*Rev. Roum. Sci. Techn.– Électrotechn. et Énerg.*
Vol. **68**, *4*, pp. 412–417, Bucarest, 2023

**Automatique et ordinateurs**
**Automatic Control and Computer Sciences**

# SMART SYSTEM FOR STANDBY POWER CONSUMPTION REDUCTION OF HOUSEHOLD EQUIPMENT

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**Keywords: Household equipment; Stand-by power consumption; Arduino system; Android; Bluetooth.**

**One of the characteristics of household equipment is that it also consumes power in standby mode, which can take considerable amounts over time. A smart system that can automatically cut off the equipment's power supply in standby mode must be important to reduce power consumption and financial expenses. To design the system, first, the power consumption in standby mode for 3 basic household equipment was measured. In one month, the total energy consumption measured in standby mode was 28.31 kWh. Then, the system's functions, based on the Arduino Nano microcontroller, have the role of controlling a relay module status, which is given by the equipment's consumed current. The system's control is done using an application developed for Android Operating System devices, which can be used to set the time delay current value and manually activate/disable the system. By implementing the proposed system on the 3 previously measured household equipment, the energy consumption on stand-by mode is reduced by 19.83 kWh per month.**

## 1. INTRODUCTION

Year after year, due to energy price growth, optimizing power consumption by reducing it and implicitly the cost becomes an increasingly important topic. One of the general characteristics of common household equipment is the power consumption in standby mode [1].

The delay in domestic energy conservation results from the need for more essential knowledge about energy consumption. Many households use various energy types in their daily lives; however, the purpose of each type remains to be determined. The link between household characteristics and energy consumption is also unknown [2,3]. Households play an important role in global energy demand and, precisely, in electricity demand. Reductions in electric power consumption have generally been relevant for the environmental and energy security areas, even though electricity is essential in our lives. Eurostat (2020) claimed that in 2018, the residential area was responsible for 26 % of the final energy consumption, and the total energy consumption in the EU was 29 %. Consecutively, 24.7 % of the total energy consumption in the residential sector is represented by electricity, although this number can reach as high as 73 % in Norway. The needs of the EU for lighting and space cooling are met 100 % by electricity. Also, 83.4 % is used for other end-uses, which includes 49.2 % for the kitchen area [4,5].

There is extensive literature on power quality in household systems where residential electrical nonlinear loads influence the harmonics and cause distortion that leads to excessive heat, representing lost energy [6–9].

In past articles, one of the solutions for the power consumption reduction in a household was to propose methods of predicting the power consumption of household appliances by using statistical distributions, machine learning, binary grey wolf optimization, and modeling the on-off times. Still, the studies do not clearly show if these factors are responsible for reducing stand-by consumption [10–12]. Regarding the power consumption reduction in residential buildings, the solution for smart energy management systems was proposed, which integrates the system in a smart building/house where the main purpose is to optimize the power consumption by turning off/on the appliances without affecting the user's comfort [13,14]. These methods did not yield the expected improvements in reducing the power consumption of the appliances in stand-by mode.

Several studies suggest that one of the most important influencing factors for the energy consumption of a household is user behavior. Modifying the user's behavior regarding energy usage led to efficient energy consumption, thus saving money and reducing the pollution done to the environment [15–19]. Some authors have also suggested that appropriate electricity-saving measures can be achieved by identifying electrical household appliances with energy-saving properties and analyzing their behavior to raise consumer awareness [20]. It is impossible to draw strong conclusions from the studies because it depends on the user following and respecting the power-saving recommendations. A previous study has almost exclusively focused on determining the power consumption of standard household appliances, including the power consumption in standby mode [21,22], without developing a system that automatically reduces the standby power consumption.

This paper proposes the development of a system capable of reducing the standby power consumption of common equipment found in a home. Before implementing the system, several 3 household types of equipment were chosen and measured to confirm the power consumption in standby mode.

The proposed system is, at this stage, only a proof-of-concept. It is implemented in its minimum configuration only with the measuring equipment and configuring mobile application via Bluetooth. Before, during, and after system activation, the household equipment is measured again to prove that the proposed system reduces consumption by disconnecting the equipment from the power network.

