Experimental Verification of Algorithm for Indirect Domestic Load Recognition

Konstantin Gerasimov[1], Yulian Rangelov[2] and Nikolay Nikolaev[3]

Abstract – **The paper presents experimental verification of the efficiency of a developed by the authors algorithm for indirect domestic load recognition. For this purpose was developed a utility which measures instantaneous values of current and voltage at the household's feed in cable. The obtained data is then recorded and processed by software which implements the recognition algorithm. The output of the algorithm is information about the individual electrical consumption of the particular domestic appliances. The experimental results show that the algorithm successfully recognizes the more powerful consumers which form about 80% of a household electrical consumption.**

Keywords – **appliances, fuzzy logic, energy consumption, indirect load recognition.**

I. Introduction

During the last decade there is a big emphasis on not only the industrial, but on the domestic the energy efficiency as well. The fast developing economies consume more and more energy. The main sources of energy are still the fossil fuels. At the same time EC has set long-term goals which guarantee the gradual shift from this non-ecological production towards technologies based on renewable energy sources.

The plans for development of the electric power sector are that big part of the electrical energy for domestic needs should be covered by own photovoltaic, wind or other installations. Along with this it is necessary to increase not only the energy efficiency of the domestic appliances but also the efficiency of their use. The practice shows that a major problem for the domestic consumers is identification of the energy consumption of the separate appliances. Knowing this information each user can be educated to understand the impact of his energy consumer behavior and thus start improving the efficiency of use of the electrical appliances and making savings. For this purpose, during the last years there are many investigations aimed at creating tools which are capable of recognizing the switched on in a household domestic electrical appliances.

In this context, the authors have developed a new algorithm for indirect recognition of the switched on electrical appliances in a domestic household electric network. The algorithm detects the deviation of the power at the main feed in cable of the household and by means of signal processing and a controller based on fuzzy logic determines which appliance has been switched. The algorithm itself is described in details in [1, 2]. Its efficiency has been verified by a computer simulation reproducing the energy consumption behavior of a household.

This paper aims at presenting an experimental verification of the efficiency of the algorithm for indirect recognition of the switched on domestic appliances. For this purpose was developed a measurement tool and it was used to record real processes of commutations of domestic appliances in random order. The obtained data is then recorded and processed by software which implements the recognition algorithm. The experimental data shows promising results.

The article is organized as follows: section II presents some details of the developed tool for measurement of current and voltage, as well as brief description of the algorithm itself. Section III presents the obtained experimental results. The main conclusions are drawn in section IV.

II. Algorithm

A. Measurement device

The measurement device is implemented on a microcontroller development kit Cerebot MX4cK with 8 MHz 32-bit processor of Microchip and 32KB SRAM memory chip. The sampling frequency of current and voltage is about 1.8 kHz. The analog-digital converter of the voltage sensor is 8-bit, while the current sensor is 12-bit. The measurement device is shown in Fig. 1. By means of USB 2.0 serial interface the data is transferred in real time to a computer, equipped with software which records it.

B. Computer Algorithm for Indirect Load Recognition

The structural diagram of the algorithm for indirect domestic load recognition is shown in Fig. 2. The input data is the measurement of the instantaneous values of the current and the voltage.

The block for control of signal processing detects the occurrence of event – switching on or off of an electric appliance. For this purpose, the input of the block is the instantaneous value of the current. After that follows the calculation of its mean value. During normal regime of operation (i.e. there is no switching of electric appliance) the mean value of the current oscillates around zero. At the moment of commutation is observed a short peak value. This peak value is differentiated and filters by the next block. In order to operate correctly, the relay block accepts the absolute

