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Universal Electric Pole Module

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Abstract: This paper presents a prototype module of Universal Electric Pole Module (UEPM) that aim to serve for smart city order of Thailand 4.0 with modern infrastructure based or high value facilities based and also suitable used in the future situations. The prototype module of universal electric pole is designed by engineering concept both for physical approach and multi-functions usage. The physical structure is constructed from light weight metal based that cover or enclosure again by thin aluminum alloy sheet for rust protection and shorten the body ratio from the actual electricity pole to a height of about 9 meters shrink to 3 meters high, zoom out 3:1 (1/3) that usually installed for main or sub-community streets or the streets of Department of Rural Roads recommended. The traffic lights and street lighting control are the two main functions of this module that it can serve for main traffic lights and pedestrian or crosswalk lights in the same time. While the light emitting diode (LED) size rated 80 W is designed for street lighting control that has a single branch lamp of the illumination coverage area is standard designed for installation on two lane roads. The width of the road includes a shoulder path of 10 meters that this aim design corresponds to the standard value TIS 2316-2546 (2006). For others functional list such as closed circuit television (CCTV), PM 2.5 dust sensors, temperature and humidity sensor or wireless fidelity (Wi-Fi) access point are controlled by Arduino board that installed in this module for universal usage. For renewable energy such as photovoltaic (PV) solar cell is simulated by Proteus 8. The experimental results are shown that the prototype module can work well as design concept but must be improved for real street areas installation or allow any users to remote or monitor to the system with the real time working status through internet or any other public communication network easily as a new and next normal life style of corona virus disease-19 (COVID-19) effect.

***Keywords*—Universal electric pole module, Street lighting, Traffic light control**

I. Introduction

Now a day, the coronavirus diseases 2019 (COVID-19) is the global crisis of our world and WHO declared them as a pandemic [1]. One of the best spread stopper way in the present scenario is the social distancing [2] and all affected countries are applied to implement this method in the universal ways especially in the public or crowded area as new normal of people day life behaviors that must be private sector areas or keep 1 or 2 meters between each of other, so the smart facilities that many development countries are developed the smart public area for more convenience of their people life called as smart city. Smart city [3] as a collaborative ecosystem that compose of private sector, public sector and other such residents. The three layers of the smart city which can change the traditional infrastructure to the modern infrastructure are composed of technology based network of connect devices and sensors especially for Internet of Things (IoTs) technologies and cloud computing services [4-6], applications data analysis compatibilities and tools especially for big data analysis technology [7] and finally for public adaptation and usage. In the public area section is the main issue of this work assume that if we have the modern infrastructure such as smart street lighting [8], they will be improving quality of their life and convenience to access to any of public facilities. So, our proposed a UEPM system that is focusing for assisting the new and next normal of people day life in public area facilities which smart city and technology usage friendly. The main idea concept of UEPM is designed by V-shape model analysis that is shown in Fig. 1. This model is based on an essential knowledge of electrical system model with engineering mindset combined with IoTs and cloud communication.

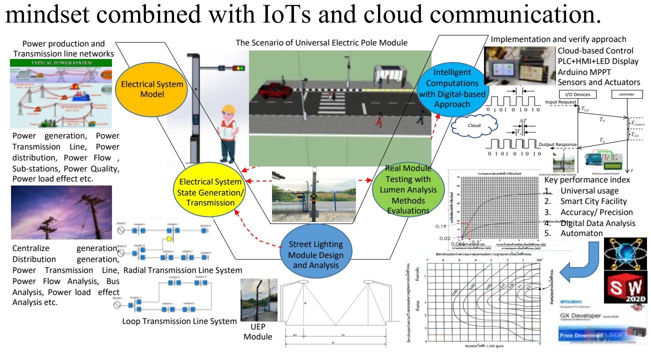

Fig. 1. The V-shape model design of universal electric pole module

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The remainder of the paper is organized as follows: Section II provides the UEPM structure module design. Section III presents the street lighting design. Section IV shows the databased software design and system accessing approach. Section V presents the experimental results and finally section VI for paper conclusions.

