Smart Metering and Scheduling of Electrical Loads of Buildings

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Abstract. The article analyzes global trends in the development of smart metering and energy planning in buildings, the development and implementation of intelligent energy monitoring to collect and analyze data on energy consumption for management to improve energy efficiency, it considers the implementation of infrastructure for advanced smart metering smart home using NILM-technology non-intrusive load monitoring. It is shown that equipping buildings of various purposes in a smart city with real-time energy accounting systems with smart meters generates a new approach to improving the energy efficiency of buildings and contributes to the successful implementation of energy service contracts and energy management systems in them.

1. Introduction

About one-third of the world's energy is consumed in residential, public, and commercial buildings, where it is used for heating, cooling, ventilation and air conditioning, lighting, food storage and cooking, water heating, and various utility systems.

Most of the existing buildings in the world today, and especially in Russia, were built with little or no attention to energy efficiency. Therefore, reducing the energy consumption of residential, public and commercial buildings is a huge untapped source of energy efficiency improvements.

Sustainable development of smart cities is impossible without continuous development and implementation of smart systems of energy management of urban infrastructures and energy management of individual buildings, structures and facilities. These are buildings for various purposes in the city: residential buildings, state municipal institutions, office buildings, higher education institutions, schools, hospitals and clinics, sports and entertainment facilities, shopping malls, etc. All these buildings have different floors and year of construction, with different modes of operation and volume of energy consumption.

Efficient energy of a smart city should become "smart" in order to provide a cost-effective and environmentally friendly environment for city dwellers. However, at this stage of the development of smart cities in Russia, the implementation of smart energy solutions is still poorly implemented in the tasks of digitalization of urban economy.

In the developed world economies a great deal of attention is paid to this issue. For example, in Europe, the key legislation to improve the energy efficiency of buildings is the Energy Performance of Buildings Directive (EPBD) of the European Union, which provides for the reduction of energy consumption by buildings. EPBD requires to determine on the basis of actual energy consumption
energy consumption required for heating and cooling of the building, ventilation, hot water and lighting, and other building energy needs to improve the quality of the indoor climate [1,2].

In Russia, using the experience of European countries, there is a consistent change in the legal framework, both in the field of smart metering of electricity, and in improving energy efficiency in buildings, structures and facilities.

Among the most recently adopted legislative documents we should mention the Federal Law №522-FZ of 27.12.2018, which officially introduced the concept of "smart metering system of electric energy (power)", as well as the requirements for the installation of "smart" electricity meters in apartment buildings [3].

Decree of the Government of the Russian Federation No. 1289 of 7.10.2019 established requirements for the reduction of energy resources consumed by state (municipal) institutions in comparable conditions, set the target level of reduction of resource consumption for the three-year period (2021 - 2023 and subsequent three-year periods) in comparable conditions for major functional and typological groups of buildings and public facilities [4].

Russian Government Decree No. 1289 requires state (municipal) institutions, and this is a large number of public buildings in the metropolis, to steadily reduce their consumption of energy resources and improve the energy efficiency of buildings, which in turn leads to the investment of significant funds for energy saving measures or, in the absence of such funds, the involvement of energy service companies.

These legislative initiatives mainly apply to electric energy metering systems in residential and public buildings, but may also apply to other consumers of electricity and other energy resources: water, heat and gas in Smart City [5].

One of the main ways to improve energy efficiency in residential, public and commercial buildings is to actively manage energy consumption by creating effective systems for monitoring, control, planning and management of energy consumption in the building, which, in turn, is impossible without smart metering of energy resources.

Electricity is the most demanded and the most difficult to manage energy resource, which is necessary for all life-supporting activities. The lighting of premises, heat, cold and hot water, sewage, operation of electrical appliances and power equipment necessary for full functioning and comfortable conditions in a building come from electricity.

The activation of various mechanisms and the control of technological processes, as well as the operation of modern means of communication (telephone, television, computer technology, the Internet) is impossible without the use of electrical energy.

The rapid development of digital devices and information and communication technologies is beginning to significantly change the principles and methods used in analyzing the energy consumption of buildings.

Advanced technological solutions for smart cities involves a gradual transition to intelligent systems of energy accounting and remote control networks of heat, water, electricity, which allow monitoring and control of infrastructure facilities in real time by receiving and analyzing real-time data on the state of networks and equipment with sensors.