This research is organized into four sections. Section 2 presents the measuring system used to measure the household equipment power consumption in standby mode. Also, the hardware and software applications of smart systems are described. Section 3 presents the results and compares data measurements made before and after the system implementation, which can clearly show the decrease in the

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DOI: 10.59277/RRST-EE.2023.68.4.1

stand-by equipment power consumption. The conclusions are drawn in section 4 to highlight the utility of the proposed system along with future improvements of the system.

## 2. MATERIALS AND METHODS

One of the general characteristics of the standard equipment found in the average household is that it consumes power even when in standby mode. Measuring the power consumption of the equipment in stand-by mode over time is necessary. This study's power measurements are based on the IEC 61000-4-30 standard specification and represent active power.

### 2.1. STAND-BY POWER CONSUMPTION DATA MEASUREMENT

The equipment's absorbed current values and power consumption in standby mode are measured using a separate data acquisition system presented in Fig. 1.

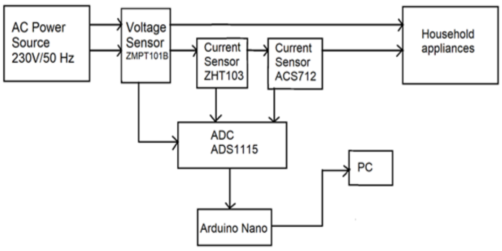


Fig. 1 – Data acquisition system.

The data acquisition system includes a microprocessor-based development board (Arduino Nano) that takes information from the sensors and sends it to a computer via the serial data interface, an analog-to-digital converter (ADC) with 16 bits resolution (ADC ADS1115) that converts analog inputs from the sensors into digital signals. The current sensors used are current sensor ZHT103 (5 A), used for measuring low currents; current sensor ACS712 (20 A), used for measuring high currents (not used in this study); and voltage sensor ZMPT101(200 V) used to measure the supply voltage. The data acquisition system also measures power consumption before and after implementation. It should be mentioned that the same ZHT103 current sensor used in the data acquisition system is identical to the one used for the proposed system [23,24].

The equipment chosen for testing the system is a Beko washing machine (WUE81436), a Lenovo Legion laptop (15ACH6H), and an LG TV (40UH630 V).

#### 2.1.1. Beko washing machine (WUE81436)

Figure 2 presents the data measurements in standby mode for the Beko washing machine.

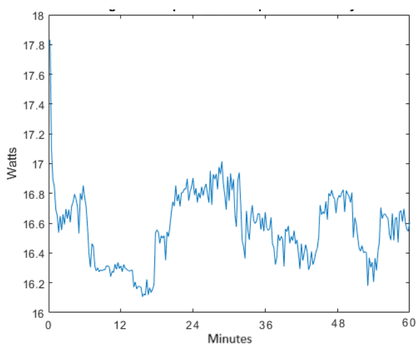


Fig. 2 – Power consumption of washing machine in standby mode.

The washing machine has a power consumption in standby mode between 16W and 17W, respectively. The absorbed current in stand-by mode was between 0.074 A and 0.078 A. In this case, the total energy consumption in standby mode for 1 hour is 0.01618kWh.

#### 2.1.2. Lenovo legion laptop (15ACH6H)

Figure 3 presents the data measurements in standby mode for the laptop.

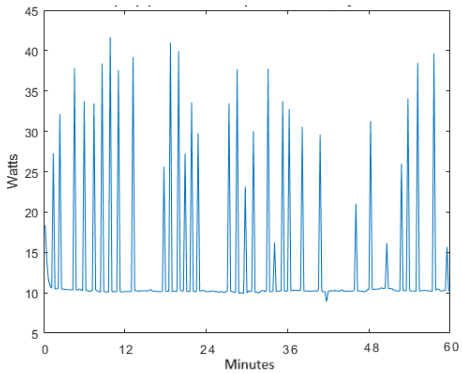


Fig. 3 – Power consumption of laptop in standby mode.

The laptop has a power consumption in stand-by mode between 10 W and 15 W with frequent spikes between 20 W and 43 W because of the switched-mode operation of the power supply, from which the absorbed current in stand-by mode was between 0.06 A and 0.04 A with frequent spikes between 0.2 A and 0.08 A. The total energy consumption in standby mode for 1 hour is 0.01373 kWh.

