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Communication Structures and Rule Based Energy Management in AMI Systems

Abstract. *In the paper authors present basic Communication Structures and Energy Management System based on application of the rules database in Advanced Measurement Infrastructure (AMI). Some important issues concerning Automatic Meter Reading, AMI and micro Smart Grid Suystems, like rule based distributed data processing are outlined.*

Streszczenie. *W artykule opisano podstawowe struktury komunikacyjne oraz system zarządzania energią wykorzystujący bazę reguł w zaawansowanych infrastrukturach systemów pomiarowych. Omówiono także szereg zagadnień związanych z automatycznym odczytem liczników energii elektrycznej oraz systemem mikro Smart Grid, jak na przykład przetwarzanie rozproszone bazujące na wykorzystaniu reguł. (**Struktury komunikacyjne i zarządzanie energią bazujące na wykorzystaniu reguł w systemach AMI**).*

Keywords: AMI, Energy Management, Communication Structures
Słowa kluczowe: AMI, Zarządzanie energią, Struktury komunikacyjne

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Introduction

The urgent need to increase energy efficiency requires the involvement of IT solutions to energy management both at the utilities and the consumers side. Even at the Micro grid level, according to the local state of the power sources and customer demands, in order to satisfy utility and customer requirements should be installed locally controllable loads [1,8].

According to EC directives and widely accepted ESMIG (European Smart Metering Interest Group) communication model, AMI (Advanced Metering Infrastructure) system should provide bi-directional and secure communications via standard interfaces and with the standard data format, between utility service providers and digital meters and two-way communication between meters and customers (Fig. 1) [2,5,6]. While the solution of a two-way communication between digital meters and service providers is now not too much problem, proposing a solution to meet the second requirement is not so obvious. The problem is not due to lack of technical capacity, but some of the consequences of proposed solutions.

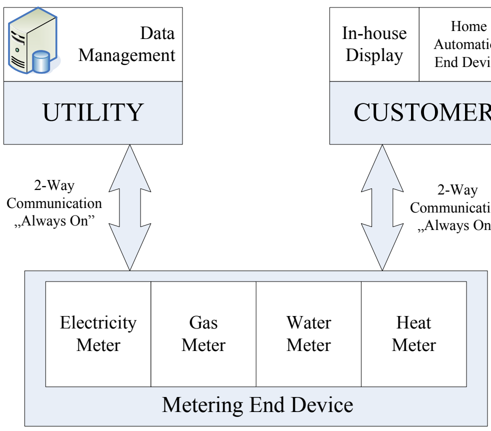

Fig. 1. ESMIG AMI model

This paper presents the selected communication structures dedicated to AMI system and scalability to ensure that they will be ready to introduce the concept of distributed processing for individual structures. Measurement data processing strategy is another dilemma in AMI systems. Due to the fact that these systems will provide the basis for Smart Grids, the solutions to the measurement data that will be used not only for billing purposes, has a significant impact on the reliability of the whole system and affects the load paths of communication.

Observed in the world and in the our country growth activities in the area of implementing smart grid technology arise from the needs to improve the efficiency of electricity use, requiring two-way communication and optimal control of distributed power network elements as well as existing opportunities to achieve this goal by using solutions of modern information and communication technologies (ICT). The implementation of advanced solutions in the area of ICT is a necessary condition but not sufficient to achieve this goal. Precondition for the operation of Smart Grid technology is the existence of AMI infrastructure. The article focuses on issues in the field of information and communication technologies that can be used in local-scale power micro grids.

Automatic meter reading

The first generation systems for remote digital meter reading AMR (Automated Reading Meters) allowed the collection of data from measurement devices for electricity, gas, water and heat, and transfer them to the central database of the measurement results.

Many devices for remote data reading can in addition to reading current meter, recording and storage for some time, such as data stored meter reading at the beginning of the settlement period for different time zones. The AMR systems apply a variety of techniques for reading the data. For example, the device can be read by the data acquisition server, which with the use of mobile technology, establish connectivity directly with the communication module integrated in an electronic meter. Remote reading electronic meters can also be made by the handheld computer from a distance of several meters using Bluetooth wireless standards, AirM-Bus or ZigBee. This paper will present the main advantages and disadvantages of remote meter reading AMR system for ESMIG model.

