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IoT Based for Monitoring Power Consumption of Electronic Home Appliances

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ABSTRACT

In daily life in various activities, including in households and industry. The Ministry of Energy and Mineral Resources noted that electricity consumption per capita in Indonesia will be 1,173 kWh in 2022. This number has increased by 4.45% from the previous year which was 1,123 kWh. The use of fossil energy sources are increasing as demand increases, making reserves of fossil energy sources increasingly depleted. Nowadays, some measuring tools that sold commercially require wiring process to the MCB, so there is potential danger of electric shock and also the tools can't store historical data that so the data can't be analyze. Monitoring electricity usage can help users to alert about household appliances that have been accidentally left on. This is become the research topic by implemented monitoring electrical power consumption in household electronic equipment and storing historical data so users can analyze which electronic equipment with the largest power consumption based on real time and historical data displayed on a Web-based dashboard. Data was taken from testing using the SCT-013 5A 1V Current Transformer Sensor and Arduino Uno R3 microcontroller. Electronic equipment that will be monitored are air conditioner, water heater, washing machine, rice cooker, refrigerator, laptop, dispenser, iron, fan, and lamp. User able to monitor the amount of electrical power consumption used in various electronic equipment and control lamp via Web-based Dashboard.

1. Introduction

Electrical energy is one of the basic human needs in daily life for various activities including in the household and industry. World's electricity consumption has increased. Measuring energy consumption used for efficiency of electricity usage. Fossil fuels usage for generate electricity impact to CO2 gas emission elevation which responsible to global warming phenomenon. Fossil energy sources usage increasing along with fossil reserve energy sources decreasing. Electronic home appliances are easy to find in daily and it's appearance help human to work faster, efficient, and effective. Electricity consumption management isrequired, but it doesn't enough if only using kWh meter because only functions to monitor overall electricity usage in household so awareness to save electricity consumption is needed. Electricity management can be done by monitoring electricity consumption on electronic home appliances and turn off the appliance which doesn't used so the electricity costs wouldn't swell.

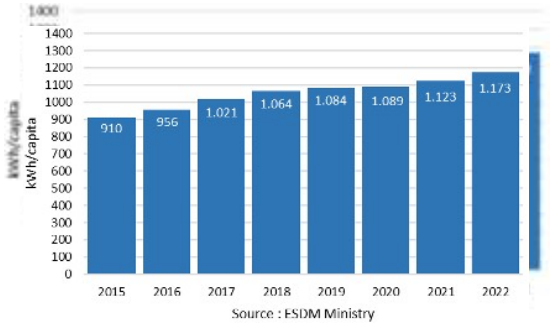


Fig. 1. Electricity Consumption per Capita in Indonesia

Figure 1 displayed Ministry of Energy and Resources Mineral (ESDM) declared that electricity consumption per capita in Indonesia was 1,173 kWh in 2022 which is increases 4.45% from previous year was 1,123 kWh.

Internet of Things (IoT) is a concept where a particular object has the ability to send data over the network and to integrate each other. Main purpose of IoT is data mining. IoT search and collect various data from the area that will processed to become more useful. Internet of Things (IoT) is a system to connect sensors with Internet. Long-distance monitoring and control device can use IoT.

According to Kompas.com (2022) there are six electronic devices that consumes lots electrical power. First is washing machine, it consumes lots electrical power especially when using various mode. Washing machine has various modes for each clothing material. The second is microwave, the electrical power released depends on the type of food was heated. The third is rice cooker. It consumes lots electricity based on the duration of cooking. Fourth is refrigerator which uses lots electricity because it must be turned on for 24 hours. Methods to store foods is one The way food is stored affect the electricity consumption by the refrigerator. Fifth is air conditioner, the methods of using air conditioner also affects the amount of electricity consumption. Sixth is water heater, electricity power consumption while heating the water could reach kilowatts within just 10-20 minutes. Researchers intend to collect power consumption data on electronic home appliances so users could analyze home appliance that consumes the largest power and estimate electricity costs to be paid. There wasn't international journal found about monitoring electronic home appliances that consume most electricity are refrigerator, fan, AC, water heater, water dispenser, and iron. Monitoring power consumption on home appliances that consume most electricity power based on Kompas.com is needed so user can estimate electricity bill that must be paid. There are several tools for power consumption measurement that are sold commercially. Installation that measurement tools require wiring process to the MCB so there is the potential electric shock danger if user has insufficient electrical knowledge. Measurement tools that sold commercially cannot store historical data for each electronic home appliances so user cannot analyze electronic home appliance that consume most power and estimate electricity bill that must be paid.

