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Design for Optimization of Solatube Lighting System and Lights with GA-PID Controller

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Abstract--Solatube is a pipe casing used to channel sunlight from the roof of a building into an enclosed space. The advantage of using Solatube is that it can avoid excess light being directed. However, there is no mechanism for controlling the intensity of sunlight entering the room through the Solatube. By adding control settings, the intensity of incoming sunlight can be adjusted so that it can help visually comfort. It is necessary to control the opening and closing valves to adjust the power of the light produced by the Solatube and the lamp. So, it is needed to design an optimal lighting source to regulate the quantity of light received by the room and the people in the room. The paper aims to achieve good control results by valve controlling using PID control which tunes the parameter by the Genetic Algorithm. Thus, the light intensity entering the room will be stable 24 hours a day. So, that eye comfort, visual coolness and energy savings can be achieved.

Keywords--Arduino Uno, Energy Efficiency, Lamp Dimmers, PID, Solatube Valve.

I. INTRODUCTION

Energy efficiency is an essential thing to do. For the sake of the survival of this world, we have to do many things related to energy saving, especially non-renewable energies (petroleum, coal, etc.). The need for electrical energy continues to increase, so the choice of renewable energy will be a solution for energy sources in the future. Although renewable energy sources are increasingly being used, reducing energy consumption is the best way to reduce energy consumption [1, 2, 3].

One of the most popular renewable energies today is solar energy which can be converted into electrical energy. Sunlight can also be used as natural lighting in a room to reduce energy consumption. The primary source of electrical energy in Indonesia is still produced from fossil fuels that undergo processing and produce carbon dioxide emissions. Reducing electricity for lighting is one way to create energy-efficient buildings. In Indonesia, a tropical region, the potential for using natural lighting is very high to be used as the leading lighting solution during the day. Natural lighting from sunlight has the potential to reduce carbon dioxide emissions and ultimately aims to reduce the effects on the environment [4, 5, 6, 7].

Based on research, passive lighting systems can save 20% - 30% of the total consumption of electrical energy consumed [6]. In addition to the need for room lighting, sunlight can also be used to minimize energy consumption during the day [7]. Therefore, the lighting factor is one of the critical factors used in designing a room. There are three room lighting sources: lamp light, glass curtains, and sunlight. This room lighting source ultimately aims to achieve visual comfort [8].

However, some problems will arise if direct sunlight's lighting source is not regulated. First, the amount of exposure to excessive sunlight will be insufficient because it can become light pollution [9], and there will be overheating problems which can cause visual discomfort. In research [10], the guide structure of the diffuser was described to ensure adequate lighting levels. So that the advantages of natural lighting sources can be felt if the quality can be arranged then that it is comfortable for humans [11]. Therefore, the optimal lighting source design includes optimizing the quantity of light that humans and the room can receive, visual comfort and coolness can be felt and save energy. Natural light sources will be complicated because of the room's location, such as in the basement, which is too narrow and blocked by objects in the room, causing a dark atmosphere even during the day, or a room office partition located on the inside a large room. The conditions can cause a decrease in light intensity which in the long term can affect the physical and mental health of the occupants [12].

One method that can be used to maximize the utilization of sunlight in a room without light ventilation can be a tool called Solatube [13][14]. Solatube is a pipe casing used to channel sunlight from the roof of a building into a closed

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room that requires a light source. Research [10] described the introduction of innovative technologies in natural lighting. The advantage of using a Solatube is that it can reduce the excess light transmitted compared to receiving direct sunlight. In addition, it can help keep the extra temperature rise in a room. In research [14], various prototypes of natural lighting systems can be understood. Then the use of Solatube can save energy consumption and has a high economic value with a percentage of room light usage of 1% - 79% [15] during the day. Solatube is also very suitable to be applied to Smart City because it follows the concept of energy-saving [16]. Based on research, the combination of Solatube and lamp dimmer settings has the most significant potential to save electricity by 27% [17].

Many energy efficiencies or energy-saving issues have been discussed in several journals. Among them are talking about energy savings in terms of using energy-efficient lighting, using AC with an inverter that is more energy-efficient, and installing Solar Panels. In previous studies, energy efficiency was carried out by utilizing solar energy (solar cells), both integrated with solar PV and solar PV smart grids [18][19]. However, the weakness is still using solar cells and batteries to accommodate electrical energy generated from sunlight. Solar energy thus requires more complex funds and equipment.

