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Building a model of the street lighting energy-saving system

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Abstract— **General lighting and public lighting in particular are accounting for a large proportion of power consumption, including street lighting system. Modernizing the street lighting system to save energy and reduce operating costs, while ensuring the quality of lighting is considered an urgent solution today. This article is the result of the research to create energy-saving control cabinet for the street lighting system. The result of the research show that, by reducing and stabling voltage at the off-peak time, the power consumption of the bulbs is reduced. This stabilization also avoids overvoltage when the voltage is high at night which enhances the life of the bulbs.**

Index Terms— **Enrgy saving; Using energy efficiently; PLC S7 1200; High pressure street lights; Industrial communication network.**

I. Introduction

A public lighting system is evaluated through the following standards: Energy saving; the reduction of investment and labor costs; Safety for lighting equipment; Safety for road users; urban aesthetics.

Nowaday, in some places, these systems are not operating effectively: During the off-peak time (For example, from 22:30 pm to 5:30 am), the number of vehicles is low but the street lights still work the same such as the peak time (Example: From 18h to 22h30), this is the cause of wasted power. On the other hand, at night, the grid voltage is often higher than the rated voltage (about 240 - 250V), so the power consumption of each bulb also increases, which not only wastes power but also reduces the bulb's life.

The solution uses a microprocessor with real-time feature combined with dynamic devices to adjust the volttage of the bulb was mentioned in studies [1]–[4]. The communication through GSM telecommunications network to create intelligent lighting control system was used in research [5]. With the communication method by GSM, but [6] uses solar energy as a power source for lighting instead of using grid voltage. A system that automatically turns off street lights when there are no vehicles and automatically turns on lights when several vehicles are approaching has also been tested [7]. Along with the classical theory control, the modern theory control have been applied to street lighting systems, including: The Fuzzy Control [8] and Artificial Neural Networks [6] and [9].

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In Vietnam, energy saving solutions for street lighting systems have been researched and applied [10] - [12]. Some solutions include:

Solution 1: Turn off alternating the lights at night;
Solution 2: Replacing halogen bulbs by LED bulbs;
Solution 3: Using bulbs with two-level ballasts;
Solution 4: Using an autotransformer to reduce the voltage of the bulb to save energy.

The above solutions have effectively to save power consumption. However, solution 1 does not guarantee lighting quality. Solutions 2, 3, 4 have high investment costs. Solution 4 has stepless voltage regulation, but the loss at transformer is large and there is no automation. Along with saving electricity, the problem of power loss monitoring or fault warning needs to be taken care of. This paper presents a research to create an electrical cabinet to control the street light. The control cabinet can automatically adjust the lighting power with many different working modes and measure energy consumption and problems to send to the central control room. Especially with this design, it is possible to take advantage of the existing facilities at the roads, just replace the new control cabinet for the old one.

II. Experimental Model Design

A. Solution Design

We used PLC controller and power semiconductor devices to create a control cabinet. The control cabinet has the ability to adjust automatically the optimal power and stabilizes the voltage applied to the bulb through the PID controller integrated in the PLC S7- 1200. This solution has a higher investment cost than the off-interlacing solution, but still lower than other solutions.

This solution can:

- Reduce up to 40% of voltage, but still ensures the allowable light intensity
- Ensure the urban beauty of the city
- Stabilize the bulb's voltage to help increase the life of the bulb
- Take advantage of existing lighting infrastructure equipment.

In addition, due to the use of semiconductor devices, the system has little loss.

B. Hardware model design

The diagram of the single-phase control structure is shown in fig1. The detailed functional diagram of each unit is shown in fig2. In which, energy meter is used to compare energy consumption before and after using energy-saving cabinet. It is communicated by modbus RTU protocol with PLC S7 1200.

