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by F Yudi Limpraptono

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Design of Power Monitoring and Electrical Control Systems to Support Energy Conservation

Fransiscus Yudi Limpraptono^{1*}, Eko Nurcahyo¹, Mochammad Ibrahim Ashari¹,
Erkata Yandri², and Yahya Jani³

¹Department of Electrical Engineering, National Institute of Technology Malang,
Jl. Raya Karanglo, Km. 2, Malang 65143, Indonesia

²Graduate School of Renewable Energy, Darma Persada University, Jl. Radin Inten 2,
Pondok Kelapa, East Jakarta 13450, Indonesia

³Department of Urban Studies, Malmö University, Nordenskiöldsgatan 1,
21119 Malmö, Sweden

Abstract: The increasing demand for electrical energy and the decreasing supply of fossil fuels in recent years have increased the cost of electrical energy. So that the culture of saving electrical energy is a habit that must be cultivated in the community. On the other hand, energy-saving behavior cannot be realized massively without a support system that can control energy use. With these concerns, it is necessary to develop a method that encourages a culture of saving electrical energy. This paper proposes a system that supports active energy efficiency methods that can support an energy-efficient culture. This system is an electric power monitoring system that is integrated with a smart electrical panel that continuously monitors the use of electrical energy and can control electrical loads automatically, record electricity usage, provide comprehensive reports and analyze energy usage. The method used to carry out this research is research and development. This research has produced a prototype of electrical power control and monitoring system that has a smart panel based on a raspberry PI 3 and PZEM-004t power energy meter. The monitoring system performs and executes automatic control of electrical loads. The system can also provide reports in the form of data monitoring in daily, weekly, monthly or annual period. From the test results, it can be concluded that the system can work well. This research is expected to contribute to providing a system that can support government efforts in saving energy.

Keywords: Active Energy Efficiency, Electrical Energy Management System, Saving Electrical Energy, Smart Panel

1. INTRODUCTION

The massive development of energy conversion technologies and the invention of various equipment that ease human activities leads to a significant increase in energy usage involving electricity. With the continuous increase of energy consumption, the price of electric energy is getting more expensive [1, 2]. This condition is worsened by the declining supply of fossil fuel as the main resource for power generations.

The increase in energy price and energy consumption encouraged the government to

improve the culture of saving electrical energy [3–5]. Moreover, the environmental concern such as pollution and gas emission has also motivated the energy-saving promotion. The saving energy campaign can be started by using the electrical energy in the residential and building premises wisely [6]. According to the obtained data from the previous researches, it was observed that the energy requirement in the building absorbs 40% of the total world energy needs. In Indonesia specifically, the building sector requires about 50 % of total energy expenditure and more than 70 % of overall electricity consumption [7]. As a consequence of high energy consumption, the building sector

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*Corresponding Author: FransiscusYudi Limpraptono <fyudil@lecturer.itn.ac.id>

in Indonesia contributes to 30 % of greenhouse gas emissions [8]. According to the United States Department of Energy, building premises contribute to 40 % of the country's major energy consumption and 40 % of CO₂ emissions [9]. In a crowded urban environment, this trend is much higher. The buildings in New York City contribute 75 % of city energy consumptions [10].

The needs of electrical energy in commercial buildings are mostly for heating or cooling, ventilation, air conditioning (HVAC), and lighting. With the increase of energy prices and environmental issues of fossil fuel energy supplies, many researchers have been developing the use of alternative and renewable energy to promote green energy [11, 12].

Energy efficiency can be achieved by optimizing the use of lighting systems and implementing lighting system design in proportion with the room functionalities. Most importantly, the operation of heating/ cooling systems and ventilation should be controlled continuously according to the actual needs [13]. To make sure efficient consumption of electrical energy, effective power metering, and monitoring systems are required. The power metering and monitoring systems would provide important information to the owners and operators correlating to the performance of building energy consumption. An effective metering and monitoring system can involve tenants, property managers, and owners in measuring energy consumption. Hence, substantial actions can be implemented immediately to maintain the use of energy in an efficient way. The integrated energy management and monitoring system are sufficient to improve energy efficiency. An effective measurement and monitoring system may bring 10 % direct energy savings and hence reduce the operational costs of the building [14].

