# An Energy-Saving Concept of the Smart Building Power Grid with Separated Lines for Standby Devices

*Dmytro Zubov*
Universidad Politécnica de San Luis Potosí, San Luis Potosí, Mexico
dzubov@ieee.org

**Abstract**

Standby power takes 5-10 % of the residential electricity around the world. Some countries lose more than 14 % of the total electricity used in the residential sector. Hence, a new energy-saving concept that could help to decrease the power losses is discussed in this paper. Firstly, the two power lines of infrastructure for continuously connected equipment and for standby devices is proposed for new smart buildings. Secondly, the segmented infrastructure with unified hardware units is proposed for existing smart buildings (the new one can apply this principle as well). The contactors (i.e. unified hardware units) consist of the NodeMcu Lua ESP8266 WiFi IoT development board, ACS712T ELC-30A current sensor, and the Songle relay. The automatic mode is based on three steps: measurement of the current using ACS712T ELC-30A sensor in all segments except the root; switching off the relays with the current less than or equal to any number in the historical data; switching off the root contactor if all the descendent relays (i.e. contactors) are switched off. Second step represents the linear classification with sliding window in machine learning. The software consists of two parts, low-level Arduino sketches and high-level C# Windows form app. They are connected by MQTT broker Mosquitto. The proposed concept was successfully tested using a prototype with three segments, one of which includes smart lighting. The payback period is of approximately one month and a half for the whole-building switch concept.

**Keywords:** Smart power grid, energy-saving, standby power, IoT, MQTT.

## 1. Introduction

Standby power takes 5-10 % of the residential electricity in the most developed countries[1]. For instance, the average Canadian or USA home already has 25 or even more standby devices with active power consumption, greater than 50 W[2], which is from 2 % to 10 % of the total energy consumption. However, some developed countries, e.g. Italy and Denmark, have higher standby loss – greater than 14 % of the total electricity used in the residential sector (Solanki, Sarma Mallela, & Zhou, 2013). In developing countries, standby devices are not widely in use, as well as statistics is not available for some of them (Ajay-D-Vimal Raj et al., 2009). For instance, a typical university building loses 12.7 % of the total energy in China (Li-juan Qu et al., 2015), while the average standby power in a Mexican home is 24 W, which represents about 10 % (up to 160 kWh annually) of the average household consumption in Mexico (Lang, 2014). In addition, approximately 1 % of global $CO_2$ emissions is a result of the standby energy wasting[3].

Nowadays, many countries accept the standards limiting standby power. For instance, Mexican official standard NORMA Oficial Mexicana NOM-032-ENER-2013 "Límites máximos de potencia eléctrica para equipos y aparatos que demandan energía en espera. Métodos de prueba y etiquetado" ("Electrical power limits for equipment and devices that require standby power. Test procedures and labeling") sets a limit of 2-15 W, depending on the type of equipment and / or device that requires standby power. [4] The European Union Commission Regulation No. 801/2013 with respect to the ecodesign requirements for standby, off mode electric power consumption of

1 Standby Power: Lawrence Berkeley National Laboratory. (2016). Retrieved from http://standby.lbl.gov

2 Cut Phantom Power to Lower Energy Costs. (2016). Retrieved from http://www.greenlivingonline.com/article/cut-phantom-power-lower-energy-costs

3 Idem 1

4 NORMA Oficial Mexicana NOM-032-ENER-2013, Límites Máximos de Potencia Eléctrica para Equipos y Aparatos que Demandan Energía en Espera. Métodos de prueba y etiquetado. (2014). Retrieved from http://www.dof.gob.mx/nota_detalle.php?codigo=5330530&fecha=23/01/2014

electrical and electronic household and office equipment, and televisions recommends the maximum networked standby power consumption to be of 8 W for the High Network Availability (HiNA) equipment (it resumes functions within milliseconds, e.g. router, network switch, wireless network access point) and of 2 W for the non-HiNA devices by Jan 1, 2019.[5] The measurement of the power consumption is the bottleneck in the analysis of the standby energy. Here, two main approaches are as follows:

1. Determining the power consumption using the date, time, and physical location of the consumer.
2. Determining the power consumption using the current sensors.

