such as light dependent resistor (LDR) and Motion Sensor (PIR) for LED dimming system to achieve intelligent LED lighting system to manage energy consumption. The data collected by sensors is processed by Artificial Neural Network (ANN), which is implemented by using Field Programmable Gate Arrays (FPGAs), Spartan 3A starter kit that controls the light intensity of LED from changing the duty cycle of the PWM signals. FPGA was used to implement the design, because of the re-programmability of the FPGAs, which can support the re-configuration necessary to implement the design. VHDL program was used to describe the functions of all necessary components used. Xilinx ISE 14.7 design suite and MATLAB R2012A were used as software tools to perform Spartan 3A starter kit program. The Simulation results were obtained with Xilinx blocks found in MATLAB program.

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1. Introduction

Because of the importance of lighting in daily life, the use of lighting management systems is steadily increasing in indoor and outdoor lightings. These systems provide many advantages to lighting users. One of the main advantages is to reduce the consumption of electrical energy in lighting [1]. In recent years, researchers have been interested in power management for the lighting system for various reasons, such as preserving the environment and economic advantages. Lighting accounts for approximately 19% of the consumption of power electricity in all cities of the world, which represents a great possibility to reduce the consumption of electricity over the coming years. Electrical lighting is so important to every person that he or she cannot live without it. Studies indicate the use of 30 billion light lamps on the surface of the earth, consuming each year 2650 TWh [2]. The light emitting diode is distinguished by many characteristics that make it more widely used in lighting systems. The most important of these is the low energy consumption compared to the rest. It is highly efficient, less expensive in manufacturing, and needs less maintenance for its longevity. It is friendly to the environment because it emits less CO_2 and is smaller. It has spectrum of colors that can be controlled in different ways [3]. It is possible to control the level of LED lighting on demand, this control is called the dimming, and there are many control strategies used to control the amount of dc current flowing through the LED, which in turn controls the light intensity of the LED. The control of LED lighting is mostly done by contrast either in the dc current level or by controlling the current of LED by using pulse width modulation (PWM). It is more used as a way to control the intensity of the LED lighting and it is more suitable. The change is only at the time of current flow in each period (duty cycle) [2, 4]. In this study, we will use different sensors (light sensor and motion sensor) and FPGA, Spartan 3A starter kit to design and implement intelligent lighting system where the artificial neural network will be built on FPGA kit to control the LED driver circuit. The proposed system for dimming LED lighting is shown in Figure 1.

2. Dimming and Pulse Width Modulation

The control of illumination level is done by means of dimming. There are two ways to dim the LED: adjusted dc current level of the LED linearly and may be called analog dimming, or the current of the LED can be adjusted from the control of the duty cycle of pulse width modulation (PWM) signal. This method may be called digital dimming and it is more used to control the light intensity of the LED for easy use, simple implementation and high efficiency [4, 6].

Duty cycle defines as the time ratio between the “on” state (Mark period) and the period of the pulse (Frame period), simple PWM waveform is shown in Figure 2 [2, 5].

Duty cycle = (Mark period)/(Frame period) (1)

Mark period = 2M*Tclock (2)

Frame period = 2n *Tclock (3)

Frame period = PWM period = 2n*Tclock (4)

Where:

n: is the number of bits in the frame period.

M: is the number of bits in mark period (ones).

Tclock: is the time of clock signal.

From Eq. (4):

n = log2(PWM period)/Tclock (5)

Tclock = 1/Fclock = 20 nsec. (Fclock: is the frequency of clock signal equal to 50 MHz is provided by Spartan3A kit).

The dimming by using PWM is implemented by switching on and off the lighting of LED, the human eye does not perceive the flickering in lighting due to dimming method if the dimming frequency is 50 Hz or more, but the recommended minimum frequency is 200 Hz [2].

From the above, PWM with 200 Hz was chosen as dimming signal, PWM period was (5msec). Using Eq (5).

n = log2(5 msec)/(20 nsec) ≈18bits.

From the previous equations, we can obtain the number of bits in mark period (ones).

M= INT (n* duty cycle) (6)

Table 1 illustrates some PWM value and equivalent duty cycle. Eq (6) used to determine these values.