In another study [6, 17, 20, 21], it was mentioned the use of Solatube as a renewable energy source derived from solar energy for lighting is an energy-saving solution, thus utilizing natural light from the sun without the use of electrical energy for room lighting. However, the weakness is that there is no mechanism for controlling the intensity of sunlight entering the room through the Solatube. So, only research is carried out on the benefits of Solatube as a substitute for lighting. And in the study, [17] explained the request to continue research by adding control settings so that the intensity of incoming sunlight can be adjusted to help visually comfort. So, in [15], this energy-efficient lighting system was created by combining lamp dimmers and Solatube. The combination to maximize natural resources from sunlight as a light source in rooms that do not have light ventilation to achieve light with the expected intensity with less lamp power consumption. However, there are still weaknesses in the research carried out because there is no control of the opening and closing valves that can automatically be moved to adjust the intensity of the light produced by the Solatube. The condition is necessary because the sun shines brightly on a sunny day. The intensity of light produced by Solatube is light above 350 lux, even more than 450 lux. Of course, this is disturbing the comfort of people in the room. Besides, the room will also feel hotter.

Tiwari et al. [22] stated that the Genetic Algorithm (GA) is the best algorithm that can be used to determine optimal Proportional, Integral and Derivative (PID) controller values for motor speed DC. The PID parameter tuned with the GA has a faster response when compared to the standard or classical method, such as Ziegler Nichols Method. The classical approach is used to generate the initial value of the PID parameter, which is then used to evaluate the optimized parameters through the Genetic Algorithm. The process will give better overshoot and maximum rise time results.

So, it is necessary to design an optimal lighting source to regulate the quantity of light that can be received with comfort and coolness visual sense can be felt. This paper controls the Solatube valve and lamp dimmer with the Arduino Uno controller to achieve good control results. It is expected to reach a precise and efficient valve position. The amount of light transmitted into the room corresponds to the amount of Lux light, which is stable at 350 lux and reduces the occurrence of flickering light [14]. Therefore, the room's eye feels comfortable, and the visual coolness and heat of the room will be maintained as expected. It is also equipped with a dimmer to maintain a stable light in cloudy, rainy, or night conditions.

The remaining sections of this paper are organized as follows: Section 2 contains the methods used. Section 3 presents the discussion. Finally, section 4 presents the conclusions.

II. METHOD

A. Solatube System

Solatube is a pipe casing that directs sunlight from a building's roof into a closed room that requires lighting. Then the light in the pipe will be channelled into the room. The results of the light intensity produced by the Solatube system can be used to meet the needs of the light intensity of the room. Fig. 1 shows the block diagram of the Solatube system.

There are zones in a Solatube system, namely: Capture Zone, Transfer Zone and Delivery Zone, as shown in Fig. 2. The capture zone section functions to capture sunlight and direct sunlight to the transfer zone. In contrast to skylights that are usually installed on the roof of a building, skylights will continue all the sunlight that penetrates it. Then it will feel hot or sometimes even not enough light can pass when the sun's light is at a certain angle. At the same time, the Solatube lighting system is equipped with raybender 3000 technology which uses a Fresnel lens series to reflect sunlight in the right amount based on the angle of the incoming sunlight.

In the transfer zone area, it has been designed so that the inner surface of the Solatube can reflect sunlight perfectly. Equipped with Solatube spectra light infinity tubing, with a reflective inner wall surface of the tube so that it can transfer sunlight with minimal loss due to absorption. Then, that light can be channelled into hard-to-reach places even with a few turns of the Solatube tube needed to reach the point where the room needs it. The delivery zone section acts as a lamp glass. It is equipped with a light diffuser with various shapes and designs that can be selected based on consumer tastes and desires. Diffusers can spread light in a room in multiple forms, and some are made plain or patterned according to consumer desires.