Promotion of energy saving in residential and building premises should also be included in communication strategies since it is understood mainly by experts and industry, but not by commons [15]. To reduce the electrical energy consumption through the improvement of the habit of energy saving, the Indonesian government issued the Regulation of the Minister of Energy and Mineral Resources (ESDM) on Electricity Energy Saving. It states that all office buildings must

implement the electricity energy-saving program on the air conditioning system, lighting system, and other supporting equipment. Some references in the implementation of the policy are by using energy-efficient appliances, the implementation of a good energy management system, and change the behavior of people who live in the building [14].

There are two approaches in the efforts of energy efficiency, namely passive and active energy efficiency. Passive energy efficiency activities can be done by installing and using energy-saving equipment and efforts to correct power factors. Passive energy efficiency is a fundamental effort for energy conservation. However, the passive approach alone is not sufficient to reach the desired level of energy efficiency. It needs a system that can support energy efficiency with the method of active approach. Energy efficiency requires an active approach such as load control, system automation, and monitoring of energy consumption to obtain a better saving energy scheme which eventually results in a better energy efficiency performance [16–18].

The electric energy efficiency of the active approach method requires an electrical energy monitoring system that must have the ability to provide reports and data analysis and be able to communicate with various devices. This system is connected to an electric load distribution panel which is capable of recording power consumption and being able to control the electrical load automatically. More importantly, the system must be able to connect with a number of separate measuring equipment, transmit data between devices, store measurement data, and produce the various analyses required for decision making. On the other hand, with the rapidly growing field of information and communication technology, the system is required to use effective communication methods such as IP-based, autodial, and connection with mobile devices or smartphones.

So far, it is costly to implement the monitoring system with the required capabilities as described. Therefore, the implementation of the saving-energy monitoring system is limited. This research proposed a system that supports active energy efficiency method which can help the energy-saving cultures. Low-cost power monitoring and

energy management system is designed for building premises. The proposed system is connected with a distribution panel in each building and equipped with a communication protocol for remote monitoring purposes. It has some advantages features involved the ability to control the electric load automatically, record the use of electric power, provide comprehensive reports and analyze the use of energy.

2. MATERIALS AND METHODS

2.1 Research Methods

To develop a smart-panel system for power consumption control and monitoring, the research and development (R&D) method is conducted in this paper. The proposed method mainly consists of two parts; the development of a smart-panel prototype and the development of application software that would be used to control and monitor energy consumption. The initial stage of smart-panel prototype development is hardware and software design. Followed by the realization of the obtained design to develop the smart panel. The next stage is testing and calibrating the developed smart-panel to obtain a proper design and parameter control setting.

The second part of the method is to design software applications for controlling and monitoring energy consumption. In this stage, the comprehensive application software was developed to control and monitor the electrical parameter involving the energy consumption accurately. The final step is integrating the developed smart-panel dan application software before employed the smart-panel to the real test system.

2.2 System Design

This research addressed the efficient design of a prototype system to support the conservation of electrical energy. The designed system has smart and low-cost features. It comprises several smart panel units, a local computer network (LAN), database server as data storage, web server containing application of system controller, and a power monitoring display. The proposed monitoring design is depicted in Figure 1.

The design of the server-based system is embedded system Raspberry Pi 3, which has low power, low price, small size, and high performance. An open-source operating system was implemented to reduce the cost. The monitoring system is responsible for recording the electrical energy consumption in a building and monitoring electrical quantities such as voltage, current, power factor, and electrical power. The monitoring system performs and executes automatic control of electrical loads that have been set by the operator. The system can also provide reports in the form of data monitoring in daily, weekly, monthly or annual period. Real-time reports are displayed on the dashboard power monitoring system. That dashboard is situated on a strategic location that can be seen by building users as part of an active approach method of energy conservation.

Smart panels are part of the system that serves as a power distribution panel. The architecture of the proposed smart panel is depicted in Figure 2. Smart panels are controlled by an embedded system Raspberry Pi 3, which has a Broadcom BCM2837B0, Cortex-A53 (ARMv8) 64-bit 1.4 GHz processor, with the Storage Capacity of 1GB LPDDR2 SDRAM. It has 2.4 GHz wireless LAN and 5 GHz IEEE 802.11 b/g/n/ac, Bluetooth 4.2. Besides, it has Gigabit Ethernet, 40-pin GPIO, 4 USB 2.0 ports, and HDMI. Raspberry Pi uses the Raspbian Linux-based operating system, which comes with several applications such as Apache web server and MySQL database. Raspberry Pi is expanded with I/O port expander MCP23017, so it can add 16 bits of the I/O port. The interface of MCP23017 chip with Raspberry pi using I2C line.

