Smart System for Domestic Power Consumption Measurement

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Abstract – **Smart-meters are devices that record the consumption of electrical energy with a certain time step and are able to analyze and communicate this data to the user or grid operator. This paper presents a conception how to add similar functionalities to any power-meter available on the market equipped with pulse output for external counter connection.**

Keywords – **Power, Data-logger, Wireless, M2M, Smart-meter.**

I. Introduction

A multitude of devices for data acquisition and logging exist on the market for metering the consumption of natural gas, water, electricity and other communal services essential for the modern society. Smart meters of electrical energy exist for metering of single or three phase power supply. Having in mind the popularity of single-phase power supply of domestic consumers, the study is focused on this type of smart meters, although the functionality of the device described in this paper is not dependent on the number of phases. The one thing necessary for its correct operation is an electrical or optical signal output for external metering of the already installed power meter.

For example, the South Korean company "Sanxing electric" [1] offers multiple types of smart meters, metering boxes and other customer-side solutions. Some smart meters have option for metering of prepaid services, according to the tariffs and the consumption forecast. A short survey of existing smart metering devices on the internet shows multiple producers, installers and operators of such devices. By the introduction of options for communication between the devices and the grid operator, as well as algorithms for clustered operation of smart metering devices, one of the aspects of the Smart Grid is being implemented. The Smart grid includes automated data acquisition and treatment of collected data for improvement of the efficiency and reliability of power supply from the distribution grid operator. The device described in this paper complies with the above stated, which can also be regarded as one of the aspects of Internet of Things which encompasses bidirectional communication between devices. For this to be implemented every device should have its own IPV4 or IPV6 address in the internet or in the local network behind the consumers' router. In search for originality many producers give alternative names to their devices including advance, intelligent, smart, think, etc., but the main functionalities are mostly the same: machine to machine bidirectional communication, data logging and statistical calculations of the resource consumption (electricity, water, gas etc.).

The annual expenses related to renewal of the metering devices and installation of smart meters of several distribution system operators are presented in table 1. The increasing trend is clearly pronounced. A considerable leap was observed in 2009 and 2010 which is a consequence of the restoration after the global economic crisis in 2008. It should be noted that these annual costs include the prices for replacement of the obsolete metering devices and annual servicing and inspection of the smart meters.

TABLE I
ANNUAL METER CHARGE

Annual meter charge increases with smart meter costs in 2010 and projections to 2017 ($)

Distributor	2005	2006	2007	2008	2009	2010	2011	2012	2013	2015	2016 2017
SP AusNet	17.49	17.49	17.49	17.49	17.49	86.1	93.83	101.02	108.75	117.08	126.04
United Energy Distribution	6.60	6.60	6.60	6.60	6.60	69.21	89.18	99.57	107.62	116.33	125.73
Jemena Electricity Networks	12.87	12.87	12.87	12.87	12.87	134.63	136.7	155.84	159.86	162.34	164.88
Citipower	15.20	15.20	15.20	15.20	15.20	104.79	108.4	93.38	95.26	97.17	99.13
Powercor	17.20	17.20	17.20	17.20	17.20	96.67	105.35	92.72	93.91	95.12	96.34

The above presented is just one of the aspects. Although the technological progress and the more and more informed society, there are still numerous non-governmental organizations that are concerned by the risks (sometimes due to misinformation or other reasons) related to high-frequency communications, radiation, risks of fire or electrical shock, as well as the risks related to privacy and theft of personal data from these smart devices, etc. [2] [3] [4].

As a response to these arguments, for example the British government announced that installation of smart meters at every consumer will result in economies exceeding 6 billion of British pounds [5]. A brief synthesis of the risks is presented in table 2 [6].