II. Mechanism Design of Universal Electric Pole

A. Modelling Module Design

The scenario model of main idea concept is shown in Fig. 2 that used the Google Sketch Up program for structuring the simply modeling module in the first time and next is simulating again by Solid Work program that is focusing on real standard ratio and user friendly interface in the smart city as shown in Fig. 3. This model will be constructed the real one of UEPM that can be coverage area of two road lens of 10m width and one crosswalk path beside it and all of functional works are automatically controlled by programmable logic controller (PLC) with human machine interface (HMI), IoTs, sensors and actuators that are installed on it and a long distance control by NETPIE cloud-based communication.

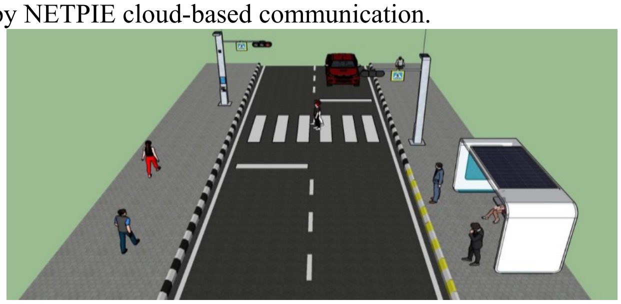


Fig. 2. The scenario of universal electric pole module (UEPM) usage

Fig. 3. The prototype modelling module design of universal electric pole

B. Prototype Module Design

The Solid Work simulation program is used to redesign again with the real prototype module shown in Fig. 4 that it is composed of LED street lamp, traffic lights, crosswalk lights, CCTV, Wi-Fi router, Dust and Temperature sensors.

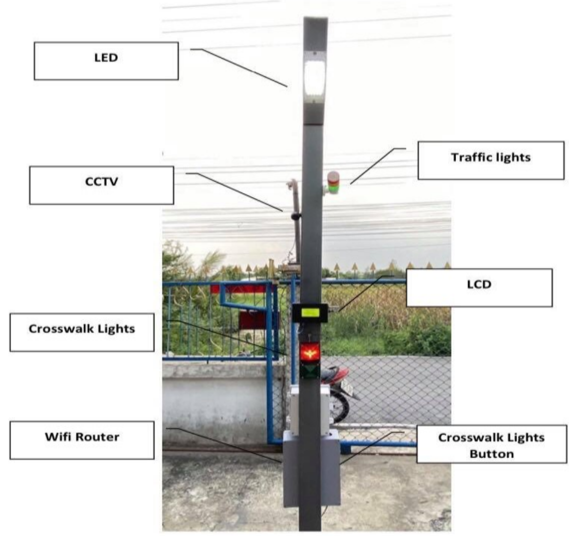


Fig. 4. The real prototype mechanical structure of UEPM

III. Street Lighting Design

The street lighting design by lumen method as shown in equations (1) to (4) given the data from Fig. 5 to Fig. 7. Where S mean the distance length between the two electric poles and W mean the road width. The electric pole high 9m is installed on two road lens of 10m width with the branch of lamp equal to 0.5m. The isofootcandle curve in Fig. 5 is shown the equipotential illumination line of 1,000 lumen of 30 ft. electric pole high and the coefficient graph in Fig. 6 is used to evaluate the $CU = 0.02 + 0.19 = 0.21$ and if we used the lamp about 20,000 lumen and $S = 30m$, so $E = 20{,}000 \times 0.21 \times 0.8 / 30 \times 4.5 = 24.8 lux$. For reduce the illuminance value about 3:1 ratio or 1/3 that is equal to about 8.2 lux of LED lamp that is installed as the street light of the UEPM in Fig. 7.

$$E = \frac{F \times CU \times MF}{S \times W} \tag{1}$$

$$CU = CU(front\_roadside) + CU(back\_poleside) \tag{2}$$

$$frontroad\_ratio = \frac{ss}{MH} = \frac{0.5}{9} = 0.055 \tag{3}$$

$$backside\_pole\_ratio = \frac{ks}{MH} = \frac{4.5}{9} = 0.5 \tag{4}$$

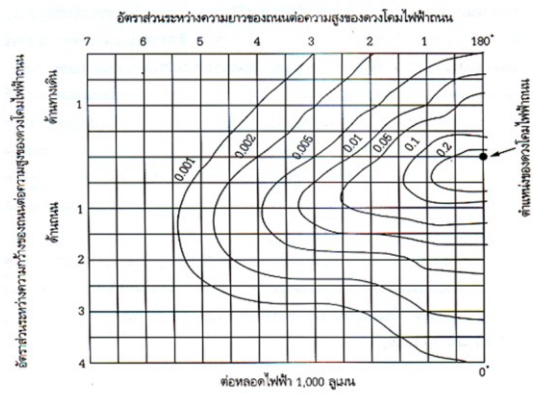


Fig. 5. An example of isofootcandle curve graph (in Thai language)