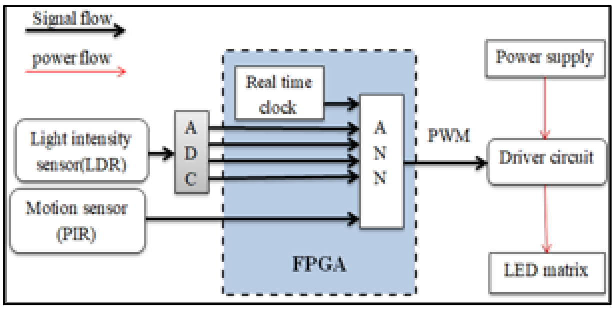

Figure 1: The proposed intelligent dimming system for LED

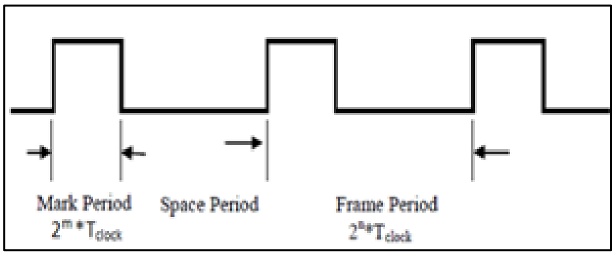

Figure 2: Pulse Width Modulation waveform [2].

Table 1: Some PWM value for different duty cycles

PWM Value (Hexadecimal)	Duty Cycle%
3FFFF	100
0FFFF	90
03FFF	80
00FFF	70
003FF	60
001FF	50
000FF	40
0003F	30
0000F	20
00003	10
00000	0

PWM signal includes 18 bits. It means that we have 256 (2^{18}) lighting level for dimming. The resolution of designed PWM is $1/2^{18}$, 0.00038%.

Figure 3 shows the proposed dimming scenario. The light intensity of LED gets bigger gradually after sunset whenever the darkness increases according to light sensor (LDR). After midnight (traffic is decreased) the light of LED dimming to 50%, but when found movement according to motion sensor (PIR) the light will be increasing to 100% for some minutes.

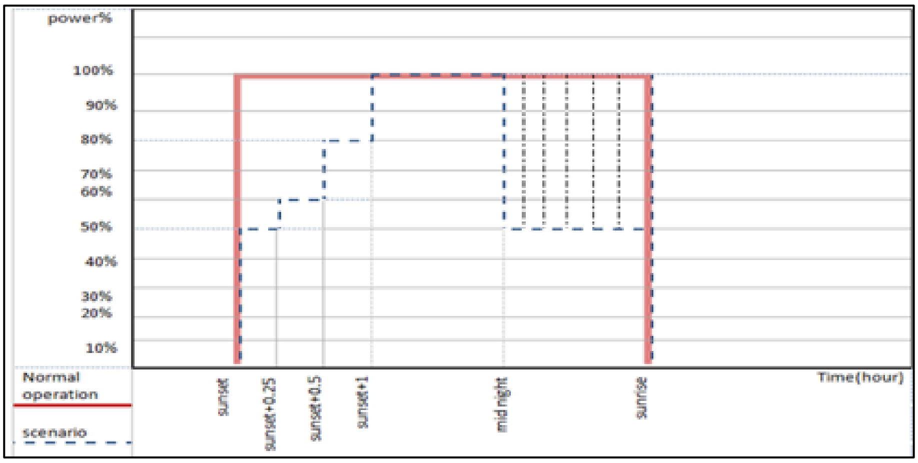

Figure 3: The proposed diming scenario

3. Intelligent Control Design

It is possible to have an intelligent dimming system without the need for manual control using two different sensors and hour. Lighting sensor (LDR) that monitors the intensity of the ambient light, the motion sensor (PIR) provides traffic data for road and hours provide real time clock to control the brightness of the LED light through ANN.

The LDR is a device that has a resistance changes with the lighting intensity. The LDR has a resistance that increases when the light intensity is decreasing and vice versa [7].

