Event based low-cost energy consumption monitoring method and device

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Abstract

Electrical and heat energy production expenses are constantly rising nowadays.

Energy consumption monitoring allows reducing overall energy consumption by identifying ineffective energy use.

The article deals with event based energy consumption monitoring method and system.

Event based monitoring simplifies communication between monitoring devices and central module, allowing to reduce monitoring system's consumption and the overall equipment costs.

Keywords: Electrical energy, Monitoring, Wireless, Costs

Introduction

About 40 % of energy consumption in Europe is related to buildings - residential, public, commercial or industrial [1]. The Energy Efficiency Action Plan has stated that the biggest cost-effective energy savings potential is in residential buildings (around 27 %) and commercial buildings sector (around 30 %), therefore, a special emphasis on energy efficiency and need of integration of alternative energy sources, must be made.

At the same time, load growth forecast for the household sector shows that, due to raise in quality of life, households are becoming increasingly fitted with to a wide range of household electrical appliances, thus contributing to further increase of electrical load.

In order to solve the problem of non-efficient energy consumption, the end-user must be informed about the possibilities to save energy, which could be reached by implementing smart metering systems with graphical indicators, or visualization on PC with help and tips for possible solutions for energy consumption reduction possibilities of each consuming device.

Energy consumption monitoring system can also improve energy efficiency, as it can change consumer non-saving habits [2].

Several monitoring systems can be found on the market, for example [3]. Nevertheless, the existing solutions for wide application typically are expensive and pay-back period is usually very long.

It is obvious that costs of metering equipment must be lowered.

Moreover, the consumption of the monitoring system itself must be low.

1 Energy consumption monitoring system

Typical household electrical connection diagram is shown on Fig.1. It includes only one energy counter, which doesn't allow identifying energy consumption of a separate device.

Methods to identify the influence of an individual consumer on the overall energy consumption differ from adding counter to each device (expensive) to a more advanced approach of identifying each electrical consumer's apportionment in the overall energy consumption [1].

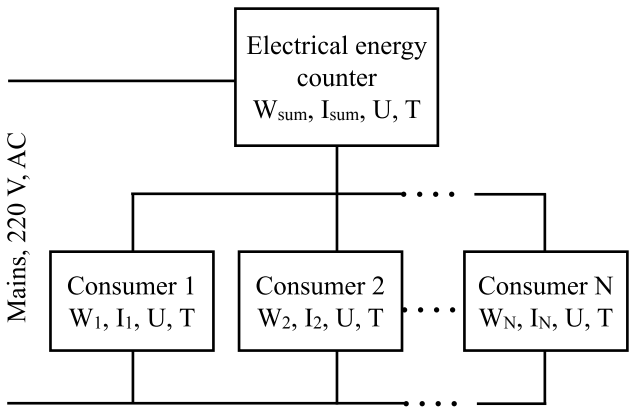

Fig.1. Typical household electrical consumers connection diagram.

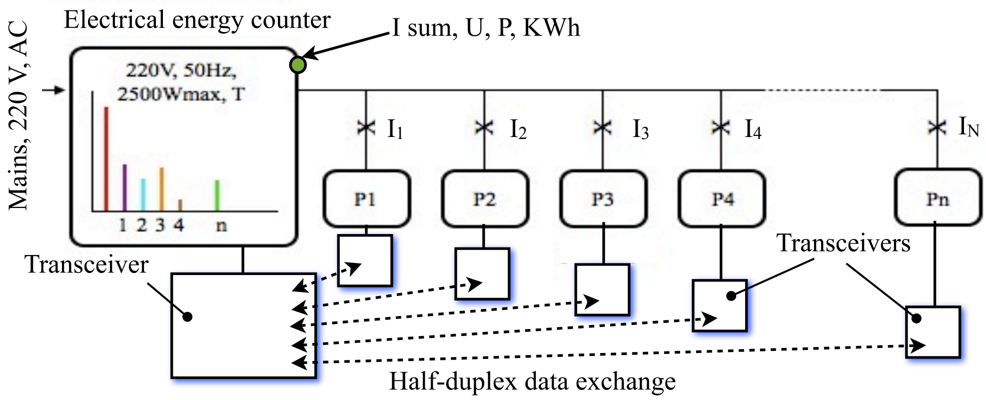

Fig.2. Energy consumption monitoring system's wireless data exchange.