There are several tools for power consumption measurement that are sold commercially. Installation that measurement tools require wiring process to the MCB so there is the potential electric shock danger if user has insufficient electrical knowledge. Measurement tools that sold commercially cannot store historical data for each electronic home appliances so user cannot analyze electronic home appliance that consume most power and estimate electricity bill that must be paid.

Monitoring power consumption needed so user know how much power used at home, so user become more aware of the power consumption. To find out an overview of power consumption in every single day on each electronic home appliances. Monitoring power consumption can help remind user about the appliances that accidentally left on. By monitoring power consumption, the user could rethink about the method and frequency of using the appliances to become more efficient.

In this research, power consumption measurement tool will be created for measure each home appliances and store historical data most power in real time and the historical data will be

displayed on Web-based Dashboard. Home appliances to measure are AC, water heater, washing machine, rice cooker, refrigerator, laptop, dispenser, iron, fan, and lamp. Efficiency electricity could be reach by controlling light usage through the Web-based Dashboard display.

Journal “Web Based Smart Meter for General Purpose Smart Home Systems with ESP8266” represent web- based smart meter implementation for smart home system. Electricity demand is increasing day by day due to technology developments and increasing population. Thus, the demand to control electrical power consumption in homes increases. CIoT network applications are developed for monitoring power consumption by smart home applications. Iron and heater were used for current and voltage measurements. Iron and heater separately connected to the grid simultaneously for current and voltage measurement. Measurements and calculations on Arduino Nano using Emonlib library. Measurements using a laptop or mobile phone connected to CIoT network. The hardware used includes Arduino Nano, ESP8266 NodeMCU, Current sensor SCT-013 CT, 9 V AC/AC step-down transformer, Burden resistor, and TP-Link wireless N router.

Journal "IoT Based Household Electrical Energy Monitoring and Control" represent monitoring and control power consumption tool implementation that monitor power and temperature. The system measuring power consumption, temperature, and upload values to MATLAB application by cloud thingspeak using Wi-Fi module. ESP32 microcontroller sends the informations to the internet via cloud thingspeak server and the informations can be seen through the MATLAB application that provides additional options to control (ON/OFF) electronic home appliances. Notification about over power consumption or temperature sent by e- mail.

Journal "An internet of things-based smart energy meter for monitoring device level consumption of energy" represent monitoring power consumption implementation so customers get information about electricity bill. Government provided conventional electricity meters that only measures power consumption of an entire home or industry on every month. Consumers did not have tools to monitor power consumption on each electronic devices. The billing system based on overall consumption so consumers did not know which behavior is related to power consumption. This research helps users to manage energy consumption. The information can be used by consumers for detect and replace devices that already damaged and wastes power.

Journal "Design and implementation of IoT based smart laboratory" represent power consumption monitoring, environment sensors, and required infrastructure communications for transmit information to servers. Management problems and power consumption problems increase every year. Main problem is monitoring and controlling devices that do not use during the absence of humans but still consume power. Difficult to monitor all subsystems such as lighting, projection equipment and air conditioning so power could be wasted. Hardware used are Arduino UNO, ESP 8266, current transformer, relay, sensors (temperature, humidity, light), and raspberry pi 3.

Journal "IoT Based Energy Monitoring and Management System for Smart Home Using Renewable Energy Resources” represent power consumption monitoring using Internet of Things (IoT). Due to electricity bill increased and Global Warming campaigns then actions to reduce power consumption in general and interest to analyze power consumption in households are increased. With analyze power consumption of each appliance so conclusion to reach efficiency could be more accurate. Hardware used are Arduino UNO, energy meter, LCD displays, potential transformers, current transformers, PIR sensors, batteries and solar panels.

