Domestic Electrical Energy Monitoring and Alerting Using SCADA and IoT

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***Abstract*—SCADA stands for Supervisory Control and Data Acquisition. It helps industrials to control process remotely, monitor the real time data, interact directly with transmitter, control valves, motor through human interface technology and lastly to record data. Most of the SCADA system was installed for industrial automation. In housing distribution switchboard (DB), it is not common to install SCADA system. A DB with SCADA system that is capable to collect and transmit data to the control unit such as personal computer (PC) or smartphone and further remote control was proposed. Since it is dangerous when there is sudden cut-off of power supply of the main switch. Some user may face difficulty to re-activate the circuit breaker or main switch. The main objective is to integrate the serial communication between the IoT and the control unit. The fault alarm message will be sent to user when there is fault. The first domestic system for electrical energy monitoring by remote controlling using SCADA and human machine interface was developed. The main component of the proposed system is Arduino Uno, 8 channels relay module, miniature circuit breaker (MCB), auto manual AC contactor, and switch mode power supply (SMPS). Main supply is from the AC voltage 240V to the switchboard. The main switch is connected to the auto manual AC contactor for the auto and manual control of the electrical flow. A smart domestic switchboard was designed with the function of sending out the fault alarm message when overload (over current) happened. The proposed system is reliable, safer, environmentally sound and achieved 80% of accuracy for notification sent out and 100% of tripped if overload was detected.**

Keywords—SCADA, IoT, domestic, energy monitoring, fault

I. Introduction

An electrical switchboard is very common in our daily life until little attentions was paid from people. The switchboard is a critical thing at home that every person must pay attention for. According to [1], more than 5300 cases recorded as faulty electrical sources which are the top of the list in Malaysia in past three years among all the causes of fire hazard. From the interview of Electrical and Electronics Association president, the awareness of electrical safety was low among Malaysians because many people are not aware that human body was a conductor, most of them think they can fix the switchboard by referring to some videos online. Thus, the installation of domestic electrical switchboard by using SCADA and IoT system was proposed to provide the people with safer way to control and monitor the condition of switchboard instead of direct touching.

It is dangerous when there is sudden cut-off of power supply of the main switch. The direct touch to re-open the circuit breaker or main switch will cause electrical shock if there is overload current leaking in the main switch board. Thus, a remotely control on main switch is needed to re-open the tripped switch which is more safety compare to direct touching. By using the SCADA and IoT system, the alarm message used to alert the user about the fault occurred inside the switchboard and able to remotely control the operation of circuit breaker. The condition of the overload current can be monitored through pc or mobile apps application.

The design of domestic electrical switchboard by using SCADA and IoT is a more safety device than the traditional switchboard that is able to prevent one from getting a fatal electric shock from direct touching when there is needed to re-operate the electrical switchboard. On the other hand, it also acts as a home automation system for convenience. The SCADA system will allow user to do the lighting control, on/off of the circuit breaker and the electrical equipment automation in timing mode for energy saving, increase efficiency and cost effective.

II. Research Review

A. *Controlling of Electrical Power System Network*

According to [2], the study was about the use of SCADA system in Dhaka city, to control and monitor the Bangladesh electrical power system transmission and distribution network. The Dhaka Power Distribution Company Limited, is the authority responsible for managing the electrical power network in Dhaka City. 132 and 33kV circuit breakers are typically run for the continuous power supply to consumers through the SCADA system.

B. *Working Principle of Programmable Logic Controller (PLC)*

According to [3], PLC was used to monitor the input values from sensors continuously and the outputs produced for the operation of actuators based on the program. Each PLC system has three modules which stated in [4]. A central processing unit (CPU) consists of memory and central processor which accept the inputs and generating the correct outputs. The system has a power supply module for the supply of the whole system by rectifying the AC power to 5V DC output for the CPU and I/O (input and output) modules. The I/O modules are used to connect the transmitter and actuators to the PLC system for monitoring and controlling different parameters such as temperature, density and pressure.