#### 2.1.3. LG TV (40UH630V)

Figure 4 presents the data measurements in stand-by mode for TV.

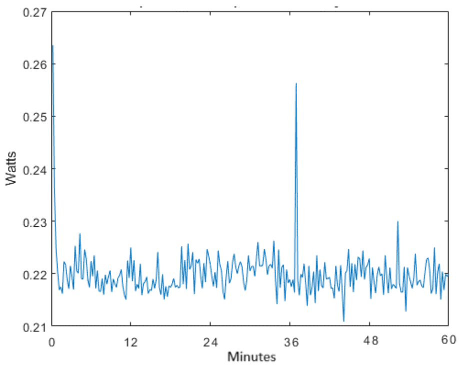


Fig. 4 – Power consumption of TV in standby mode.

The TV's power consumption in stand-by mode is between 0.0361W and 0.0375 W, respectively. The absorbed current in stand-by mode was between 0.0375 A and 0.036 A. In this case, the total energy consumption in standby mode for 1 hour is 0.00815 kW.

In the next sections, synthetically, all the data measurements are presented.

### 2.2. DESIGN OF A SMART SYSTEM FOR POWER CONSUMPTION REDUCTION

For this stage of development (proof-of-concept), several “off-the-shelf” components were selected to ease the implementation and accelerate the development. The main idea was to estimate the power consumption during stand-by mode and how much power can be saved. Following this direction, an AVR microsystem (Arduino Nano development board), a relay-type module supporting a voltage of up to 250 V and a current of up to 10 A, an HC-06 Bluetooth module, one button, a ZMCT103C current sensor, and an additional ADC ADS1115 were used. The system's housing is designed in AutoCAD 3D and then printed using a 3D printer. The AutoCAD 3D software is very important in developing the housing used by the system because the case is created to protect the user and all the components from high voltage. AutoCAD 3D is a software tool used for mechanical design [25]. For the design of PCB, the Proteus circuit design software is used [26].

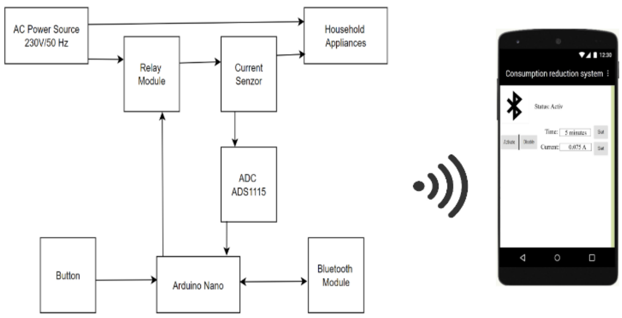


Fig. 5 – Power consumption reduction system for testing purposes.

Figure 5 presents the schematic of the power consumption reduction system for testing purposes. The relay module and the current sensor are placed between the AC power source and the household equipment. The mobile application connects with the system via Bluetooth and is used for setup and control of the system. Suppose a microcontroller with embedded wireless technology is chosen over the Arduino Nano. In that case, the system can be controlled from around the globe via an internet connection, thus achieving an IoT system status.

### 2.2.1. Software application

Figure 6 presents the software application flow chart.

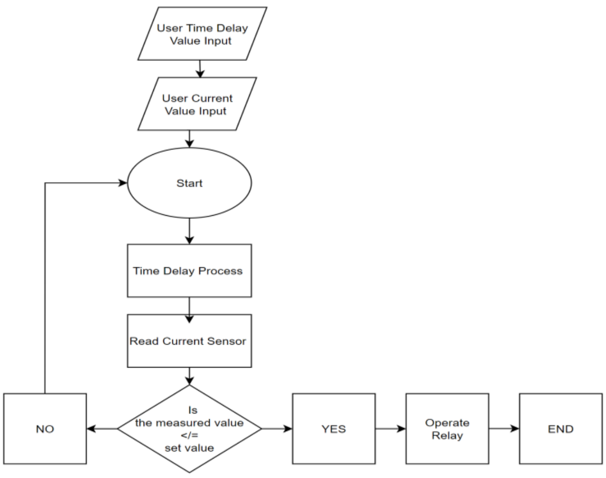


Fig. 6 – Flow chart of software of the proposed system.