Journal “Energy Aware: A Non-intrusive Load Monitoring System to Improve the Domestic Energy Consumption Awareness” represent monitoring household energy consumption through a non-intrusive device that interacts with electricity meter using photo sensor. Android application represent information regarding power usage, cost forecast, total power consumption, and total cost. Hardware used are NodeMCU Devkit 1.0 microcontroller, SCT-013, RTC.

Journal “Design of an electricity consumption measurement system for Non Intrusive Load Monitoring” represent monitoring usage of Home Electrical Appliances (HEAs) using Arduino

MKR Zero microcontroller. Direct feedback about electricity consumption in residential sector helps consumer to get real-time information down to the HEA level. It has proved to induce considerable behaviour changes and substantial energy savings, almost 12% of reduction in the total residential energy consumption.

Journal "Energy management using non-intrusive load monitoring techniques-State-of-the-art and future research directions" represent monitoring energy consumption of appliances in residential buildings using NILM techniques. Development of smart sustainable cities become the primary focus among urban planners and policy makers to make responsible resources usage, conserve the environment and improve the well-being of the society.

Journal "IoT Based Approach for Load Monitoring and Activity Recognition in Smart Homes" represent a NILM approach for load monitoring to develop an activity recognition system based on IoT architecture using CT-sensor.

Journal "Design of IoT based smart compact energy meter for monitoring and controlling the usage of energy and power quality issues with demand side management for a commercial building" represent monitor and control the energy usage and power quality issues in a commercial building.

Journal "Electricity Usage Monitoring Based on Internet of Things" represent control and monitor household electricity accumulation consumption based on current parameter via smartphones using ESP8266 Wi-Fi module.

Journal "IoT Power Monitoring System for Smart Environments" represent monitor power consumption and identify energetic waste using current transformer sensor, Raspberry Pi, and LoRa which applied for measure electronic equipment in auditorium, farm, pool, and apartment.

Journal "Energy consumption monitoring in smart home system" represent energy consumption monitoring system for home appliances which can be used to calculate the energy consumption of household to predict the electricity consumed in a month. Hardware used are Arduino UNO and ACS712 current sensors.

Journal "Smart Energy Meter and Monitoring System using IoT" represent accumulation electricity consumption monitoring using energy meter and calculate into bill for reduce human effort to record meter reading which existing situation still manual record by visiting consumer's house.

Journal "Monitoring the Consumption of Electrical Energy Based on the Internet of Things Applications" represent monitoring voltage, current, and power of Wasit university buildings for optimize and reduce power usage using ESP32 microcontroller.

Table 1. Literature Review Comparison

No	Research Title	Electronic Home Appliances	Sensor
1	Web Based SmartMeter for GeneralPurpose Smart Home Sytems with ESP8266	Iron and room heater	Current transformer sensor SCT013
2	IoT Based Household Electricity EnergyMonitoring and Control	Iron and hair dryer	Current transformer sensor SCT013-000 and DHT11
3	An Internet of Things-Based Smart Energy Meter for Monitoring Device-Level Consumption of Energy	Table lamp, television, toaster, iron, table fan, and hair dryer	Hall effect based on SCT-013
4	Design and Implementation of IoT Based Smart Laboratory	Lamp, projector, fan, and AC	Temperature sensor, humadity sensor, and LDR
5	IoT Based Energy Monitoring and Management System for Smart Home Using Renewable Energy Resources	Fan and lamp	Current transformer sensor and PIR sensor
6	Energy Aware: A Non-intrusive Load Monitoring System to Improve the Domestic Energy Consumption Awareness	Electricity meter	Current transformer sensor SCT-013, RTC
7	Design of an electricity consumption measurement	LG washing machine,	Chauvin Arnoux E3N