C. *Working Principle of Remote Terminal Unit (RTU)*

According to [5], RTU works as the key of monitoring system such as controlling the power switch by digital output port, monitoring the switch status by digital input port, and measuring the output voltage and power by analog input quantity port. RTU adopts an integrated microprocessor unit to process data from external switches signal and analog quantity, follow by the data transmitted to the computer according to serial communication interface. In order to monitor devices like relay and switch, RTU would emit the switch signal.

D. *Internet of Things (IoT)*

IoT platform is a cloud-based software packages related to administrations that enable and support complex IoT services. In some cases, IoT platforms enable application developers to streamline and computerize common features that would somehow require extensive time, efforts and expenses. In other cases, IoT platforms enable companies to manage thousands, millions and even billions of devices and associations over various advances and conventions. In some cases, IoT platform enable developers to join devices and connections with associated data with company specific client [6].

E. *Case Study*

1) Substation Automation System for Energy Monitoring and Control: According to [7], MF (multiplication factor) meter, RTU, Modem, and SCADA control are the main components used for the substation automation system. The MF meter gathers and shows the electrical parameter from the industrial substation and transmits the data to the RTU. The RTU can control the main circuit breaker according to the data received from the process plant. By using a pc via ethernet cable, the RTU can be configured. The SCADA controllers IP address was installed in the RTU. By using the SCADA system, the substation can operated from point-to-point communication.

2) Remote Data Acquisition Using Wireless SCADA System: Based on [8], the author built an integrated wireless SCADA system to track and access the output remotely located device parameters such temperature, real-time humidity and pressure. The authors used the current mobile network system based on GPRS. SCADA is a crucial area of continuous research and development.

3) Automation of Tank Level by PLC and Establishment of HMI: Based on [9], a system includes a simulation model and components needed by the PLC to incorporate an automatic level management system was built. SCADA and the HMI has been developed. In multiple tanks, the proposed model will efficiently track the level control. Using these information, PLC took the necessary decisions andby switching a pump on or off. There was also a manual option for modifying the automatic system. The main decision-making unit was the SIMATIC S7-300 universal controller.

4) Control of Boiler Operation using PLC: This paper [10] described the different operating stages involved in turning a boiler which is manually operated into a fully automation boiler. The demand for higher performance, efficiency and automated systems in this globalized world has increased over the years. The initial phase of this study focused on transferring the inputs to the boiler at the required temperature to keep a specific temperature in the boiler constantly

F. *Summary*

The existing systems using PLC, RTU for SCADA control and GPRS network for communication with control unit. Meanwhile, the proposed system used the Network IP Web Relay for controlling the switchboard and communication with HMI based on Internet Protocol. Basically, the main purpose of the existing system and proposed system is to control and monitor by SCADA in real time situation, for safer purposes to reduce the accident happen at household usage. The proposed system was the first domestic system that is able to control the electrical switchboard and monitor the condition of the circuit breaker by using SCADA. The proposed SCADA imitates the existing SCADA system in the industries. It increases the safety and efficiency for the users when re-operate the circuit breaker and alarm message alert when there is tripping or abnormal happened in the distribution board. Therefore, the new experience of using Web Relay and IoT in this single phase distribution board has provided a safety and efficiency way in controlling and monitoring electrical quantities for domestic household.

III. METHODOLOGY

A. *Flow Chart*

As shown in Fig. 1, the core components of the proposed system are Arduino and relay module with the help of serial communication from ESP8266-01s-WiFi module. The relay module has 8 outputs. At the input part, the sensor is connected to Arduino for detection of the electrical quantities and the data was sent to the device for further analysis. If the sensor is triggered, the alarm message will be sent out to the user for further action through internet. The user can monitor the condition of the circuit breaker that controlled all the loads in the house.