Both approaches can be realized using machine learning methods (Mitchell, 2016). For instance, the prediction of power consumption is discussed in Rudin et al. (2012), Voynichka (2014), and Wu et al. (2011) (the first approach). However, the most efficient control is based on feedback from the consumption side (the second approach). The current sensors like ACS712 (Warren et al., 2011) (maximum 5 A, 20 A, and 30 A versions are available now) can implement this algorithm. However, the issue about the usage of standby devices remains open – only end-users know exactly what device(s) must be connected or disconnected.

Many research scholars and industry professionals have already discussed the standby power losses (Solanki et al., 2013; Ajay-D-Vimal Raj, 2009; Li-juan Qu et al., 2015; Chakraborty & Pfaelzer, 2011; Alan Meier, 2001; Mohanty, 2001) and different concepts of the smart power grids (Joseph Burgett & Abdol Chini, 2013; Cheng-Hung Tsai, 2013; Varghese & Premi, 2013; López-de-Armentia et al., 2014) to improve the overall energy efficiency. International Electrotechnical Commission standard IEC 62301:2011 "Household electrical appliances – Measurement of standby power" specifies "methods of measurement of electrical power consumption in standby mode(s) and other low power modes (off mode and network mode), as applicable".[6] In Joseph Burgett & Abdol Chini (2013), the whole-house (i.e. whole-building) switch concept is presented. In Rudin et al. (2012), the algorithms and hardware design are discussed to reduce the standby power consumption for the home appliances; here, the main idea is to analyze the power consumed by the appropriate device and disconnect it if standby level is detected; the devices are connected according to specific algorithms, e.g. PIR sensor detects the presence of person, the light sensor detects the dark. In López-de-Armentia et al. (2014), the concept of eco-aware devices is proposed; here, Arduino Uno and Ethernet shields are used for the learning of several devices, and then this information is applied for the forecasting of next-day operations. However, the segmented structure of the power grid and budget unified hardware are not discussed in these papers.

The above-stated analysis shows that the most efficient approach to minimize the standby energy loss is to install the separate power lines for the standby devices (the whole-building switch (WBS) concept in Joseph Burgett & Abdol Chini, 2013) or split the power grid into segments with remote control of the contactors (e.g. relays Songle SRD-05VDC-SL-C [22]). The networking technologies like the Internet of Things (IoT) (Slama et al., 2015) can be in use to provide reliable budget solutions of the energy-saving power grids. Nowadays, the most known IoT hardware platforms are Arduino/Genuino and Raspberry Pi (Norris, 2015; Doukas, 2012). Arduino has an industrial version – microcontroller Industruino.[7] Arduino Uno run-time is 50 days approximately,

[5] COMMISSION REGULATION (EU) No 801/2013 of 22 August 2013 amending Regulation (EC) No 1275/2008 with regard to ecodesign requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment, and amending Regulation (EC) No 642/2009 with regard to ecodesign requirements for televisions. (2013). Retrieved from http://www.greenlivingonline.com/article/cut-phantom-power-lower-energy-costs http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:225:0001:0012:en:PDF

[6] IEC 62301:2011: Household Electrical Appliances - Measurement of Standby Power. International Electrotechnical Commission Standard. (2011). Retrieved from https://webstore.iec.ch/publication/6789

[7] Industruino. (2016). Retrieved from https://industruino.com

as well as the price of Arduino boards is several times less than the Raspberry Pi analogues usually.[8] Hence, Arduino boards are used widely in IoT area. In addition, new WiFi Arduino-compatible boards like NodeMcu Lua ESP8266 are applied for the wireless connection; here, sketches can be developed in Arduino integrated development environment (IDE).[9]

The IoT devices are connected by specific IoT protocols because of the real-time communication requirements (e.g. limited Internet traffic), low performance and memory of IoT hardware, as well as the Internet connections are slow sometimes. In addition, standard IoT protocols connect devices of different brands, which are not able to communicate otherwise because of software and hardware incompatibilities. Nowadays, two IoT protocols, MQTT and CoAP (Jaffey, 2014; Stansberry, 2015), are mainly in use. The first one is based on Internet TCP (Transmission Control Protocol), and the second one on UDP (User Datagram Protocol). The viable alternative of the IoT protocol depends on the project. If the message is going to be published from one node to many nodes, the MQTT protocol is recommended to use. In the systems with traffic limitations, CoAP is recommended because it uses UDP, which eliminates the overhead of TCP/IP. It makes a big difference in traffic for the system with 1000s of nodes. In the following, the MQTT protocol is applied to transmit/receive the data because of the number of nodes (up to 100 for smart building), feasibility to provide the secure TCP connection among clients/broker (passwords and Secure Sockets Layer cryptography), as well as for the fact that it uses approximately 10 KB of memory for Arduino compatible devices (PubSubClient library).