The major advantages of remote meter reading AMR include:

- greater comfort consumers whose presence is no longer required at the time of meter reading,
- significant reduction of errors related to the so-called. human factors during the meter reading,
- reduction of costs associated with the acquisition of metering data,

- ensure timely settlement based on real data, ability to create custom reports, such as daily, weekly or monthly,
- collected during the automatic reading data can be used not only by the billing systems but also to improve the customer services,
- possibility of early discovering of irregularities in energy consumption,
- possibility to use tools for monitoring customer behaviour related to energy consumption based on the analysis of collected data.

Advanced meter reading system

Existing features of the remote meter reading data are developing in the direction of a much more complex functionalities. The actual implementation of these functions is dependent on the existence of an advanced metering infrastructure AMI, which meets the requirements of the model ESMIG. AMI is an integrated set of elements: smart meters, communications modules and systems, hubs and recorders, allowing bi-directional and secure communication, through a variety of different media and communication technologies, between the central system and the selected meters. Such a network enables the collection of consumption data by certain customers, sending control signals to remote devices and even reconfigure their [1,3].

The main difference between the advanced AMI infrastructure and AMR remote reading system is the possibility of two-way communication with meters in the AMI system. This affect the complexity of networks and communication protocols used. In addition, AMI is also ready to work with HAN network, intelligent building systems and is prepared to cooperate with intelligent power grids. A consequence of the use of smart meters is distribution of data sources across the grid. It is necessary, therefore, fast, efficient and secure communication infrastructure [2]. Due to the size of the coverage area communication infrastructure AMI can be divided into:

- Home Area Network – local nodes can be controlled by the smart meter,
- Local Area Network - used to direct meter reading by hubs or other devices,
- Wide Area Network - providing data exchange between the hubs and the corresponding acquisition servers, which acquire data from smart meters.

Desirable features of an advanced metering infrastructure are [1]:

- standard communication interface - recognized standard for the interface to the measuring device and a communication module,
- standard model of data - the use of a standard model for data exchanged between the measurement devices and customers,
- security - protect your network from unauthorized attempts to personalize and modify data, protection against attacks and against the use of eavesdropping across the measurement infrastructure using open standards,
- two-way communication - the possibility of reliably sending data to the receiver and to receive information from the customer,
- remote reading of the data - the possibility of remote updating the meter, security clearances, modify its configuration and software updates all system AMI,
- use of multi-zone fare - the meter can record measurement data in a particular cycle, such as 15 minutes for several days,
- measurement of energy flow in both directions, meters, four-quadrant - the meter can record energy flow in both directions and energy inductive or capacitive depending on the direction of energy flow agent,
- long-term retention of data on equipment - storing data in the numerator for at least 45 days for the two channels,
- ability to remotely disconnect - the ability to remotely disconnect and connect the client receiving system,
- network management - the ability to remotely diagnose meters and various elements of the network to monitor and control the status of individual elements AMI communication network,
- self-healing network - the ability to automatically detect and fix network problems,
- gateway to intelligent building - AMI system acts as a gateway to communicate with devices at the customer site,
- many users - AMI system allows many clients who make access authorization applications, access to measurement data,
- measurement of power quality - to measure and report information on the quality of energy recorded by the meter at the customer,
- tamper detection and theft - AMI system should detect, report and test cases indicate tampering and interference in the system of meter and suspected energy theft,
- pulling power outages - AMI system can detect and report the events recorded in the meters due to power failure,
- scalability - the development of the AMI system is not limited in any component,
- location - the ability to use GPS or other equipment to the meter location.

Further development of the AMI systems will take into account not only the current needs but also those that occur as a result of these changes in the electro-energy sector. AMI systems should take into account the growing scale distributed generation, i.e. some customers, as a prosuments will give energy to the grid and will generate electricity for their own needs, which noticeably change the daily load profile of the network. AMI systems should also ensure interoperability with devices that recharge electric cars, and should allow the use of a wider range of applications for projects programs allow demand-side response.

