Smart Home Subsystem for Calculating the Quality of Public Utilities

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Abstract

This article proposed a new approach for calculating the quality of public utilities, and the ways for integrating proposed algorithms and methods in a "smart home" system. This approach will be useful for determining the quality of public utilities, which provide consumers with needed services through complex hierarchical engineering networks such as electricity and natural gas supply networks, heating, and hot and cold water. Was proposed structure of a subsystem for calculating the quality of public utilities and its main components of it were considered.

Keywords

Internet of Things, smart house, quality of public utilities.

1. Introduction

Attempts to create "smart" power systems that could measure and control it automatically were made in the 80s of the 20th century. In the 90s has been created the components of an automated commercial accounting system (for example, in [1] was mentioned the components for the electricity control system, that measured the metrics of the resulting energy and time of its use).

At the beginning of the 21st century, control systems, which use "smart" meters and combine a large number of households and industries began to emerge and grow [2]. These meters can transmit data along the power lines and using wireless networks (for example, devices using ZigBee, Wi-Fi, and Blue-Fi protocols). The use of standardized wireless networks helps to connect heterogeneous devices in the house and also maintains an accounting of other utilities such as gas and water [3]. "Smart" meters in real-time not only monitor but can also become a "bridge" to other "smart" devices, accumulating statistics for further generalization of the scenarios of the typical consumer. It can be said that shortly that kind of "smart" meters and based on its systems will be integrated into the main system of "smart home", and the meters themselves will act as components of the "Internet of Things."

The term "Internet of Things" (IoT) was used first by Kevin Ashton in 1999 during a presentation for "Procter and Gamble" to describe a system in which physical objects are connected via radio frequency sensors (RFID) with the Internet. That type of thing made it possible in corporate deliveries to track products without the need for human interaction.

Nowadays, the IoT is the concept of a data transmission network between physical objects ("things"), equipped with built-in tools and technologies for interaction with each other or with the environment [4]. These "things" can be energy-consuming devices—industrial and home air conditioners, refrigerators, and heaters, which build their work cycles to minimize work when the power system goes through the peak of its consumption.

IoT systems may include any sensor that transforms the physical parameters of the object into a digital code to transmit through the Internet and provide control to the object without human involvement.

The concept of "smart house" is implemented by the development of subsystems of IoT in specific main areas, namely subsystems of home security, climate controls, control, and management of the technical condition of household appliances [5–7].

CPITS 2023: Workshop on Cybersecurity Providing in Information and Telecommunication Systems, February 28, 2023, Kyiv, Ukraine
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CEUR Workshop Proceedings (CEUR-WS.org)
CEUR-WS.org/Vol-3421/short1.pdf

In this case, the integration into the "smart house," "smart" meters, and other "smart" systems requires the development of a system, which can use the data that characterize the consumed public utilities.

Public utilities will further understand the services provided to consumers in cities using multi-level hierarchical engineering networks, i.e. supply of natural gas and electricity, heating, and hot and cold water. These networks can be characterized by two types of parameters—potential, and flow. According to the international standard IEEE 1076.1, these kinds of concepts are called "across quantity" and "through quantity" [8]. The potential parameters that create generating capacity (e.g. power plant) are, for example, the voltage and frequency of the electrical network, the pressure, temperature, and Wobbe number of the natural gas network, the pressure and temperature of cold and hot water wherever flow parameters, which are formed in the network by consumer nodes are a current and amount of gas and water consumed per unit of time. At present, the measurement of both potential and flow parameters is provided with devices that have a service supplier, but the consumer has only "standard" meters of the amount of product consumed.

That should be noted, that when consumers connect and use some public utilities via consumer nodes, they changed the parameters of the flow. These parameters change in quantity and time in a very large range, which can depend on the season of the year, time of day, and temperature of the environment and can be statistically calculated. Due to the limited generating capacity and the loss of transmission of the product in the networks, there is a relation between potential parameters and the flow parameters. The degree of relation determines the quality of the network and, accordingly, the quality of public utilities.

