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Load Shedding Analysis in Local Energy Management Systems

***Abstract**. In the paper load shedding time analysis in Buildings Energy Management Systems are presented. Influence of the communication system structures on the data exchange duration is analysed and its results for a few communication structures are presented.*

***Streszczenie.** W artykule przedstawiono analizy czasowe operacji redukcji obciążenia w budynkowych systemach zarządzania energią. Przeanalizowano wpływ struktury systemów komunikacyjnych na czas trwania wymiany danych wraz z wynikami dla kilku przykładów struktur.* **(Analizy czasu zrzutu obciążenia w lokalnych systemach zarządzania energią)**

Keywords: BEMS – Buildings Energy Management Systems, EMC – Energy Management Controller.
Słowa kluczowe: Budynkowe systemy zarządzania energią, Sterownik do zarządzania energią.

Introduction

Intelligent power systems called Smart Grid are recently intensively developed. Smart Grids integrates the activities of all parties involved in the generation, transmission, distribution and consumption of the electricity. In these systems, the provision of electricity in a safe, reliable and economical way together with the environment in mind is accompanied by the use of information and communication technologies [1, 2].

Power system built according to the concept of Smart Grid should meet a number of criteria. It should provide a means of access to the network for all its users, particularly those who use renewable energy sources and highly efficient local sources with low emissions. Also important is the flexibility, or the ability to meet the changing demands of customers. It is also important to provide suitable level of the security and supply quality. It is also expected that the Smart Grid will not be vulnerable to various types of threats and interferences, and will allow for innovations and should be efficient in energy management [1, 2].

To meet the aforementioned requirements it is necessary to adopt technical standards and protocols that provide open access to the network and allow use of the devices from different manufacturers. Development of information, computing and telecommunications systems that allow the use of innovation in services to improve the quality and efficiency of energy management is also important [3, 4, 5].

In order to achieve efficient power management, there are many different areas of intensive development focused on Smart Grid. One of these area is introducing the power management in buildings and households. It requires to meet several technical and formal conditions. In the buildings should be installed Buildings Energy Management Systems (BEMS), equipped with a gateway for integration of devices. Gateway should also make it possible to connect the building to the wide area network (WAN). It is also necessary in the context of the BEMS use of controllers EMC (Energy Management Controller) with the software for local energy management, and in addition it is necessary to attempt for use in home appliances uniform interface devoted to support functions relating to such management.

In recent years, a number of international standards referred to the implementation of Smart Grid technologies for buildings and households were established. According to the authors the most significant are presented in [6, 7, 8].

The primary task of the BEMS is the effective management of electricity within the building. The implementation of this functionality requires cooperation within the framework of the system services with DNO (Distribution Network Operator) where data are collected concerning prices and electricity tariffs. The DNO part sends commands to the BEMS according to the functioning of the Demand Response System (DR) [10].

One of the most important function performed by the DR systems is to control the load shedding. Individual building devices equipped in communication interfaces and use of EMC's allows to take account of the distributed home appliances in the load shedding.

The article presents the BEMS classifications and proposes the t_{LS} quantity introduction. This quantity describes time load shedding defining time characteristics of such a system, which can be useful to assess the ability of the BEMS to function in DR systems. The influence of system structure on the value of the t_{LS} quantity will be discussed.

Load shedding systems

Traditional solutions of the load shedding systems are based on automatic protection and the effect of their actions is to completely disconnect the power supply to certain areas [11].