Based on the above-stated brief analysis of the previous studies, this paper's main goal is to discuss the new energy-saving concept of the smart building power grid with separated lines for standby devices. The main principles are as follows:

1. The power grid of new smart buildings is installed using two power lines – the first one is for continuously connected equipment like alarm systems and refrigerators, while the second one is for standby devices. In this case, the WBS algorithm (Kurkinen, 2016) is recommended.

2. The power grids of existing smart buildings are split into segments with appropriate contactors at the beginning of each segment. In this case, the segments are connected / disconnected according to the needs of the end-users. New smart buildings can apply this principle as well.

3. The contactors are unified hardware units based on NodeMcu Lua ESP8266 WiFi IoT development board, ACS712T ELC-30A current sensor, and Songle relay, which is budget solution of approximately 5 USD price. The current sensor provides on-line feedback in the intelligent algorithm to switch off the standby devices automatically.

This paper is organized as follows: In Section 2, the infrastructure of smart building power grid with separated lines for standby devices is discussed. In Section 3, the software, automatic mode, and smart lighting are described. The conclusions are summarized in Section 4.

## 2. The infrastructure of smart building power grid with separated lines for standby devices

68 million houses in North America and Europe will be smart by 2019 (Kurkinen, 2016) with a compound annual growth rate of 37 % and 61 %, respectively. The smart equipment is usually installed together with an upgrade (e.g. aluminum wires are replaced by copper ones) of the power grid. In this case, additional power lines for standby devices are cabled, and the WBS concept is applied using one power switch only (see figure 1). For instance, the Songle high-power relay T90

[8] Arduino – Maximum Run Time and Fault Tolerance. (2013). Retrieved from http://forum.arduino.cc/index.php?topic=191416.0

[9] User Manual for ESP-12E DevKit based on ESP8266. (2016). Retrieved from https://smartarduino.gitbooks.io/user-manual-for-esp-12e-devkit/content/index.html

can control the whole building electricity with load up to 30 A using NodeMcu Lua ESP8266 WiFi and/or Arduino Uno / Mega boards.[10]

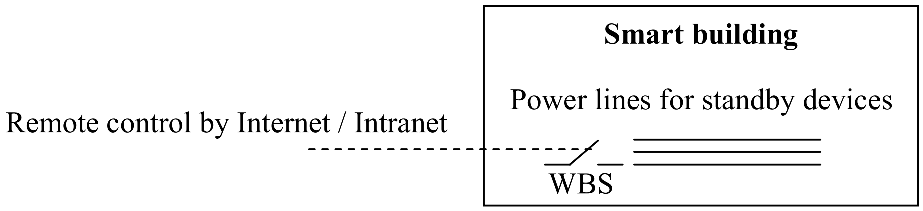


*Figure 1. The whole-building switch concept for the power lines of standby devices*

The segmented power grid concept is in use if WBS cannot be installed or independent control of different segments is needed. In this case, the NodeMcu Lua ESP8266 WiFi board, ACS712T ELC-30A current sensor, and relay SRD-05VDC-SL-C (load is up to 10 A) are proposed to compose the unified hardware unit. This is a budget solution of approximately 5 USD price. The sketches are developed in Arduino IDE with MQTT protocol for the remote control. Figure 2 shows an example of smart power grid with hierarchical structure, where every segment equals a room or office. This approach is similar to the idea presented in Alboteanu et al. (2015), where the connecting / disconnecting of renewable energy sources and consumers are made via the appropriate contactors, automatically (or manually) controlled according to the energy consumption/generation. However, the management of micro smart grid is discussed in Alboteanu et al. (2015) only. Figure 3 shows unified hardware unit based on NodeMcu Lua ESP8266 WiFi board (LoLin version), ACS712T ELC-30A current sensor, and relay SRD-05VDC-SL-C.

The payback period of the WBS concept is calculated for the power lines of standby devices given the active standby active power consumption of 50 W and a price of 0.1 USD per kW. Hence, 5 USD divided by 0.12 USD (0.050 kW multiplied by 24 hours and then multiplied by 0.1 USD) equals 42 days, which is payback period for the proposed unified hardware unit with ACS712T ELC-30A current sensor, and Songle high-power relay T90.