Due to the development of complex hardware, software and platform products and services, with the help of which the user can assemble the necessary and functional solution as a constructor, a new technological niche with high growth potential is actively developing - the market of smart homes and buildings, including means of controlling the energy equipment of buildings.

The introduction of digital smart city technologies in Russian cities, the development of intelligent power supply systems for buildings and active consumer technologies, progress in the development of electricity metering and instantaneous data transmission based on wireless communication and the Internet, cloud technologies and big data processing, distributed control systems, gives all participants in the power supply, and consumers in the first place, the opportunity to benefit significantly from the synergies created by new technologies [6-9].
2. Intelligent energy metering infrastructure in buildings and structures

Modern large buildings and production facilities consume large amounts of electrical energy, which is the main expendable energy resource and is used for lighting, operation of various electromechanisms and office equipment, ventilation and air conditioning systems, heat and water supply and much more.

The existing electricity metering systems of such buildings have the commercial task of calculating with the electricity supplier and are installed at the boundary of the balance belonging of the consumer. Such a metering system does not allow a qualitative analysis of energy consumption within the premises of individual sections of the network or powerful electrical consumers, as well as to take measures to optimize energy consumption.

To improve the energy efficiency of buildings, it is necessary to implement an automatic energy accounting and monitoring system capable of working with a large amount of accounting equipment, to produce internal billing and qualitative analysis of electricity consumption, which contribute to prompt decision-making on optimization. Having a large amount of data and the results of its analysis, a company can more accurately predict power consumption.

To assess the potential for reducing energy consumption by the end user, an accurate assessment of energy efficiency over a shorter period of the production process than is done in commercial metering systems, as well as a more accurate assessment of the effectiveness of energy saving measures implemented, especially if these measures are costly and with a long payback period.

One of the basic solutions, which will bring current issues of improving energy efficiency of the "smart" city to a new level, is the concept of Smart Grid by providing electricity to the "smart" home through the introduction of systems for metering, monitoring and management of engineering infrastructure in buildings in real time.

With the development of intelligent power supply systems, a new form of building electrical efficiency management at the level of the consumer triad "smart" house - building - enterprise, with the creation of a unique infrastructure of smart meters and automatic power management system [10,11].

Advanced metering infrastructure is the information basis of the new generation network, which has already received a stable abbreviation AMI. The tone on the AMI market is set by global companies, which carry out the largest implementations of such systems in the world.

A typical functional scheme of power supply for a smart home was proposed by the IEC. It is presented in Fig. 1 [12].

![Functional scheme of power supply for a smart house.](image_url)
The management of such a complex system of power supply of a smart house is impossible without creating the appropriate infrastructure of smart meters (AMI) and the system of automatic control of electricity consumption, which should become the information conductor of the smart house with both market and technical operators of the electric power market [13].

In buildings of various purposes, for the purpose of settling accounts with the supplier of energy resources, there is a general accounting of electricity at the meter of commercial accounting of electricity, installed at the entrance to the building. Billing is performed with a certain periodicity, usually once a month.

For detailed monitoring of electricity consumption of individual devices and equipment inside the "smart" house it is necessary to install a smart meter at the entrance to the building for settlements with the utility company together with an electronic monitor, which allows you to observe the structure of energy consumption in real time through a convenient visual interface, analyze the accumulated information, predict the load and make informed decisions on energy conservation.

A common set of guidelines for the implementation of smart energy systems is presented by the IEC in the Smart Grid standardization roadmap and covers the improvement of the power grid using smart technologies to address pressing issues of improving the efficiency, reliability, observability and controllability of the power system and connected consumers, for the benefit of all stakeholders [14].

One of the main tasks of "smart" house power supply is to organize the optimal functioning of the house system in automatic mode in order to increase the energy efficiency of energy consumption. It is envisaged to build up smart electrical equipment and electrical appliances and their interaction with each other and control systems using Internet resources and wireless communication using Wi-Fi network to implement the tasks of automatic and beneficial for the consumer participation (provision of services) by its regulating energy resources in the external energy system both in providing excess produced/accumulated electricity and automatically reduced consumption power.

Being at the center of any smart infrastructure, consumers should get an adequate understanding of smart metering solutions, with a focus on energy conservation and solutions to implement building energy efficiency measures.

Intelligent power management monitoring systems are already available and used in large commercial buildings and industrial facilities abroad. A large number of works abroad are devoted to the analysis of operation, development and peculiarities of electronic load monitoring.

