Design of direct load control device and its effect on load reduction

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Abstract. Demand for air conditioning is rising at an unprecedented level. Sudden increase in air conditioning usage has a potential of destabilizing the power grid and at extreme condition can cause power outages. Ability to control air conditioning is therefore a very significant subject for both the electric power utility and electric power consumer. In some developed countries, this is realized by a program called demand-side management. The progress of information technology and the increasing affordability of the cost of fabricating electronic devices have given rise to new concepts in the implementation of demand-side management programs, namely the direct load control method. Direct load control is a mechanism that allows demand-side management programs to run automatically without interference from consumers. This is done by directly controlling consumer electricity equipment through the internet or other wireless communication networks. This study analyzes a method to design a controlling device to be used in direct load control implementation. Load demand of the system is compared between before and after the installation of direct load control devices. Significant load reduction is noticed after the installation of direct load control devices.

1. Introduction
Demand for air conditioning (AC) has increased dramatically in recent years, largely due to the increasing ambient air temperature and frequent heat wave occurring in almost all parts of the world [1]. In Indonesia, economic growth and increasing people’s quality of life also contributes significantly to the expansion of AC usage among middle-class families. Air conditioning is an electrical equipment which consumes large amounts of electricity, especially during start up due to the inrush current. Large quantities of ACs can collectively generate stability problems to the grid if they are to be started at the same time, for example during heat wave. In such case, heat wave can cause a power outage due to large quantities of ACs being suddenly started at narrow time frame. This happened in Los Angeles in the summer of 2018 and caused massive losses to electric power utility companies [2].

In addition, air conditioning is the most significant electrical equipment among households, in terms of electricity usage. For household consumers, electricity consumption from air conditioning constitute more than 60% of the entire electricity bills [3]. While for building consumers, especially in big cities, electricity consumption from air conditioners can reach more than 80% [4]. If not controlled properly, large amounts of electricity consumption from AC usage increases the potential wasted energy.

Thus, the ability to control air conditioning is a significant subject for both the utility companies and the consumers. For utility companies, ability to control air conditioning can be used to maintain grid stability during heat wave or during peak demand. For end-consumers, ability to control air conditioning...
can be used to save electricity consumption and reduce wasted energy. In European Union there is an energy efficiency standard in which buildings must adhere to.

In some developed countries, ability to control air conditioning is realized by a program called demand-side management [5]. The demand-side management (DSM) program is rolled out by electric power utility companies and provides incentives for consumers who are willing to turn off their ACs when given instruction to do so. Time period in which the utility companies give such instruction to consumers is called "DSM events". This mechanism emphasizes only on the benefit generated by utility companies by shaving peak demand and maintaining stability of the grid. Meanwhile for end-consumers, incentives are given only when utility companies issued DSM events, which is often uncertain and unpredictable.

In consequence, DSM is still faced with problems in the form of low participation rates from consumers. Of the 65 million smart-meter users in the United States that are equipped with DSM features, only 8 million users actually participate in the DSM program [6]. Therefore, the benefits of implementing the DSM cannot be fully realized.

The advancement of information technology and the increasing affordability of the electronic device fabrication have given rise to a new concept in the implementation of demand-side management program: the direct load control method. Direct load control (DLC) is a mechanism that allows DSM programs to run on their own without interference from consumers. This is done by directly controlling consumer electricity equipment through the internet or other wireless communication networks.

In some cases, implementing DLC can significantly increase DSM participation rates. The state of Texas in the United States has implemented DSM since the 1970s, but consumer participation rates are still very low, at 0.11%. Meanwhile, in the state of Florida that has implemented the DLC the participation rates are more than 14.5% [7].

To that end, this paper presents a design of direct load control device for use by end-consumers. Data regarding how much reduction can take place in electricity consumption are also presented.

2. System design

Direct load control (DLC) device in this paper is designed to control air conditioning units installed in typical residential buildings in Indonesia. This device is limited to only control air conditioning units because other types of electrical appliances do not consume energy as much as air conditioning [3].

Most of the residential air conditioning units installed in Indonesia are typically equipped with infrared remotes [8]. In order to best mimic how the original remotes work, design of this DLC device needs to consider not only how to turn on and off, but also how to change set point temperature, fan speed, and cooling modes.

An infrared remote uses light emitting diode (LED) light to transmit their infrared signals. The signals are in the form of pulses of infrared lights which corresponds to specific command codes. These codes in the form of infrared light pulses is detected by a sensor inside an air conditioning unit. Each code corresponds to a specific command such as turning on or off, increase or decrease temperature, or change fan speed or cooling modes. Therefore, to control an air conditioning, DLC device needs to be able to save these command codes and generate infrared pulses according to these codes.