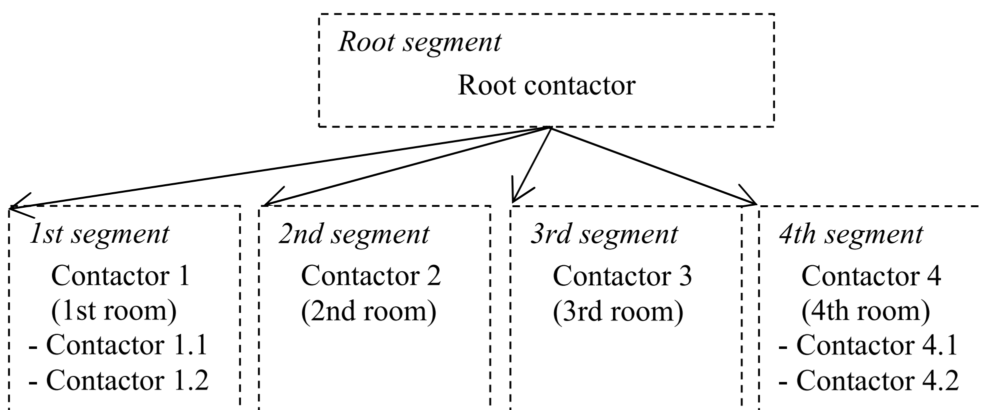


*Figure 2. An example of smart power grid with hierarchical structure*

[10] Songle Relay T90. (2016). Retrieved from http://www.songle.com/en/pdf/2008414165561000.pdf

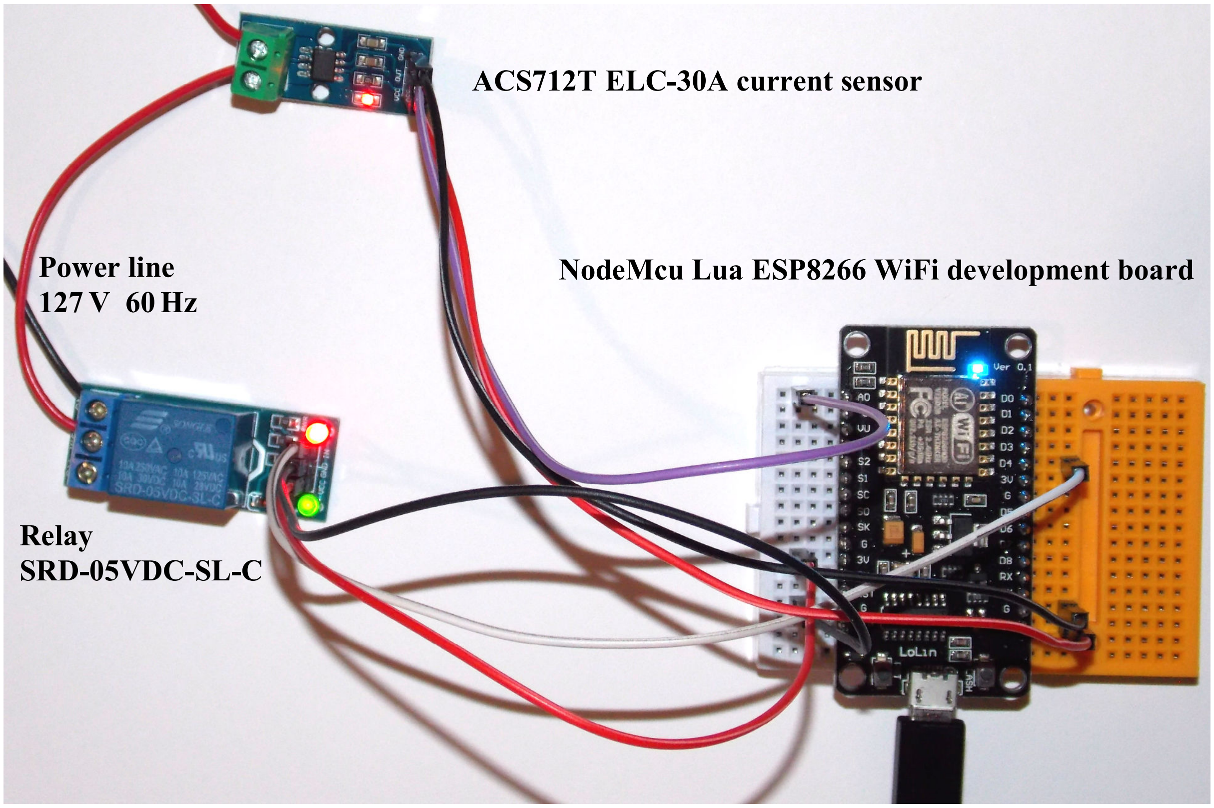


*Figure 3. The unified hardware unit based on NodeMcu Lua ESP8266 WiFi development board, ACS712T ELC-30A current sensor, and relay SRD-05VDC-SL-C*

