Remote AC Power Control by Using Microcontroller

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***Abstract*—AC power control is already existed in our daily lifestyle but there are some limitations for presence control technology, such as some AC power control devices could not control remotely and provide limited power controlling range. To improve presence power control technology, this paper presented a phase control method implemented on Arduino microcontroller to control power delivered to AC loads by using TRIAC. In this paper, a lamp load is used as the AC load. Moreover, wireless remote technology based on Bluetooth is used to control the AC loads. Thus, users are able to control the AC loads with a Bluetooth enabled smartphone as graphical user interface (GUI). This system has provided a convenient solution to control AC load wirelessly which required only a smartphone as GUI. Furthermore, the response of the developed remote AC power control system is compared with a conventional dimmer switch available in market.**

***Index Terms*—AC Load; Android; Arduino; Phase Control Method.**

I. INTRODUCTION

Controlling AC power (like switch on/off, change brightness of lamp, control fan speed etc.) is not a new thing, it is already existed in our daily lifestyle. However, existing AC power controlling is inconvenience as user required to go near to the appliance to control the device. Therefore, controlling AC power remotely is becoming the trend when the concept of Internet of Things (IoT) is becoming an increasingly growing conversation topic in the world. IoT enables embedded system, hand phone, electrical appliances, software, sensors etc. to collect and exchange data wirelessly. Bluetooth technology is one of the best way to implement IoT [14].

Wireless remote AC power control provides much of benefits such as extended range, elimination the need for wire, less maintenance, provide safety and reliable.

Lamp, heater, and AC induction motor are the most common electrical appliances in this modern world. These AC loads could be found at every residence house and industry area. Greatest interest of this paper is on controlling the power on AC load by Arduino microcontroller via Bluetooth. An Android app is developed to enable users to control the electrical appliances through Bluetooth. A circuit has been developed where the Arduino microcontroller is connected to opto-isolators, TRIAC and Bluetooth device.

Varying the root means square (rms) value of voltage supply resulting in varying of power delivered to the AC loads [8]. Varying the rms value of supply voltage could be done by using a TRIAC [12]. TRIAC is a bidirectional silicon controlled rectifier (SCR) or thyristor. Unlike SCR, TRIAC could conduct current in both directions which makes them convenient to regulate the AC voltage. Figure 1 shows TRIAC output voltage waveform.

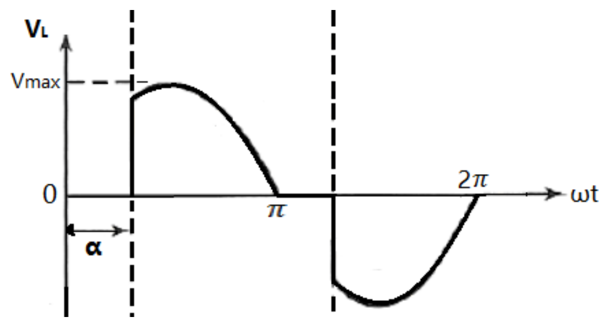

Figure 1: TRIAC Output Voltage Waveform

The load rms voltage is same as the TRIAC's output rms voltage. The TRIAC's output rms voltage is related to delay angle, α [15] which is represented as:

$$V_{L(RMS)} = V_s\sqrt{\frac{1}{\pi}\left[(\pi-\alpha)+\frac{\sin 2\alpha}{2}\right]} \quad (1)$$

where: $V_{L(RMS)}$ = TRIAC rms output voltage
V_s = Supply voltage
α = delay angle, in radian

II. BACKGROUND AND LITERATURE REVIEW

Arduino [2, 13] is convenient to use to create electronics and electrical prototypes. It is based on open-source prototyping platform that provide easy-to-use features both in hardware and software. Although there are many types of Arduino microcontroller in the market, Arduino Uno R3 microcontroller is using as the main microcontroller in this paper for its robust features. Arduino Uno is based on the ATmega328P, running on 16MHz, and provide a serial port for develop communication between devices and Arduino, such as Bluetooth module, Wi-Fi module, sensors module, keypad, computer, other microcontroller etc.