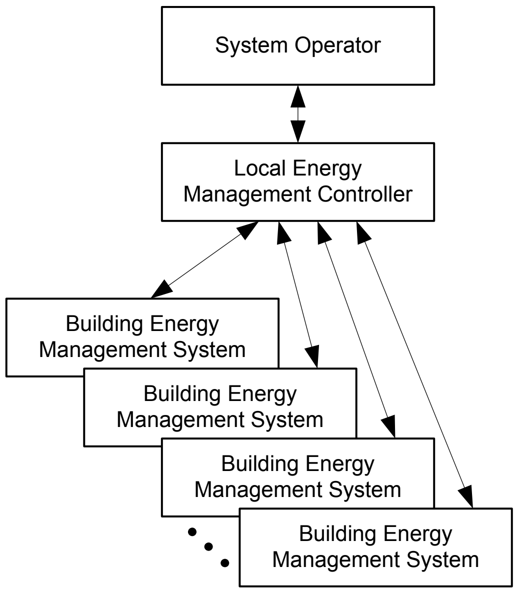

Fig 1. The block diagram of a Local Energy Management System

Appliances equipped with communication interfaces and using EMC controllers in buildings allows to achieve many functionalities within the BEMS among which are the system's ability to perform load shedding. Block diagram of the local energy management system is shown in Fig. 1.

The local power management controller (LEMC) and buildings energy management systems (BEMS) are the primary components of the system.

LEMC systematically gathers data from BEMS about current electricity consumption. Based on the collected data and using artificial intelligence methods forecasting of the short-term energy consumption in the area, are carried out. If short-term forecasts indicates the exceed of acceptable levels of energy consumption, the LEMC, begins the load shedding procedure, which starts by sending out commands of load shedding to the BEMS. The launch of the load shedding procedures can also be initiated by a load shedding command received from the master system operator.

Buildings Energy Management Systems

Block diagram of the Buildings Energy Management System is shown in Fig. 2. The basic elements of such a system besides of the energy meter, appliances and distributed energy sources, should be home gateway RG (Residential Gateway) and EMC controller (Energy Management Controller).

Home gateway is primarily used to integrating different types of systems used in buildings and households. In these systems should be devices important for implementation the functionality of the energy management. The gateway should also be able to communicate using different types of WAN with supervise systems, network operators or service providers related to the operation of the Smart Grid. By means of the WAN link, the BEMS system will receive information about energy prices from the regional distributor and commands related to the functioning of the system within the DR [6].

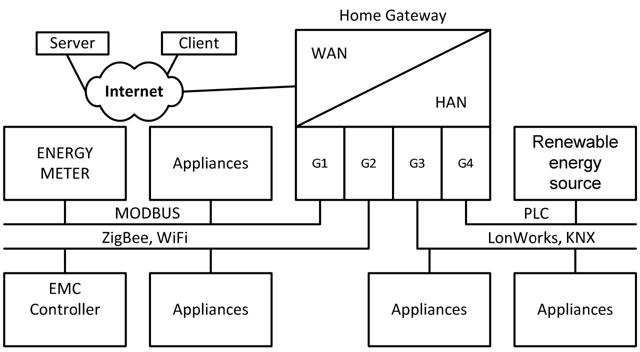

Fig. 2. Block diagram of the BEMS

The EMC controller is an important element of the BEMS. Its main task is to implement pre-defined scenarios referred to the control of appliances or energy sources. Choice of control scenarios depends on rates of price notifications of multi-zone tariffs, and is based on user preferences system (Fig. 3) [7]. The BEMS systems in which there are local distributed energy sources (DES), control scenarios of appliances implemented by EMC should also take into account the possibility of supplying appliances from its own energy sources.

The EMC controller also relieves the user of the system, in terms of interpreting the data on energy consumption and appropriate action on the appliances. Most of the customers do not understand the concepts of the electricity measurement they cannot use the data correctly. The use of the EMC controller adds functionality to load control, enabling distribution of a limited amount of energy (or a limited allocation of energy) between the device depending on the consumers preferences.

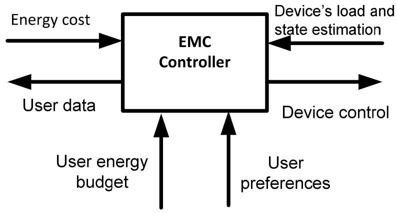

Fig. 3. Functions of the EMC controller

Taking into account the nature of the building control systems, energy management systems can be divided into centralized processing and distributed computing systems. In the first case, the decisions concerning scenario of controlling various devices are made in the EMC controller and there are worked out signals on controlling various appliances such as a reduction in the level of power consumption, enable or disable the appliance, postponement the appliance supply due to the tariff plan. In the case of distributed processing, appliances on the basis of the EMC controller tariff schedule information and energy prices, independently make decisions about transition to the reduced power consumption mode. Each solution has its advantages and disadvantages. In the second solution it is certainly harder to achieve measurable and efficient use of energy.