Processing and aggregating data services in AMI systems

The AMI system assumes the possibility of collecting data on electricity consumption automatically. Measuring meters beyond the typical current consumption of the measurement and summing it to the total amount of energy consumed can keep sending information on current consumption data to a central billing system energy consumption (CBSEC) per given operator(Fig. 2). This data can be processed in CBSEC to use for various tasks, such as monitoring of current consumption in different locations, forecasting future energy consumption, detecting theft and other purposes. Transferring data from meters to CBSEC can be done in different ways depending on the operator's technical capabilities in a given location. Energy meters devices must be able to communicate electronically with operator billing systems. Electricity meters, as small hardware capabilities devices will be able to collect a certain amount of data about the course of the energy consumption. But rather, there will be small data buffers.

Although technically it should not be difficult to implement, however, equipping meters in high-capacity, non-volatile memory for allows the collection of large portions of the data can be cost ineffective. More economically effective will be building and running dedicated equipment responsible for the collection of more data from large groups of meters in order to send them in larger batches of data to the billing operator. These devices are called devices energy data concentrators (DEDC). Such a devices will communicate locally with energy meters that are within their reach. They may be equipped with larger buffers of non-volatile memory for caching data from multiple meters. There are different solutions to communicate with meters possible to use. In the case of organising billing in a multi-family building two solutions can be considered, communications with meters using wireless communications, such as ZigBee or WiFi or wired PLC. Data from a number of meters can be read by the DEDC device and cached in the memory. In case of difficulties in providing wireless communications, such as on the estate of single-family houses it is possible to implement a PLC connections only. If, however, the two solutions are not feasible, for example, due to the large distance between the buildings wireless connectivity is not possible to run or interferences cause the PLC connectivity fails, it is possible to consider installing special meters integrated with DEDC, but with limited buffer size memory. Such devices will be of course more expensive, but in some cases it may be the only solution. It may turn out that in such cases meter will be equipped with wireless modems, eg. using GSM, UMTS, LTE or WiMax. DEDC devices collect energy consumption data from the meters on the principle of client-server using DLMS protocol. In this case, the server will assume the role of the meter, client will be DEDC.

The meter will never send data if not asked for it. This solution reduces network traffic because only the meter, which was asked about the data sends a response. In another case, formation of collisions on the network or generating much traffic similar to the type of broadcast traffic (called broadcast storm) is possible. There will also be difficult to run so called sniffing network packets sent by the meter, it will be harder to capture the data sent on the network and break into the system.

Consumption data cached in the device DEDC will be sent to a central electricity billing system. The CBSEC system will be adequately prepared to gather data in database systems. The data transfer will also be able to be done on a client-server architecture. In this case, the DEDC device will act as a server and CBSEC as a client.