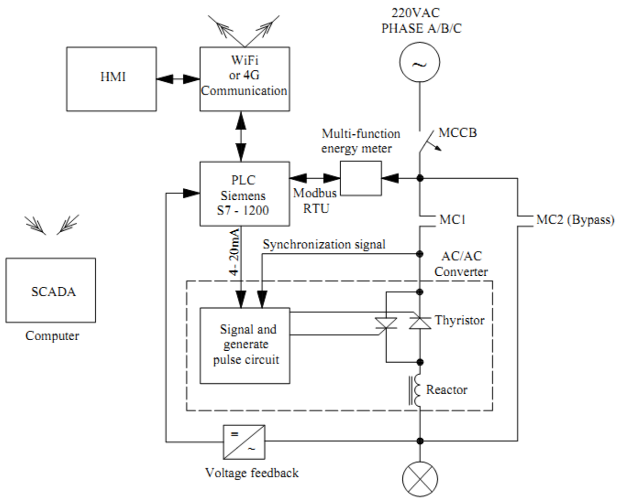

Fig1. Diagram of single-phase control structure

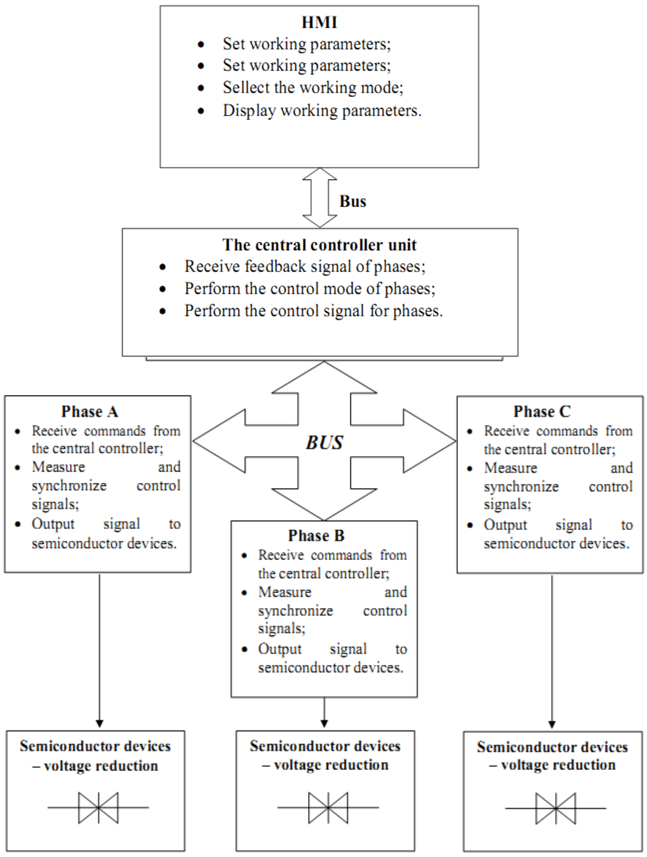

Fig2. The detailed functional diagram of each unit in the street lighting energy-saving system

The voltage feedback unit receives the signal feedback and send to the PLC unit. The PLC unit is the central controller, it will compare the feedback signal with the set value to adjust the output signal to the AC/AC converter according to the PID algorithm. The wifi unit or 4G communication unit is connected to the computer by wireless waves. The control software is built on the computer to monitor the entire system.

Working modes:

The system has 3 working modes including the standard mode, the turn off alternating mode and the mixed mode.

Standard mode or mixed mode is used to reduce the voltage applied to the bulbs during off-peak time to reduce power consumption. The percentage reduction is set from the HMI at the control cabinet or from the computer at the central control room. Based on the set value, the controller will automatically stabilize the output voltage according to the PID algorithm.

The working characteristic in the standard mode is shown in fig3 and the mixed mode is shown in fig4.