	system for Non Intrusive Load Monitoring	electric oven, LCD TV, electrical heater	probe (current), LEM LV25-P (voltage)
8	Energy management using non-intrusive load monitoring techniques – State-of-the-art and future research directions	Kettle, air conditioner, fridge	Smart meter
9	IoT Based Approach for Load Monitoring and Activity Recognition in Smart Homes	Washing machine, iron, microwave, oven, dishwasher	Current transformer sensor
10	IoT based real time energy monitoring system using Raspberry Pi	Machines, industrial fans, lamp	Schneider energy meters, Elmeasure energy meters
11	Design of IoT based smart compact energy meter for monitoring and controlling the usage of energy and power quality issues with demand side management for a commercial building	LED Lamp, fan, printer, laptop, water dispenser, refrigerator, oven, toaster, pump, AC	PZEM-004T
12	Electricity Usage Monitoring Based on Internet of Things	MCB	SCT-013
13	IoT Power Monitoring System for Smart Environments	lamp (auditorium), heater (pool), pump (farm), boiler (apartement)	SCT-013
14	Energy consumption monitoring in smart home system	buzzer, motor, LED	ACS712 current sensor, Arduino UNO, Node MCU
15	Monitoring the Consumption of Electrical Energy Based on the Internet of Things Applications	MCB	PZEM-004
16	Smart Energy Meter and Monitoring System using IoT	MCB	Energy meter (energy), PIR sensor (motion)

Table 1 displays differences between each literature review. Electronic home appliances used in the research above must be complete by doing research for electronic home appliances most power consumption monitoring such as refrigerator, fan, air conditioner, washing machine, water heater, water dispenser, and iron so forecast electricity bill could be represented.

Several power measurement tools sold commercially are :

1. Phase Digital kWh Meter
2. Smart Monitoring Energy (SME)
3. IoT Energy Meter

Fig. 2.1-Phase Digital kWh Meter

Figure 2 displays 1-phase digital kWh meter using IoT. The power supply used is a 12 Volt adapter. The hardware used are PZEM004T sensor and Arduino / NodeMCU microcontroller Wemos ESP8266 / ESP32 / STM32. To install this tool required this tool with MCB.While install this tool, there is electric shock potential danger if user has less knowledge of electrical wiring.

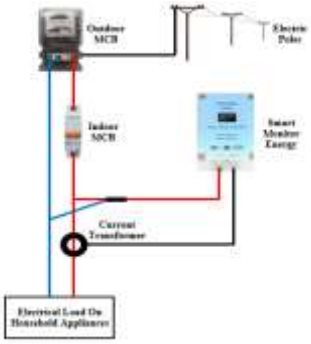


Fig. 3. Wiring Diagram SME

Figure 3 displays wiring diagram SME. Steps to install SME are:

1. Make sure indoor MCB is connected to outdoor MCB (MCB PLN).
2. Choose indoor MCB which would to measure.
3. Connect Current Transformer current sensor that connected with box to one output cable of indoor MCB.
4. Connect input power box with power 220 volt

Fig. 4. IoT Energy Meter

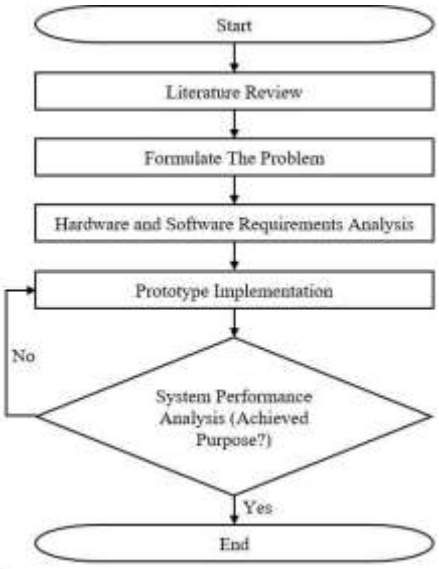
Figure 4 displays IoT Energy Meter to measure voltage, current, power, kWh, and frequency. The hardware used are NodeMCU V3, PZEM-004T V3 sensor, LCD, and devices that connected to internet network such as Android phone. Measurement result will be displayed on LCD and Android phone. The used applications are Blynk IoT and telegram. IoT Energy Meter used to display data in real time but historical data could not store so data analytics could not be done.

Fig. 5. Power Consumption Display using SME

Figure 5 displays Smart Monitoring Energy (SME) for measure voltage (volt), current (ampere), power (watt), frequency, power factor, kilowatt hour (kWh). Measurement result displayed on OLED. Measurement results such as historical data, forecast power consumption a day, and forecast power consumption a month in real time would be displayed on website.