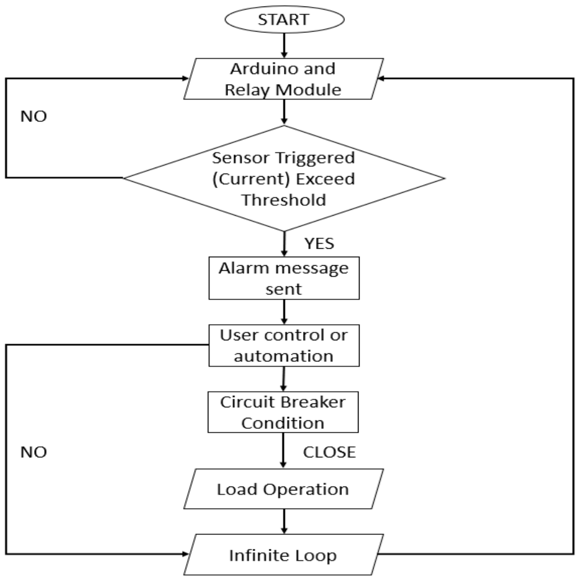

Fig. 1. Flow chart of the proposed system.

The output part is connected to the auto manual operation contactor for the switching either auto or manual operations. The manual control function is the additional feature in operating the MCB by hand, if something goes wrong with the network or other electrical problem. If there is no alarm message sent after the triggered of the sensor, then it would be either the power failure of the entire system or the Main Supply have been cut-off. The contactor will be connected to the miniature circuit breaker for the protection of the switchboard. The relay module offers an optically isolated input that enables user to monitor the system status or manipulate the relay contacts by applying voltage to it. By simply connect the relay contacts to the managed machines, the relay can be turned on or off remotely through a web browser.

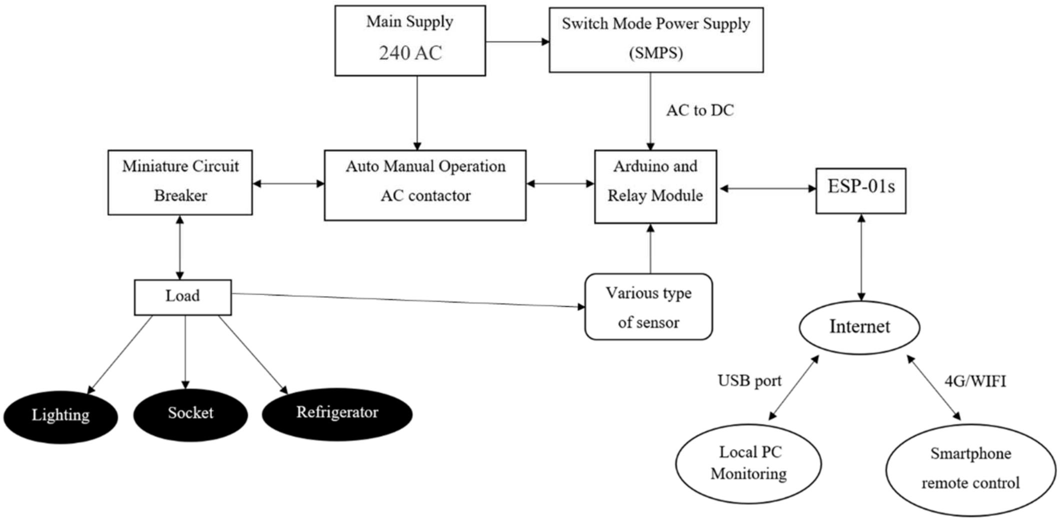

Fig. 2. Block diagram of the proposed system.

B. Proposed Design

The main components of the proposed system are Arduino, relay module, MCB, auto manual AC contactor, and the switch mode power supply (SMPS). The main supply is from the AC voltage 240V to the switchboard. By using necessary connections, the main switch was connected to the auto manual AC contactor for the auto and manual control of the electrical flow.

The Arduino and relay module were deployed at the top of the AC contactor for the convenience of wiring with the sensors and the and the modem. The input voltage of the Arduino is 12VDC. By installing the SMPS, the AC voltage flow from the main supply was rectified to DC voltage for the input of the web relay. The voltage from the main supply is rectified from 240VAC to 12VDC.