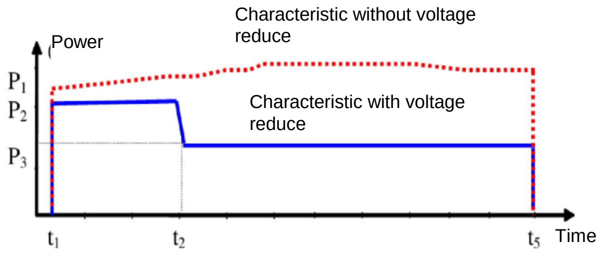

Fig3. The working characteristic in the standard mode

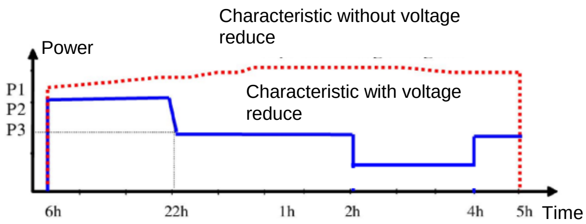

Fig4. The working characteristic in the mixed mode

In the turn off alternating mode, the AC/AC voltage converter is separated from the system by the bypass contactor K2. The system will automatically turn off the interphase of the bulbs when the set time is reached and it is not able to stabilize the voltage according to the set value. In this mode, the power consumption at the off-peak time is only 50% of the rated power because of alternating phase cutting. This mode does not ensure the quality of lighting, it is suitable only for roads with little traffic or the AC/AC converter is fault. The working characteristic in the turn off alternating mode is shown in fig5.

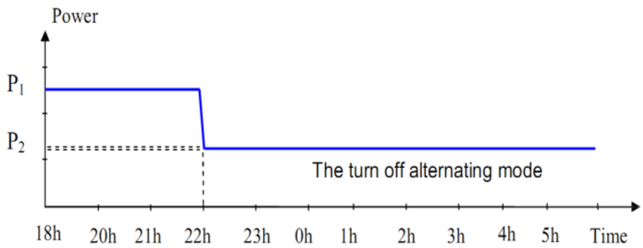

Fig5. The working characteristic in the turn off alternating mode

Working parameters, including current, voltage, frequency, power factor, KW, KVAR, KVA, KWh, KVARh... are measured and displayed by the multi-function energy meter. This energy meter is communicated with the PLC through the MODBUS RS485 protocol to display the parameters on the HMI and the computer. When the measured values exceed the set value of the protection, the PLC will give alarms or shut down the system.

III. EXPERIMENTAL RESULTS

The experimental model is shown in fig6 and the SCADA software on the computer is show in fig7.

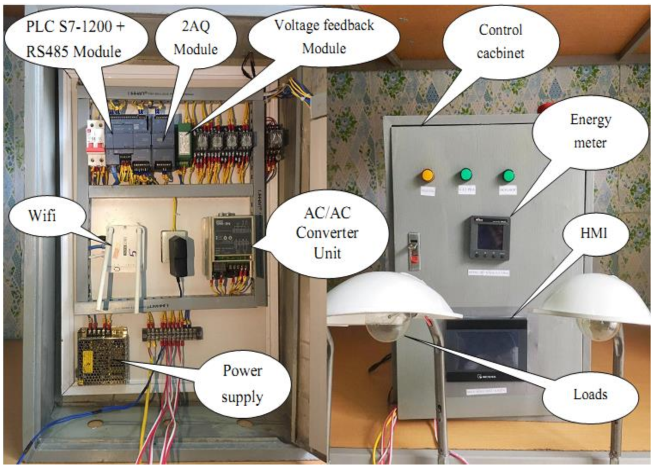

Fig6. The experimental model of the street lighting energy-saving system

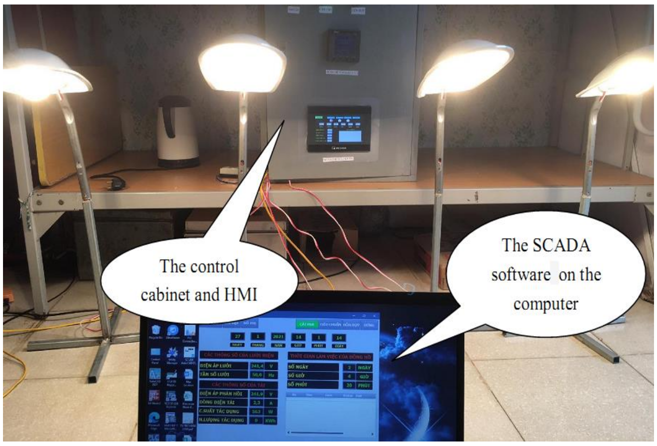

Fig7. The SCADA software of the street lighting energy-saving system

The specifications of equipments are shown in table 1.