Investing in an AMI smart home is a long-term investment, so it is essential to have a view of the cost and return on future investment as a basis for sustainability of this technology for the end consumer.

For example, in [15,16], a survey of 54 different companies gave a detailed overview of various optimized control systems for energy and comfort management in smart buildings, evaluating the cost of solutions and the prospects for device-level load monitoring in off-the-shelf energy monitors. Seventy-nine different off-the-shelf electronic monitors participated in the survey, all of which worked directly in an existing building energy monitoring system.

The cost of energy monitoring solutions is one of the most important factors in the implementation of AMI "smart" home. The results of a large-scale study by the UK Department of Energy and Climate [17] show the cost of individual monitoring packages ranging from £210 to £950 per building.

3. Development of technologies for smart metering and analysis of electricity consumption in buildings

Modern smart energy metering solutions provide an opportunity to achieve the most effective management of activities, increase the reliability of energy supply, and give all stakeholders and consumers a qualitatively new level of service. Open software architecture simplifies the management of business processes and equipment: billing, financial calculations, planning, engineering and technological systems, etc.

The introduction of modern AMI systems represents a technological revolution that benefits everyone without exception. For the power supply company, it improves operational efficiency, network reliability and power quality, makes it possible to optimize capital investments in infrastructure and
improves the quality of customer service. The consumer, in turn, receives rational use of energy, improves energy efficiency and receives savings in energy consumption.

Today's solutions are built on standard communication protocols to ensure compatibility with metering devices and systems from different manufacturers. The systems use open communication standards that provide flexibility in use and confidence in future applications.

The AMI infrastructure is an integrated system of smart meters, communication networks, and data management systems that provides two-way communication between consumers and energy providers. The system provides a number of important functions that were previously impossible or had to be done manually, such as the ability to automatically and remotely measure electricity consumption, connect and disconnect services, detect unauthorized interference, use new time-based rate plans, and incentives to reduce peak demand and manage energy consumption.

Consumers can now manage their own energy consumption in real time and receive information on how and how much the subscriber spends on energy resources, clearly encouraging them to take action to optimize their costs.

Today, the infrastructure of smart meters is the most promising scientific direction, it is mentioned in many scientific papers abroad and is already being implemented on real objects.

Russian studies are also represented by a number of works, of which the following can be highlighted [18,19].

In [18] a review of foreign sources on smart meter infrastructure is given, and AMI technology, its structural elements and integration into the Smart Grid are described.

An overview of the Russian Ministry of Energy [19] presents international and national research on the current topic of the impact of digitalization on the energy industry, systematizing Smart Grid at the technological and infrastructure level on innovative areas, including consumption management and building automation, as well as a significant number of publications illustrating practical examples. It was noted that at the end of 2016 there were already about 700 million smart metering devices installed in the world, and another 88 million were put into operation in 2017.

A smart meter is quite a complex, multifunctional and expensive device. The more functions it performs, the more expensive it will be, but the more effectively the building will be managed and the greater will be the economic effect of reducing electricity consumption in it. To get information about the load of the main electricity consuming equipment in the building, a metering device must be installed at the entrance to each unit. In large buildings, as well as in production facilities with a large amount of equipment, the number of meters will correspond to the number of this equipment, so the installation and subsequent maintenance of the metering system can become critically expensive.

A large number of projects and works abroad are devoted to the tasks and methods of reducing the cost of installing AMI technologies in the Smart Grid. Here we would like to focus on one of them, which makes it possible to significantly reduce the cost of analyzing the power consumption of a "smart" house. This is the NILM (Nonintrusive Load Monitoring) project.

A review [19] mentions this project, which uses big data processing to control a heat pump, boiler, electric vehicle charging station, battery packs and energy consuming installations installed in a building to optimize the energy costs of the consumer and reduce the load on the distribution network.