The relay module consists of 8 output relays, 8 load node input and ESP8266 as protocol. The 8-output relay is connected to the AC contactor which can control the power supply remotely. The Arduino analog and digital input pins can be connected to the wired sensors such as rain sensor, door lock sensor, leakage sensor or power lose sensor for smart home purpose. The external power supply, 5V and 3.3V were provided by the Arduino for external supply to the sensors.

The ESP was connected to the internet, which allowed the device to interface with network through the IP address. The user can access and control the device through internet with higher efficiency and more safety. Furthermore, it can be controlled through the local pc. The alarm message will be sent out through registered email address if the sensors detected any fault.

The output of the relay module was connected to the auto manual AC contactor to control the ON/OFF of the power flow. The AC contactor was connected to the MCB and supply the loads at the household. The controllable system will cover the entire room, floor, and even the whole house depend on the connection of loads, MCB and the contactor.

The current sensor was connected to Arduino Uno analog pin, for data transmission. The rated current of the relay is the maximum current (over load) set for cutting off the power supply (trip) of the contactor to the MCB automatically. The user is able to control the relay which acts as a switch to operate the AC contactor remotely.

C. Proposed Switchboard Design

Regarding to the proposed switchboard design, the enclosure was made of metallic material and the size was around 400mm × 420mm. The main switch, MCB, earth and neutral links are installed like the conventional switchboard. The Arduino Uno and relay module were connected with ESP which functioned as the remote control and monitoring system. The input at upper part was connected with sensors and the relay was connected to the AC contactor for controlling. The ESP is a WiFi module that communicate with the Internet through an user interface of IoT platform. The SMPS was installed for the supply of the Arduino Uno.

D. Measurement and Instrumentation

4 circuit breakers rated in 6A were used for experiments and the current flow values were monitored through a proposed system. In order to evaluate the efficiency (rate of true positive) of sending out an alarm message, the switchboard was tested by overloading and repeated with 100 times. The threshold current load for this preliminary stage testing was set as 0.13A. Two light bulbs were used to simulate the overload condition. Any current recorded more than 0.13A was defined as overcurrent (overload)

IV. Result and Analysis

A. Hardware

Fig. 3 shows the proposed monitoring and alerting system integrated into the conventional switchboard for remote operation.

Tab. I shows the rate of the fault alarm message sent to the user. The overload was tested by using a 2-gang switches connected with 2 sets of lighting circuits (light bulbs). Each switch was used to control a single light bulb. The power of user switched on either one of the light bulbs, the Blynk (IoT platform) will show the value of the current flow. The overload can be created when both of the light bulbs were switched on together. Once overload detected, an alarm message (email) will be sent out to notify the user. The data was transmitted to the cloud every 5 seconds and stored in the Blynk platform with real time condition.

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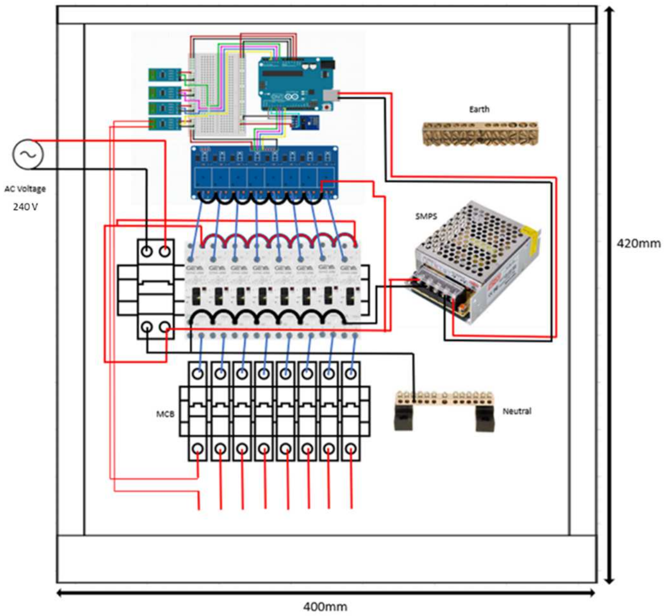

Fig. 3. Hardware design of the proposed domestic system.