There are much of propose methods to control AC loads. The proposed method could be improved by implementing Bluetooth technology. Users could control the AC loads from the Android smartphone as GUI via Bluetooth.

To implement the Bluetooth technology on the Arduino microcontroller, HC-05 module is used in the system. HC-05 module is a Bluetooth module, designed for Bluetooth serial connection setup [5]. Compared to other Bluetooth module, HC-05 is a more capable module as it could be either master or slave device, which make HC-05 not only transmitting Bluetooth signal but also a receiver. It is used to build up the Bluetooth connection between the Arduino microcontroller and the Android based smartphone.

Android is a famous mobile operating system (OS) currently developed by Google. Android is open source which enables the manufacturers and developers to extend the functionality of devices by modify the OS or writing applications (app). As of third quarter of 2015, 84.7% smartphone market share is dominated by Android smartphone [9]. Thus, Android is chosen as the main platform to develop the GUI app to benefit most of the smartphone user. In fact, any Bluetooth controller app could be used as the GUI. However, to improve the convenience, Android Studio developed by Google is using to construct the GUI to let user to control the AC loads [6]. Android Studio is an integrated development environment (IDE) for Android app development [7]. After constructing the GUI, the Android application package (apk) file will be released from the Android Studio and be installed on Android based smartphone. The Android app is acted as GUI for user to control the AC loads.

A. Identification of Problems

Controlling electrical appliances manually is inconvenient that the users are required to move near to the electrical appliances to control it. Therefore, controlling the electrical appliances wirelessly could be a solution for this problem. Remote AC power control not only provide convenience, but also provide safety that reduce the risk that the controlling devices are damaged or in worst case, users get electrical shock.

One of the problem of existing remote controller is the remote controller is needed to point directly to the infrared receiver on the devices [11]. Remote controller also provide limited range of effective controlling distance between the controller and the devices' receiver. A better solution is using smartphone app to allow user to control electrical appliances via Bluetooth technology. Bluetooth technology provide a wider effective controlling range between devices, it have a range up to 10m between devices [17]. Also, most of the smartphone nowadays have built-in Bluetooth feature. Instead of only switch on and off, the app should enable user to control AC power delivered to the electrical appliances, such like controlling the brightness of lamp [4].

Furthermore, much of the AC control system available in the market, such as dimmer, provide a limited range of power controlling on AC load. Thus, a better power control system in terms of wider range of power controlling with wireless technology is necessary to provide convenient and acceptable power control range.

III. AIM AND OBJECTIVES

The main focus in this paper is to improve the presence AC power control system to more convenient system in terms of control AC loads remotely and provide wider power controlling range.

IV. METHODOLOGY

The power delivered to the AC loads is directly proportional to the rms voltage supply. Since socket's supply voltage on wall is always fixed, phase control technique could use to adjust the rms value of the supply voltage to the AC loads. The whole implemented circuit is shown in Figure 2.

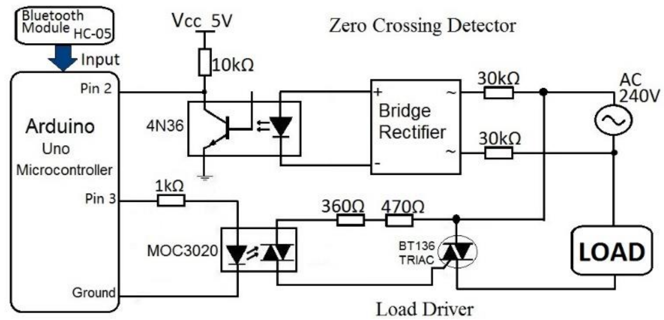

Figure 2: Phase Control Technique Circuit Diagram

The main circuit could separate to two parts, zero-crossing detector and AC load driver circuit. The zero-crossing detector [1] is the upper part with optocoupler, bridge rectifier, and two current limiting resistors. While the lower part is the AC load driver constructed by TRIAC, MOC3020 optocoupler with 2 resistors (360Ω and 470Ω). For inductive load (such as motor), resistors-capacitors (RC) combined snubber circuit is added in the circuit and connected parallel across the TRIAC, with 39Ω resistor and 0.01μF capacitor. The snubber circuit is excluded in the figure as resistive load is used in this paper. The main purpose of snubber circuit is to improve the TRIAC's switching behavior on inductive load, such as induction motor [16]. The HC-05 Bluetooth module is connected to the serial port on the Arduino Uno microcontroller.