The commercial power measurement system above needs to be completed with historical data storage and electronic home appliances with most power consumption, power consumption percentage of each electronic home appliances and electricity bill forecast for a month.

2. Method



2.1 Literature Review

The initial method to start this research is literature review by collecting research journals which related to power monitoring. At this step, the author reads the problems, solutions, shortcomings, and developments that can be carried out further. Then conclude and grouping literature review before compare them.

2.2 Formulate Problems

The results problems got from literature review are method to collect power consumption in each electronic home appliances and display data for user to achieve the efficiency.

2.3 Hardware and Software Requirements Analysis

Determines hardware and software for implement this research.

2.4 Prototype Implementation

Assembly tool to measure power consumption and write code to process data on the Arduino Uno R3 microcontroller using Arduino IDE software, Visual Studio, and MySQL database.

2.5 System Performance Analysis

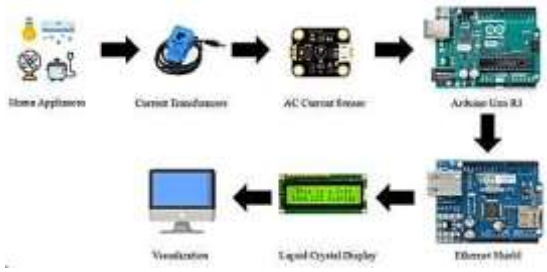


Fig. 6. Architectural Design

Testing process to make sure the system is running properly according to research purposes. System performance will be test using Black Box.

Figure 7 displays the architectural design of monitoring power consumption measurement system. Electronic home appliances will be connected to a Current Transformer and AC Current Signal Conversion Module to measure how much current that flow in each electronic home appliances. The data read by Current Transformer will be processed by Arduino Uno R3 microcontroller and display on Liquid Crystal Display (LCD). Microcontroller connected to user using Ethernet Shield so user could monitor power consumption of each home appliances.

The output data from measurement process are current values. After current values are known, kWh cost for each load could be calculated from multiply power consumption with usage duration.

Evaluation for determine the system is running appropriate to the purposes. There are few steps to evaluate the system. First, determine monitoring display on LCD and web-based Dashboard are running appropriate the purposes. Second, error system testing while measurement. Third, determine control the electronic home appliances system by web-based Dashboard display for power consumption efficiency

3. Results and Discussion

The results show objectively the presentation of the research key results without any interpretation using text, tables and figures. The results begin with text, presenting the key finding, and referring to the tables and figures. The table must not print screen, specific numerical values, compare and contrast values, and minimum of 2 row and column. The figures must clear (provide original file as supplementary file in article submission), highlight trends, pattern, and relationship. The results must present how the author ensure the data validity and reliability.

Hardware used in this researches are :

1) Sensor Current Transformer (SCT-013 5A 1V)

Fig. 7.SCT-013

Current Transformer is sensor used for measure alternating current in a building. CT is suitable for DIY project because it can be installed directly into one of the load cable or ground cable without do high voltage electrical wiring.

2) AC Current Signal Conversion Module

Fig. 8.AC Current Signal Conversion Module

Wiring and soldering processes are required while measuring AC current using Current Transformer. Wiring and soldering processes do not necessary while using AC Current Signal Conversion Module so installation process become safer. Clamp one of the AC power cables then plug 3.5mm jack of Current Transformer to the AC Current Signal Conversion Module for read the current value. Input module is AC voltage in range 0 – 1 V (AC RMS). Output module is analog voltage in range 0.2 – 2.8 VDC. Analog output of this module is designed to be compatible with 3.3V/5V microcontroller.

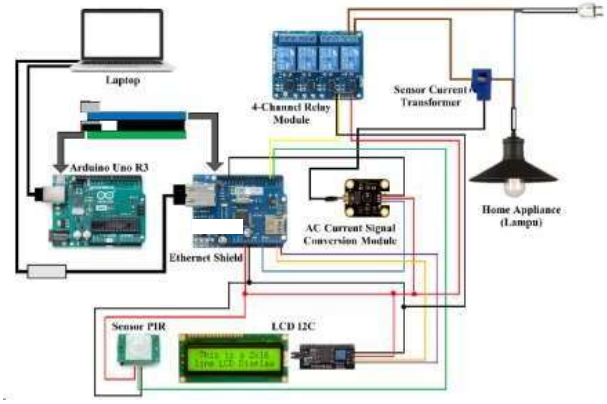


Fig. 9. Wiring Diagram.