Table 1: The specifications of equipments

No	The name of equipments	The specifications of equipments
1.	PLC Siemens S7 1200 – CPU 1212C AC/DC/RLY	Work memory 75 KB; 120/240VAC power supply with DI8 x 24VDC SINK/SOURCE, DQ6 x relay and AI2 on board; 4 high-speed counters and 4 pulse outputs on board; signal board expands on-board I/O; up to 3 communication modules for serial communication; up to 2 signal modules for I/O expansion; 0.04 ms/1000 instructions; PROFINET interface.
2.	Output analog module S7-1200 SM 1232 2AO	2AO, +/-10V, 14 bit resolution, or 0 – 20 mA/4 – 20 mA, 13 bit resolution.
3.	Simatic S7-1200, communication board CB 1241	RS485, screw connector supports message based freeport.
4.	Voltage feedback module: CE-VJ03-84MS2 -0.5/0-500V	+ Input range: voltage 0~500V AC + Output: 0-10V + Power supply: 24VDC + Accuracy: 0.5
5.	AC/AC Converter Unit	+ Power supply: 220VAC + Rated current: 35A + Function: Soft start/Soft down, slope setting + Time of Soft start/Soft down: 0-50 seconds + Input control: 4-20mA ON/OFF, external volume
6.	HMI MT8071 IP	+ Display 4.3” TFT LCD + Flash memory: 128 MB + RAM memory: 64 + USB Host: USB 1.1 x 1 + Ethernet: 10/100 Base-T + COM1: RS-232, + COM2: RS-485 2W/4W + COM3 RS-485 2W + RTC: Built-in (CR2032 3V lithium battery.) + Power supply: 24VDC
7.	Multi-function energy meter: Mikro DMP 380	+ Backlit LCD display. + Communication via MODBUS-RTU communication + Measure and display Current, voltage, frequency power factor, KW, KVAR, KVA, KWh, KVARh, THD harmonics of voltage and current...

+ The system is operated at the standard mode: When it's time to turn on the lights, all the bulbs are on and the power consumption is equal to the rated power. The system automatically stabilizes at rated voltage (fig8). at the time of power reduction, the system automatically reduces and stabilizes the voltage, and the power consumption also decreases (fig9).

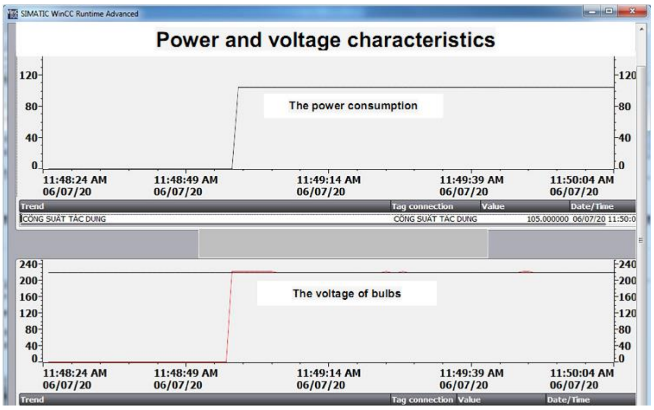

Fig8. All bulbs are turned on at the peak time in standard mode

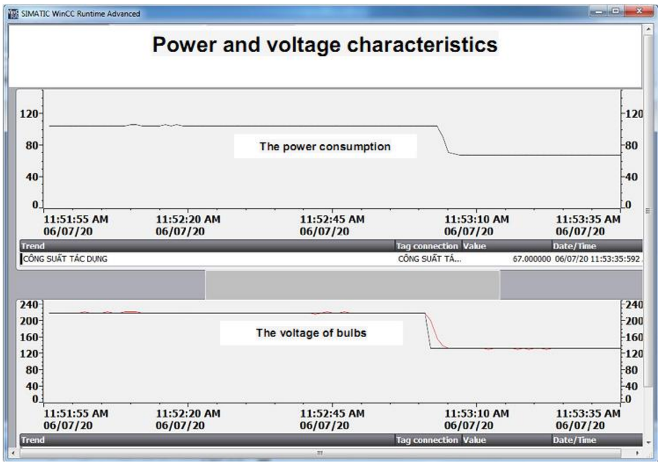

Fig9. 40 percent of the power is reduced at the off-peak time in the standard mode and all bulbs are still on

+ The system is operated at the turn off alternating mode: When it is time to cut the phase, the number of bulbs will be turned off by half, so the power consumption is only about 50 percent of the rated capacity (fig10).