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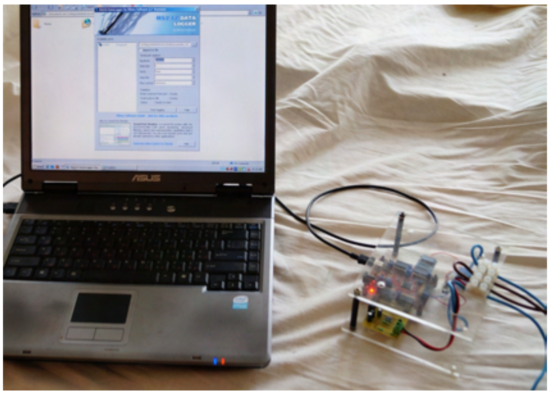

Fig. 1. Indirect load recognition algorithm structure diagram

value of the filtered signal. When an electric appliance is switched on or off is observed a sudden increase of this signal and when it reaches a preset threshold, the relay starts working. The obtained from the relay increasing front activates the block which produces an impulse signal with a fixed duration of 0.2 seconds.

The purpose of this block for compensation of the voltage magnitude is to correct the amplitude of the measured voltage when it is different from the nominal for the network. This is due to the fact that power consumption of the electrical appliances with heating elements (active resistance) follows a quadratic law of deviation, depending on the voltage.

The inputs of the block for signal processing are the instantaneous value of the current and the corrected magnitude of the voltage. By multiplying these two values is obtained the normalized power, and after a consequent calculation of the mean values is obtained the normalized value of the active power. In order to differentiate the moment of commutation of any electrical appliance from the steady state of operation, the normalized active power is passed through a transfer function with parameters shown in Fig. 2.

When from the control block enters a rectangular impulse with duration of exactly 0.2 seconds, a logical Switch switches over to a position which takes as input the output of the aforementioned transfer function. At this state the integrator starts working. After 0,2 seconds, when the impulse changes from 1 to 0, the integrator is restarted and the logical switch is returned into position “switched off”. At the output is obtained an impulse with a particular maximal value, according to which appliance is switched on or off.

To the Sample/Hold block are passed the impulses obtained from the block for signal processing. Apart from that, the S/H block is controlled by the control block. This configuration produces at the output of this block a short impulse with magnitude equal to the maximal value of the impulse obtained from the block for signal processing.

The operation of the Fuzzy logic controller is obviously based on the logic of the fuzzy sets. For each particular appliance is set a participation function corresponding to switching on and another participation function corresponding to the switching off of this appliance. According to what value enters at the input of the Fuzzy logic controller, at the