The functionality of the appliances in terms of electricity consumption or generation can be the basis criterion of the division of the Buildings Energy Management Systems. The basic division, in this regard, takes into account the systems only with energy consuming appliances and systems with appliances and distributed energy sources. In both systems in energy storages can be used. This classification has an influence on the level of complexity of the control algorithm (control scenario) implemented in the EMC controller. Control algorithms are less complex for systems comprised only of consumers of energy, and such systems are present in most cases. Using DES control algorithm will take into account the scenarios of switching on and off specific appliances in a given time slot but also activation of the DES in order to obtain cheaper energy to power appliances or of storing it in case of planned outages from the energy distributor.

Load shedding algorithms

Many works devoted to the problems of control algorithms for the individual devices in BEMS are available. Presented solutions are usually optimal from the point of view of energy costs or maximizing the use of local DES. In critical situations, where command of load shedding arrived from the master systems, control algorithms implemented in the appliances must be modified (suspended) in order to achieve a reduction in power consumption of a given building. The power reduction may be immediate, then it applies to the appliances that can be switched off immediately or instantly reduce the power consumed by the given appliance. Reduction of the consumed power in a building may also be delayed, then refers to appliances that can be turned off (or limit the power consumed by the appliance) but with some delay.

Fig. 4 shows the algorithm of the EMC controller in case of receiving commands from DR systems concerning the load shedding.

The implementation of the algorithm will start from sending out load shedding commands to the appliances. The next step will be to gather responses from the devices, which will include information on immediate and delayed load shedding. Based on the responses from EMC, the controller creates a summary of the load shedding characteristics which contains information about the immediate and possible delayed load shedding.

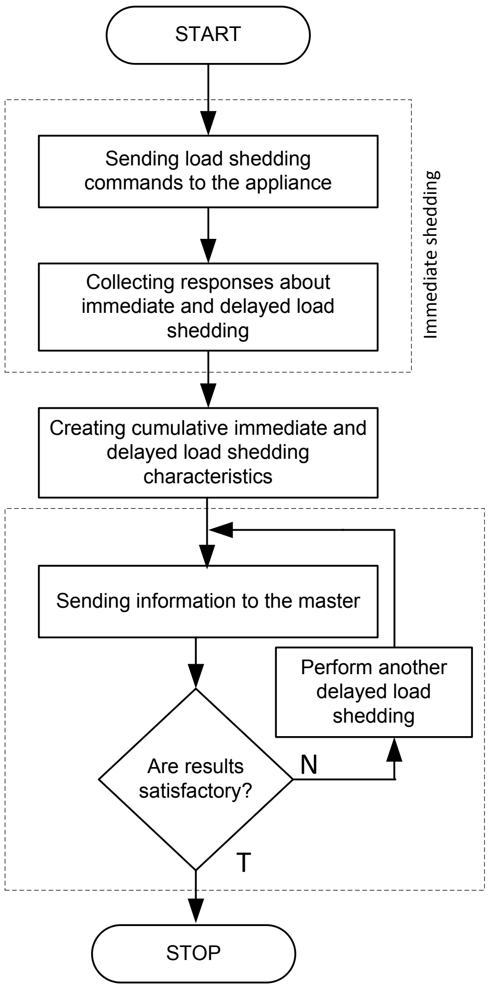

Fig. 4. Load shedding algorithm

This information is also send to the master system, which taking into account the responses from other BEMS will decide whether the next step in delayed load shedding should be performed.

The Load shedding time

To assess the suitability the BEMS for functioning in the DR systems implementing the load shedding, or in the case of planned outages could be used the time load shedding t_{LS}. The t_{LS} is defined as the period of the time between the moment of arrival the commands of the power consumed reduction in the system, to the EMC (t_{LS_START}) and the time of command execution confirmation t_{LS_END}:

(1) $$t_{LS} = t_{LS\_END} - t_{LS\_START} \ .$$

It is assumed that the appliances have the appropriate technical capabilities, ex: are able to change their mode of operation in terms of power consumption levels.

