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DESIGN OF PROGRAMMABLE POWER CONTROLLER TO REDUCE ENERGY CONSUMPTION OF HVAC DEVICES IN OFFICE BUILDING

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ABSTRACT

This paper presents the design and performance analysis of a programmable power controller (PPC) to reduce electrical energy consumption of heating, ventilating, air-conditioning (HVAC) devices used in office buildings. This PPC operates based on the pre-programmed turning-on and turning-off HVAC devices such as air conditioners, fans, etc. including lightings in a building automatically with the use of a computer program. Programming can be done either based on pre-scheduled functioning of the devices considering the users behaviour or using feedback sensors of the room conditions. It concludes that in general there is still common to find the negligence of occupants/users to turn off the HVAC equipments of the building under consideration, being potential as priorities of energy management and conservation measures. It shows also that the use of PPC is prospective in energy management and conservation efforts, resulting in a prospective reduction of up to 20% - 30% of electrical energy consumption of the building under study.

Keywords: programmable power controller, energy consumption, energy management.

INTRODUCTION

High-energy consumption is one of the most serious problems in the world nowadays [1]. The number of new buildings and energy consumption in developing countries has been increasing rapidly due to recent economic growth and development [2, 3]. Energy consumption in commercial buildings has been increasing rapidly in the past decade. The knowledge of future energy consumption can bring significant value to commercial building energy management [4]. Energy management on the demand side is the practice that deals with design, application, utilization and maintenance to optimize electrical energy consumption aimed at energy and peak demand reduction [5].

Energy consumption in the residential sector offers an important opportunity for conserving resources, and understanding the key determinants of residential energy consumption is important for the design and implementation of effective policies aiming to increase the energy efficiency of the building stock [6].

The energy in buildings may be divided into two categories, which are embodied energy and operational energy. Embodied energy is the energy requirement to construct and maintain the premises, whereas operational energy is the energy requirement of the building during its life from commissioning up to demolition [7]. Occupant behavior affects the building energy use directly and indirectly by opening/closing windows, turning on/off or dimming lights, turning on/off office equipments, turning on/off heating, ventilation, and air-conditioning (HVAC) systems, and setting indoor thermal, acoustic, and visual comfort criteria [8]. It is common knowledge that the presence and actions of building occupants have a significant impact on the performance of buildings (energy efficiency, indoor climate, etc.) [9]. Energy consumption of public buildings includes air conditioning, lightings, elevator, office equipment, waterbowl and auxiliary equipments [10].

Various energy conservation strategies have been applied including standards, isolated and integrated implementation of energy conservation measures [11]. The proportion of energy consumed by only the cooling (AC) systems could range from 3% to 43% of the whole building energy consumption and 21% on average [12].

Nowadays, power or current is the most valuable thing in the world, so that in using it we are also required to think of our next generation. Automatic controlling systems are preferred over manual controlling. The design of power controlling and saving project can handle controlling of electrical and electronic devices, appliances, etc. [13, 14]. The identification of major determinants of building energy consumption, together with a thorough understanding of the impacts of the identified determinants on energy consumption patterns, could assist in achieving the goal of improving building energy performance and reducing greenhouse gas emissions due to the building energy consumption [15]. A growing body of research suggests that efficient control of HVAC systems might significantly increase the energy efficiency of future smart-buildings [16].

As one of the efforts to manage and conserve energy, this paper presents a device called Programmable Power Controller (PPC), which has been designed and its performance has been examined and analyzed. The PPC has been designed to work automatically by scheduling the operation of the HVAC unit in the office building under study.

DESIGN OF PPC

Basic principle of PPC

The work purpose of PPC is to turn-on and turn-off equipments in a building such as air conditioner, lamps, etc. automatically using a pre-programmed action with the help of a computer software. The software programming is undertaken to schedule the operation of

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electrical and electronic equipments, especially HVAC system. The electrical equipments or devices to be controlled by the PPC are of 220V of AC input voltage.

As can be seen from Figure-1, the basic principle of PPC system is shown. A personal computer PC is used as the main controller, as shown in Figure-2. An interface programme VB is required to send data from the PC to the PPC. Visual Basic is used as compiler. An exmaple of the display of Visual Basic programme for the PPC is shown in Figure-3.