TABLE I
RISKS RELATED TO PRIVACY AND THEFT OF PERSONAL DATA [6]

1. **Identity Theft**
2. **Determine Personal Behavior Patterns**
3. **Determine Specific Appliances Used**
4. **Perform Real-Time Surveillance**
5. **Reveal Activities Through Residual Data**
6. **Targeted Home Invasions (latch key children, elderly, etc.)**
7. **Provide Accidental Invasions**
8. **Activity Censorship**
9. **Decisions and Actions Based Upon Inaccurate Data**
10. **Profiling**
11. **Unwanted Publicity and Embarrassment**
12. **Tracking Behavior Of Renters/Leasers**
13. **Behavior Tracking (possible combination with Personal Behavior Patterns)**
14. **Public Aggregated Searches Revealing Individual Behavior**

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The following figure presents a typical household consumption data for a 24 hour period: it comprises a morning peak between 08:00 and 09:30 AM, a few short peaks during the day (optional, for appliances with timers for automatic start and shutdown, like boilers, washing machines etc.) and two evening peaks – one in the early evening and one later (fig.2).

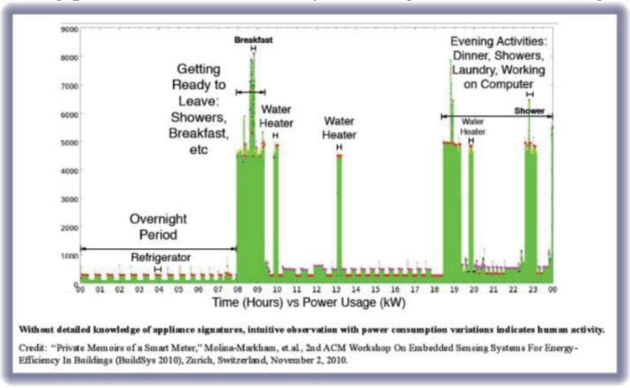

Fig. 1. Typical profile of daily power use [6]

This paper presents a smart metering device with multiple functions, which can be installed without interventions in the existing electrical installation at the consumer's side. In this way the possible dangers and risks are reduced to a minimum if not excluded at all. Mounting and operating with the device are simplified, so that even persons without qualification are able to install the device and operate with it. Furthermore, the proposed system is flexible and modular for easy implementation, cooperation with other components of a smart home energy management system and the possibility for cooperation with other components and posterior upgrades of the home system.

II. Implementation

The proposed system architecture is composed of a master controller and several slave-devices (called nodes) connected to the power meter, ensuring a safe communication channel with the concentrator (hub) device. Every node communicates data from the actual metering interface to the concentrator. As a concentrator can serve either a dedicated Raspberry PI-based computer or every smartphone featuring Bluetooth LE communication.

The Raspberry PI system itself presents an integrated microcomputer with ARM processor with 4 cores, 1 GB of random access memory with high throughput and multiple input/output interfaces for digital and analog communication. The raspberry PI platform includes its own open source linux-based operating system – the Rasperian that facilitates development of user interfaces and applications.

As mentioned above, in this paper the communication channel between the nodes and the concentrator is implemented by Bluetooth Low-Energy (BLE) or the Bluetooth Smart technology. It uses a short range radio with a minimal amount of power to operate for a longer time (even for years) compared to its previous versions. Its range coverage (about 100 meter) is ten times that of the classic Bluetooth while its latency is 15 times shorter [8]. This choice is logical, bearing in mind the paradigm for maximal node lifetime when using batteries as a power source and the option for interconnection with SCADA system or external database. The so exposed concept is completely compliant and ready for integration in the Internet of Things (IoT) and the future Smart Grid [1, 7].

A. Block Diagram

In this chapter are detailed the functions of the system blocks, presented at fig. 2 and their interfaces. The argumentation for the chosen electronic components for device implementation will also be presented in this chapter.