One of the domestic papers [20] reviews mostly foreign sources on the NILM project, analyzes the most cited articles on the subject, considers the range of effects for households, buildings, energy companies, businesses and authorities. It is noted that NILM is a promising way to identify individual equipment, determine their energy consumption and operating schedules. The NILM sensor solves this problem by decomposing the aggregated energy consumption data from a single measurement point into different appliance consumption profiles. The accuracy of total load measurement with the NILM sensor is as accurate as traditional energy metering systems. The cost savings of a building installation can be demonstrated already at the household level. NILM provides the necessary measurement accuracy at a significantly lower cost of connection: Only one meter per building is needed, and its installation and removal is straightforward.
The guiding principle of the new generation of smart meters with NILM is that each electrical installation affects the current and voltage parameters in a characteristic way, leaving a kind of individual imprint in the power supply system of the consumer. This imprint is recorded in the aggregate total energy consumption by the smart meter at only one metering point with the help of special algorithms. Machine learning methods are used for pattern recognition, automatic extraction and classification of consumption patterns of each electrical installation from the total consumption.

Through a combination of pattern recognition and machine learning algorithms, NILM technology improves and simplifies the disaggregation of electricity consumption metering. Instead of multiple meters, the intelligent NILM system uses a single meter to identify the devices that consume the most electricity.

After disaggregation, the measurement data is made available in real time. The system consists of an advanced smart meter, gateway and consumption analysis software. The high-end NILM system has a sampling rate of up to 1 megasample per second (MS/s). The sampling rate is a measure of how much information is available in a given signal [21].

This not only saves the cost of expensive metering equipment and installation and maintenance efforts, it also saves energy costs.

Companies such as Schneider Electric, startup Verdigris Technologies and German automation firm Dabbel are already implementing energy forecasting and alerting solutions for commercial and industrial buildings using a high-end NILM system for adaptive building automation and learning its actions without user input [22].

Adaptive automation is intelligent automation based on periodic analysis and optimization of energy consumption. Algorithms learn building behavior by considering many inputs, such as historical building consumption, weather, number of people, and equipment consumption forecasts.

The system engine is an adapter that is the gateway between an intelligent metering system for collecting energy consumption information such as power consumption, peak demand, power quality and equipment usage time and the local building automation system, installed at the building inlet and primary mechanical devices.

Verdigris sensors monitor energy usage thousands of times per second. They can be used to accurately measure about 42 different channels.

The artificial intelligence adds local weather data, utility prices, building management system data, and other available data sets to create forecasts. Where data may not be available explicitly, Verdigris artificial intelligence detects it. A detailed monthly savings report shows detailed information about savings and changes made to the equipment schedule.

As one example of the installation of such an intelligent building automation system can be seen at the Grand Hyatt San Francisco Hotel. In fact, the new system consistently saved more than 20% of the cost of the controlled load, resulting in an average monthly return on investment of 41% and a payback on the initial investment in less than six months [23].

In Europe, an example of a company that uses a similar approach using a new generation of smart meters with NILM in real estate is the German company Discovergy GmbH, where for a large number of electrical consumers a single meter is sufficient, and the NILM algorithm allows to separate the consumption of each device in the total electrical consumption of the building [24].

4. Implementing smart energy metering to improve energy efficiency in buildings in Russia
The global trend of smart cities requires new control models to collect information generated by smart sensors deployed in various smart infrastructures. One such important structure is smart power management, which includes such innovations as distributed renewable generation and energy storage, microgrids and smart grid technologies, automated demand response, virtual power plants, and smart metering and energy management devices.

Such innovations provide an expanded network of smart energy devices throughout the city, with a detailed view of energy consumption patterns, enabling programs at the city, neighborhood, and individual building level.
To increase energy efficiency and ensure optimal use of energy resources in buildings, to reduce the impact of cities on the environment, as well as to increase the efficiency of operation of numerous buildings of different purposes in the city, it is necessary to conduct real-time monitoring of energy consumption through the introduction of smart building management systems. The introduction of such solutions can save up to 40 percent of energy consumption, and reduce the overall cost of operating the building by 10-30 percent [25].

The building sector in Russian cities is a large energy consumer with great potential for savings. Therefore, improving energy efficiency in both new buildings and those that have already been built for a long time is quite an important task for the country.

According to the plans of the Russian government in 50 cities (including 15 cities with a total population of 50 million people) in the next few years it is planned to implement mass introduction of cyberphysical systems in the management of urban resources, which will reduce their losses by 5%, ensure the quality of services and citizen involvement in urban management processes, create an environmentally friendly and safe environment in cities, as well as develop innovative infrastructure. As part of the digitalization of housing and communal services in the industry it is planned to introduce "smart" meters, robotize routine processes, use the power of artificial intelligence. However, as experts admit, achieving the goals set in the program may become too costly [26].