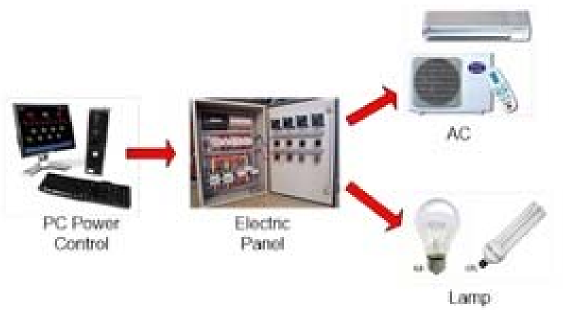

Figure-1. Basic principle of PPC system.

The characters resulted by the VB are to be sent in serial to microcontroller MK through the port DB9 on the PC. Before reaching the microcontroller, these data will be passed through IC MAX485, whose function is for signal conditioning. The voltage level of the computer is adapted to the working voltage of microcontroller.

On the microcontroller, the data coming from the computer will be passed forward to the driver. Every character received from the computer will be interpreted by the microcontroller to determine which electronic devices to be turned ON or OFF.

The driver represents a circuit with relay as its main component. Relay serves as a switch that will be ON or OFF in accordance with the current flowing in its coil. Data transmitted by the microcontroller are in the form of binary signals which will determine the coil of relay to energize.

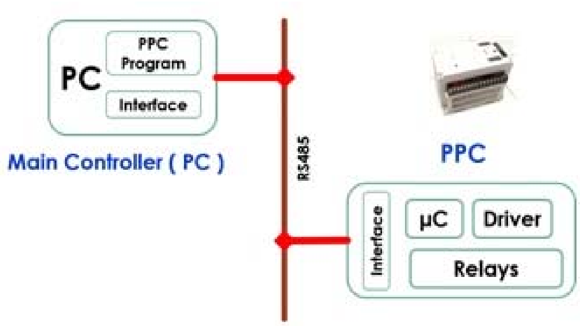

Figure-2. Block diagram of PPC design.

In the driver circuit, an optocoupler has been added to serve as a separator between two circuits. It isolates the circuit of 5V of voltage from that of 12V of voltage.

Figure-3. Display of visual basic programme for PPC.

As can be seen in Figure-3, to run the program, at the first time the ComPort on the computer must be selected and confirmed by pressing the Connect button. It is used to communicate serially with the microcontroller. On each of the relays to be controlled, there are 3 commands available, namely:

- **Auto:** to activate the relay based on the time setting in the PPC Program.
- **Manual On:** to activate relay manually
- **Manual Off:** to disable relay manually and disable time setting in the PPC Program.

Each relay is equipped with two color indicators, i.e. RED for the OFF condition and GREEN for the ON condition.

Signals conditioning using IC MAX485

The signals conditioning circuit is shown in Figure-4. IC MAX485 performs the function to change the output voltage level of serial RX-TX of the microcontroller into that of standard RS485 serial protocol. JP1 may become the input/ouput of the channel RS485. JP2 is connected to the Tx and Rx pins of microcontroller. The IC needs a supply voltage of 5V.

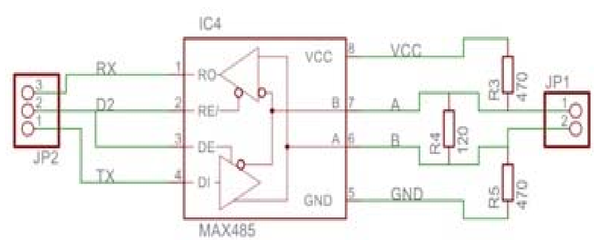

Figure-4. Signals conditioning circuit.

Optocoupler circuit

As shown in Figure-5, optocoupler is an electronic device used to isolate the power circuit from the control circuit. As indicated from its name, optocopler utilizes light (optic) to trigger (couple) its on-and-off functioning. As a sensor, it covers two parts, i.e. transmitter and receiver.