We will record reading the resistance of Light Dependent Resistor (LDR) (using ohmmeter) and illumination intensity (using digital Lux meter) at various illumination level. Figure 4 shows the link between the illumination and the corresponding resistance of the LDR in order to obtain the information about the change in lighting level. We will place the LDR in a voltage divider circuit. The amount of voltage will be affected by the change in the value of LDR resistivity resulting from sensitivity to change in intensity of illumination. Analog to digital converter was used to convert the LDR output to a digital form, the digital output was used to provide light intensity information to ANN then PWM signal was generated.

By using the NI Multisim 12.0 program, we got the results in Table 2 as showing in Figure 5.

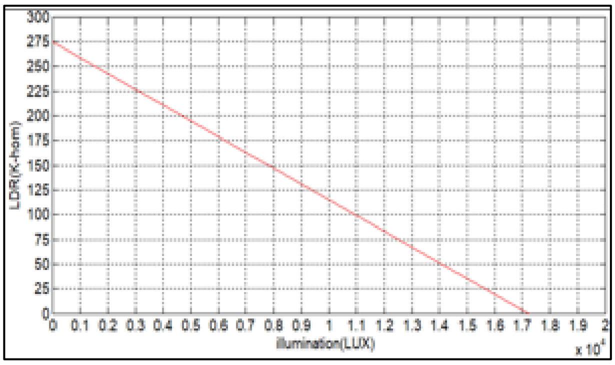

Figure 4: Resistance as function of illumination

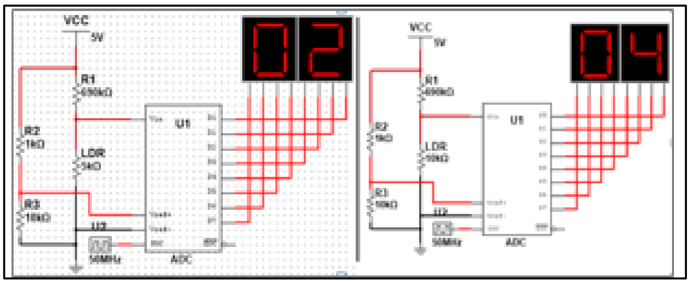

Figure 5: LDR circuit as light sensor

Table 2: Some ADC_{out} and duty cycle of PWM signal for different illumination levels

Illumination (LUX)	LDR (KΩ)	ADC_{out} (hexa)	Duty Cycle%
more 100	Leas 2.5	00	0
98-37	2.5- 4.9	01	0
35-17	5-7.5	02	50
16-10	7.6-9.95	03	60
9-2	10-12.48	04	80
Leas 1	more 12.5	05-FF	100

4. Artificial Neural Network

Artificial neural network (ANN) is one of the most important techniques of artificial intelligence. The artificial neural network is similar to human brain because it has gained mission through training. It consists of a large number of cells called neurons where these cells tend to have less connection in the artificial neural network than biological neurons. Figure 6 illustrates the typical shape of the artificial neuron. The artificial neural network consists of three main layers: output layer, input layer, and hidden layer, which may not exist, one layer or more one-layer dependent on design of artificial neural network. [8,9].

$$Y=f(net) \tag{7}$$

$$Net = \sum_{i=1}^{n} [a_i * w_i] + w_0 \tag{8}$$

Where:
w: weight.
a: input.
n: no. of inputs.
w0: bias.

5. Procedure for Designing Neural Network

The most artificial neural networks commonly used is the Multi-Layer Perceptron (MLP) Network because they give more realistic and amazing results and are very simple.

The best algorithm that provides fast training for the artificial neural network compared to other algorithms is Levenberg-Marquardt (trainlm) where they possess a decent gradient of training which is evident through experimental results [10]. Choice of algorithm, activation function and number of neurons in hidden layer is dependent on many training attempts. The best neural network is shown in Figures 7-8.

Figure 9 illustrates the internal structure of neural network (NN) model.

Note that the model shown in Figure 9 contains many elements that cannot be converted to VHDL code because they are not supported by Xilinx programs and hardware platforms. Therefore, we will face many challenges when converting.

We will be creating VHDL code after changing all elements not supported by Xilinx programs as shown in Figure 10, which contains many sub-systems. When generating VHDL code for model, it will generate many VHDL files result of the subsystems that connect with each other by map in the configuration m-file, and now VHDL code this can be downloaded to FPGA kit.