In the latter case, each consumer's active current values are send to advanced energy counter. Communication can be designed by installing separate data wires, data-over-power line or wirelessly (Fig.2.).

2 Change detection in individual consumer's consumption

Consumer current detection methods are based on continuous current or power readings through current and voltage sampling and calculation of the RMS values.

Typically household consumers have states "ON", "OFF","Power level I, II,III", "Standby" with the states changing not too frequently. Lights, TV, computer, washing machine etc. are turned on and of only several times per day.

State change detection is related to real-time energy counter readings change - any change in energy meter readings is caused by state change of one or more consumer's.

Combining state change with change in real-time energy counter readings prides a way to determine individual consumer's energy consumption comparing readings before and after the change of state.

In practice only one of the consumer's changes state at given time instant (except when powering up the system). The mentioned allows to reduce communication between individual measuring device and energy counter to simplex instead of duplex communication.

Simple peak detection circuit, micro-controller and wireless data exchange can be applied to detect the state change (Fig. 3.).

Operational amplifier IC1A amplifies voltage drop on shunt resistor. Here non-inverting amplifier amplifies only positive voltage against the ground - no special rectifier needed.

The peak value of the amplified signal is detected by D2, C1 circuit.

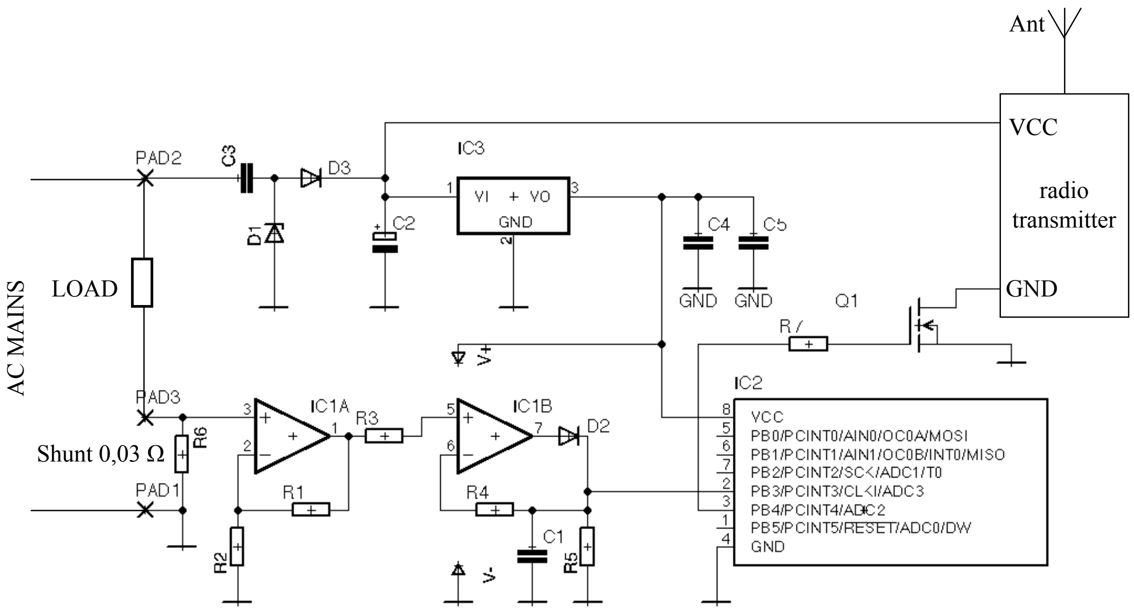

Fig.3. Single consumer current change detection diagram.

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Fig.4. Monitoring device prototype

The value decrease as the capacitor is discharged by parallel connected resistor R5 and micro-controller ADC input current. Discharge is set to 9-10 % during 20 ms (one period of 50 Hz AC). Micro-controller ADC reads the capacitor voltage every 20 ms.

Shunt resistor is shown here mainly for information purposes. Shunt resistor consume considerable power (3 W at 10 A for 0,03 Ohm, for example) , so Hall effect based current sensing IC's can be applied instead.

The prototype of the monitoring device is shown above on Fig. 4.

3 Self-consumption of the monitoring device

Monitoring device typically contain four parts:

- device power supply - AC/DC converter,
- current sensor signal amplifier,
- micro-controller,
- radio transmitter or transceiver.