To regulate the amount of light intensity that is channelled into a room, Solatube is equipped with a Solatube valve and its driving control. The drive control uses a DC motor and requires a voltage of 0 – 10 VDC to drive it. For more details, the following Fig. 3 illustrate the shape of the Solatube valve and its driving control. At the same time, the direction of

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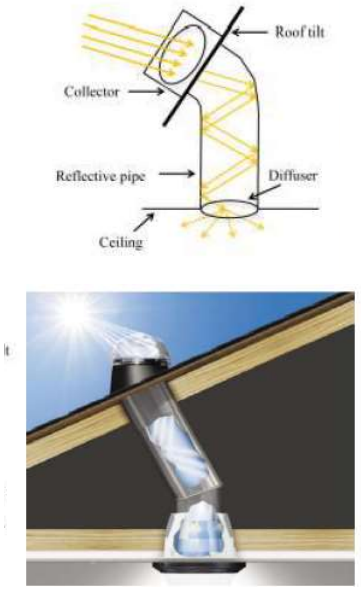

Fig. 1. Block Diagram of a Solatube system

Fig. 2. Zones in Solatube System

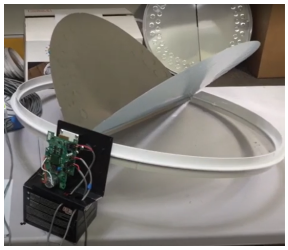

Fig. 3. Valve Control in Solatube System

B. Experiment Settings

There are three steps carried out in this experiment. The first step starts with designing the system model. Second, the research tries to analyze the system model. And third, it tests the system design to get a stable and unblinking lighting intensity at 350 Lux. The method used in this research is the design method with the model system design, as shown in Fig. 4.

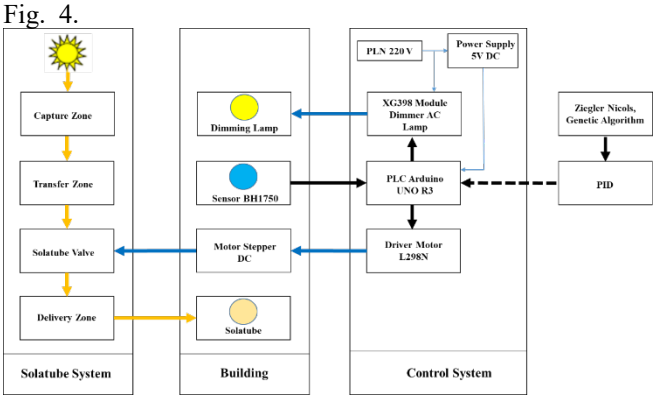

Fig. 4. Model System

The system model consists of three large blocks: the Solatube system block, the system-built block, and the control system block. The Solatube system block, as previously explained, consists of the capture zone, transfer zone, solatube valve and delivery zone. Meanwhile, the system-built block consists of a dimming lamp, a light sensor by BH1750, DC and stepper motor, and a solatube tube. At the same time, the control system block consists of a power system, control of the dimmer lamp by XG 398 Module, Arduino UNO R3 controller, and L298 N motor driver. In addition, there is PID Controller software in this control system with tuning using Ziegler Nicols and Genetic Algorithm.

C. Method System

In a previous study, this energy-efficient lighting system was made by combining lamp dimmers and Solatube [12] to maximize the natural resources of sunlight as a light source in a room that does not have light ventilation.

Therefore, light with the expected intensity can be achieved with less lamp power consumption. But there is still no control of the opening and closing valves that can automatically be moved to adjust the intensity of the light produced by the Solatube. Consequently, the light intensity produced in the room cannot be stable at 350 lux. The proposed method combines light sources from dimmer and Solatube lamps, regulated by automatic control of the Solatube valve. Then, perhaps the indoor light intensity can reach 350 lux stably for 24 hours a day without flickering.

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The system process is as follows: the light sensor will work continuously to detect changes in light intensity on the table in the room from Solatube and lamps. If there is a change in light beyond the set point of 350 lux, the sensor will signal the Arduino Uno Controller to process this condition. Then, the controller will send a signal to the motor driver to drive the motor in the direction of opening the valve until it gets a light equal to 350 Lux. If the valve is 100% open, it is indicated by the activation of the 100% valve opening limit switch. In this condition, if the light read by the sensor has not reached 350 Lux, the controller will send a signal to the dimmer module to turn on the light by making adjustments until the light produced matches a setpoint of 350 Lux as a control feedback system is carried out by the light sensor BH1750. In night situations, this control will still be able to work with the whole light from the lamp. The amount of lux has been determined at 350 lux for the lights installed, so without Solatube light at night, 350 lux will be produced from the lights established. The flowchart of the lighting control system is shown in Fig. 5.