After generating the VHDL code for the model in Figure 10, we will fetch the code into the black box inside MATLAB R2012A program with the support of Xilinx ISE 14.7 design suite tools as showing in Figure 11.

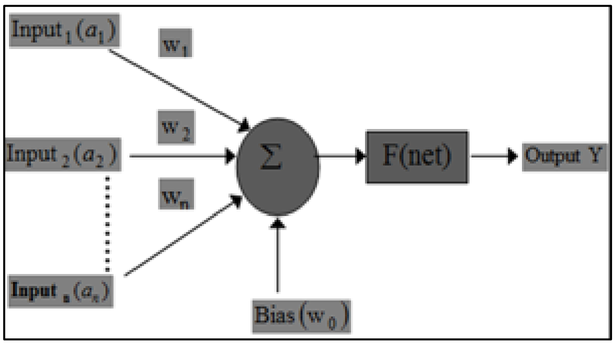

Figure 6: The typical form of neuron [8]

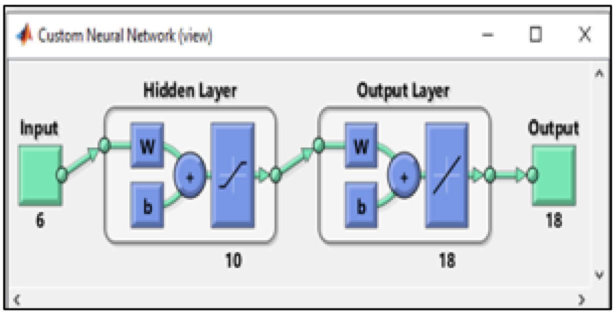

Figure 7: Neural network Simulation

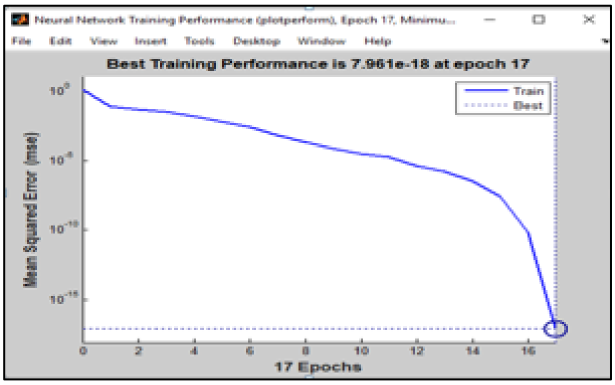

Figure 8: The Mean Square Error of neural network training

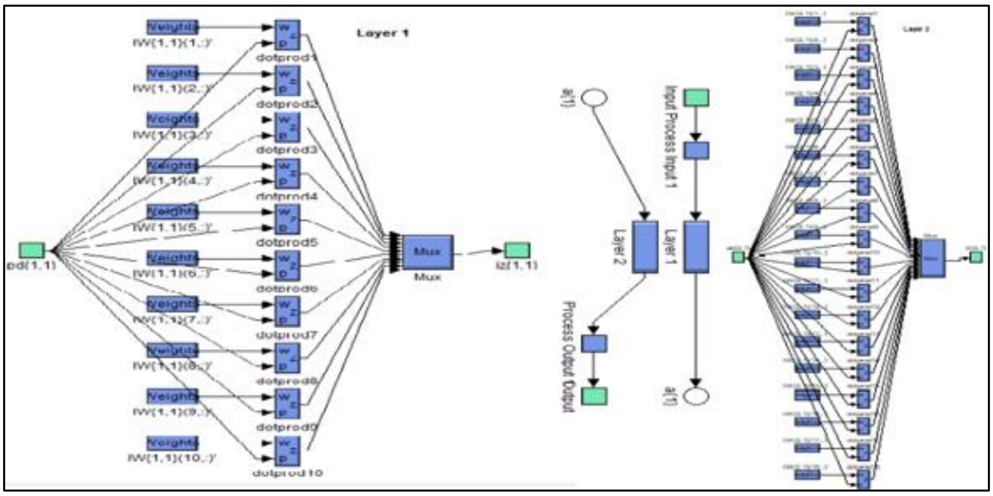

Figure 9: Internal structure of ANN model