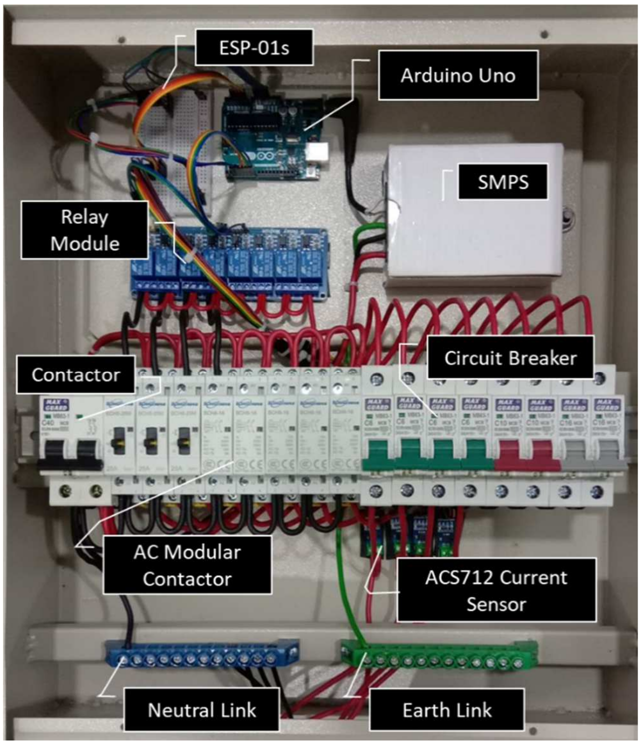

Fig. 4. Hardware of the proposed domestic switchboard

TABLE I. OVERCURRENT TESTING (THRESHOLD CURRENT – 0.13A)

Relay	Rated (A)	Load (W)	Voltage (V)	Current (A)	Trip (Yes/No)	Alarm Message
1	6	15	240	0.06	No	No
		25		0.10	No	No
		40		0.17	Yes	Sent
2		15		0.06	No	No
		25		0.11	No	No
		40		0.14	Yes	Sent
3		15		0.06	No	No
		25		0.09	No	No
		40		0.14	Yes	Sent
4		15		0.06	No	No
		25		0.10	No	No
		40		0.15	Yes	Sent

Tab. II shows the rate of the fault alarm message sent to the user when there is an internet connection. The test was repeated 25 times for each relay to ensure the relay will turn off when the current exceeds the threshold, which considered as circuit breaker trip. The threshold has been set as 0.13A. As shown in Tab. II, there were 5 times that the messages were not sent out successfully. As a result, 80% of the alarm message has been sent to the user while there is another 20% of the alarm message has an error communication at the Blynk platform.

TABLE II. OVERCURRENT TESTING (THRESHOLD CURRENT – 0.13A)

Circuit Breaker	Load	Current (A)	Trip (Yes/No)	Alarm Message
1	40 W	0.17	Yes	Sent
2		0.14		Sent
3		0.15		No
4		0.15		Sent
1		0.16		Sent
2		0.14		Sent
3		0.14		Sent
4		0.15		Sent
1		0.14		Sent
2		0.15		No
3		0.17		Sent
4		0.16		Sent
1		0.13		Sent
2		0.14		Sent
3		0.14		Sent
4		0.13		Sent
1		0.16		No
2		0.15		Sent
3		0.13		No
4		0.14		Sent
1		0.14		Sent
2		0.16		Sent
3		0.14		Sent
4		0.14		Sent
1		0.13		Sent

V. DISCUSSION

The trip condition was set to turn off the relay if current exceeded the threshold value. According to Tab. II, it shows the relays are turning off when there is overload. When both of the light bulbs are switching on at the same time, overload happened, the current exceeds the threshold value which is 0.13A and the relay will turn off automatically by cutting-off the current flow from the AC contactor to the circuit breaker and finally turn off the load. After the overload detected, an alert message will be sent out through email to the user as notification. The circuit breaker can be re-activated remotely

Fig. 5. User interface of the monitoring and alerting proposed system

by controlling the relay to switch on through Blynk. Overall, the proposed switchboard has achieved more than 80% for the rate of the fault alarm message notification to the user, however, the system will trip automatically with accuracy of 100% once overload was detected.