In the phase control technique implemented, Arduino is programmed to fire the gate pulses to TRIAC for a number of microseconds after a period of time the main supply voltage cross zero. Therefore, a zero crossing detector (ZCD) is necessary to detect when the sinusoidal supply voltage goes through zero [1]. This could avoid unpredictable time for TRIAC conducts or in other words, during what part of the sinusoidal wave the TRIAC is turn on and lead to unpredictable power of loads. The pulses generated by the ZCD acts as interrupt signals to the Arduino microcontroller [18]. Arduino microcontroller is then firing a pulse to the TRIAC. By controlling the time delay between zero crossing point and firing gate pulses to TRIAC, power delivered to the AC load is controlled smoothly and effectively. To protect the Arduino microcontroller being damaged by high voltage, an optocoupler MOC3020 is placed in between the microcontroller and TRIAC to isolate the high voltage side of loads and low voltage side of the Arduino microcontroller.

A. Measuring Methods

A dimmable 240 V light bulb is using as the AC load to demonstrate the functionality of the system. The illuminance of the lamp is measured using a lux meter (Extech LT45) as shown as in Figure 3. The distance between the lamp and the lux meter is fixed at 8 cm for every data taken. All data is taken at dark environment (illuminance below 10 lux) to maintain accuracy.

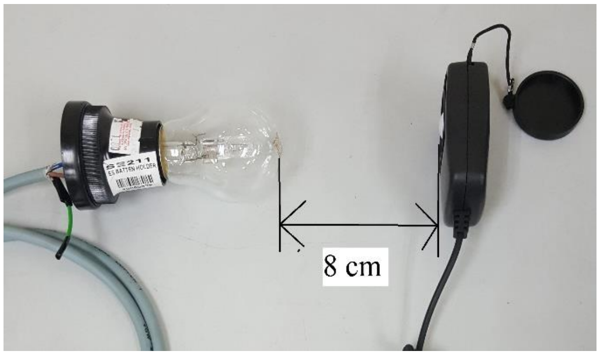

Figure 3: Illuminance of Lamp is measured by Lux Meter

To measure the load rms voltage, a Tektronix TDS2014B digital storage oscilloscope with differential probe is using to measure the actual time delay, t as shown as in Figure 4. The delay time measured is then convert to delay angle using equation as shown:

$$\text{Delay angle, } \alpha = \frac{time\ delay,\ t}{10\ ms} \times 180 \quad (2)$$

10 ms is using in the equation as the frequency of the voltage supply is 50 Hz. The delay angle, α is then convert to radian and been used to calculate the load rms voltage using Equation (1) with measured voltage supply.

Figure 4: Measuring Exact Delay Time

To make comparison of the method implemented on the Arduino microcontroller with a normal dimmer available in market, a phase-angle control dimmer switch (Promark 9008) is using to compare the behaviour of the method implemented on Arduino microcontroller.

V. Software Implementation

The method implemented in this paper is coding on Arduino Uno microcontroller using Arduino Software. The flowchart of the coding is shown at Figure 5.