## 3. The automatic mode algorithm and smart lighting

### 3.1. Description of software

The software consists of two parts, low-level Arduino sketches and high-level C# Windows form appplication. They are connected using the open-source message MQTT broker Mosquitto.[11] Every hardware unit has the unique identifier and commands to control the relay. The MQTT topic "/VPP/Relays" is used by subscribers and publishers. The number "50" sent from C# Windows form (it equals number "2" sent from the standard Mosquitto publisher) is a command to switch on the second relay, "51" ("3") – to switch off, respectively. The prototype was developed with one root controller and two descendant relays. The commands are as follows: "52" ("4") / "53" ("5") – to switch on / off the first relay, "54" ("6") / "55" ("7") – to switch on / off the third relay, respectively. This solution is similar to the one presented in [22], but ACS712T ELC-30A current sensor and ESP8266WiFi.h library are applied here. In addition, other commands, e.g. "56" ("8") to get the value of the current in the 3rd segment, are in use as well.

The screen shot of the C# Windows form app is shown in figure 4. The text field on the left side includes numbers from 2 to 7, which are commands to control the states of relays.

[11] An Open Source MQTT v3.1/v3.1.1 Broker Mosquitto. (2016). Retrieved from http://mosquitto.org

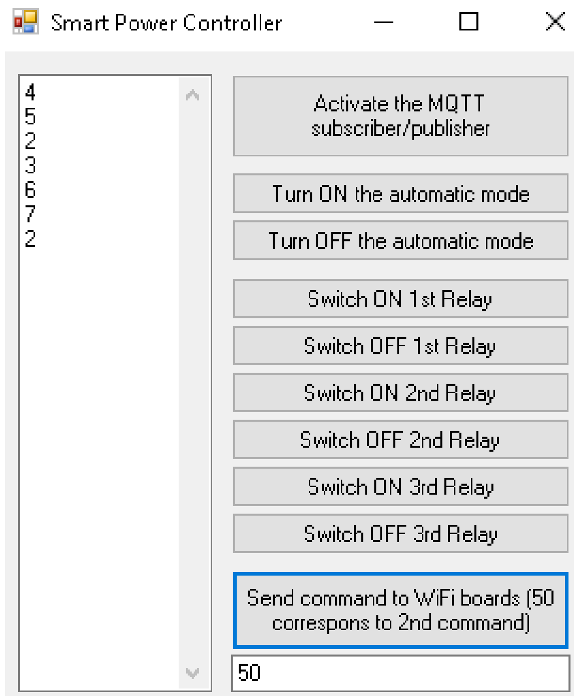


*Figure 4. Screen shot of the C# Windows form app*

### 3.2. The automatic mode algorithm and smart lighting

The automatic mode is activated by clicking the button “Turn ON the automatic mode” on the Windows form appplication. The algorithm is based on the analysis of the states of descendant relays as follows:

*Step* 1. Measurement of the current using ACS712T ELC-30A sensor in all segments except for the root.

*Step* 2. Switching off the relays, where the current is less than or equals any number in the historical data.

*Step* 3. Switching off the root contactor if all descendent relays (i.e. contactors) are switched off.

In step 2, historical data are represented by the last ten values of the current measured when the appropriate relay is switched off by clicking a button on the C# Windows form application. The method was successfully tested for the office equipment in the building for the professors at Politécnica University of San Luis Potosí. This approach is a simplified version of the linear classification with sliding window in machine learning (Mitchell, 2016). The ACS712T ELC-30A current sensor on the consumption side, as well as the uniformity of the office equipment, allows using this approach.

In case of temporary problems with the WiFi router (overheating, troubles with WiFi signal, non-stable power supply, etc.), the additional electrical switches are installed. Hence, the end-users can manually control the power grid segments.