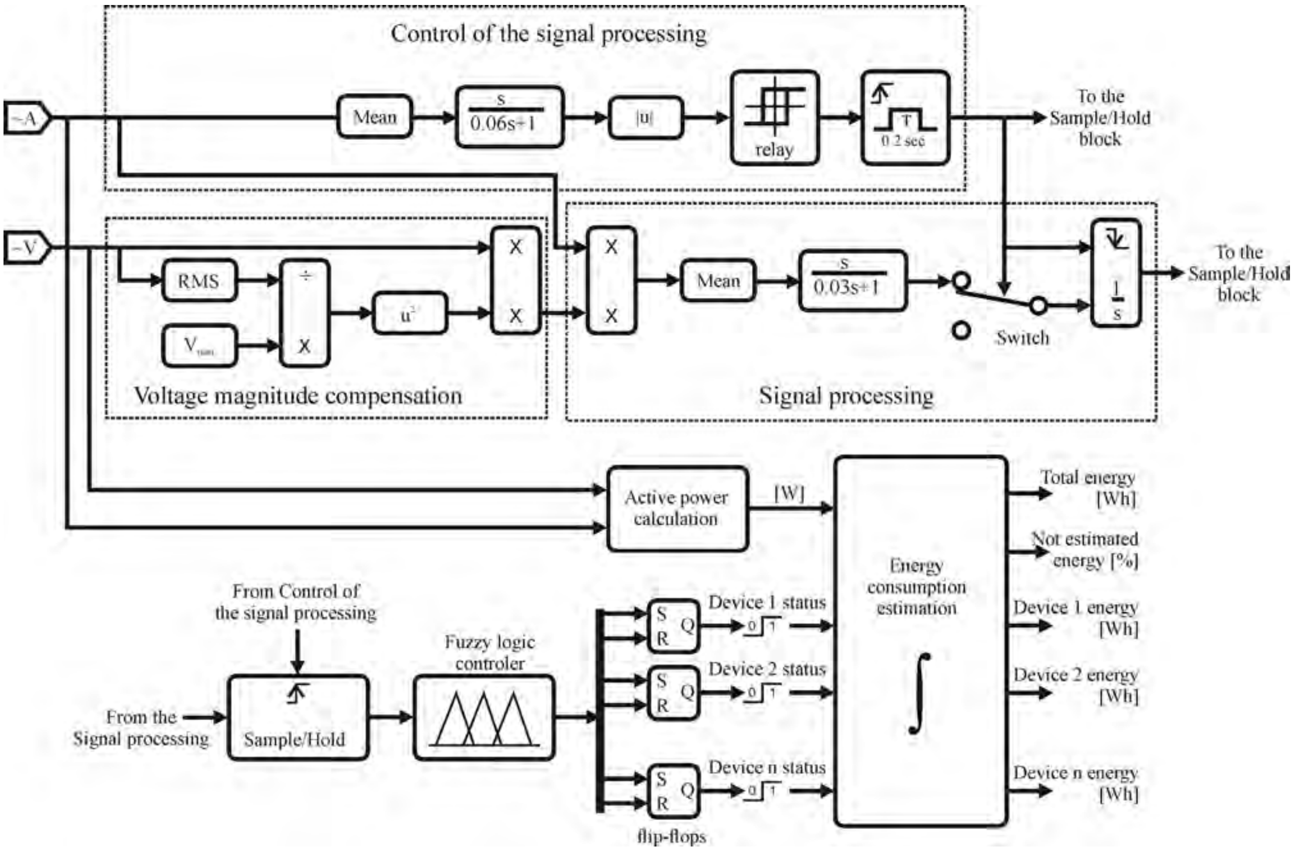

Fig. 2. Indirect load recognition algorithm structure diagram

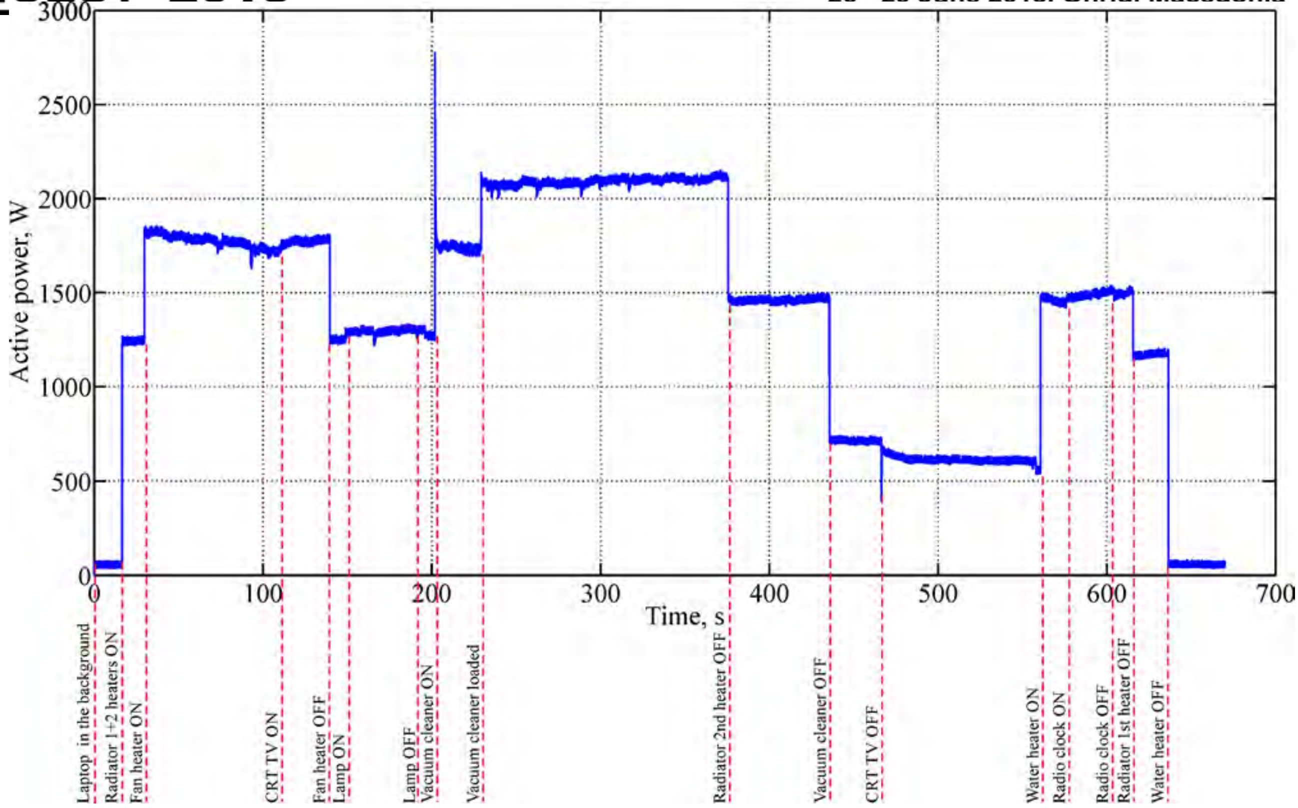

Fig. 3. Calculated active power

particular moment 1 appears at only one of the outputs. As already mentioned, for each appliance there are two outputs – for switching on and for switching off. These outputs, two by two, are passed to a corresponding RS trigger (separate one for each electrical appliance). At the trigger output of the corresponding appliance appears 1 if it is switched on, and respectively 0 if it is switched off.

When information about the states of all appliances is available, then data about their consumption can be accumulated. For a particular period of time the individual consumption of each electrical appliance can be determined the following integral:

$$E_{device} = \int_{0}^{\text{end of period}} \left[state \cdot \left(\frac{V_{rms}}{V_{nom}} \right)^2 \cdot P_{nom} \right] \cdot dt \qquad (1)$$

III. Experimental Verification

In order to test the algorithm was created a scenario of switching on and off of the following electrical appliances: radiator (with two heaters), CRT television, vacuum cleaner, laptop, water heater, lamp, fan heater and a radio-clock. In Fig. 3 is shown the graphics of the calculated active power which passes through the main feed in cable. In the figure are shown also the instances of switching on and off of the electrical appliances. It should be noted that at the beginning both radiator's heaters are switched on and the laptop is switched on during the whole measurement. For the normal operation of the algorithm is necessary that for each heater, as well as for their combination, there is a participation function and a corresponding state output. Though, the information about the consumed electric power has to be accumulated separately for each heater.

The experiment shows that the algorithm is capable of recognizing the radiator, the vacuum cleaner, the fan heater and the water heater. The rest of the appliances cannot be detected by the control block and the signal processing because the implemented analogue-digital converter is not sensitive enough to the small values of the current.

Fig. 4 shows the outputs of the algorithm, presenting the states of the recognized electrical appliances. It is seen that moments of switching on and off coincide with the corresponding ones from Fig. 3.

Table I presents information about the consumed by the recognized by the algorithm electrical appliances power during the experiment. The energy which they have consumed amounts for about 80 % of the total energy. The other 20 % is respectively consumed by the unrecognized electrical appliances.