Figure 10 displays hardware wiring diagram. One cable from electronic home appliance that would be measured is clamp by current transformer sensor. 3.5mm jack cable in CT is connect to the Analog AC Current Signal Conversion Module. AC Current Signal Conversion Module is connects to Ethernet Shield which is connected to the Arduino Uno R3 Microcontroller. Measurement results will be display using the I2C LCD and web-based dashboard on laptop. Control function is using 4-channel relay module to turn on and turn off the electronic home appliance via dashboard display.

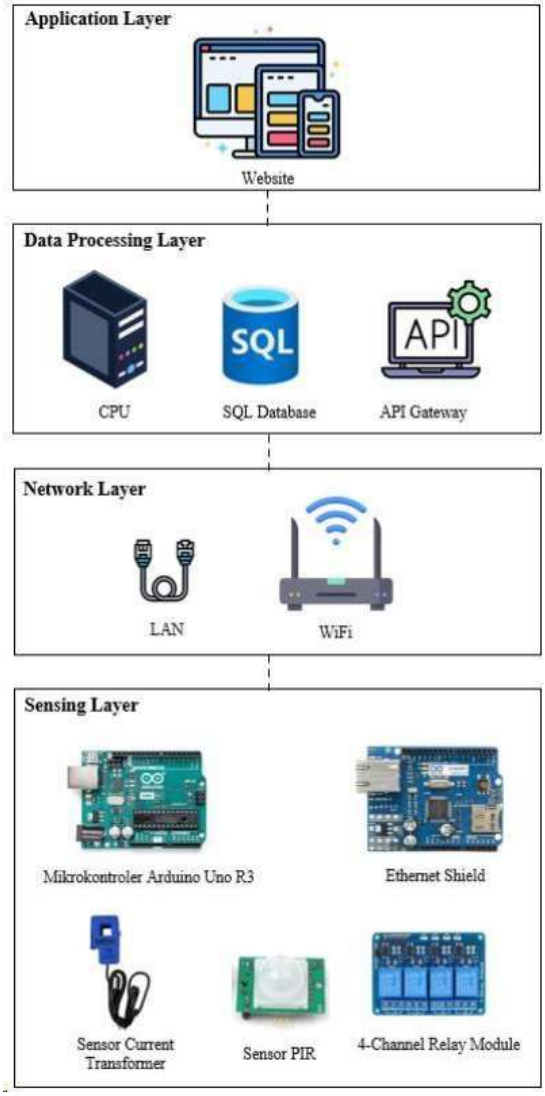


Fig. 10. IoT Architecture

Figure 11 displays IoT Architecture which divide to four layers. First, sensing layer contains all appliances and sensors used for collect data. In sensing layer there are Arduino Uno R3, ethernet shield, current transformer sensor, PIR sensor, and 4-channel relay module. Second, network layer used for transmit data between appliances and internet. This research using LAN cable and Wi-fi to communicate between appliances and internet. Third, data processing layer used to manage all data analysis. CPU, SQL database, and API gateway are used for data analysis. Fourth, application layer used for process data and display the result to end users. Application displays data and decision based on given information. Analysis data will be display on web-based Dashboard.

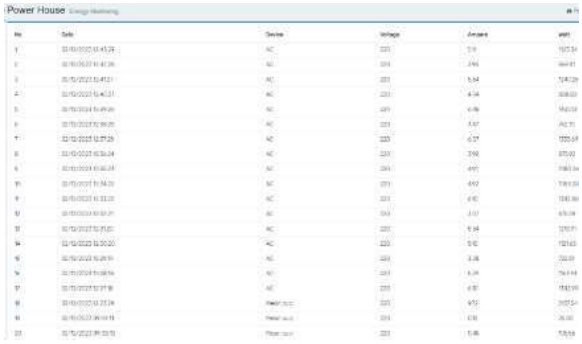


Fig. 11. Realtime Monitoring Page

Figure 12 displays Realtime Monitoring Page which contains 20 recent measurement data most recent measurement data. This page displayed numbers, date, time, measured electronic home appliances, voltage, current, and, power.