The panel is controlled by a programmed Raspberry Pi embedded system to control the electrical load. Smart panels are also capable of communicating with the server over a computer network, hence it can either send or receive commands from the server. The smart panel contains an embedded system that will be in charge of reading input signals from all push buttons and activating a switch contactor that will turn on or offload directly. Also, the smart panel has a measuring instrument of electrical quantities that continuously records the consumption of electric power.

The design of the smart panel prototype has 16 inputs and 16 outputs. The input unit is used to read the push button status that serves to turn on and off the electrical load. The output unit is used to connect or disconnect the electrical load. The switch circuit on the output unit employs a G3MB-202P solid-state relay. Both the input and output unit circuits are protected by optical isolation to avoid the inclusion of undesired electrical voltage. The proposed smart panel design implements a PZEM-004t power energy meter for electrical power measurement. This module can measure voltage, current, active power, and electrical energy. PZEM-004 can store data when power is

off and able to communicate with the controller unit through the serial port. The implemented design of the smart panel is depicted in Figure 3.

3. RESULTS AND DISCUSSION

3.1 Power Meter Unit Test Results

The validation of the designed power meter is carried out by comparing the performance of the proposed metering design to the standard power meters. Three different loads were considered in the experimental setup. It was monitored that the PZEM-004T module provided high accuracy measurement

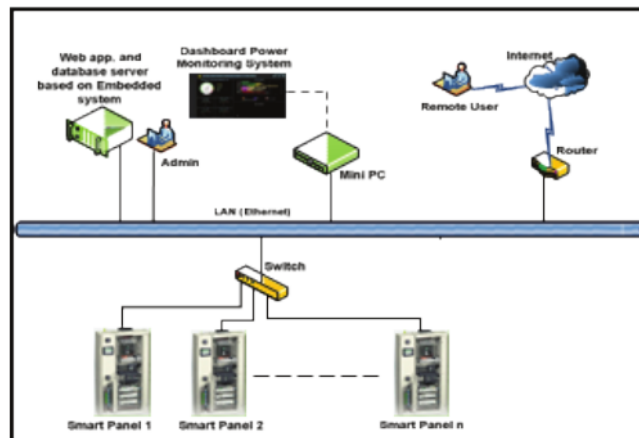


Fig. 1. Smart Panel and Power Monitoring System

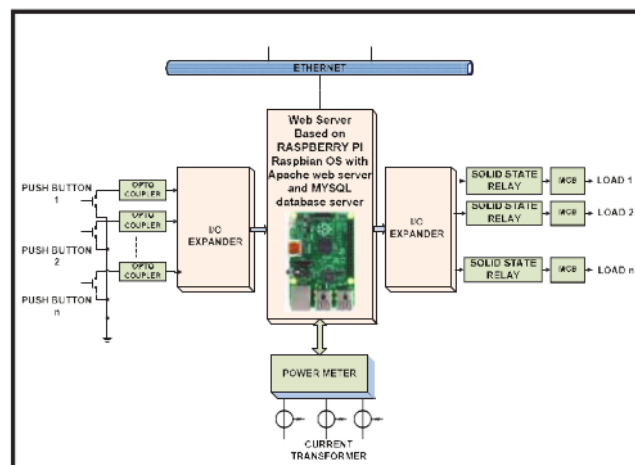


Fig. 2. Architecture of the Smart Panel

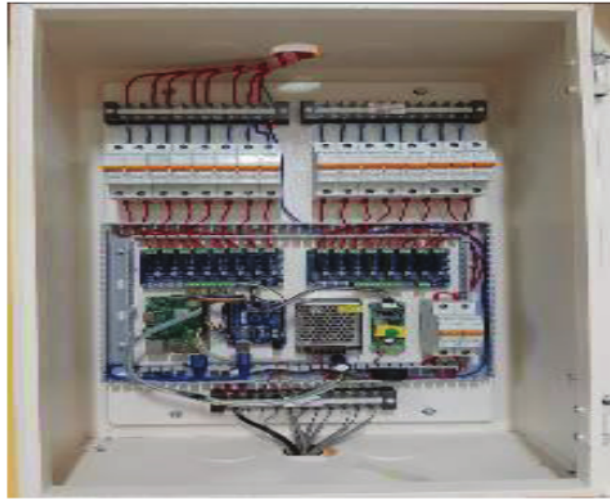


Fig. 3. Smart Panel.