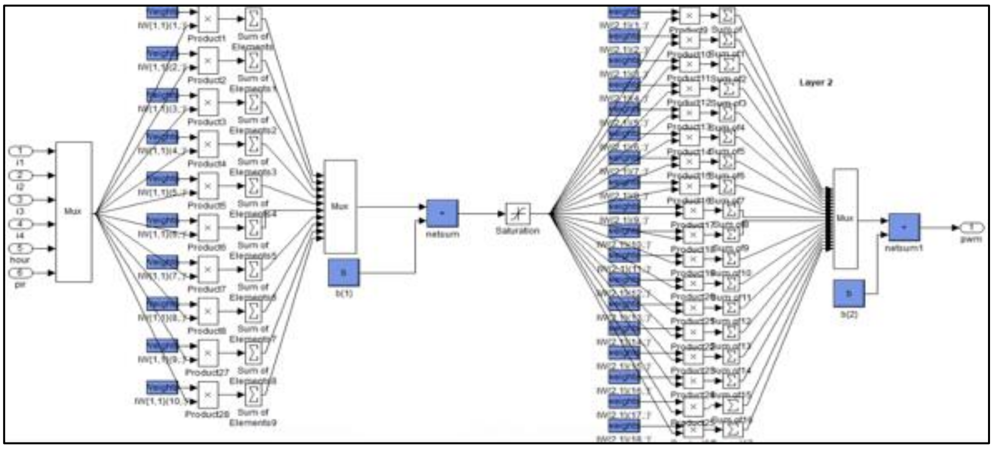

Figure 10: Final ANN model that will be converted to VHDL

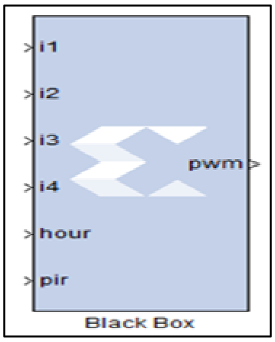

Figure 11: Black box of the VHDL code

5. Simulation Results

Connect the inputs with the block in Figure 11 to illustrate manual check as in Figures 12-14. From Table 2, we note that the output of ADC is 8 bits, but we can convert it to 4bits (using OR gate) to minimization input ANN.

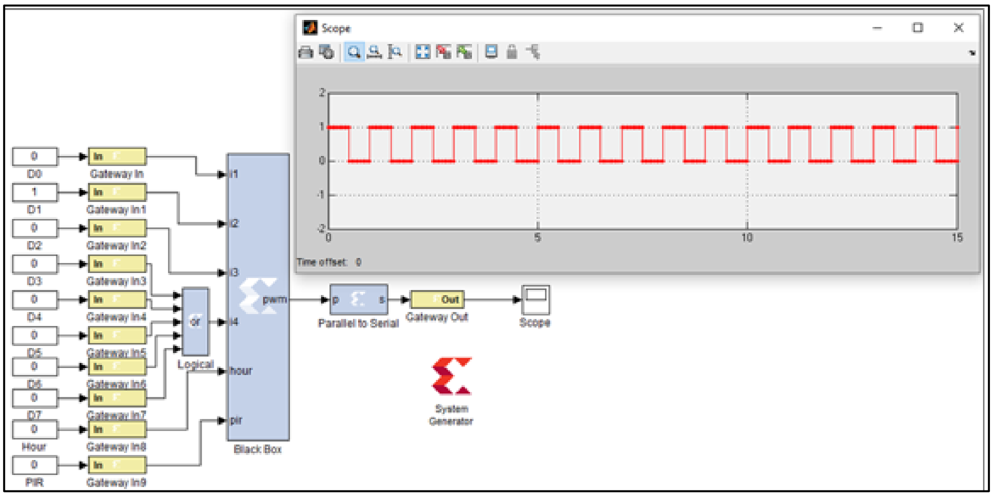

Figure 12: The PWM signal generated by NN model at 50% duty cycle.