Currently paying for consumed service P is calculated by each consumer in manual mode by formula (1) for all types of services

$$P = T \cdot A, \qquad (1)$$

where T is the tariff for service, and A is the amount of service consumed (for example, in kWh).

According to this formula, payment does not depend on the quality of the service.

However, consumers (for example, new homes and even whole neighborhoods) are constantly connected to the existing supply networks, which leads to a deterioration of the service parameters and therefore the quality, as an integral characteristic of service parameters, is reduced. Suppliers try to preserve regulatory quality at the consumer cost, namely change the cost use of services at the peak consumption time.

Unlike the manufacturer or service provider, the average consumer does not have technical and economic capabilities for determining, documenting, and improving the quality of services and he has the only opportunity to influence the quality of service—pay less for poor quality services. To do this average consumer need to start some legal actions: make measurements of quality parameters using special technical means, make legal acts, contact the manufacturer or provider of services with claims, and, in the end, go to court. At present the technical means and all the necessary technical information belongs to the manufacturer so it is extremely difficult to win the court for the average consumer.

To do this payment for the consumed utility service must be calculated using the modified formula (1) with some quality coefficient (2)

$$P = T \cdot A \cdot C_{GQ}, \qquad (2)$$

where C_{GQ} is a generalized quality factor.

To determine the quality ratios for each type of service, the development, manufacture, and introduction of new "smart" meters requires a lot of time. This problem can be solved with the "smart" house that can integrate both "smart" and "ordinary" meters and methods for calculating the quality of service. This is possible when the normative values of quality parameters, are equal to the value of the quality coefficient and set as 1. If the quality deteriorates the deviation from the nominal value increases, the quality coefficient decreases, and payment for the service also decreases. According to this, the coefficient should be dimensionless and change from 1 to 0.

2. Determination of Instant Quality by One Parameter

Utilities are characterized by nominal quality parameters and "maximum" deviations from them, which are symmetrical at nominal value. Knowing three values it can be created the function of compliance. This function can be a piecewise linear, quadratic, or "quadratic-like" and each value of this function for a specific value of the quality parameter (potential) is a quality coefficient. For the nominal value, the quality coefficient is equal to 1. For values with deviations less than the maximum permissible, the quality ratio can vary from 1 to 0, depending on the rate of the nominal value. For values with deviations greater or less than the maximum permissible values, the quality coefficient is 0.

3. Partial Averaged Time Coefficient and Partial Averaged Consume Coefficient

In standards, the time for measurement of the potential parameter is defined as one day (for example, Standard EN 50160 for electricity).

The authors propose a new approach to assessing the quality of utilities, which are evaluated by the quality of the service as a whole using three interrelated coefficients.

The deviation of each quality parameter from the nominal value is converted using a function of compliance to an instant quality factor [9].

The partial quality coefficient estimates the quality of one parameter, depending on its change in time using instant coefficients for each moment by the formula [9]:

$$C_{PQ} = \frac{T_{p1}}{T_{all}} \cdot C_1 + \cdots + \frac{T_{pi}}{T_{all}} \cdot C_i + \cdots + \frac{T_{pn}}{T_{all}} \cdot C_n, \tag{3}$$

where C_{PQ} is the partial quality coefficient, T_i is the time of stay of the quality signal on the i^{th} area, C_I is the quality coefficient for the i^{th} area, T_{all} is the full time of quality registration, and n is the number of areas at the potential signal range.

The formula for T_{all} is simple:

$$T_{all} = \sum_{j=1}^{k} T_{ij}, \tag{4}$$

where j is the number of the time area on which the quality signal is on the i^{th} area of the range, and k is the number of time area on the i^{th} area.

Thus, the quality of the service can be estimated by scalar value in the form of one number.

Depending on the quality of the service, the coefficients change in the range from 1 to 0. If the parameter corresponds to the nominal value or deviates from it on the values permissible according to the normative document, then the quality coefficient is 1.

Since the averaging is done by time it is possible to determine the quality of some public utility by one quality parameter, and that parameter will be the potential parameter.