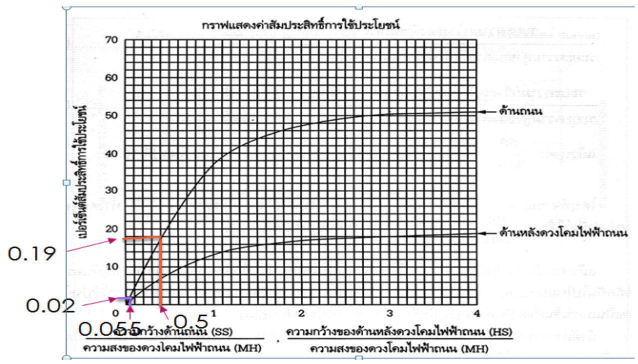


Fig. 6. An example of usage coefficient graph (in Thai language)

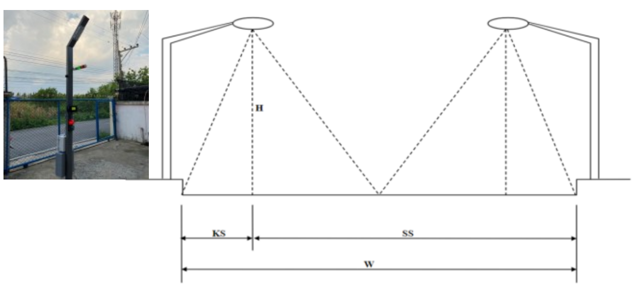


Fig. 7. The illumination design of universal electric pole scenario

IV. System Accessing Design

A. Databased system design and PLC+HMI control

The work flow diagram of this system is shown in Fig. 8 that based on MySQL Database for databased server management while phpMyAdmin is the program for managing the MySQL via by website and PHP Hypertext Preprocessor is the processing program by PHP language. When starting, the Arduino board commands dust sensor and temperature sensors. When both sensors are done finished, they will be displayed. If the value is not displayed, both sensors will re-measure again. When pressing the power button on the UEPM or touching start button on touchscreen of HMI, the pedestrian or crosswalk control (Red and Green bulbs) will start working in the first time for the traffic light control system and after that the traffic light control (Red, Green and Yellow bulbs) will be done consequences according with time setting interval. The CCTV camera will be start with Wi-Fi internet signal occupy the operating radius about 3 meters.

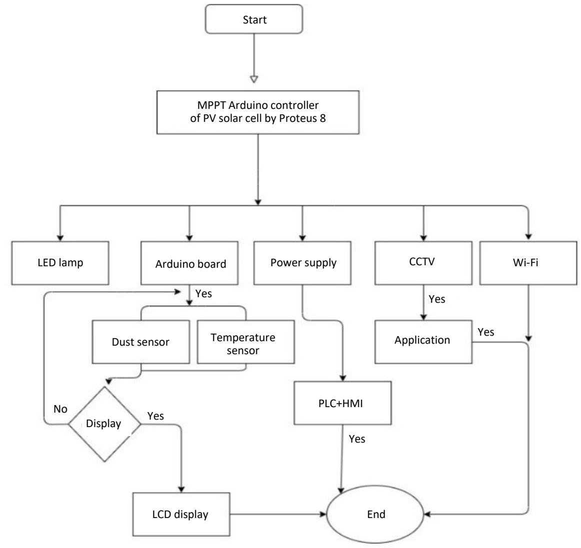


Fig. 8. Workflow diagram of UEPM control system

B. Current Function of standalone PV solar cell

An equivalent circuits of crystalline silicon or photovoltaic (PV) of solar cell (24VDC, 80W, 5A with poly type) and I-V curve characteristic are shown in Fig. 9 to 10 respectively, which can be express some importance terms of active cell current by mathematical analysis as shown in equations (5) to (8), while the conversion efficiency of crystalline silicon is equal to 12-13% based on IEC 61215 and IEC 60904 standard. The intensity standard of solar cell (G_{stc}) is equal to $1{,}000W/m^2$ with AM.1.5 (Air mass 1.5) and the effectiveness of temperature rise is about $+1C^{\circ}$ increasing will reduce the 0.5% of running voltage.