If the current absorbed by the equipment has a certain value corresponding to the current absorbed in standby mode by the appliance, the system closes the relay to save power. The control and setup of the power consumption system can be made using the mobile application developed for Android devices via Bluetooth connection. The application sets the current delay time values. It activates or disables the system as testing equipment with power consumption in standby mode, such as a laptop, TV, and washing machine, is chosen.

Another main contribution of the paper is controlling the relay status of the developed source code. Based on the IEC 61000-4-30 standard, the aggregation interval for measuring voltage and current is 10 cycles (200 ms) at 50 Hz. In this period, the RMS values for voltage and current are calculated based on the standard formula.

### 2.2.2. Hardware components

The Arduino Nano is an open-source development board with an 8-bit AVR microcontroller featuring 14 digital and 6 analog pins, a 5 V operating voltage, and a 16 MHz clock frequency. The relay module controls high voltage (250V ac, 10 A) and is compatible with most 5 V microcontrollers. The ZMCT103C sensor accurately measures ac up to 5 A, allowing users to fine-tune output using the onboard potentiometer [27, 28].

To address idle current concerns, a magnetic flux concentrator reduced the sensor's current domain to 0.03 – 0.5 A. Future developments include using a professional LEM sensor. The HC-06 module enables full-duplex wireless serial communications via Bluetooth 2.0 (Class 2) in the 2.40-2.48 GHz frequency range. The ADS1115 module is a precise 16-bit analog-to-digital converter with four inputs, a measurement range of –300 mV to +300 mV, and internal noise reduction mechanisms for enhanced performance.

### 2.2.3. Control application

Figure 7 presents the application developed for mobile devices that use the Android operating system. The test application presented in the above figure is used to configure/control just one system device. The application components are the Bluetooth icon (1) that is used to connect to the system, buttons that are used to activate or disable the system (2,3), system status (4), time input field (5), current value input field (8) and set buttons for current and voltage (6,7). The Android application is developed in the integrated development environment of the MIT App Inventor web application. It can be modified to monitor/control multiple household devices and even work using an internet connection.

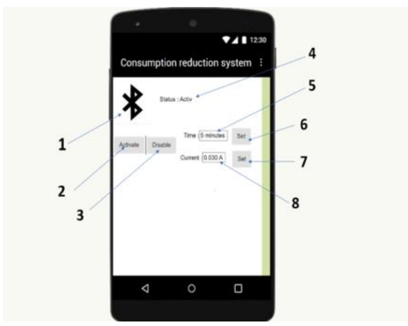


Fig. 7 – Android application of the proposed system.

## 3. **RESULTS AND DISCUSSIONS**

The system is placed between the ac power source and the household appliance, along with the data acquisition system used to validate the proposed device's working principle. The connection schematic can be seen in Fig.8. The proposed system is set to default to have a delay of 5 minutes, meaning that every 5 minutes, the system verifies if the current that passed through the current sensor matches or is below the value set in the mobile application, the delay time can be adjusted based on the user's requirements. If the value matches or is below the current value set, the system disconnects the household appliance from the network, thus eliminating the standby power consumption.

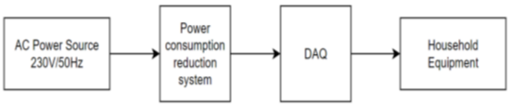


Fig. 8 – Connection schematic of the proposed system.

### 3.1. BEKO WASHING MACHINE (WUE81436)

Figure 9 presents the power consumption of the washing machine with the proposed system implemented. After the default time of 5 minutes, the system reads the current sensor value, compares it with the set value, and then cuts off the power supply using the relay. The washing machine's energy consumption for the default period is only 0.00134 kWh. After that, the consumption is reduced to 0 kWh until the system is restarted/deactivated using the application/button for normal use.