Table I
Energy consumption estimation

Radiator 1st heater	74.74 Wh
Radiator 2nd heater	52.21 Wh
Fan heater	21.92 Wh
Vacuum cleaner	36.41 Wh
Water heater	19.69 Wh
Total energy consumed	255.2 Wh
Not estimated energy	20.55 % of the total

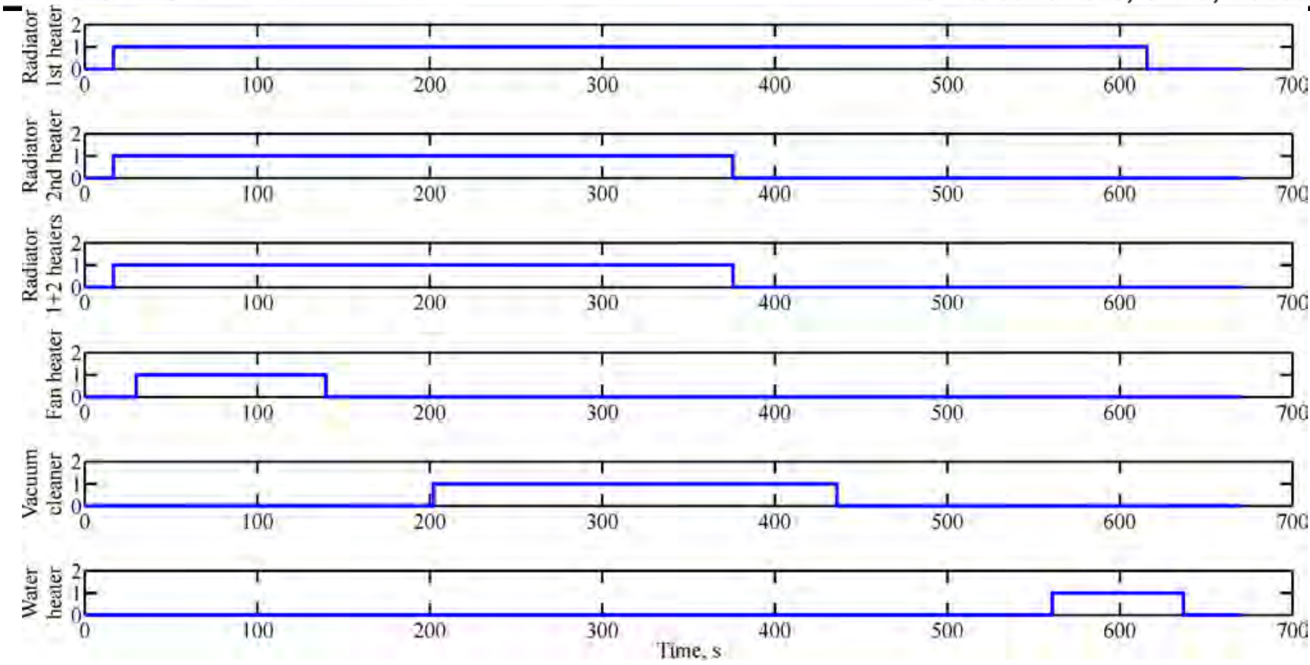

Fig. 4. Device status

IV. Conclusion

The conducted experimental study with real data from measurements show that the developed algorithm for indirect recognition of the electrical appliances switched on in a domestic household is capable of identifying the source of consumption of about 80 % of the consumed electrical energy.

Future improvements should be done in direction of use of analogue-digital converter with higher accuracy, as well as improvements in the control block. Thus the influence of the measurement noise will be decreased and the capabilities for recognition of lower-power consumers will be improved.

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References

[1] N. Nikolaev, Y. Rangelov, A. Marinov “Algorithm for indirect load recognition in domestic power consumption”, International conference PCIM 2013, Nuremberg, Germany (accepted for presentation).

[2] N. Nikolaev, Y. Rangelov, V. Valchev, A. Marinov “Technique for indirect analysis of domestic power consumers based on power pattern recognition for smart energy metering”, International conference MiPro 2013, Opatija, Croatia (accepted for presentation).