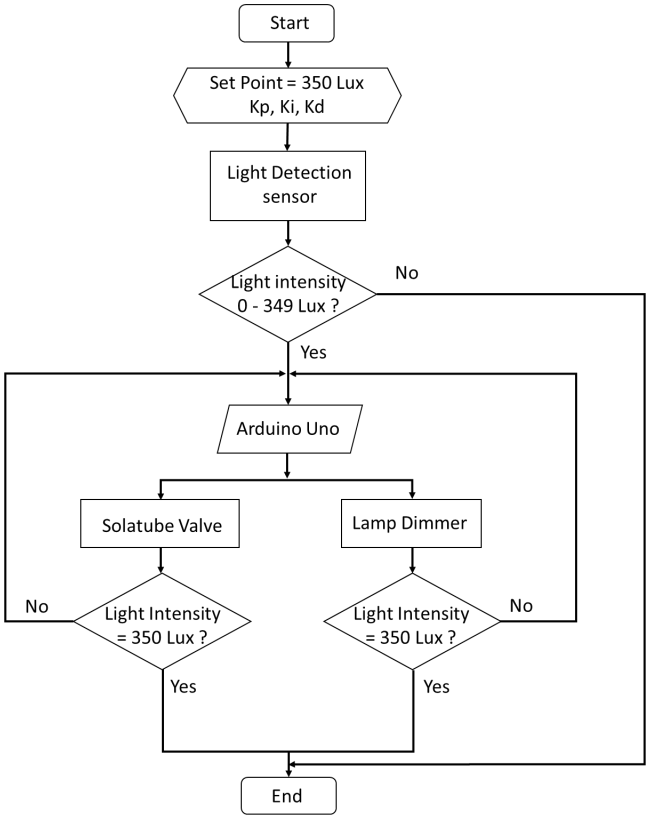

Fig. 5. Lighting Control System Flowchart

D. DC Stepper Motor Testing and Control

It is necessary to control a DC stepper motor to smoothly open and close the Solatube valve and adjust the lamp dimmer properly. Based on previous research [19], the speed of the DC Stepper motor can be controlled using the PID control. PID is the most popular controller used in control systems in today's industrial world. The PID controller is used to improve dynamic response and reduce errors. PID has advantages over other controllers, such as fast control, low settling time, and low operating costs. One of the PID controls on a DC Stepper motor is speed control.

The controller is conducted to improve the performance of the DC Stepper Motor to get better response results. Based on the speed response graph made, the performance parameters of the DC Stepper Motor can be seen from the overshoot, rise time, settling time and steady-state error values.

The PID Controller is needed PID parameters tuning design. Various tunning methods include the manual approach, Ziegler Nichols (ZN), Genetic Algorithm, Fuzzy Gain Scheduling (FGS) and others. Compared with other tunning methods, the Ziegler Nichols method and Genetic Algorithm give good results in achieving a set point. At the same time, the Genetic Algorithm can determine the best optimization of Kp, Ki, and Kd values. In this study, the Ziegler Nichols method and the Genetics Algorithm are used to tune the PID parameters in the Arduino UNO Controller program to move the Solatube valve smoothly with light intensity. Then it will compare both methods to get the best results. Finally, if the optimal Kp, Ki and Kd values have been obtained in the simulation, it will enter the PID parameter in the actual system.

The DC stepper motor characteristic used as a PID simulation tuning parameter is the necessary parameter data. And it will produce measurements of Kp, Ki, Kd, maximum peak overshoot, rise time, settling time and error value. Some tables will later contain the PID parameters measured by the Tunning Zigler Nichols Method and Genetic Algorithm. In addition, the analysis will be made a graph of the test results, such as a graph of motor response without PID, a graph of motor response with PID and a Lux vs time stability graph. Several simulations work, such as manual tuning and performance analysis using MATLAB software

III. Results And Discussion

The PID close loop process and the characteristics of the PID parameters to drive the Solatube valve motor are shown in Fig. 6 and Fig. 7. Fig. 6 shows the PID close loop process. In this process, the PID controller gets input from the error analysis results by comparing the Setpoint (SP) value and Process Value (PV) read by the sensor. The output of the PID controller is the Control Value (CV) which is the input for the process in the solatube system.