Fig. 12. Daily Monitoring Page

Figure 13 displays Daily Monitoring Page which contains measurement results data based on selected electronic home appliance during one day. This page displayed table contains numbers, date, time, measured electronic home appliance, voltage, current, and power. Measurement data displayed on line graph based on time and the total power consumption during one hour.

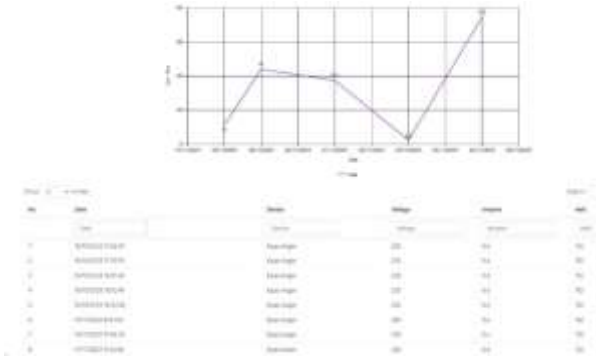


Fig. 13. Power House Data Page

Figure 14 displays Power House Data Page which contains measurement data for each electronic home appliances based on measurement date. This page displayed numbers, date, time, measured electronic home appliance, voltage, current, and power. Measurement data displayed on line graph is displayed based on date and total power consumption during selected date.

Fig. 14. Dashboard Summary Page

Figure 15 displays Dashboard Summary Page which contains measurement data for all electronic home appliances based on the selected date. This page displayed table contains numbers, electronic home appliances, voltage, current, kwh power consumption percentage for each appliances, current electricity bill, and estimated electricity for a month. Measurement data displayed on bar chart based on electronic home appliances and kWh power consumption.

Fig. 15. Device Management Page

Figure 16 displays Device Management Page which contains recent home appliances status. There are buttons for turn on or turn off the selected appliances.

Fig. 16. Measurement and Control Process

Figure 17 displays measurement and control process that used lamp as the load. Power input Arduino Uno R3 which connected to Ethernet Shield from adapter charger. Adapter charger connect to microcontroller using USB cable type A to B. Laptop connect to Ethernet Shield using USB cable type A to ethernet cable adapter. Clamp one lamp cable to SCT013 5A 1V current transformer sensor. Jack pin in current transformer sensor connect to AC Current Signal Conversion Module. Measurement result displayed on LCD and web-based Dashboard.

If current lamp status is OFF and user turn ON the lamp using the button on Dashboard, then the lights will be automatic active while the PIR sensor determines whether there is movement in the room or not. If there is no movement in the room for 5 minutes then the light automatically turns OFF. If the current lamp status is ON and user turns OFF the lamp using button on Dashboard then the light will automatically turn OFF.

Fig. 17. LCD Display While Measurement

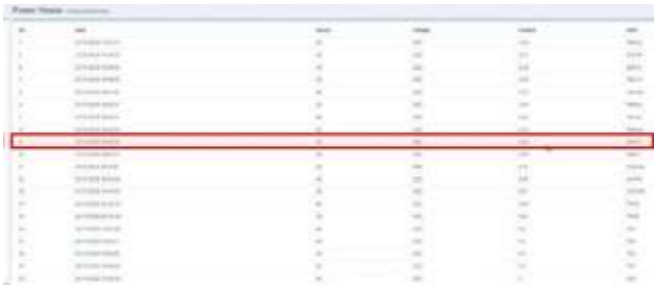


Fig. 18. Realtime Monitoring Page While Measuring AC

Figure 18 and figure 19 display measurement result using Current Transformer sensor displayed on LCD and Dashboard is 4.03 Ampere.

Fig. 19. Measurement Using Clamp Meter

Figure 20 displays measurement result using clamp meter is 4.0 A. So can be concluded that the measurement using Current Transformer sensor and Clamp Meter produce the same output result.