$$I_L = I_{ph} - I_0\left(\exp\left(\frac{q(V_t + I_L R_s)}{N_{cs}\gamma.T_c}\right) - 1\right) - \left(\frac{V_t + I_L R_s}{R_{sh}}\right) \tag{5}$$

$$I_L\big|_{R_{sh}\to\infty} = I_{ph} - I_0\left(\exp\left(\frac{q(V_t + I_L R_s)}{N_{cs}\gamma T_c}\right) - 1\right) \tag{6}$$

$$I_{ph} = \left(\frac{G}{G_{stc}}\right) \times \left(I_{phstc} + muISC\left(T_c - T_{cref}\right)\right) \tag{7}$$

$$I_{ph} = I_{0ref}\left(\frac{T_c}{T_{cref}}\right)^3 \times \left(\exp\left(\left(\frac{qE_{gap}}{\gamma k}\right) \times \left(\frac{1}{T_{cref}} - \frac{1}{T_c}\right)\right)\right) \tag{8}$$

While I_L is the active solar cell current (A), I_{ph} is the short circuit of solar cell current (A) at $25C^{\circ}$, I_0 and I_{0ref} is the saturated and standard reverse bias current (A) of solar cell, $q = 1.602\times 10^{-19}C$, N_{cs} is the number of solar cell in each sub-panel, T_c is the active p-n junction temperature (K) while the T_{cref} is the reference temperature (K) of solar cell, V_t is the terminal voltage (V) of solar cell, γ is the surface azimuth angle, R_s and R_{sh} are the series and parallel resistance of solar cell, G is the sun light intensity (W/m^2), I_{phstc} is the standard current (A) test, $muISC$ is the temperature coefficient of cell current from manufacturing or under standard or conventional testing condition, $k = 1.3806504 \times 10^{-23}\, J/K^{-1}$ and $E_{gap} = 1.12eV$ is the material bandgap energy of silicon cell.

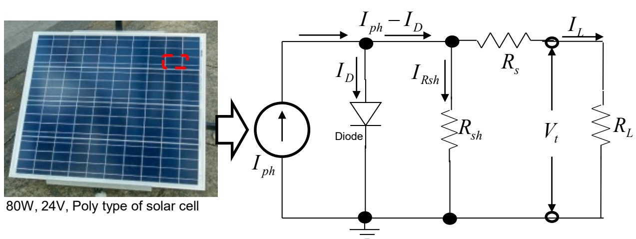


Fig. 9. An equivalent circuit model of standalone PV solar cell

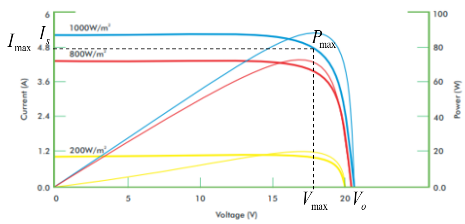


Fig. 10. The characteristic of I-V curve of standalone PV solar cell

The Arduino Uno microcontroller [9] is used to validate the function of perturb and observe (P&O) the maximum power point tracking (MPPT) [10] control used with a stand-alone photovoltaic (PV) [11] system under constant climate or STC conditions and step variations in the connected load and which will be implement by Proteus 8 simulation with hall effect ACS712 (5A) module as shown in Fig. 11 to Fig. 12. In Fig. 11 the buck DC to DC converter is used to step down the power energy that come from the PV solar cell energy to charge to the suitable battery storage voltage level, while the power MOSFETs are used as power switching circuit to supply or usage the power energy that are storage in the inductance, resistance and capacitance circuits. The simulation results are shown that the available maximum power of the PV solar panel is successfully extracted by using Arduino Uno (MPPT) controlled irrespective of the variable load conditions.