In the design of PPC in this paper, the optocoupler is used to isolate the circuit requiring 5V of supply voltage from the circuit on the driver which needs

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12V of supply voltage. In this way the occurence of short-circuit could be minimalized.

Relay circuit

Relay is an electronic switch which is activated using an electric current. A relay comprises a contact and a solenoid with iron core. The coil is made of winding to let flow current, whereas the contact is like a switch whose movement is dependent on the existence of current flowing in the coil. As shown in Figure-6, when current is flowing into the solenoid, the contact will close because of the resulted magnetic force. When there is no more flowing current, the contact will open.

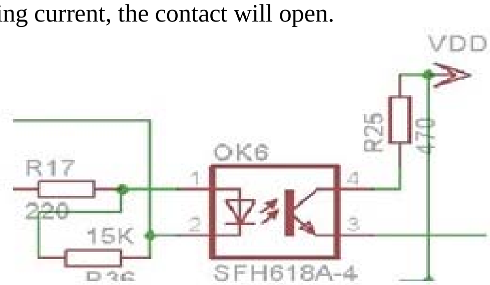


Figure-5. Optocoupler circuit.

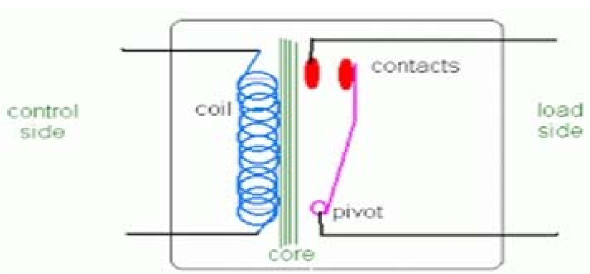


Figure-6. Simple relay circuit.

In brief, when the coil is energized, certain electromagnetic force will enable the contacts to close for a Normally Open contacts, or otherwise will open for a Normally-Closed contacts, as seen in Figure-7. The Change-Over (CO) or Double-Throw (DT) contact controls two circuits: one normally-open contact and one normally-closed contact with a common terminal.

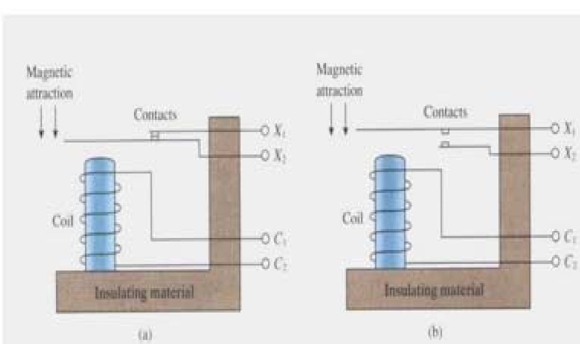


Figure-7. (a) Relays with Normally-Closed contact (b) Normally-Open

The simplest type of relay is the electromechanical relay, which is working on the principle of generating mechanical movement when energized electrically. A relay which is energized using DC current is normally equipped with a diode being parallel to the windings, the anode is connected to negative (-) polarity of the voltage, and cathode to the positive (+) polarity of the voltage. It is purposed to anticipate electric spark during the movement of relay from ON to OFF position in order not to harm the related components.

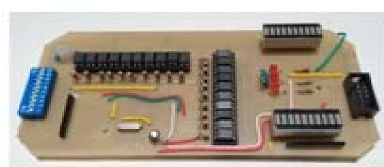
Relay can be used to activate devices with high current/voltage (for example 4A, 220V-AC) using small current/voltage (for example 0.1A, 12V-DC).

Performance testing

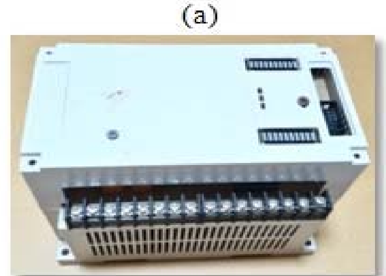
The functioning of PPC has been tested through partial testings of the composing components. The completion of hardware construction has been followed with the software design using Visual Basic. The designed software programming was then implemented on the hardware part in order to test the whole performance of the integration of hardware and software parts, shown in Figure-8. It has been done by connecting the PPC board to a computer being pre-installed with the software programming.