Sensor amplifiers typically are based on operational amplifiers and with several operational amplifiers integrated in one IC the consumption is about 0,7 mA for 3,3-5 V supply voltage ((LM358, for example).

Micro-controller consumption depends on software code and clock frequency and is about 4-5 mA at 10MHz clock frequency and 5 V supply voltage.

So sensor amplifier together with micro-controller consume about 5,2-5,5 mA from 5 V source.

General data of tested radio frequency transmitter / receiver modules are shown on Table 1.

ZigBee modules as well as WiFi modules are quite expensive [4] so for inexpensive monitoring system such transceivers should be omitted in spite of higher data transfer rates.

For UART compatible transceivers [5] three byte long information transmission take approx. 45 milliseconds at 9600 bit/s data baud rate.

Coded transmitters / receivers like ZF7 / ZR7AZ [6] are an inexpensive choice but information data transmission times are about 175 - 200 milliseconds.

Table 1. RF transmitter data.

transmitter	transmit mode current	receive mode current	supply voltage
ZigBee/Xbee	35 mA,	38 mA	3,3 V
HM-TRP; UART	40 mA	25 mA	5 V
ZF-7	9 mA/9V	2,7 mA/5V	5 V/9 V

Generally, self-consumption of one monitoring point depends on data reading period - every second, every 30 seconds, every minute and/or so on.

Here highest current consumption occurs at highest data reading / sending frequencies. Current during 1 sec period is (duplex data communication):

- in case of UART compatible transceiver application:
  40 [mA] * 0,045 [s] +25 [mA] * 0,955 [s] +5,5 [mA]= 24,2 [mA],
- in case of coded transmitter application,
  9 [mA] * 0,175 [s] +2,7 [mA] * 0,825 [s] +5,5 [mA]= 9,3 [mA].

Coded transmitter application (simplex communication):
9 [mA] * 0,175 [s] +5,5 [mA]= 7,1 [mA].

Obviously, the event based monitoring system consume less power due to the rare necessity to transmit data. Here average current consumption is 6 mA (coded transmitter) if state changes occurs rarely - once every 3 seconds.

As mentioned before, shunt resistors can consume considerable power so Hall effect current sensors could be considered. However, Hall current sensors available on the market typically are expensive.

A choice has to be made between a less expensive monitoring device with higher expenses during operation or a more expensive device with lower operation expenses.

Single shunt resistance must be at least 0,03 Ohm to detect current over a wide range (from 100 mA to 10 A) - loads from 22 W to 2200 W.

In order to keep micro-controller's ADC signal input voltage in 0,0352 - 5 V range, operational amplifier's gain has to be:

5 / 0,3* sqrt(2) = 11,74,

in order to keep operational micro-controller ADC signal input voltage in 0,0352 - 5 V range.

A single step of the micro controller's 10-bit ADC is 4,88 mV (5 V reference voltage). Lowest current value reading (35,2 mV) refers to 7 ADC steps or 3 LSB (Least Significant Bits - the 3 right-most bits). Three LSB is an acceptable resolution and reading error for the purpose of monitoring.

Shunt resistor generates 0,72 Wh energy waste during 24 hours (0,26 kWh per year) for continuous 220 W load.

Hall sensor price is approx. 1,5 times the shunt's price [7] or about 10 kWh more (0,15 EUR per kWh) if calculated as expenses to cover the energy losses.

This means - expenses could become equal after 38,5 years (based on current prices).

The numbers mentioned above are just an example - the real numbers can differ but in any case years will pass until expenses become equal.

In order to power a monitoring device battery operation or mains power supply are the general options. It is assumed here that electrical energy consumption monitoring system must be powered from mains supply.

Line frequency transformer, a SMPS or a transformer-less [8] solution are the main options to power monitoring device from supply grid.

Efficiency of small transformers is typically around 80%.

Transformer-less capacitive power supply (Fig.3.) is inexpensive choice but generates about 7 VA reactive power for each monitoring device.

Conclusions

An event based low-cost wireless energy consumption monitoring method and device is described in the paper. A simple design is offered facilitating reduced monitoring devices self-consumption.

Future work on the system should include sensor circuit optimization, reduction of micro-controller's consumption, correction of the generated reactive power flow of the supply unit as well as further reduction of the overall price.

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