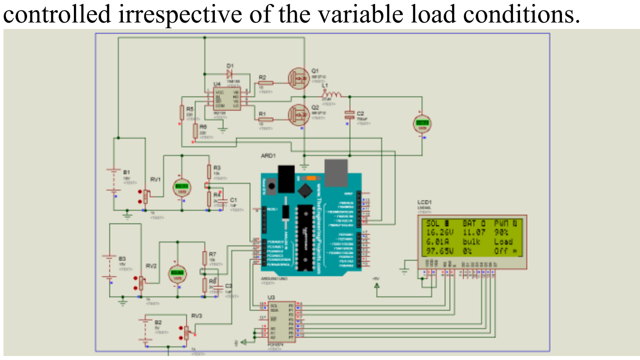


Fig. 11. An example of MPPT Arduino control by Proteus 8 simulation

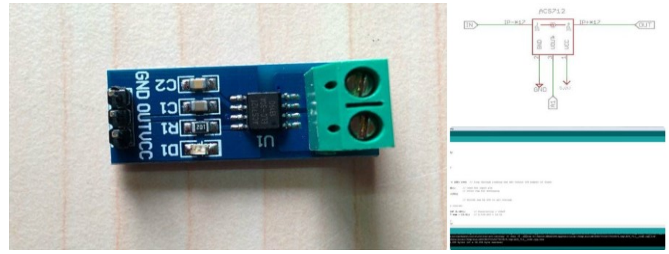


Fig. 12. The Hall Effect ACS 712 (5A) current module development

Until now, lithium-ion batteries have been widely used and believed to exhibit no memory effects, but some mainly caused damaged was belong to the thermal runaway effect that must have a way of temperature rises controlled. For battery control usage, the Battery Management System (BMS) is designed here as shown in Fig. 13 which can be controlled and monitored the battery charger circuit of Lithium Iron Phosphate ($LiFePO_4$) package in the charging and discharging state for more efficiency of used and will span a long life cycle in the same time that may be caused by overcharging or over discharging. The battery charging circuit is shown in Fig. 14 that must be controlled the constant current (CC) charging mode in the first time until upon to 70% of state of charge (70%SOC) and after that will change to constant voltage (CV) mode until equal to full %SOC. For the overload or over current protection circuit is simulated here as shown in Fig. 15 that is used to limit the current load consumption must not more than some limit of loading effect such as 702.48mA to protect the overheat of battery in the loading condition that must be prevent the battery damage by the thermal runaway effect.