In the centralized processing mode, command to reduce the power is coming into the EMC system controller, which sends appropriate control signals to the respectful appliances and collects confirmation. Communication between EMC and a single appliance related to sending commands and receiving the message response is defined as a single exchange time tw_i.

The communication architecture of the BEMS, for each segment of the system depends on media access method, used topology, communication rate, and the has the same communication coprocessors, thus method of determining a single communications exchange time tw_i will be different.

In the case where both the system controller and other system nodes are connected to a single segment of the system and use the same method of accessing the media, working with the same bitrate and uniform communication coprocessors, the t_{LS} time can be determined using the formula (2):

(2) $$t_{LS} = \sum_{i=1}^{n} tw_i \ ,$$

where: n - the number of nodes in the system, which will be sent the command for the reduction of power consumption, tw_i - the duration of a single exchange.

Single time exchange t_{wi} for master-slave media access methods is the sum of the partial time related to the execution of the corresponding subroutine in the EMC, the time of communication frame transmission, the time of passing through the EMC communication stack, the time of passing through the communication stack on the side of appliance node and execution of appropriate subroutine in appliance node. Sending the feedback message will be referred to execution of mentioned above sequence in reverse order.

Start of the each sub-task may be delayed due to occupancy of the shared resource (e.g. EMC node microprocessor, receiver communication coprocessor and the bus system), so the time of a single exchange will be included within certain ranges (3):

(3) $$tw_{\min} \le tw_i \le tw_{\max} \ .$$

In the case where in the system are also highlighted segments using other communication techniques with which communication is done through the gateways, the load shedding time t_{LS} will be expressed by the formula (4):

(4) $$t_{LS} = \sum_{i=1}^{n} tw_i + \sum_{j=1}^{b} \sum_{i=1}^{ni} tw_{ji}$$

where: b - the number of segments dependent on the media access method, topology, data rate in case when communication from EMC requires the use of gateways, ni - number of nodes in the i-th segment of the system, where command reduction of the power consumption will be send, tw_{ij} - the duration of a single exchange with the i-th node of the j-th segment of the system.

Duration of a single tw_{ij} for master-slave media access method, exchange is defined analogously to formula (2). In addition, in the sum of partial time, the transition over the gateway linking appropriate system segments should be added.

In the article examples of BEMS structures will be presented, for which t_{LS} time will be calculated.

Time analysis examples

In order to illustrate the practical usefulness of load shedding time factor, in the article there are analysed two examples of different BEMS systems structures. In each analysed case the expansion is planned. Design assumptions recommend to maintain the value of the coefficient t_{LS} at the same level as it was before BEMS structure expansion (Example 1) and reduction of coefficient t_{LS} after change of BEMS structure (Example 2).

Example No. 1. Expansion of the system by adding appliance in one segment of the system. According to (2), data exchange with added appliance may lead to an increase t_{LS} above allowable limits. The problem can be solved by reducing the time of the individual exchanges. In Fig. 5 is shown the dependence of the ratio of time to reduce the exchange of a single k_w as a function of the number of appliances added in the system n_d while maintaining the same value of the t_{LS} time .

The k_w factor is defined by the formula (5):

$$k_w = \frac{tw_i^*}{tw_i}, \tag{5}$$

where: tw_i – initial time of a single exchange, tw_i^* – modified duration of a single exchange.

Three options were considered, regarding the base number of appliances in the system. At the beginning, an analysed system comprise of 8, 16, or 32 nodes. In every case, the system was extended from 1 to 32 nodes. From presented in Fig. 5 characteristics results, that the largest reduction in the time of a single exchange will be required for the expansion of a system containing 8 nodes before expansion.

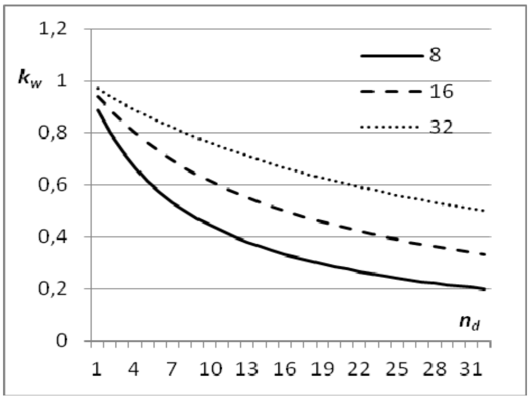

Fig. 5. The k_w coefficient value as a function of added appliances in the system n_d.