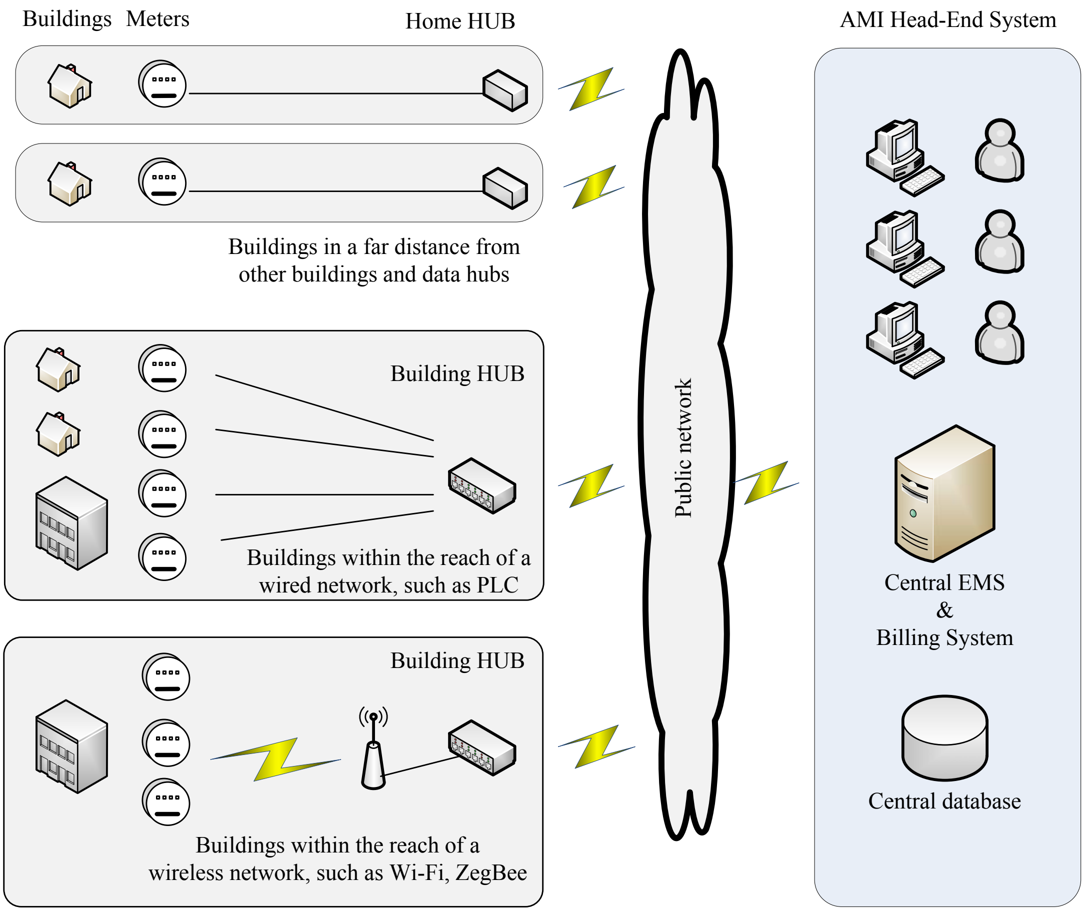

Fig. 2. AMI system structureDepending on needs, the data can be transmitted by means of different types of media used in conventional WAN connections based on copper, fibre optic or wireless. Because consumption data will be stored in the DEDC memory it can be sent in larger batches to CBSEC.

It should also be beneficial in terms of reducing unnecessary traffic in the network. Before sending the data can be compressed to reduce their size. Both the communication between the meter and the DEDC, as well as between CBSEC must be made to ensure confidentiality and data integrity, and authentication of the parties involved in the exchange of data.

For this purpose, there must be used the appropriate encryption method such as AES or RSA using the appropriate power levels of encryption and symmetric or asymmetric keys in combination with authentication methods. It may be difficult to ensure for meters because providing such functions may require the use of the more expensive components to build a meter such as faster processors, more memory or special hardware encryption modules. Transferring data in an encrypted way is used in many existing solutions, for example: banking systems or in systems handling credit cards. It seems that it will be possible to use multiple mechanisms that are already in use for many years. However, there are many aspects of the transmission of encrypted data that needs to pay special attention because of the possibility of unauthorized interference in the communication process between the AMI system devices. One of them is how to use, store and exchange encryption keys [4,7] data. Meters installed on customer premises will be designed for many years of work without interfering with the service, however, it's hard to expect that digital certificates used to encrypt data will be perpetual. From time to time they will have to be exchanged.

The data collected in the databases in CBSEC can be used in many ways. This may include, between the others:

Monitoring of the current energy consumption in large areas with the possibility of aggregation up to the level of individual customers. For this purpose, SCADA systems can be used.

Accounting for current energy costs. Based on the accounting records actual energy consumption for selected period without forecasting and collection advance payments and subsequent accounting for them will be possible.

Generating accurate billing of energy consumption at the request of the recipient. Since the meters will send consumption data at the selected interval will be possible to prepare the compilation of aggregate consumption to the level of minutes or seconds.

Processing of consumption data at different times of the day and year to adjust and propose a suitable tariff plan for the energy consumers. Billing centre on the basis of consumption information will be able to develop a profile of the recipient.