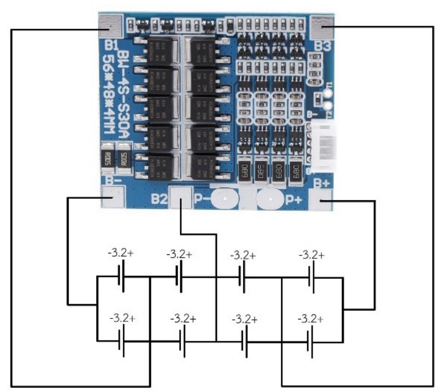


Fig. 13. An example of battery management system (BMS) of $LiFePO_4$

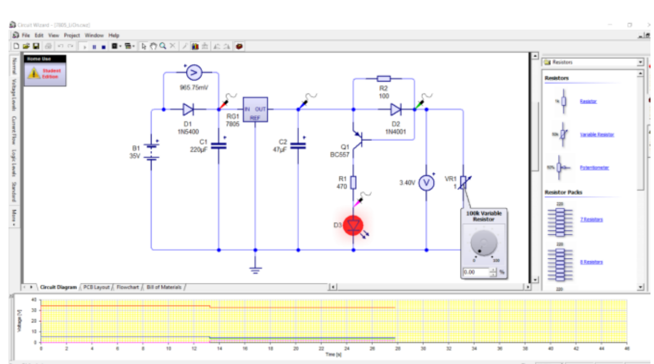


Fig. 14. The circuit wizard simulation of battery $LiFePO_4$ charging circuit

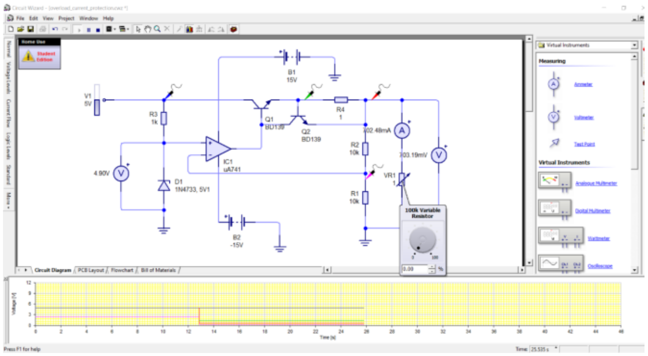


Fig. 15. The circuit wizard simulation of over current protection circuit

The voltage level indicator of battery usage is simulated in Fig. 16 for voltage monitoring and warning that is used the LM3914N controller which will be 10 digit of LEDs display both in dot and bar graph display mode.

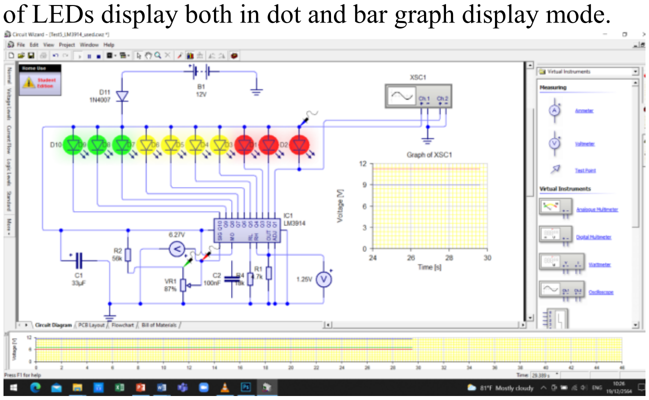


Fig. 16. The circuit wizard simulation of voltage level indicator circuit

The DHT11 module is designed for dust sensor while the GP2Y1010AU0F module is used for temperature and humidity sensor with its coding as shown in Fig. 17.

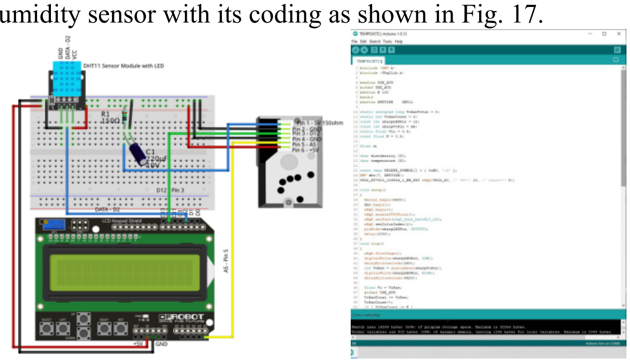


Fig. 17. The wiring diagram of dust sensor and temperature sensors circuit

For CCTV display circuit of UEPM is shown in Fig. 18 that will be start with Wi-Fi internet signal coverage area 3m.

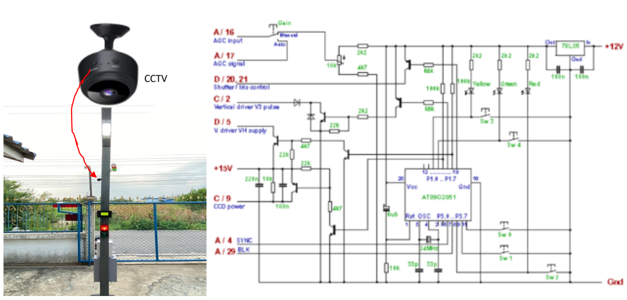
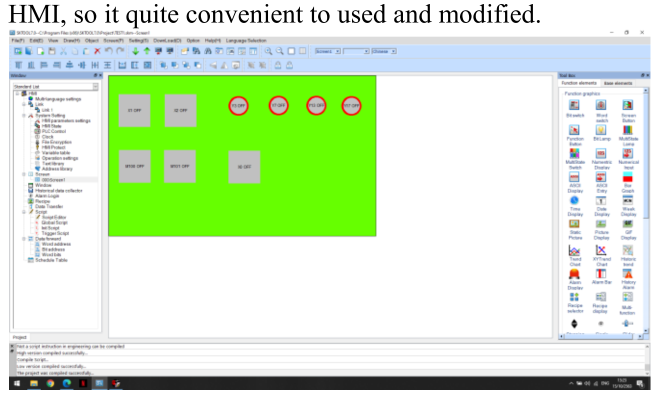