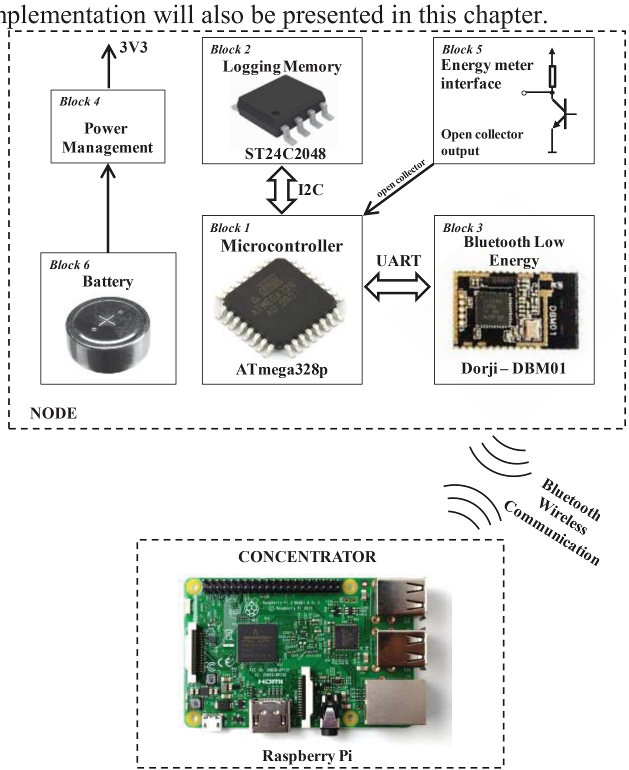

Fig. 2. Block diagram of one node and the concentrator

Block 1 "Microcontroller" is implemented by an ATmega328P microcontroller of the Atmel Company. The choice of this microcontroller is based mainly on its compatibility with the Arduino system developer environment and the power supply of 3,3V. Furthermore, this microcontroller features all the peripheral modules required for implementation of the system presented in this paper.

The Block 2 - "Logging memory" is an external memory module EEPROM, type 24C1014 of the ST Microelectronics Company. The memory size is 1 Mb, which is completely enough for storage of the electrical consumption data for more than one year. The connection between this block and the "Microcontroller" block is realized by an I2C digital interface.

Block 3 of the system diagram is responsible for the wireless communication between the node and the concentrator. The block is implemented by an integrated module DBM01 of the "Dorji" company. The module is compliant with the Bluetooth 4.0 specification and communication is performed by standard AT commands on the microcontroller UART interface.

The Block 4 - "Power Management"ensures the necessary power supply with a voltage 3,3V corresponding to the requirements of the device components. The block is actually a buck/boost DC-DC converter. This is necessary because the voltage of a fully charger lithium-ion battery exceeds 3,6V and a step-down conversion is required. At contrary, by a partially discharged Li-ion battery the voltage may drop below 3,3V and the converter has to work in “boost” mode (corresponding to the actual duty ratio of the electronic switch) to supply the necessary voltage to the device.

Block 5 of the presented block diagram is the interface to the power metering device. Most if not all of the modern electronic power meters have an “open collector/drain” type pulse output for connection of external counter. The number of pulses per second at this output is proportional to the power consumption (for example 1800 or 3600 pulses per kWh). Connection of the external metering device only requires an external pull up resistor and a port of the microcontroller featuring an interrupt request (IRQ).

The battery block consists of the battery supplying voltage to the DC-DC converter. A Lithium-ion battery is chosen for their high energy density and low self-discharge. The device is designed to be able to work at least one year on battery and also the metered domestic power consumption doesn’t affect the battery lifetime.

B. Block Algorithm

The block diagram of the device operation algorithm is presented on fig. 3. The algorithm is composed of three major parts: 1) The main program (main function), 2) the subprogram for operation by a GPIO interrupt request and 3) subprogram for operation by an interrupt from the timer subsystem of the microcontroller. The main program executes first a system initialization, including initialization of the microcontroller peripheral modules, the Bluetooth module and the external EEPROM memory.

The subprogram for operation by a GPIO interrupt is triggered by an active front at the microcontroller input pin connected to the metering circuit, in other words when power consumption is registered by the power meter. This program is developed on an algorithm with the goal of minimal data recorded on the EEPROM memory. This is achieved by a comparison in the timestamp values of two consecutive pulses (recorded by the timeStamp variable). If the difference of the two timestamps is longer than a certain critical value (t_{cr}), in the memory is recorded a timestamp for every next pulse. But if the difference between the two first timestamps is less than t_{cr}, in the memory is recorded a number of pulses for a given time period. In this way, when power consumption is greater than a certain value, the unnecessary recording of a timestamp for every pulse at every 1/10000 of the second is not performed, but instead a timestamp for several hundred pulses is recorded. This reduces the memory requirement. The data format will be detailed in the next chapter of this paper.