To determine the quality of some public utility, which is already consumed by customers, the partial quality coefficient, which is already consumed by consumers in equation (5) [10]

$$C_{PQC} = \frac{A_{p1}}{A_{all}} \cdot C_1 + \cdots + \frac{A_{pi}}{A_{all}} \cdot C_i + \cdots + \frac{A_{pn}}{A_{all}} \cdot C_n, \tag{5}$$

where C_{PQC} is the partial quality coefficient of some public utility, which is already consumed, A_{pi} is the number of services consumed on the i^{th} section of the potential parameter, A_{all} is the total number of services consumed at a time, C_i is the quality coefficient for the i^{th} area, n is the number of areas at the potential parameter range.

The formula for A_{all} is (6):

$$A_{all} = \sum_{j=1}^{k} A_{ij}, \tag{6}$$

where j is the number of the potential area on which the quality signal is on the i^{th} area of the range, and k is the number of time area on the i^{th} area.

Thus, the quality of the service can be estimated by scalar value in the form of one number.

As can be seen, the formulae (3) and (5) are similar except that in (3) had been calculated the potential quality by one parameter whereas in (5) is the potential and flow quality by one parameter.

The partial quality coefficient, which is used to characterize the quality of some public utility service (or consumed public utility service), as well as the compliance coefficient, must be a fraction in the range from 1 to 0.

4. Generalized Quality Coefficients

The quality of utilities can be characterized by several potential parameters. For hot water, it is temperature and pressure, for natural gas—temperature, pressure, and Wobbe number, for electricity—voltage and frequency. To calculate the generalized quality coefficient, the average quality coefficients are combined by multiplication operation, i.e. by formula (7)

$$C_{GQ} = \prod_{j=1}^{j=n} C_{PQj}, \quad (7)$$

where C_{GQ} is a generalized quality coefficient, C_{PQj} is the partial quality coefficient of j^{st} quality parameter of some public utility, and n is the number of partial quality coefficients.

Similarly can be calculated generalized quality coefficient for consumed utility (8):

$$C_{GQC} = \prod_{j=1}^{j=n} C_{PQCj}, \quad (8)$$

where C_{GQC} is a generalized quality coefficient for consumed utility, C_{PQCj} is the partial quality coefficient of j^{st} quality parameter of some public utility, which is already consumed, and n is the number of partial quality coefficients.

The partial quality coefficients by means are less than one or equal to one, so the generalized quality coefficient is also will be the fraction in the range from 1 to 0. The generalized quality coefficient can be called the “worse or worsen than the worse” quality coefficient for this public utility.

And now, after calculating the generalized quality coefficient C_{GQ}, the payment for the consumed public utilities, which is performed monthly by the formula (2) can be easily calculated. As C_{GQ} also can be used in formula (2) in the future, but at present no supplier in Ukraine can guarantee the consumer both the potential and flow nominal parameters of any public utility service.

The next question is how to integrate proposed methods and algorithms into a “smart home” system.

5. The Structure of the Quality Calculated Hierarchal Subsystem

Because all of the public utilities had multilevel hierarchical engineering networks, it is natural that the subsystem for calculating the quality of public utilities will be hierarchical too. It can be seen as an example of this kind of subsystem in Fig. 1. Information on utility parameters comes from several “smart” meters (devices) that can transmit the measured parameters of utilities through the communication channels to the concentrator located in the apartment. After processing the data with a concentrator, it sends this data to a next-level concentrator who processes data from the whole house, and then the processed data transmits to the higher level of the hierarchy and so on.

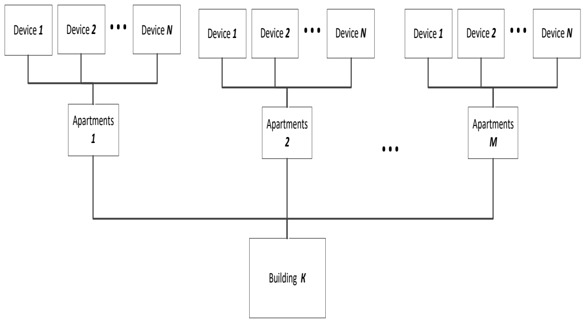

Figure 1: Example of three-leveled hierarchical subsystem

At each level of the hierarchy, there is an exchange of information—the lower-level object transmits the obtained data to the higher-level object where they are processed and transmitted further. Although the hardware components of the hierarchy are different, the software part of the system will consist of architecturally identical parts connected by hierarchical connections. These parts will differ at different levels of hierarchies by objects from which data is obtained and transmitted, data processing algorithms, data storage, and interaction of these parts with the operator. This kind of modular representation significantly reduces the time of development of the entire software part of the system and facilitates further maintenance and modernization.