Fig. 18. The circuit diagram of CCTV display circuit of UEPM

For traffic lights and crosswalk lights control, programmable logic controller (PLC) model FX1N-F32MRT (Mitsubishi) with human machine interface (HMI) model SK-070FE (Samkoon) are designed to work together as shown in Fig. 19 and Fig. 24, while the ladder diagram is shown in Fig. 20. The traffic lights and crosswalk lights can be controlled both by push button of start/stop conditions on the UEPM or HMI touch screen that are executed by ladder diagram which conclude the contact relay interface both by contact relay of PLC and HMI, so it quite convenient to used and modified.



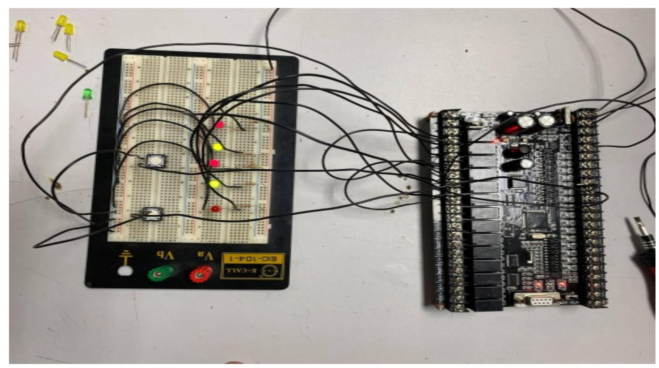


Fig. 19. An example of traffic lights control test by PLC and HMI

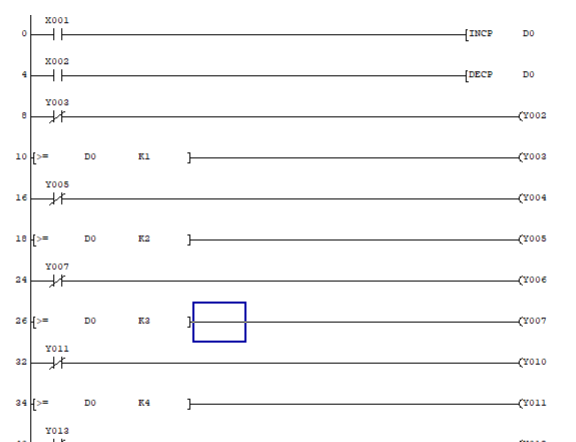


Fig. 20. An example of ladder diagram design of traffic lights and crosswalk lights control of PLC and HMI interface

C. *Cloud Communicating Design*

The cloud communicating approach of this system is designed based on PLC [12], node MCU [13-14] and NETPIE platform [15-16] as a platform-as-a-Service (PaaS) that especially developed for IoTs applications. Many IoTs devices can be communicated which each other by this platform as multi-tenant and resource sharing with micro gear library software and MQTT protocol. Node MCU (ESP8266) that set as a Wi-Fi shield tools is used for digital data controller with AT commands for a long distance accessing control as a Transmission Control Protocol (TCP) master/slave protocol stack procedure between the IoTs devices and NETPIE cloud platform as shown in Fig. 21.

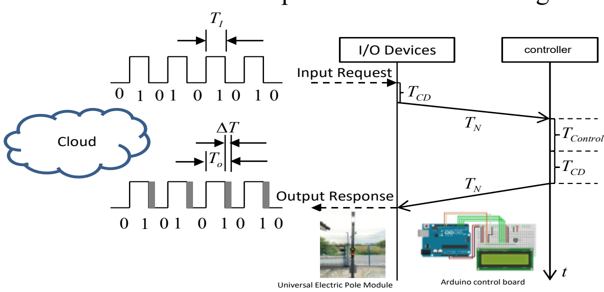


Fig. 21. The sequence of timing diagram based on the cloud-based devices approach to the cloud-based network

Define the accessing time interval of input and output command signal is T_I and T_o respectively which will be effected by some propagation delays in wireless communicating area called as ΔT shown in equation (9).