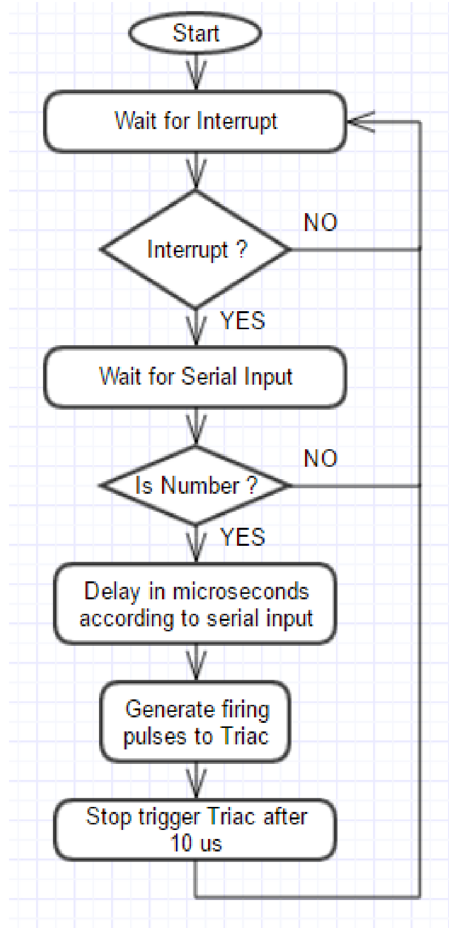

Figure 5: Arduino Coding Flow Chart

Determining the required time delay of sending triggering pulses to TRIAC after the zero-crossing is the most crucial part. The delayed time is according to the Bluetooth Serial input. To determine the time delay, first it is a need to aware of the frequency of the supply voltage. In this paper, 50 Hz supply voltage is used, which means that every 10 ms, the supply voltage will cross zero point. The step resolution used is 64 steps, which means that every step is around 150 µs. Thus, the total delay time required is 150 µs multiply with Bluetooth serial input (1 to 64).

Before trigger the TRIAC, it is a need to check whether the Bluetooth serial input is a number and lies in the range of 0 to 64 to avoid weird result (such like flickering on lamp load). The last step in the flowchart is to stop trigger the TRIAC after 10 µs. In fact, it is only remove the triggering signal to the TRIAC, the TRIAC still conduct current until next zero-crossing point. Removing the triggering signal is to make sure no accidental ignition of TRIAC is occurred before the delay time in next cycle [3].

VI. Results

The AC load rms voltage is varied as the step input varying. In Figure 6, there are two graphs plotted, practical and ideal cases load rms voltage vs step percentage. As 64 steps is using in this paper, each step input is divided by 64 to get the percentage value. The graphs are showing that the increases of step resulting of the increases of AC load rms voltage in both cases.

The ideal case data is calculated using TRIAC output voltage formula as in Equation (1) using supply voltage as 240V. For practical case, load rms voltage is measured using a digital oscilloscope as stated in methodology, Equation (1) and Equation (2) is used with measured voltage supply of 243V. For example, the delay time shown in Figure 7 is 6.4 ms, delay angle would be 115.2° and load rms voltage would be 118.4V.

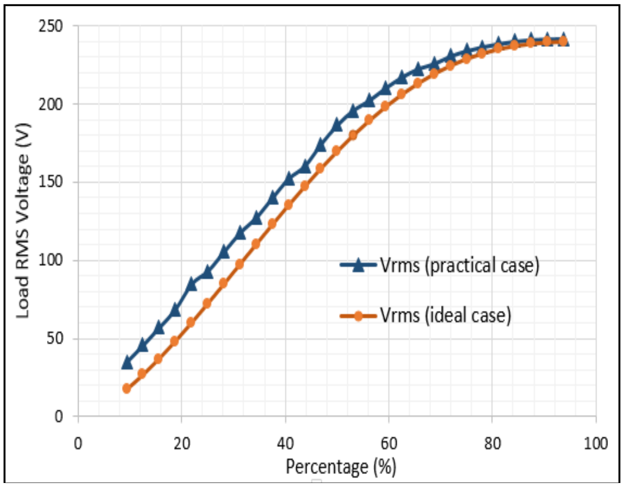

Figure 6: Load RMS Voltage vs Percentage

Figure 7: Measuring Exact Delay Time using Oscilloscope

From Figure 6, it is show that the practical load rms voltage is slightly higher than in ideal case for same step percentage although same upward trend is showing in both cases.