Meanwhile, Fig. 7 shows the effect of the PID controller parameters, namely: Kp, Ki and Kd, on system performance. Some of the system performances analyzed are Rise Time, percentage of Overshoot and Steady state error.

In a simulation of DC stepper, motor speed response control using PID are obtained by manually tuning using the Ziegler Nichols method and Genetic Algorithm. The most accurate PID measurement results will be obtained optimally, and a response graph will be formed.

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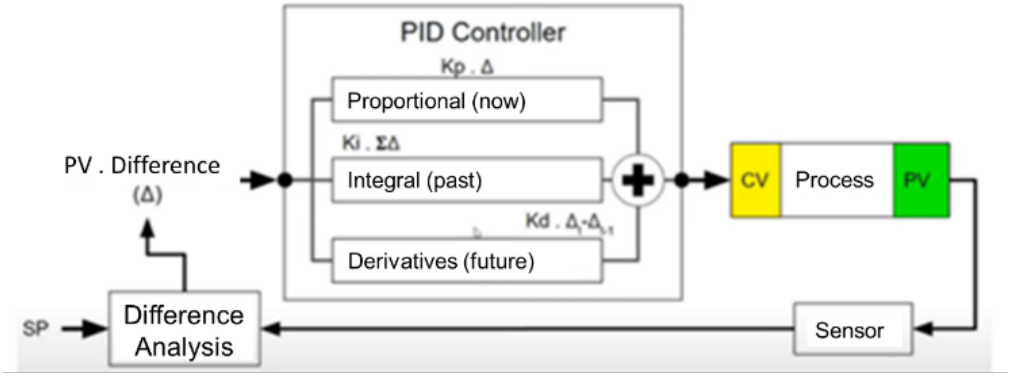

Fig. 6. PID close loop process

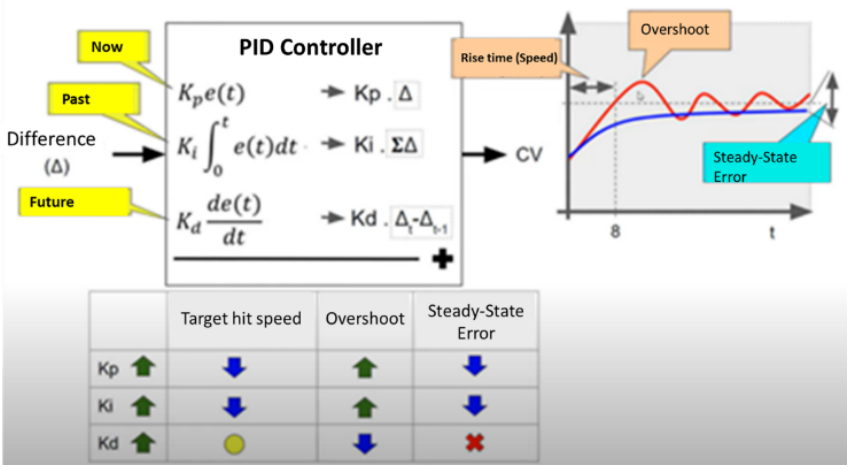

Fig. 7. Characteristics of PID parameters

Based on the response graph, it can determine the characteristics of the manual approach PID parameters, the Ziegler Nichols method or the better PID Genetic Algorithm method. Consequently, the Solatube valve's control setting will be able to run correctly to maintain a stable light intensity in the room at 350 Lux without flickering. A graph of the stability of light intensity will also be made against time. Then, based on the results of the comparison of energy use before and after the installation of Solatube, it will be known whether the resulting energy efficiency. The results will be obtained after it can be concluded from experimental tests and energy efficiency calculations, whether the system that has been created is successful or not.

IV. Conclusion

Solatube design starts with the sensor that detects the combined light between the lamp and the Solatube. To get a smooth response time from the movement of the Solatube valve motor, an appropriate PID parameter is needed. Therefore, the value will be obtained from manual tuning and simulated in MATLAB software. After getting the optimal PID value, this PID value is implemented in the actual system. After observing and experimenting, the data obtained will be analyzed at this stage. It can be concluded whether the Solatube valve control settings can work adequately to maintain the light intensity. Perhaps that visual comfort will be obtained, the room's heat will be maintained as expected, and the energy will be saved.

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