$$T_o = T_I + \Delta T \qquad (9)$$

In the first time, the network is not completely synchronized, so the initial setting conditions are required for fulfilling update time cycle of any devices is called as T_{CD}. The network delay time is called T_N, while the $T_{Control}$ is defined as the control task interval time plus execution time that is performed by the controller in each of command process. Let T_{E2E} is the End-to-End delay time of the system that is arrived for the worst case scenario of $2T_{CD}$ and $2T_N$ which will cause the variance ΔT for each of output commands shown in equation (10).

$$T_{E2E} = 2T_{CD} + T_{Control} + 2T_N \qquad (10)$$

V. Experimental Results

The performance of the system is evaluated by the specification ThinkPad Notebook, solid work simulation version 2011, The Arduino Uno with Node MCU esp8266 is used for digital control and wireless cloud connection while traffic lights and crosswalk lights are controlled by FX1N-F32MRT PLC combined with SK-070FE HMI. Many of experimental tests both for mathematical analysis with many of data computations and real take place installed were present here in Table I and Fig. 11 to Fig. 25.

Fig. 22. An example of dust sensor and temperature sensor display

TABLE I
Experimental Results of Universal Electric Pole Module

Test No.	Temp. sensor	Dust sensor	Time and date
1	27 °C	28.6 µg./m³	17-08-63: 06.00 am.
2	29 °C	19.8 µg./m³	17-08-63: 08.00 am.
3	33 °C	23.8 µg./m³	17-08-63: 10.00 am.
4	34 °C	21.9 µg./m³	17-08-63: 12.00 am.
5	35 °C	7.0 µg./m³	17-08-63: 02.00 pm.
6	34 °C	8.0 µg./m³	17-08-63: 04.00 pm.
7	33 °C	19.9 µg./m³	17-08-63: 06.00 pm.
8	31 °C	13.0 µg./m³	17-08-63: 08.00 pm.
9	29 °C	11.0 µg./m³	17-08-63: 10.00 pm.
10	29 °C	11.0 µg./m³	17-08-63: 12.00 pm.
Avg.	31.4 °C	16.4 µg./m³	17-08-63: 06.00 am.- 12.00 pm.

In table I are shown the display results of dust sensor and temperature sensor of Fig. 22 in one day at Don Yai city, Pathum Thani province, Thailand. These solutions are the key answer of UEPM that can be monitor the dust, temperature and CCTV with traffic lights control in the same time. The real structure of UEPM is shown in Fig. 23 that was installed as the same place of Fig. 25 and were already functional tested that are satisfied to use as design concept.

Fig. 23. An example of real testing take place of UEPM system

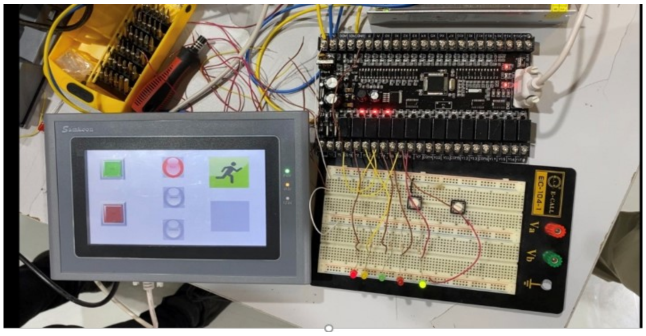


Fig. 24. An example of real testing of traffic lights control by PLC+HMI

Fig. 25. An example of CCTV displays at Don Yai city Pathumtani province Thailand

The result of luminance with time was not shown here but the overall system can work well as design concept and high precision enough to use in laboratory room, but for some real public area that the Wi-Fi signal is quite lower power, attenuation loss or lack to use it may be some inconvenience to use by wireless accessing method but it can be easily used by the cloud-based accessing instead.

VI. Conclusion

In this paper, we proposed a prototype module of universal electric pole system called as UEPM based on digital control platform with Arduino microcontroller and Node MCU for cloud communicating which integrates the LED street light, the traffic lights and crosswalk lights control by PLC+HMI combined with many usage functional such as CCTV, Wi-Fi, dust sensor, temperature and humidity sensors are all installed in one pole. The overall system can work very well as design concept. Since our proposed system is design for the new and next normal upon on digital lifestyle of smart city or Thailand 4.0.

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