The NodeMcu Lua ESP8266 WiFi board has several digital and analog pins, which can be used for different purposes together with switching on/off relays, e.g. to control the motors, to acquire the data from sensors. It allows developing multifunctional smart systems. For instance, the smart lighting unit is created using NodeMcu Lua ESP8266 ESP-12 WiFi board, Arduino light sensor, and relay SRD-05VDC-SL-C, which controls the power supply of the lamp. Figure 5 shows a simplified example of smart lighting, where the lamp is represented by eight 5 mm light-emitting diodes (LEDs).

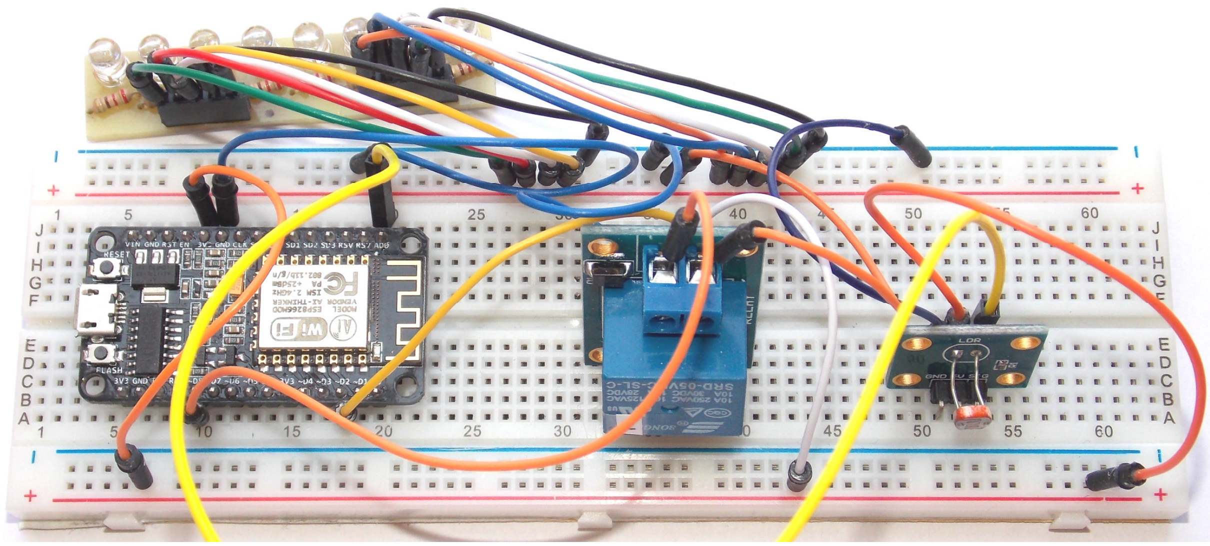

*Figure 5. An example of smart lighting using NodeMcu Lua ESP8266 ESP-12 WiFi board, Arduino light sensor, and relay SRD-05VDC-SL-C. The lamp is represented by eight 5mm LEDs*

**4. Conclusions**

In this paper, the new energy-saving concept of the smart building power grid is proposed. The main principles are as follows:

1. The power grid of new smart building is installed using two power lines – the first one is for continuously connected equipment like alarm systems and refrigerators, while the second one is for standby devices. In this case, the WBS algorithm is applied.

2. The power grids of existing smart buildings are split into segments with appropriate contactors at the beginning of each segment. In this case, the segments are connected / disconnected according to the needs of end-users. New smart buildings can apply this principle as well.

3. The contactors are unified hardware units based on NodeMcu Lua ESP8266 WiFi IoT development board, ACS712T ELC-30A current sensor, and Songle relay, which is the budget solution of approximately 5 USD price.

The automatic mode is based on the analysis of the current on the consumption side using ACS712T ELC-30A sensor. The descendant relays are switched off if the appropriate current is less than or equals any number in the historical data. The data are represented by the last ten values of the current measured when the appropriate relay is switched off by clicking a button on the C# Windows form application. This approach is a simplified version of the linear classification with sliding window in machine learning. The final step is to switch off the root contactor if all the descendent relays are switched off.

The developed software consists of two parts, low-level Arduino sketches and high-level C# Windows form appliance. They are connected by MQTT broker Mosquitto.

The proposed concept was successfully tested using a prototype with three segments, one of which includes smart lighting.

The most likely prospect for the further development of this work is the remote control of the power grid using mobile phones and GSM/GPRS modules on the smart building side.

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