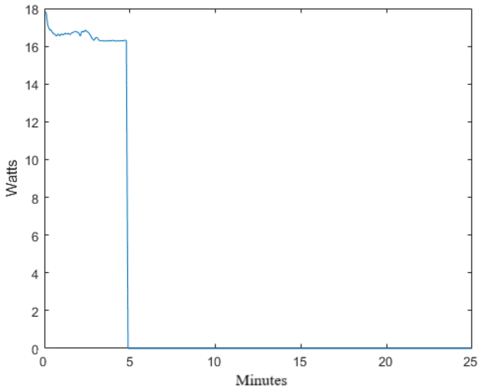


Fig. 9 – Washing machine power consumption in standby mode with the proposed system.

### 3.2. LENOVO LEGION LAPTOP (15ACH6H)

Figure 10 presents the laptop's power consumption with the proposed system implemented.

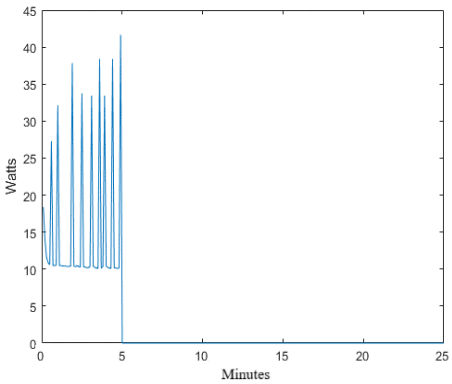


Fig. 10 – Laptop power consumption in standby mode with the proposed system.

After the default time of 5 minutes, the system reads the current sensor value, compares it with the set value, and then cuts off the power supply using the relay. The washing machine's energy consumption for the default period is only 0.00114 kWh. After that, the consumption is reduced to 0 kWh until the system is restarted/deactivated using the application/button for normal use.

### 3.3. LG TV (40UH630V)

Figure 11 presents the power consumption of the TV with the proposed system implemented. After the default time of 5 minutes, the system reads the current sensor value, compares it with the set value, and then cuts off the power supply using the relay, thus saving power. The washing machine's energy consumption for the default period is only 0.00067 kWh. After that, the consumption is reduced to 0 kWh until the system is restarted/deactivated using the application/button for normal use.

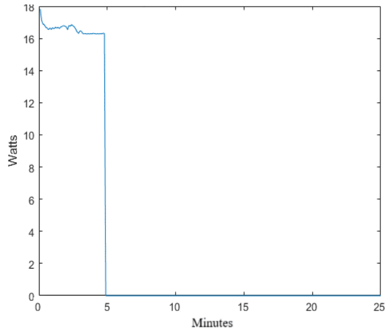


Fig. 11 – TV power consumption in stand-by mode with the proposed system.

It should be mentioned that the specific current drawn by the measured equipment is higher than the current drawn in standby mode, which allows the system to differentiate between essential standby functions and unnecessary power drain. For example, Fig. 12 presents the minimum current drawn by the washing machine in normal operation mode. The minimum current drawn is 0.093 A. The current drawn in standby mode is a constant 0.083 A.

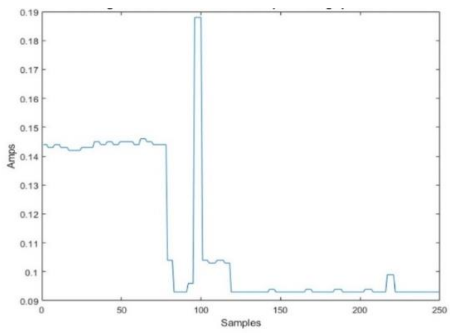


Fig. 12– Washing machine minimum current drawn in operation mode.

### 3.4. ECONOMICAL ANALYSIS

Table 1 presents the total cost of the system that is used for controlling the proposed measured equipment. The reduction in electricity consumption achieved by implementing this system per month is shown in Table 4 for the 3 household appliances, including the system's power consumption. The cost per kWh is around 0.26 euros, which equals 5.15 euros saved per month. The cost is recovered in 10 months with the system's current configuration.