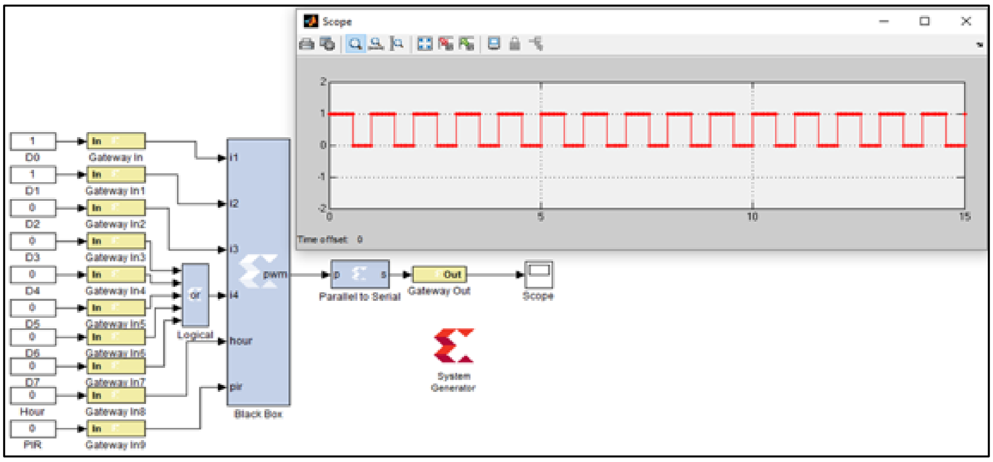

Figure 13: The PWM signal generated by NN model at 60% duty cycle

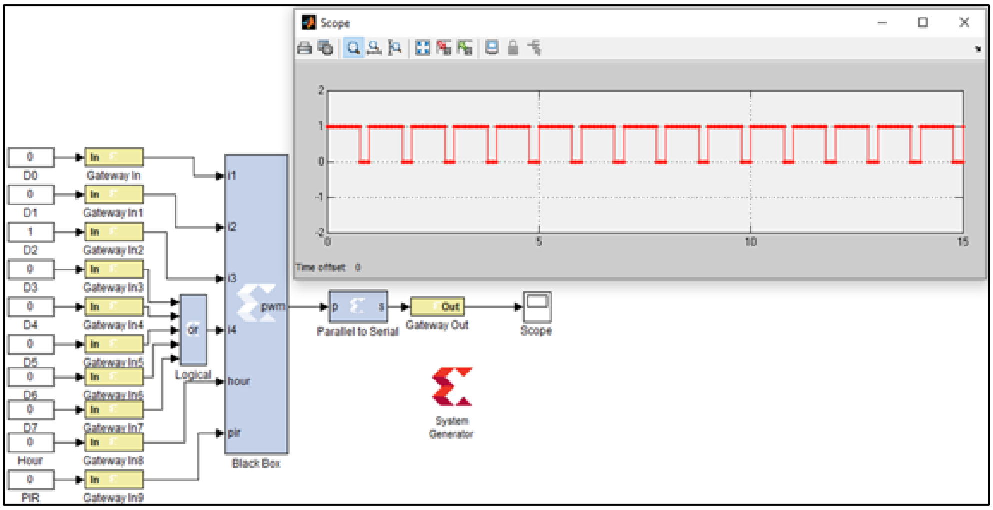

Figure 14: The PWM signal generated by NN model at 80% duty cycle.

6. Conclusions

Deduce through research, the following conclusions:

1. The proposed system has 256 lighting levels can be controlling it through duty cycle of the PWM signal, and we have system that controls the light intensity of the LED automatically and can work together with a wireless and / or wired network system anywhere.
2. The use of FPGA gave our design a great flexibility as it can change the dimming ratio of LED light easily.
3. Provide 50% from power consumption for lighting through intelligent control of LED lighting for indoor and outdoor lamps at no traffic.
4. Using 150W LED lamp for lighting instead of 400W HPS: Reduce the power consumption for lighting about 63% (provide $12822.6 annually), reduce emission CO2 about 45 ton annually.
5. Using an LED as lighting source with this proposed system: 71% power saving compared to HPS and about 22% compared to normal LED operation.

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