Table 2. Black Box Testing

TEST CASE	INPUT SCENARIO	EXPECTED RESULT	RESULT
XAMPP software connection	Click Start Module Apache and MySQL button in XAMPP software.	The Module Apache's text were green highlighted. There is statement "Status change detected: running".	✓
Collect measurement data	User fills device name in the Arduino IDE sketch based on	- Sketch done uploading and there is the text "Done	✓

	device to be measured then click Verify button and Upload button.	Uploading" at bottom of Arduino IDE software. - Device name are stored in database based on Arduino IDE filled by operator.	
Realtime monitoring	User clicks "Realtime Monitoring" on Main Navigation Dashboard Website.	Website displays Realtime Monitoring Page which contains 20 most recent measurement results data.	✓
Daily monitoring	User clicks "Daily Monitoring" on Main Navigation Dashboard Website.	Website displays Daily Monitoring Page.	✓
Daily monitoring	User clicks date on textbox.	Date pickers appears at the under of textbox.	✓

Measurements held in apartment room. User could view the electronic home appliances current status through web-based dashboard. User could turn on and turn off the lamp remotely. PIR sensor placed in the middle of the room. Measurement held on 04-05 December 2023 and 11-12 December 2023 at the same time and same human behavior habits. On 04 - 05 December 2023 the measurement held without using control system for turn on and turn off the lamp automatically. On 11 - 12 December 2023 measurement held using automatic control system to turn on and turn off the lamp. Measurement held on 17.30 o'clock until 06.00 o'clock on the next day. During the measurement, on 18.00 o'clock until 19.00 o'clock, user left the room to have dinner so there is no one in the room. With the control feature and PIR sensor, user can turn on and turn off the lamp remotely and based on necessary. This control feature is very useful for people who often forget to turn off the lamp when they are not use it.

Fig. 20. Historical Graph of Lamp Power Consumption Using Control Feature

Figure 21 displays historical graph of lamp power consumption. Power consumption on December 04th 2023 is 238,17 Watt and 315,38 on December 05th 2023. On December 04th – 05th 2023 measurement was not using control feature. Meanwhile, while using control feature the power consumption measurement on December 11th 2023 reduce become 196,99 Watt and on December 12th 2023 become 205,7045 Watt.

Fig. 21. Forecast Before Using Control Feature

Figure 22 displays forecast electricity cost before using control feature. The amount of electricity consumption for lamp on December 04th

– 05th 2023 is Rp 799,73 with forecast electricity consumption for lamp in one month is Rp 21.592,66.

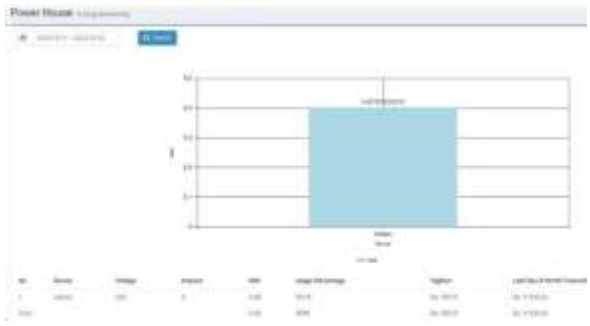


Fig. 22. Forecast After Using Control Feature

Figure 23 displays forecast electricity cost after using control feature. The amount of electricity cost for lamp on December 11th – 12th 2023 is Rp 581,79 with forecast lamp electricity cost for one month is Rp 11.635,62.

4. Conclusion

After going through design, testing, and result stages, there are several conclusions :

1. Design electric current measurement tool for each electronic home appliances was functioned well accordance with the research purposes.
2. On monitoring power consumption and estimating the electronic home appliances cost was found that AC consumed most electricity power with percentage 47.57% of the total power consumption in home.

Electrical power consumption efficiency can be achieved by using the Device Management feature which can turn on and turn off home appliances by Web-based Dashboard.

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Author Contributions: Writing-original draft, I.W.; Methodology, I.W.; Formal analysis, I.W.; Analysis result review, I.W., N.S. All authors have read and agreed to the published version of the manuscript

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