Forecasting of energy consumption of a large area, and clusters of customers. Based on the history of energy consumption in the long term it will be possible to plan consumption in future accounting periods.

Detection of fraud and theft of electricity. After the collecting adequately long history of consumption of a customer and developing its usage profile will be possible to pull out significant deviations from this profile, which may be an indication that the theft of the energy may have occurred even without the knowledge of the recipient. Another way to detect fraud and theft can be to compare the amount of consumption of individual consumers and consumption at a given point of concentration. The sum of the readings of the meters should be consistent with the summary of consumption at the point of concentration. If it is not there may be a situation of energy theft.

The data collection system of an energy consumption must be prepared to process huge amounts of data from a large number of meters. It may be necessary to use special solutions of the disk array systems and redundancy and server solutions used for large network systems. Such solutions are known and used in complex network systems, such as cloud services solutions.

Selected results of the meters data processing in the CBSEC system should be made available to all interested companies and institutions of the energy sector and its proportion in respect of the recipient should be accessible.

Besides presented in this chapter classical approach to the ways of transmission and processing of measurement data, there will be presented solutions based on so called rule-based processing, which can greatly help to increase the efficiency of the power system by making the basics for an intelligent system.

Rule-based data processing in AMI systems

Fig. 1 shows the general architecture model of the Smart Metering system developed by ESMIG. In this model, there are three elements: End Metering Devices, Customers, Utilities and two-way communication system between these elements. If the structure is clear and clarified, its implementation due to the existing heterogeneity of technologies and communications solutions and scale of the project is not a simple matter. Great help is the standardization of the solutions used at the level of communications and information technologies, including both data format and the way they are processed. This chapter focuses on issues related to the processing of the measured data at the local level of the Smart Metering and using the results to improve the processing efficiency of the whole system. For the local level in relation to the power grid is considered the part of the distribution system from the end user to the substation LV.

Fig. 3 shows the structure of the AMI communications system, which distinguishes three local levels marked in the figure as the Home Hub (HH), Building Hub (BH) and Substation Hub (SH). Occurring at the lowest level HH hub communicates with meters EM, GM, WM and HM installed in the apartment. In addition, HH hub can communicate with intelligent devices of the class of Home Automation Device End, In-House Display and customizable dashboard and with BH concentrators meter summing at the level of the building, company or institution and gathering information from the meter HH. A similar function is fulfilled by SH hubs that collect information from the hub BH. Measurement data from the meters through hubs, HH, BH and SH are sent to the AMI server.

One of the important issues in AMI systems is the standardization of the communication process and to achieving interoperability at all levels of the system. A breakthrough in resolving these issues may be the growing popularity of IEC 61850 standard used in today designed or upgraded HV, MV and LV substations [9]. The introduction of this standard at levels HH , BH and SH (Fig. 3) in addition to unifying the communication protocol to ensure proper base class solutions for Micro Smart Grid, where interoperability plays an important role. On the measurement meters level can be used hybrid communications solutions, while on the HH level standardization would occur based on IEC 61850. Such a solution would lead to the formalization of the hardware part that would make it a more open and flexible structure, functioning on a logical level. This solution would be a good base for the implementation of rule-based processing in the micro Smart Grid.

The physical implementation of the three-level structure may be limited to one level only. Then the data from the measuring meters are sent directly to the AMI server and functions of HH, BH and SH implement the AMI server software. We can speak then about virtual hubs HH, BH and SH. Hubs HH, BH and SH are identified by three field address when fields are separated by dots, eg: HH 1.3.27. This notation means the address of HH hub that is connected to the hub HB of 1.3.0 address, and this hub is connected to the hub SH of 1.0.0 address.