The construction of PPC circuit

The physical construction of PPC is shown in Figure-8. Generally, the construction includes the microcontroller, optocoupler circuits and relays.



(a)



(b)

Figure-8. (a) PPC top view circuit, (b) Programmable power controller after packaging.

PERFORMANCE ANALYSIS RESULTS

Implementation testing

After the design of PPC has been completed and its construction has been accomplished, it still required some testings, either from the point of view of its functioning or its implementation testing to verify its performances. The chosen object of implementation was a building in a university consisting of classrooms for students learning activities. The steps have been started with the recording of electrical energy consumption during certain time intervals. The next step was the functional experiment by connecting the PPC to the supplying power panel of the building. Furthermore, the turning ON and OFF of the HVAC devices are controlled using the designed PPC device.

Point of PPC application

To verify the performance of the PPC design, it has been applied on the incoming supply of the building under consideration, as can be seen in Figure-9, especially in the panel box supplying the HVAC devices, more specifically air conditioner and lamps. This choice is based on the consideration that this type of load consumes the large amount of energy and commonly becomes the object of users negligence to turn-off.

Figure-9. Point of PPC application.

Recording the Electrical Energy Consumption Patterns

Electrical energy consumption of the office building under consideration has been recorded using 3-phase Energy Mater during three different periods representing the beginning of the week, the work days and the week-end, as shown in Figure-10-12. The chosen building consists of classrooms in a university.

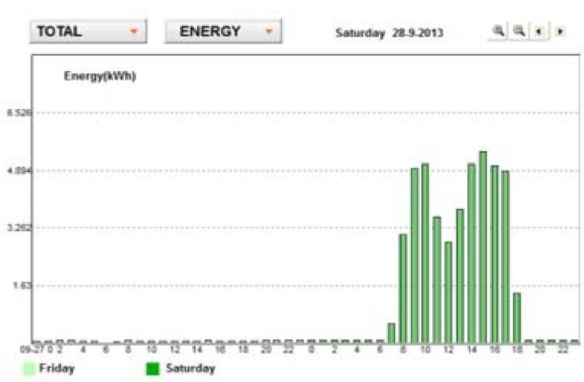


Figure-10. Electrical energy consumption, Friday-Saturday.

For the building under consideration, Figure-10 shows that electrical energy consumption for air conditioning on Friday is relatively low. It is predicted that only one of the whole ACs in 18 rooms has been functioning. The bar chart shows that the electricity consumption is low between 00:00-24:00 on Friday, but certain consumption increase appears in the morning of Saturday, between 07:30-18:00. The accompanying observation done confirmed that the increase was because of students extra-curricula activities in two rooms during the week-end.

Measurement of electrical energy consumption done on Sunday and Monday, as seen in Figure-11, shows that the energy consumption on Monday has been almost similar to that of Monday. Observation and interview done to complete the measurement data confirmed the that the similarity to consumption on workdays are due to students activities on Sunday between 07:00-16:00. The electricity consumption between Sunday at 17:00 and Monday at 07:00 was relatively constant at 2kWh each hour. It is predicted that there were certain air conditioners still functioning during that period. The common consumption on workdays began in the morning of Monday, peaking during lecturing times at 10:00, 12:00, and 15:00. The consumption decrease between 13:00-15:00 was related to the prevailing classes schedule. It is not the classroom lecturing period, but the schedule for laboratory practices. After 19:00 the consumption went back to constant value of about 2 kWh per hour, indicating that there were still ACs not being turned-off yet.

Figure-12 indicates the common pattern of electrical energy consumption during the workdays, being represented with the pattern on Tuesday and Wednesday. The daily pattern is similar to that on Monday, as shown in Figure-11. The constant consumption at around 2 kWh per hour appears between 17:00 and 07:00 of the following day. From the energy consumption recording done during 7 days consecutively, as can be seen from Figure-13, it is known that the average daily electricity consumption for air conditioning in the building under study during the active classroom lecturing period before the PPC application is less then 860.592 kWh. The result of observation also shows that energy saving possibility can still be obtained from users behaviour improvement, as certain negligence to turn-off ACs after the use was still found.