The internal timer of the microcontroller calls an interrupt over a defined period of time. Every interruption coming from the internal timer increments the *timeCnt* variable, which is later responsible for storing data in the EEPROM memory.

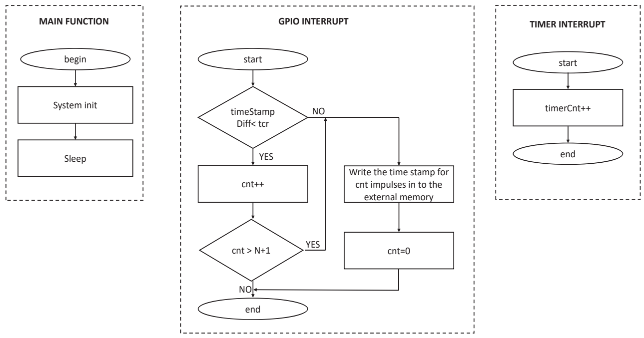

Fig. 3. Block algorithm

C. Data Format

Fig. 4 presents the data array format, recorded in the node’s external memory. By request this data is sent to the concentrator by the Bluetooth communication channel. The data array itself is composed by smaller 6-byte blocks of data that contain information about the number of recorded pulses, as well as timestamps defining the period over which the pulses are recorded.

Fig. 4. Data format

At the end of the data array is recorded certain system information like the current time and the system parameters and constants, etc.

The data blocks (grains) are the smallest unit in the data array structure. The composition of a single data block is presented on fig. 5.

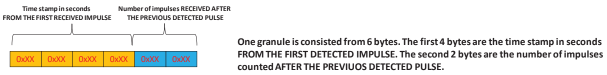

Fig. 5. One grain consists of 6 bytes

It contains a total of 6 bytes of information. The first 4 bytes are a timestamp indicating the time at which data was recorded. It should be mentioned, that time is relative to the first recorded pulse. The last 2 bytes of information contain the number of pulses recorded after the first one.

An example of data array recorded in the node memory is presented on fig. 6. The first block of the array is recorded when the first pulse from the power meter output is registered. This is the reason why the system time in the block is always 0x00 0x00 0x00 and the number of pulses is 0x00 0x01. This content is always the same and can be used as a marking for the beginning of the data array. For every N blocks of the data array, a synchronization marker is added in the array. The synchronization marker is composed by a data block with values of 0xFF on all the 6 bytes (for this reason it will be called "FF marker" below). The data array continues until all the available memory is allocated or until a data transfer request is received from the concentrator. Upon a data transfer request, the following actions are performed before sending the data:

1) A final data block is saved containing information of the actual time and the total number of pulses counted by the meter (which is in fact the total energy consumption for the recorded time period;
2) Saves an "FF marker" at the end of the data array;
3) Records 4 bytes of data with the time when the data transfer request is registered followed by the actual time and date the request is executed. Saving of the real time is important, because up to this moment all timestamps are in relative time (counted from the first pulse registration) and in this way they can be converted in calendar time for statistical consumption data or other calculations performed by the system;
4) Records another "FF marker";
5) Records 15 bytes of system (service) information: their meaning and default values are as follows:

1 – the resolution of time counting – 1s, 1 byte;
2 – the critical time *tcr* used for data loging – 1s, 1 byte;
3 – the maximal number of pulses each data block can contain – 1023 pulses , 2 bytes;
5 – the number of data blocks between the synchronization "FF markers" - 100 blocks, 2 bytes;
7 – Bytes reserved for implementation of future options and features – 6 bytes;
13 – device identification number.

III. Conclusion and Future Work

A smart system for monitoring, recording and graphical representation of information about the consumption of electrical energy. The main objectives for this device implementation are: maximum duration of device operation without the need for battery replacement/charging, intuitive user interface featuring the option for visualization of multiple values related to the instantaneous power, average power over a given time period (including historical data). A protocol was developed (including the format of the recorded data) for exchanging data between the nodes and the concentrator. Last, but not least the developed software can give advices for energy saving without influencing the consumers comfort. Future developments of this system include the options for user control over a distant node (by the use of an internet connection), remote data acquisition and logging to a remote server.

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