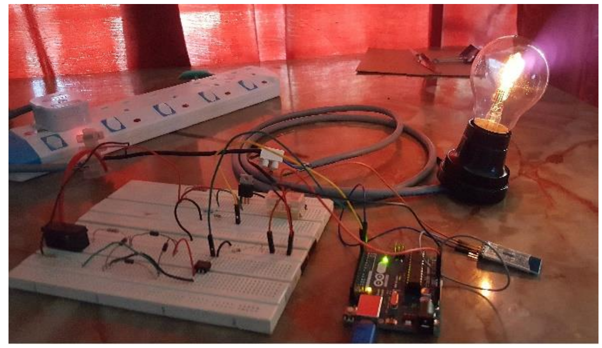

Figure 8: Lamp Load Result for '30%' Step Percentage

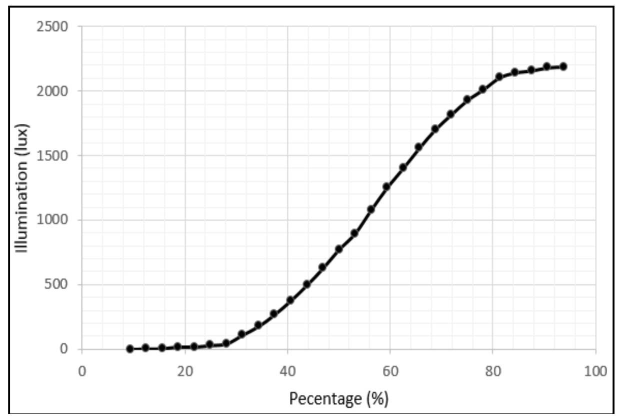

Figure 9: Illumination vs Percentage

Figure 8 shows a lamp load result for 30% step input. Figure 9 shows a graph of illumination of lamp vs percentage. From Figure 9, linear relationship of illumination and step percentage is shown in between 30 % and 85%. Illumination of the lamp is increased gradually from 110 lux to 2160 lux between 30% and 85%.

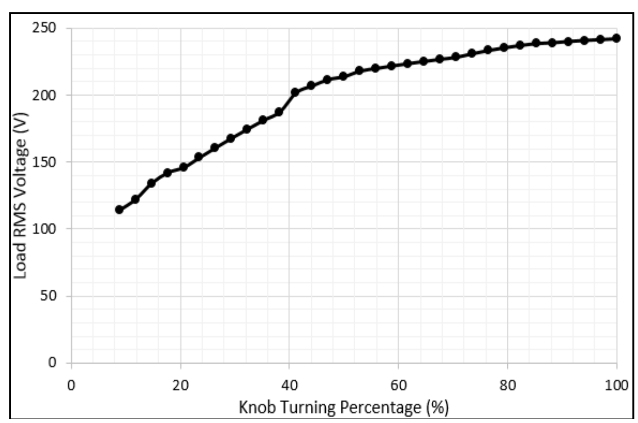

Figure 10: Load RMS Voltage vs Knob Turning Percentage

The Arduino microcontroller is compared with a dimmer available in market. Figure 10 shows the relationship between load rms voltage using the Promark dimmer and knob turning percentage. The load rms voltage of the dimmer is measured using the same method as in Figure 6 which using a digital oscilloscope. From Figure 10, it is clearly to show that the dimmer is only able to achieve the load rms voltage in the range from 113V to 241V, or 46.5% to 99.6% of voltage supply. Compared to Arduino microcontroller behaviour in Figure 6, Arduino microcontroller is able to achieve the load rms voltage from 35V to 241V, or 14.4% to 99.6% of voltage supply. Figure 11 shows the comparison of voltage range could achieved by the Arduino microcontroller and the Promark dimmer. The Arduino microcontroller provides wider range of load rms voltage controlling.