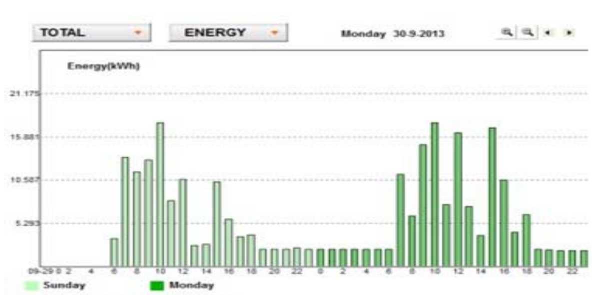


Figure-11. Electrical energy consumption, Sunday-Monday.

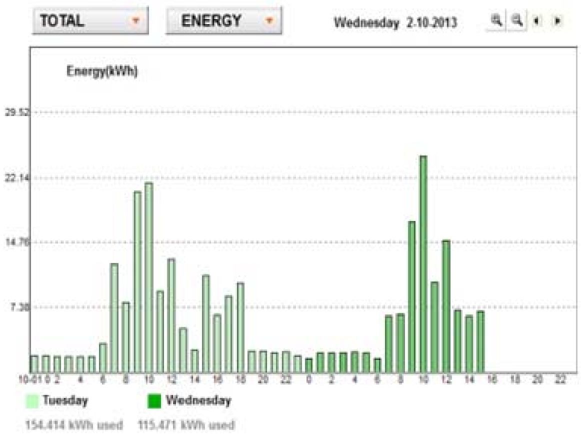


Figure-12. Electrical energy consumption, Tuesday-Wednesday.

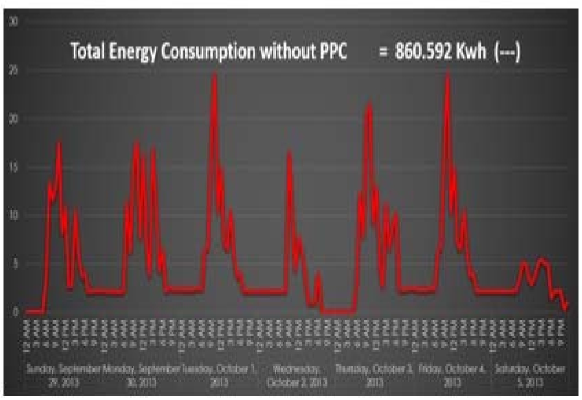


Figure-13. Energy consumption before the PPC application.

If the PPC is applied, the user negligence to turn off ACs can be anticipated so that the energy wasting can be avoided, as can be seen in the green curve of Figure-14.

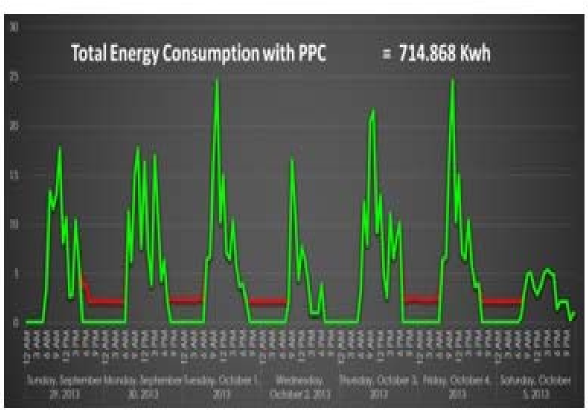


Figure-14. Energy consumption after the PPC application.

CONCLUSIONS

Some conclusions being drawn from the results of observation and measurement data analysis are as follow:

- In general there is still common to find the negligence of occupants/users of the building under consideration to turn off the HVAC equipments, being potential as priorities of energy management and conservation measures.
- The use of programmable power controller (PPC) devices is prospective in energy management and conservation efforts, resulting in the reduction of 20% - 30% of electric energy consumption of the building under study.

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