*Table 1*

Power consumption reduction system total cost

| Component | No. of components | Cost/part (Euro) | Total Cost (Euro) |
|---|---|---|---|
| Arduino Nano | 1 | 10 | 10 |
| Current sensor | 3 | 5 | 15 |
| Relay module | 3 | 2 | 6 |
| Bluetooth module | 1 | 5 | 5 |
| ADC | 1 | 15 | 15 |
| Button | 1 | 0.25 | 0.25 |
| Total cost energy consumption reduction system | | | 51.25 |

Table 2 presents the stand-by energy consumption comparison for the household equipment without and with the proposed system. It is to be mentioned that standby power consumption with the proposed system implemented is only for 5 minutes until the system is restarted/deactivated for the normal use of the equipment.

Table 3 presents the stand-by energy consumption comparison for household equipment without and with the proposed system. To be mentioned, standby power consumption with the proposed system implemented is only for 5 minutes until the system is restarted/deactivated for the normal use of the equipment.

Table 4 shows the standby power consumption of the household equipment with the proposed system implementation for an average usage period. Compared to the equipment's 1.27792 kWh per month energy consumption, the system's normal operation consumption is 7.2072 kWh per month, thus reducing the total consumption by 19.83 kWh per month.

*Table 2*

Household equipment energy consumption comparison with proposed system implementation

| Equipment | Standby consumption (kWh) | Standby consumption with system (kWh per 5 minutes) | Standby consumption (kWh per day) | Standby consumption with system (kWh per day) | Standby consumption (kWh per month) | Standby consumption with system (kWh per month) |
|---|---|---|---|---|---|---|
| Washing machine | 0.01618 | 0.00134 | 0.38832 | - | 12.03792 | - |
| Laptop | 0.01373 | 0.00114 | 0.32952 | - | 10.21512 | - |
| Tv | 0.00815 | 0.00067 | 0.1956 | - | 6.0636 | - |
| Total | 0.1836 | 0.00315 | 0.9165 | - | 28.31664 | - |

*Table 3*

Household equipment energy consumption comparison with proposed system implementation

| Equipment | Standby consumption (kWh) | Standby consumption with system (kWh per 5 minutes) | Standby consumption kWh per day | Standby consumption with system (kWh per day) | Standby consumption kWh per month | Standby con-sumption with system (kWh per month) |
|---|---|---|---|---|---|---|
| Washing machine | 0.01618 | 0.00134 | 0.38832 | - | 12.03792 | - |
| Laptop | 0.01373 | 0.00114 | 0.32952 | - | 10.21512 | - |
| Tv | 0.00815 | 0.00067 | 0.1956 | - | 6.0636 | - |
| Total | 0.1836 | 0.00315 | 0.9165 | - | 28.31664 | - |

*Table 4*

Household equipment standby energy consumption

| Equipment | Number of average usages (per day) | Standby consumption with system (kWh per 5 minutes) | Standby consumption (kWh per day) | Standby consumption with system (kWh per week) | Standby consumption with system (kWh per month) |
|---|---|---|---|---|---|
| Washing machine | 2 | 0.00134 | 0.00268 | 0.01876 | 0.07504 |
| Laptop | 5 | 0.00114 | 0.0057 | 0.0399 | 0.1596 |
| Tv | 4 | 0.00067 | 0.00268 | 0.01876 | 0.07504 |
| Total | 14 | 0.00326 | 0.04564 | 0.31948 | 1.27792 |

## 4. CONCLUSIONS

The presented system can reduce energy consumption by disconnecting household equipment from the network when it enters standby mode. The tests done with the 3 equipment mentioned above achieved a monthly energy consumption reduction of 19.83 kWh. The consumption reduction system's only challenge is requiring an electrically wired home for a smart home, implying that each power socket/light has its circuit/fuse. Individual electrical circuits for each piece of equipment allow the system to monitor and control more than one piece by mounting it to the fuse panel, thus keeping the system implementation cost low.

For future implementation, a Raspberry Pi 5 and an HLW8032 I.C will be implemented along with specially developed software using machine learning and neuronal networks that can automatically learn when the household device is in normal or stand-by mode along with the users using habit, thus creating a complete automatic system developed for power consumption reduction and eliminating the users need to use an additional application.

*Received on 30 May 2023*

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