Referring to the example shown in Fig. 5 to real conditions, three options regarding the number of devices in the system were also considered. As in the example in Fig. 5, system comprising 8, 16, or 32 devices was extended from 1 to 32 units. It was also assumed the use of MODBUS protocol for communication between EMC devices operating at the speed of data transmission on the bus as 9600 b/s, 19200 b/s and 38400 b/s.

Figure 6 shows the t_{LS} parameter values for the variant of system expansion with a base number of 8 nodes. For systems with a base number of nodes 16 and 32 the nature of t_{LS} parameter value changes will be similar but will start from the larger values.

To illustrate influence of the time load shedding value on the required data rate by given nodes number, it was assumed that for a system with the base number of eight nodes in the system, it should keep the load shedding time parameter at 0.3 s. If four nodes are added, the time of a single exchange should be shortened by increasing the speed of data transmission in the system to 19200 b/s (k_w = 0.5). Similarly, shortening of a single exchange should be carried out for the 16 added nodes by increasing the data transmission speed in the system to 38400 b/s (k_w = 0.25) (Fig. 7).

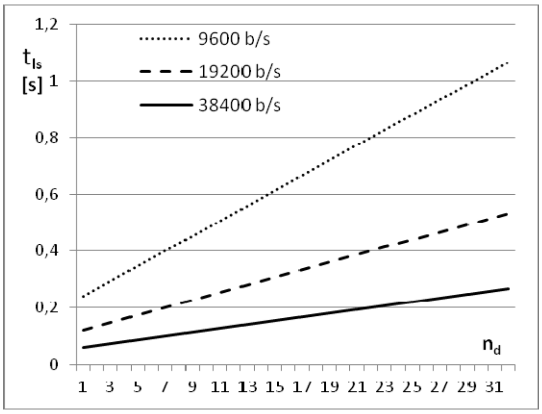

Fig. 6. The load shedding time t_{LS} as a function of the number of appliances added in the system n_d for the variant base system of 8 nodes

It was assumed that for a system with the base number of 16 nodes in the system, it should keep the load shedding time parameter at 0.5 s. level. If four nodes are added, the single exchange should be shortened by increasing data transmission rate in the system to 19200 b/s (kw = 0.5). Similarly, shortening of single exchange should be done for added 23 nodes by increasing the speed of data transmission in the system to 38400 b/s (k_w = 0.25) (Fig. 7).

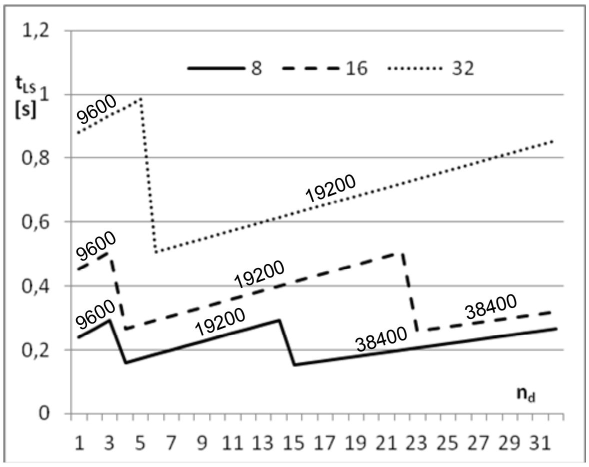

Fig. 7. The load shedding time t_{LS} as a function of the number of appliances n_d added in the system after increasing the speed of data transmission in the system (after single exchange shortening)

It was assumed that for a system with the base number of 32 nodes in the system, it should keep the load shedding time parameter at 1 sec. level. For 6 added nodes the single exchange time should be shortened by increasing data transmission rate in the system to 19200 b/s (k_w = 0.5) (Fig. 7).