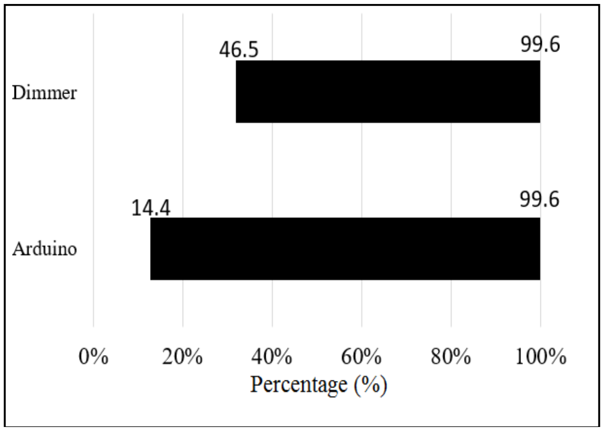

Figure 11: Comparison of Voltage Range Could Achieved

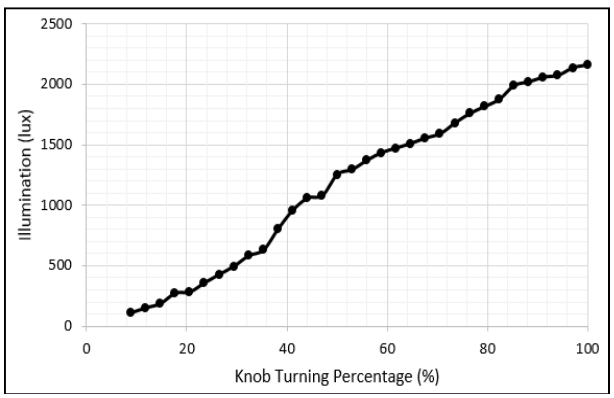

Figure 12: Illumination vs Knob Turning Percentage

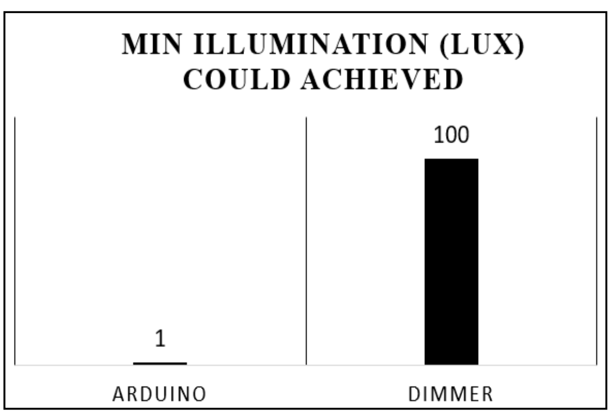

Figure 13: Comparison of Minimum Illumination Could Achieved by Arduino Microcontroller and Promark Dimmer

Figure 12 shows the graph of illumination vs knob turning percentage using the Promark dimmer. By making comparison to Arduino microcontroller,the minimum illumination of the Arduino controller able to achieve other than zero is 1 lux, which is 0.05% of maximum illumination of the lamp could achieve. In contrast, the dimmer could only regulate to mimimum of 100 lux before continue turn down the knob to switch off the lamp. The comparison is shown in Figure 13.

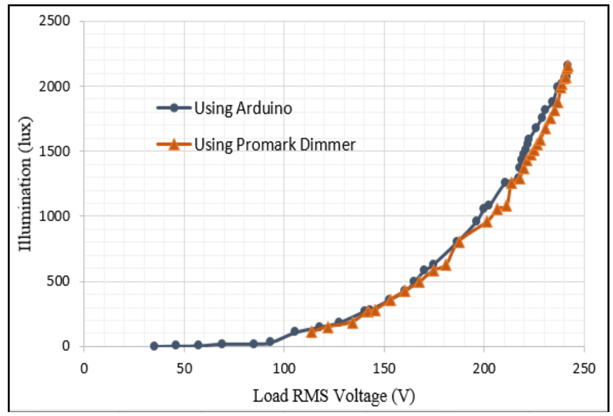

Figure 14: Illumination vs Load RMS Voltage

Figure 14 shows the graphs of illumination vs load rms voltage using Arduino microcontroller and Promark dimmer. The illumination-load rms voltage behavior for both cases are almost the same which the illumination is increased as load rms voltage went up.

VII. CONCLUSION

In short, the remote AC power control circuit by phase control method is built successfully. The control circuit is fully controllable by the Android app via Bluetooth connection. The power of load could be controlled by TRIAC with controlling the time delay of firing pulses from Arduino microcontroller. Moreover, there is insignificant of differences between practical case and ideal case. Compared with a dimmer, the Arduino microcontroller could control the AC load in a wider range of power controlling.

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