Fig. 2 shows the levels of the hierarchy “Device” and “Apartments”. It is important that at the level of “Apartments,” the concentrator must have the software that implements the functions of obtaining data from the level “Device” and calculating the quality parameters. Each of the devices that evaluate the utility parameters operates in real-time and sends asynchronous data.

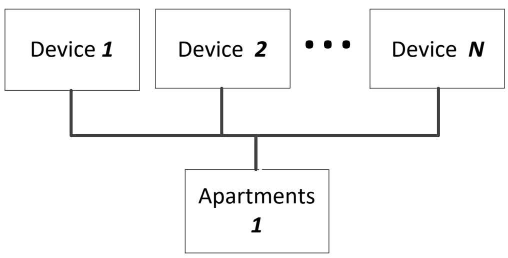

Figure 2: The lowest level of the hierarchy “Device—Apartments”

The lowest level of the hierarchy subsystem must have a base function, namely:

1. Had a possibility to identify the specific device in its connection.
2. Provide for the availability of a software module (The organization of physical connections depends on the hardware configuration of the system and is not considered in this article) that processes the data from the devices and the mode operation of the concentrator. The concentrator itself should implement the quality calculation option by utility parameters if these parameters are transferred to its level by “ordinary” meters.
3. Create new or use encryption and decryption algorithms for data; correction and control of errors algorithms are also in need [11].
4. For further data transmission or long-term storage data in the concentrator, the mechanism of storage and/or transmission of data to the next level of the hierarchy must be provided.

Obliviously, the first base function is the most valuable, because without proper identification all subsystem doesn’t work well. When a “smart” device (or subsystems of “smart” devices) connect there are two fundamentally different variants of communication from concentrator to device and vice versa:

1. Active. The device has its unique identification number that transmits to the concentrator using the data transmission protocol. In this case, the concentrator records the existing unique identifier in the base of identifiers, forms the queue by which the device interrogates and accepts, and transmits data. The connected device changed status to a concentrator as “connected” and “ready.”
2. Passive. When connecting the device, the concentrator tests the new device and provides it with a unique identification number, which is subsequently connected to obtain the data. After registration of the data, the “connected” device changed status to “connected” and “ready.”

More preferable in the new subsystem is to use a “passive” behavior, since this option is easily scaled at the following levels of the hierarchy.

To verify the possibility author’s approach of quality calculation developed the subsystem and an experimental sample of the device, which was made to determine the quality of electricity supply by two parameters: established voltage values and frequency [12]. The device is based on C8051F320 (analog-and-digital microcontroller), which measures, processes, and displays the frequency and voltage values and calculates for these values the partial quality coefficients and a generalized quality coefficient.

Also was developed software, which receives electricity quality data through the USB interface and stores them in the XML file. The developed device allows controlling the quality of electricity directly in the consumer network. Several sessions of daily monitoring of the quality of electricity supply in the city and country territory have been performed, and the monitoring results are transformed into a “Microsoft Excel table” format.

Methods and devices were protected by patents of Ukraine, and information technology for determining the quality of public utilities was registered in the Ministry of Education and Science of Ukraine under No. 0617U000030 of 30.01.2017. According to [13] our proposed subsystem can be integrated into the “smart home” as a part of the “power grid” system.

6. Conclusions

This paper proposed a unified quality determination technology for all types of utilities, which can be used in “smart” meters and as a software component of the “smart home” system. As an experimental sample, a device for determining the quality of electricity supply 220 V at 50 Hz and software for transmitting data from a “smart” device was developed.

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