Example No. 2. BEMS system is expanded with another segment - a fixed number of appliances in the system. In this case there are compared three variants expansion of the system, with different number of appliances in each segment. Option one: 14/2 (14 nodes in the first segment, two nodes in the second), option two: 8/8 and option three: 2/14. Assumed the possibility of reducing the time of exchanges in the second segment.

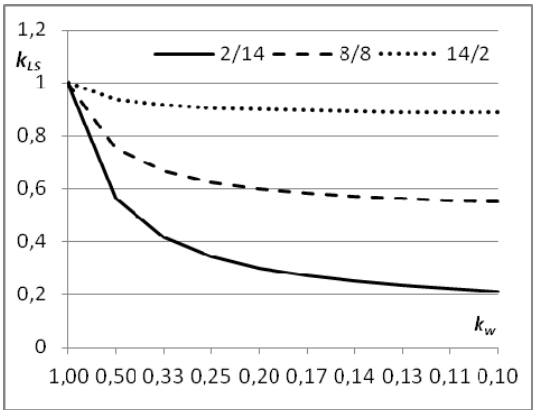

Fig. 8. The k_{LS} coefficient value in the function of k_w.

The Fig. 8 shows the dependence of the k_{LS} value in function of the k_w in the second segment of the system.

The k_{LS} factor is defined by the formula (6):

$$k_{LS} = \frac{t^*_{LS}}{t_{LS}}, \tag{6}$$

where: t_{LS} – initial time of the load shedding, t_{LS}* – modified duration of the load shedding.

From presented characteristics results that the reduction of the load shedding time for instance to the original value of 0.4 would be possible only in a variant of 2/14 with the reduction of a single exchange time at least 0.33 of the original value. In other cases, such a reduction is not possible.

Referring the example described above to the real conditions, three variants of the expansion of the system were also compared. The number of appliances in segments varies for each variant.

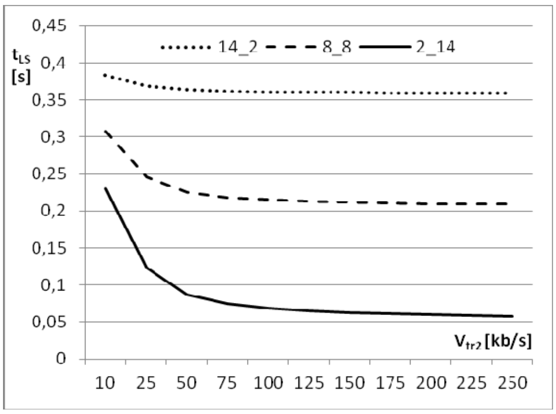

Fig. 9. Load shedding time t_{LS} in a function of the transmission data rate in the segment working with the CAN protocol.

Case first: 14/2 (14 nodes in the first segment, two nodes in the second), case second: 8/8 and case third 2/14. It was assumed the possibility of shortening of data exchanges in the second segment by increasing the speed of data transmission. It was also assumed that the MODBUS protocol with data rate of 10 kbit/s is used in first segment.

A second segment is working with the CAN network and the range of data rate changes from 10 to 250 kb/s (Fig. 9).

Presented characteristics shows that shortening the load shedding time t_{LS} for instance below the value of 0.1 s will be possible only in the case 2/14 with a data transmission rate in the second segment V_{tr2} over 50 kb/s (Fig. 9).

Summary

The dynamic development of Smart Grid in the area of energy efficiency begins to embrace the buildings and households. This development will be accompanied by the implementation of the BEMS in the such objects, whose structure and time properties are very diverse. From the BEMS point of view, an important aspect of the operation of such systems is its ability to carry out the load shedding, in particular, the time in which load shedding could be performed. This time parameter can be important in the DR systems, which on the basis of incoming commands from the DNO should be carried out as soon as possible to limit power consumption. During the design and equipment selection for the BEMS, in addition to the potential for reducing power consumption and equipment in an appropriate communication interface of the devices, it is also important to take into account time properties of the system as a whole. Presented in the paper methodology of the load shedding analysis has general purpose features and can be used for others communications protocols and BEMS systems structures.

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