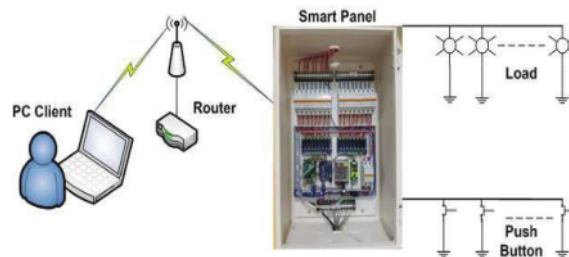


Fig. 4. Diagram of Power Monitoring and Control System Unit Testing

results. Therefore the proposed measurement module was suitable for measuring current and power. For current and power measurements, it has an average error of 0 %. While for voltage measurements, the average error is around 0.04.

3.2 Power Monitoring and Control System Test Results

The power Monitoring and Control System unit is tested with a monitor and controls the load remotely. The experimental setup is shown in Figure 4.

Initially, the experimental procedures was conducted by remotely open the Power Monitoring website with a web browser hence a web page would appear as shown in Figure 5.

To enter the Power Monitoring web application, each user must log in first. If the login procedure is

successful then the user can see a set of application features. The users would see the usage of electrical power from each panel. The measured electrical powers were displayed in graphical form with the option to select the data period on a daily, weekly, monthly and annual basis. The right-hand side of the dashboard displayed the voltage and the current for each panel. While the bottom side of the dashboard displayed the graph for $\cos\phi$.

The testing of load control features can be done by entering the system control menu. The web page display of the control system page is shown in Figure 6.

Each panel has 16 push buttons, according to the design of the smart panel. Loads can be turned "on" or "off" through each of these pushbuttons. In addition, the load can also be turned "off" or "on" automatically by scheduling the load activities.

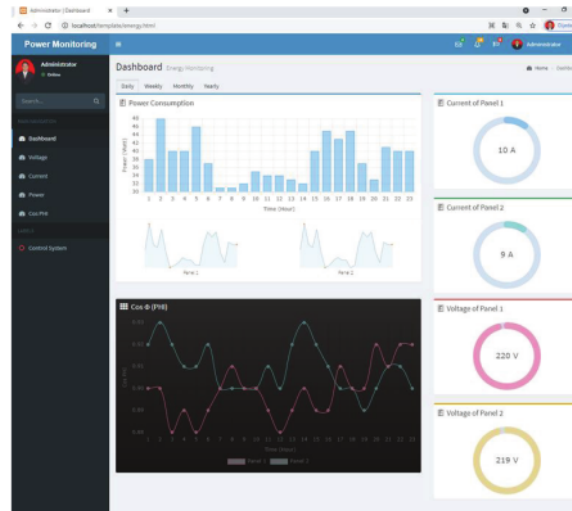


Fig. 5. Remote Power Monitoring System

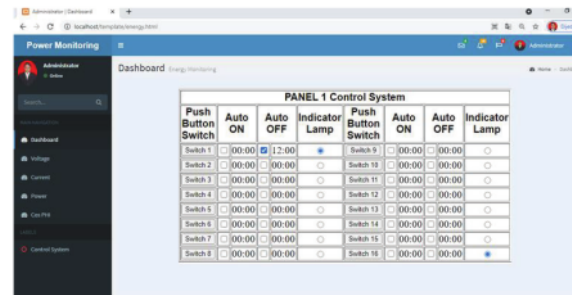


Fig. 6. Remote Control System

Each load has an auto ON and auto OFF menu that can be set by the user.

4. CONCLUSION

This paper presents research on power monitoring and electrical load control systems to support the conservation of electrical energy. From the experimental results, it can be concluded that the system can work well. The power meter unit can function properly with high accuracies. A small error of 0.04 % was observed for voltage measurement. While the measurement of current and electrical power resulted in an error of 0 %. The power monitoring system can work well and can record and display power usage at any time. The load control system can also function well to control load activity remotely and automatically. This research is expected to contribute to providing a system that can support government efforts in saving energy.

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6. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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