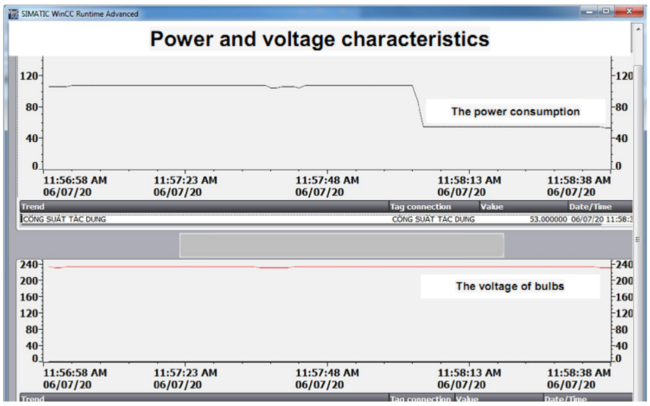

Fig10. 50 percent of the bulbs are turned off at the alternating mode

+ The system is operated at the mixed mode: When it's time to cut the interleaving phase and reduce the voltage, the bulbs will be turned off alternately and reduced the voltage. Therefore, the power consumption is even less than the turn off alternating mode. When the time is near to morning, the system automatically turns on all bulbs, but still performs voltage reduction to save electricity (Fig11).

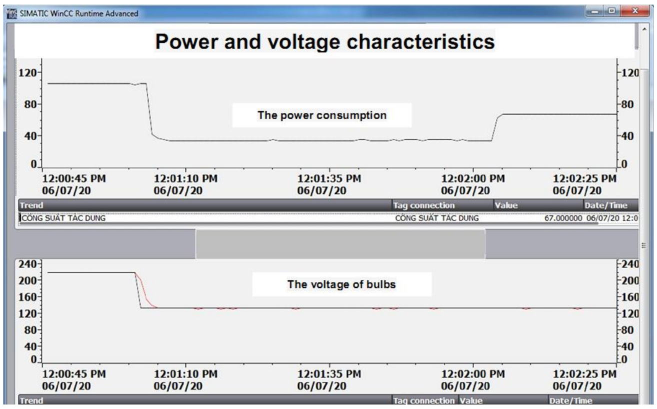

Fig 11. Power characteristics in the mixed mode

IV. CONCLUSION AND DISCUSSION

This paper presents the results of building a model of the street lighting energy-saving system. Experimental results show.

+ In the standard mode: At the end of peak traffic time, the voltage is automatically reduced to reduce power consumption, so energy can be saved up to 40 percent. The reduction should not be too large because if the voltage is reduced too much. At that time, the bulbs will be turned off and the lighting quality is not guaranteed.

+ In the turn off alternating mode: Power consumption is reduced by 50 percent because of the alternating cutting of bulbs. Lighting quality is reduced and overvoltage of the bulbs still occurs. Therefore, it is only used when the AC/AC converter is faulty or the roads have little traffic.

+ In the mixed mode: This mode is used to both cut alternating bulbs and reduce voltage, so energy is saved the most. However, this mode should only be applied on roads with very few vehicles participating in traffic at night.

The PID controller is used to stabilize the voltage applied to bulbs in standard and mixed mode to improve the stability of the system and extend the life of bulbs.

DATA AVAILABILITY

The practical data of the road profile used to support the findings of this study have been collected, measured, and processed by the research group under grant no. SV2020-11. The road profile data used to support the findings of this study are available from the corresponding author upon request.

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