The introduction of non-intrusive load monitoring (NILM) technology in the Russian market can significantly reduce the cost of installing equipment to collect reliable information on the operation of various power-consuming equipment and quickly install a metering system. This, in turn, should lead to revolutionary changes in the accounting and management of energy consumption by buildings, improve the energy performance and energy efficiency class of the building, minimize operating costs and the environmental impact of buildings, while increasing their functionality and attractiveness.

The portfolio of solutions of the Russian largest developer of digital platforms for optimization and monitoring of energy consumption costs "Forsythe Energy Strategic Development Fund" [27] has been expanded with a new product - an innovative solution of Voltaware using NILM technology, designed for households, buildings, small and medium businesses, industrial enterprises and large corporate customers. This technology is already successfully used abroad. In Russia, this technology was tested in the energy-efficient case of the Chelsea pub in Moscow, which brought savings of about 30% [28].

The Voltaware sensor for monitoring electricity consumption has already been installed and is being tested at the Power Saving Center of Mosenergosbyt PJSC. The test results will allow refining the technology taking into account Russian specifics, making the device even more user-friendly and easy for all consumer segments [29].

Installation of a small credit-card sized sensor is quick and easy at a building inlet or group of electrical receptors in 5-10 minutes without a power outage or process interruption. The same day the data with high resolution in real time starts to arrive to the monitor and is displayed in a convenient form for the management. The functional diagram of the Voltaware system is shown in Fig. 2.
Figure 2. Functional diagram of the Voltaware system.

The system using NILM Voltaware allows you to quickly identify inefficient and excessive consumption of electricity, recognizing its cause; eliminate excessive consumption through real-time load management; monitor the status of equipment and prevent failure; make forecasts of energy consumption and own load; predict and monitor the performance of established targets; evaluate the results of work performed by energy service companies; send instrument readings to the power supply company and determine the best tariff plan.

Such system can fundamentally change approaches to energy saving in buildings, as well as approaches to carrying out energy saving measures and execution of energy service contracts. Low-cost systems of accounting and control of power consumption of various engineering equipment of buildings significantly reduce the cost of collecting reliable information about the energy efficiency of the building and can serve as an alternative to a rather expensive physical energy audit, which is necessary to assess the implementation and verification of energy saving measures. Energy audit in the mode of the production process with the constant accumulation of statistical material to analyze changes will allow to check the implemented energy-saving measures, including through energy service contracts, to create an effective system of energy management at the enterprise.

This is especially true for budgetary and municipal organizations, which are legally released a plan to reduce energy consumption for a three-year period in accordance with the RF Government Decree № 1289 [4] and which must systematically improve the energy efficiency of buildings through energy-saving measures, including, in the absence of budgetary funds, involving the services of energy service companies.

The presence of a smart metering and energy management system in a building can serve as an indicator to assess the technological readiness of the building to interact with the grid and subsequently obtain additional revenue from energy efficiency improvements through effective load management.

The use of smart energy metering systems will significantly accelerate the digitalization of the electric power industry and use new services that will give consumers the opportunity to manage the use of energy resources and optimize their energy consumption.

The market for digital technology offerings for metering and energy management in buildings is rapidly evolving. Electricity consumers are beginning to have unique products for detailed monitoring
of energy consumption in real time, which use high-speed sensors with a digital artificial intelligence platform, allowing them to really understand all efforts to improve efficiency, identify opportunities to reduce energy consumption and improve energy efficiency, develop "active" home technology, thereby creating an environment of smart buildings in the smart city.

5. Conclusions
1. The analysis of global trends in the development of intelligent energy accounting in buildings allows us to conclude that the active development and implementation of intelligent energy monitoring brings the quality of data collection and analysis of energy consumption to a fundamentally new level, increases the efficiency of operational management of energy resources and enables energy consumers to participate in the regulation of their own energy consumption.
2. The cost of electricity monitoring solutions is one of the most important factors when implementing an AMI "smart" house. is achieved already at the household level. NILM technology provides significant cost savings on AMI building equipment with the necessary measurement accuracy and low connection time: only one meter per building inlet is needed, its installation and removal is not difficult, connection is fast without stopping the technological process and electricity metering system.
3. Monitoring, analysis and planning of energy consumption of buildings with the help of smart meters and systems of technical accounting of energy resources in real time gives rise to a new approach to improving the energy efficiency of buildings of various purposes in the smart city, as well as the effective implementation of energy service contracts and energy management systems.

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