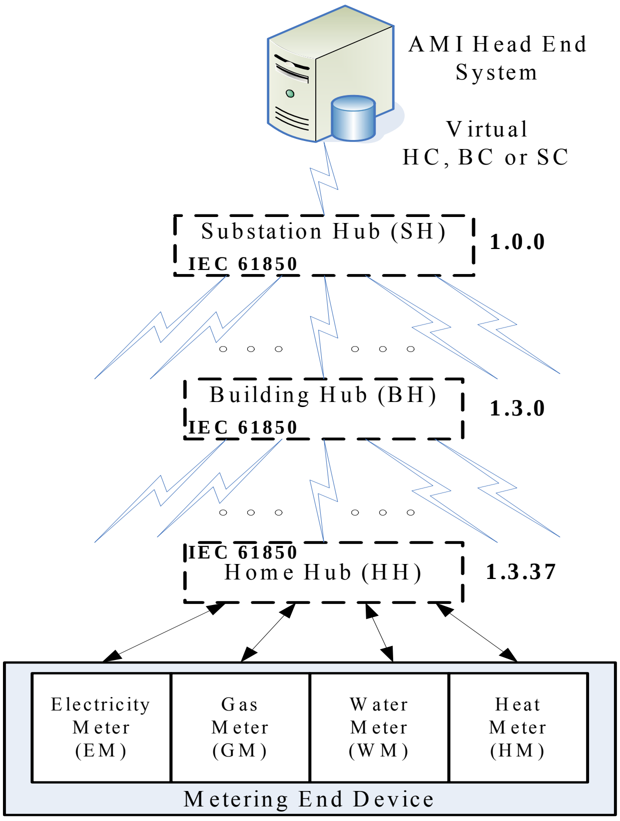

Fig. 3. Hierarchical local AMI structure

One of the key issues related to the efficient functioning of the Smart Metering is the solution of how data is processed and way of implementation of control functions at the local level. Presented in the paper the concept of processing at the local level is based on rule-based processing, so we can get some level of universality for the tasks at a level of symbolic values rather than numerical.

In such structure, it is proposed to introduce a rule-based processing at the level of hubs HH, BH and SH. The use of rule-based processing requires a transition from symbolic record to numerical record, allowing you to achieve the objective of universality that define the state such as the current electricity consumption in the hub and on a given level not in numerical values, but for example in the form of expressions: Green (G), Yellow (Y) or Red (R). Determination of the current state of the energy consumption in different hubs is the basis for rule-based processing and requires the processing of the following rules:

R1: **IF** *Power Consumption* <= 0,75 *Nominal Power*
THEN HH = “GREEN”;
R2: **IF** *Power Consumption* > 0,75 *Nominal Power*
AND *Power Consumption* <= *Nominal Power*
THEN HH = “YELOW”;
R3: **IF** *Power Consumption* > Nominal Power
THEN HH = “RED”;

The GREEN status means that the actual power consumption is significantly below nominal value. The YELOW condition means that the actual power consumption does not exceed the nominal consumption, but may be close to the exceeding value, while the RED condition means that the actual power consumption exceeds the nominal level. If there is a change of the state of the hub, the information about hub status change is sent out to all the hubs connected to the hub, that is, if the hub BH of 1.3.0 address discover the change of power consumption state, this information is sent to the hub SH 1.0.0 and to all hubs HH 1.3.i, for i = 1 to N, where N is the number of hubs HH cooperating with the hub BH of 1.3.0 address.

Triggering of the processing of the rules can be initiated by an event defined in the system such as time or generating a query (BHi Power Consumption?) through the device of Home Automation Device End, another hub or AMI server.

Putting such a hypothesis: PLUG IN? by Home Automation End Device initiates rule-based processing of the hub, to which the request has been delivered and it is about firing the following rules:

R5:**IF** HH = “RED”
THEN *PLUG IN* = “NO”;
R6:**IF** HH = “GREEN”
THEN *PLUG IN* = “YES”;
R7: **IF** HH = “YELOW” **AND** BH = “GREEN” **OR** BH = “YELOW” **THEN** *PLUG IN* = “YES”;
R8: **IF** HH = “YELOW” **AND** BH = “RED”
THEN *PLUG IN* = “NO”;

The rules are processed sequentially. First meeting the condition for the rule being processed terminates the reasoning process. Similar hypothesis (queries) can be placed in relation to many other situations.