As shown in Fig. 5, a graph consists of 4 different color lines. Each line represents one of the control relays. For instance, the red line represented the circuit breaker 1 current flow. When a 15W light bulb was on at circuit breaker 1, the current flow was about 0.05A to 0.07A. Next, the 15W light bulb was switched off and let the 25W light bulb to on, the current was about 0.09A to 0.11A. Finally, both of the bulbs were turned on, trip was happened as the current flow exceeded the threshold value (refer to the red circle). The red line then dropped to zero due to the current was cut-off and an alert message was sent to the user. The trend was similar when the 25W light bulb was initially switch on, the purple line rises until 0.08A-0.11A and then drop to 0.06A when only 15W light bulb was on. After both of the light bulbs turned on, the current value exceed 0.13A, the Relay 2 turned off and the value drop from 0.13A to 0.00A. The result proved that if one of the circuit was overloaded, the other circuit breakers will not be affected.

For this preliminary stage, some problems have been encountered due to the combination of electronics and electrical hardware in a single metallic enclosure. There are some areas that need to be paid attention for as discussed in the following.

Firstly, the power supply of the SMPS from the main switch converted the AC power 240V to DC 12V to supply the network web relay and the electronic component, Arduino in the system. Due to the high amperage of the SMPS which convert the current to 5A, the Arduino become hot the regulator blow out. Since the maximum input of the Arduino is 12V, 1A, the current solution was to use the USB adapter to powering up the Arduino by connecting to the USB port of the computer.

Next, the relay was unable to be controlled due to the ESP WiFi disconnecting issue. Thus, an automation setting of the Arduino to control the relay during the overload was performed. In order to prevent overload situation during the lost connection of the internet, the relay still able to turn off when there is an overload detection which surpass the threshold value even the WiFi is disconnected. The current values can be observed on the serial monitor from Arduino serial port when there is connection lost. The overall performance of the proposed domestic system is functioning well but the serial communication with internet might be lost due to the electromagnetic interference issue.

VI. Conclusion

The main purpose of the study is to build a domestic SCADA system for controlling and monitoring the condition of the switchboard remotely. With IoT, the system will be more efficient as it can control from anywhere through internet. The condition of the circuit breaker can be monitored with the help of the sensor and the high accuracy of the fault alert message system will help in determining the condition of the circuit breaker when there is fault occurred. The switchboard also can be used in overload detection even when the user has internet disconnection issue. From the result, the rate of the tripping due to overcurrent is 100% while alarm alerting message sent out rate was 80%. The monitoring of the current can be done with Blynk. The switch board is reliable and it will be safer in controlling the circuit breaker with a distance. The switchboard will be environmentally sound as it helps the user to monitor the electricity usage of the household.

This study has a few weaknesses that need to be solved to have better performance. Firstly, the non-responding of ESP due to the transient occurred when switching off the relay and electromagnetic interference (EMI). By referring some comments from the Blynk users, the connection of ESP is weak if compared to other WiFi module [11]. In order to have stable connection, the Arduino WiFi shield or a NodeMCU board is recommended. With this, the sensor and the control module can directly interface with those modules since they execute stronger connection than ESP.

Since transient occurred at the relay and it caused the lost connection of WiFi module, the solid-state relay (SSR) or a metal-oxide varistor (MOV) is recommended to reduce the transient. MOV is the common voltage clamping device at now as they are used at a wide range of voltages and currents.

The MOV are good in absorbing short term voltage transients and it have the capabilities to handle the higher energy. It is possible to control over unwanted and destructive transients potentially. The electromagnetic relay has reverse surge happen when the input signal is stopped. It creates a transient voltage when the surge being created. An SSR use semiconductors for no-contact operation. Therefore, there is no noise and surge when switching relay. It can be connected in series to reduce the transient energy value to prevent the propagation through a circuit [12].

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