To achieve such criteria, the design of DLC device revolves around ESP8266-12F microcontroller with built-in Wi-Fi connection capability. ESP8266-12F, or ESP-12F for short, is equipped with general-purpose input output (GPIO) pins for powering infrared LED and sufficient memory to save infrared commands. Command for DLC program will be sent from the server to DLC device using Wi-Fi network, as depicted on Fig. 1.

Upon turning on, DLC device will login to a predefined Wi-Fi network using given SSID and password. DLC device will then connect to a server and wait for a command from DLC program. Upon receiving command from the server, DLC device will generate IR pulses to control air conditioning unit according to the DLC program. DLC program, which consists of air conditioning set point temperature and other settings, is running on the server.
This device uses two infrared (IR) LEDs connected in series and is controlled by ESP-12F using a transistor. ESP-12F and IR LEDs are all powered by XC6206 voltage regulator which drops supply voltage of standard 5V micro USB charger to 3.3V. Schematics of this DLC device is illustrated on Fig. 2.

Two IR LEDs are in series with resistor R3 in order to limit the current passing through the LEDs. The transistor is connected to ESP-12F through resistor R1 to limit the base current flowing to the transistor. The XC6206 voltage regulator is installed with two decoupling capacitor C1 and C2 to improve its stability.

PCB layout is made based on the schematics depicted on Fig. 2. The PCB layout is designed with two layers of copper on the surface of 1.0 mm thick FR-4 fiber board. PCB layout design and final board with populated components is shown on Fig. 3.
3. Experiment setup
Designed device is implemented in a typical residential building to measure how much energy is being reduced. This device is installed in a room equipped with an air conditioning unit. During implementation, power consumption and room temperature are measured.

The experiment consists of two parts. On the first part, power and temperature are measured, but there is no DLC event. DLC event is a time period in which DLC device is actively controlling air conditioning unit (called DLC program), either turning off, or changing other settings.

On part two, DLC program is running and DLC event is begins by midnight at 23:59:59 and ends at 05:00:00. During DLC event, air conditioning unit located at the experiment room will be changed from 18°C to 20°C and from cool mode to dry mode. Air conditioning is also turned off automatically at exactly 05:00:00 just before DLC program ends.

During both parts of the experiment, power consumption and room temperature are measured from 21:00:00 to 05:00:00 on the next day.

4. Results and analysis
Power and temperature measurement during implementation are plotted on Fig. 4 and Fig. 5 respectively.

Typical residential buildings do not use inverter-type air conditioning, hence the compressor inside air conditioning unit is switched on and off to adjust room temperature according to a setpoint temperature. Due to the nature of how compressor works on this type of air conditioning, power consumption fluctuates a lot during this experiment.

To best illustrate how DLC program correlates to energy reduction, power consumption during experiment is averaged hourly as shown on Fig. 4 and Fig. 5.

4.1 DLC not running
As the night progresses, ambient temperature goes down, hence air conditioning power consumption also lowers, as depicted on Fig. 4. When the sun has risen at approximately 04:40 in the morning, ambient temperature rises. After sun has risen, slight increase in power consumption is observed. Total energy consumption from 23:59 to 06:00 is 7.95 kWh.
4.2 DLC running

In the second part of this experiment, DLC program initiated at 23:59 is reducing power consumption from 1743 W to 1399 W, 19.4% of power reduction. Furthermore, for the next hours before sunrise, power consumption decrement is observed to be more drastic than it is in the first part of this experiment. This is due to the change in cooling mode initiated by DLC program during DLC event.
Increment of set point temperature and change of cooling mode initiated by DLC program has led to slight increase in room temperature. Average temperature from 23:00 to 23:59 is 25.13°C meanwhile from 00:00 to 00:59 is 25.52°C, or about 1.5% raise in room temperature. Temperature change due to the DLC program is less than 0.5°C, hence unnoticeable and has no significant negative impact on comfortability [9].

Total energy consumption from 23:59 to 06:00 is 5.78 kWh. In comparison to the first part of the experiment, DLC program has successfully reduce energy consumption from 7.95 kWh to 5.78 kWh, or 27.3% of energy reduction.

5. Conclusion
The device designed in this paper successfully demonstrated the reduction of energy consumption in a residential building through the direct load control of air conditioning unit. Electrical appliance being controlled during DLC events is limited to air conditioning only because other types of electrical appliance do not consume energy as much as air conditioning.

The set point temperature of air conditioning unit is increased and the air conditioning unit is shut down in the morning at desired time using direct load control, while indoor temperature is measured. It is concluded that for this specific residential building, energy consumption is reduced by 27.3% every night during a DLC event. Cumulatively, energy reduced for each month amounts to 65.1 kWh. During DLC events, it is also concluded that the increase of indoor temperature does not exceed beyond comfortable level.

This demonstration suggests that a similar DLC program may be implemented to a large number of residential buildings to achieve a higher amount of energy reduction. In the future when this DLC program is implemented in a large scale, collective power demand reduction by this DLC program may prove to be very effective in maintaining grid stability when the grid is overloaded.

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