If the hub HH, BH or SH is in the RED state, than using rule-based processing it is possible to decide to disconnect some receivers that currently use electricity and belong to the group of devices that can be remotely disconnected. Similar action may be taken in relation to selected circuits. Currently working devices are listed in order of priority importance. Similarly to the circuit boards. The following are examples rules to control devices or circuits which are placed in one of the hubs HH:

R9: **IF** HH = “RED” **AND** BH = “RED” **OR** SH = “RED” **THEN** HAED (i) = “OFF”;
R10: **IF** HH = “RED” **AND** BH = “RED” **OR** SH = “RED” **THEN** CIRCUIT (i) = “OFF”;

where HAED (i) is the first device in the list of working devices and CIRCUIT (i) is the first in the list attached circuit with the lowest priority. Disconnecting the device or circuit removes it from the list of connected devices.

Presented examples of the rules refer to a three-level structure shown in Fig. 3, while in the case where this structure will be two or one-level or if the hub functions are implemented in the AMI server (virtual hubs), the situation like this must be taking into account during developing rules and their placement in the system. The advantage of the proposed solution is achieving the universalism of the processing involving using constant program part which affects the reliability of the software.

Advanced features of the AMI systems associated with remote disconnection or connection of a client can be developed in a way that will allow remote disconnection of certain circuits of the individual client. Such a feature may be combined with the customer implemented rule-based processing. In case of exceeding the acceptable level of used energy by the recipient rule-based processing can be used to determine the electrical circuits that need to be disconnected to the electricity consumption of a household to maintain the required level.

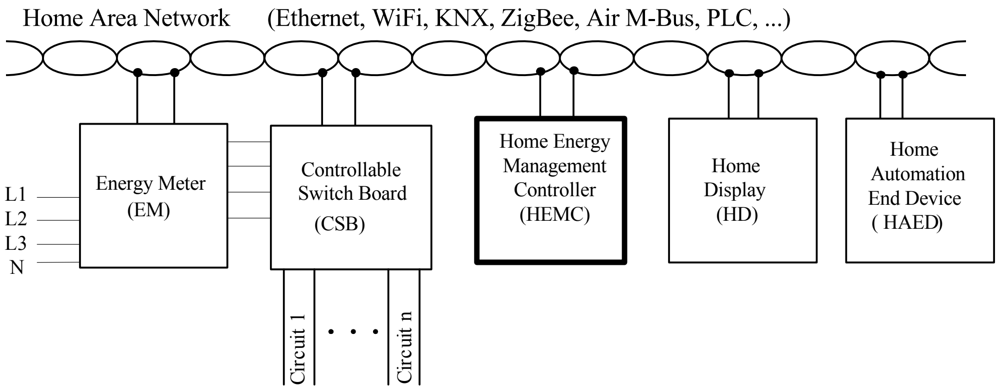

Fig. 4. Home Hub and HAN integration

The structure of the system within a single housing (Fig. 4) shall include the following elements: Electricity meter with data loggers for measuring absorbed energy, Controllable Switch Board (CSB) with the possibility of disconnection of individual circuits, Home Energy Management Controller (HEMC) with embedded rules, Home Display (HD) used as a device to configure rules, display messages and edit queries. Between the various elements of the system should be possible to exchange data in a certain range. Circuits will be assigned priorities on the basis of which will determine the order of disconnecting circuits. This functionality will be the stage of the transition until the introduction into the public following solutions:

- equipment of each unit supplied by electricity in remote turning off function through intelligent building systems,
- to enable communication between AMI systems and intelligent building systems.

Linking AMI systems and intelligent building systems is still in the conceptual phase studies. It seems that the introduction of the ability to remotely disconnect individual customer circuits will be easier to implement.

Conclusion

AMI systems can be built as a centralized or a distributed functional structure. The paper presents a solution of the distributed computing in AMI system that can be implemented both in the centralized and distributed structure of AMI system. The structures of the communication systems dedicated to AMI and the concept of hierarchical processing based on so called rule-based processing are presented. Drew attention to the heterogeneity of communication solutions and the need for interoperability with home network. AMI infrastructure based on IEC 61850 standard with the distributed processing ability will be an important component of the future micro- and macro-Smart Grid systems.

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