

Non-intrusive load monitoring: Implementation effects and distribution prospects

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ABSTRACT

The digital transition in the electric power industry is a promising goal for the development of the industry. In recent years, a wide range of technologies has been introduced into various types of activities of energy companies, including significant attention being paid to technologies that implement demand-side management, transferring consumers from the passive category to active consumers, and also opening up new opportunities in energy management. Non-intrusive load monitoring technology is of significant interest for both electricity suppliers and consumers in the USA and EEC countries, however, a Russian-language study is being carried out for the first time.

The purpose of the study is to consider the concept of non-intrusive load monitoring, to formulate and systematize the effects for electric power industry entities and consumers of electricity from the introduction of technology.

A review of literary sources is carried out, the most cited articles on this topic are analyzed. To calculate the propagation rate of non-intrusive load monitoring, the Bass innovation diffusion model was used. The model allows to perform an assessment based on data on similar products and has established itself as sufficiently effective for predicting the distribution of durable goods, the actual information for which has not yet been collected.

For the first time, a classification of effects arising from the introduction of technology is proposed. The paper obtained a range of effects for households, energy companies, business and government. The calculation of the technology distribution rate showed that without the use of technological corridors and the systematic introduction by energy companies, the peak of adoption can be reached by 8 years from the start of implementation.

Non-intrusive load monitoring allows you to get a wide range of data in order to further optimize energy consumption, increase the efficiency of enterprises, monitor the operation of equipment. There are great opportunities in the commercialization of collected data.

KEYWORDS:

non-intrusive load monitoring, energy complex, digitalization, Bass model, diffusion of innovations.

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1. INTRODUCTION

Russia is the world's fifth electricity market in terms of production and consumption, yielding the position to China, the United States, India, and Japan [Global Energy..., 2019]. In 2018, electric-power production in the Russian Federation amounted to 1070 billion kWh, as of January 1, 2019, the total station capacity of power plants of the Unified Power System in Russia reached 243,243.2 MW [SO UPS JSC, 2019].

Today, the electric power industry in Russia and around the world is undergoing significant changes due to the introduction of innovations of the fourth industrial revolution. Klaus Schwab, founder and President of the World Economic Forum, noted that the fourth industrial revolution is defined by interaction in the digital, physical, and biological fields [Schwab, 2016]. It should be noted that innovations can not only increase the efficiency and effectiveness of companies but also radically transform the market environment, leading to major changes in technical and economic paradigms and organizational models [Freeman et al., 1982; Technical Change..., 1987]. Thus, automation, the development of cyberphysical systems, the industrial Internet of things, and digital technologies radically transform the traditional technological and organizational structure in the electric power industry.

The need to transform Russia's energy sector is caused by a number of factors: on the one hand, these are internal tasks and challenges faced by the industry, on the other – global trends. Internal challenges are attributable to a high level of depreciation of fixed assets, an increase in the need for investment in the construction of new capacities due to increased energy consumption, as well as for compensation for retirees [Development Strategy..., 2013; Energy Strategy..., [b.g.]], a shortage of personnel with the necessary qualifications and a decrease in labor productivity in the energy industry [Linder, Lisovsky, 2017]. At the same time, cross-subsidizing of the population leads to an increase in the cost of electricity for commercial and industrial enterprises [Linder, Trachuk, 2017; Khovalova, 2017]. Among the world trends, we can highlight the cheapening of energy produced using renewable primary sources, the large-scale development of distributed generation and, as a result, the course towards energy decentralization, the introduction of technologies of the fourth industrial revolution, as well as

the transition of electricity end-users from passive to active (prosumers) as a result of the spread of intelligent control systems [Khokhlov et al., 2018; Digital transition..., 2017].

As one of the key technologies of digital transition in the electric power industry, researchers identify intelligent accounting based on electric energy meters equipped with communicators and equipment for collecting, processing, storing, sending and receiving data [Kempener et al., 2013].

Smart metering has several advantages in comparison with traditional systems of power consumption accounting:

- real-time monitoring of consumption volume;
- ability to aggregate data from different counters into a single database;
- storing statistical data on the electrical characteristics;
- obtaining information on power exchange and reliable determination of the level of technological and commercial losses in the power grid;
- identification of unaccounted energy consumption and the facts of impact on meters;
- formation of energy-saving strategies and assessment of their implementation;
- remote restriction of power consumption.

Among the information and measurement systems of electricity, special attention should be paid to meters designed with the use of non-intrusive load monitoring (NILM) technologies.

NILM is a method for analyzing aggregative electrical load data obtained by measuring current and voltage at a single point, then dividing the total load into individual device loads.

The concept of NILM was first proposed by George William Hart of the Massachusetts Institute of Technology in the early 1980s, and the operational procedures were patented in 1989 [Patent..., 1989]. The author described his technology as follows: "NILM is designed for monitoring an electrical circuit containing several independent devices. Specific analysis of current and voltage signals is used to evaluate the number and type of individual loads, their individual energy consumption, and other relevant statistics. Sensor installation and measurement do not require access to individual devices, which provides a very convenient and efficient way to collect load data compared to the method of placing sensors on each of the devices. The data obtained on final electricity consumption is extremely important for

consumers, power supply companies, government authorities and appliance manufacturers" [Hart, 1992].

However, at the time of its appearance, the technology did not receive due attention in view of the complexity of implementation: the computing power of computers for processing statistical data was not sufficient. Over time, many scientists became interested in the idea, and research was conducted on both technical aspects and features of application and implementation. Figure 1 shows the number of publications for the "Non-Intrusive Load Monitoring" query included in the ScienceDirect database, broken down by year.

The nature of the trend and the compound annual average growth rate of 9.4% indicate an increase in technology relevance.

The purpose of this work is to identify, systematize and determine possible economic, social, technical and other effects of implementing non-intrusive load monitoring. Such effects can occur because of changes in the behavior models of industrial and private consumers, the transformation of business models of energy companies, as well as the creation of completely new types of activities of energy consulting companies.

In order to assess the impact on the Russian energy market and identify potential effects from the implementation of NILM technologies, it is necessary to answer a number of questions:

- What technological features characterize non-intrusive load monitoring?
- What are the key features of non-intrusive load monitoring?
- In which areas of the electric power industry can we expect the most significant application effects?

2. TECHNOLOGICAL FEATURES OF NON-INTRUSIVE LOAD MONITORING

Before proceeding to a more detailed consideration of the technological aspects, it is necessary to form a unified view of the NILM in this work. A number of definitions have been compiled for this purpose, as shown in tabulation 1.

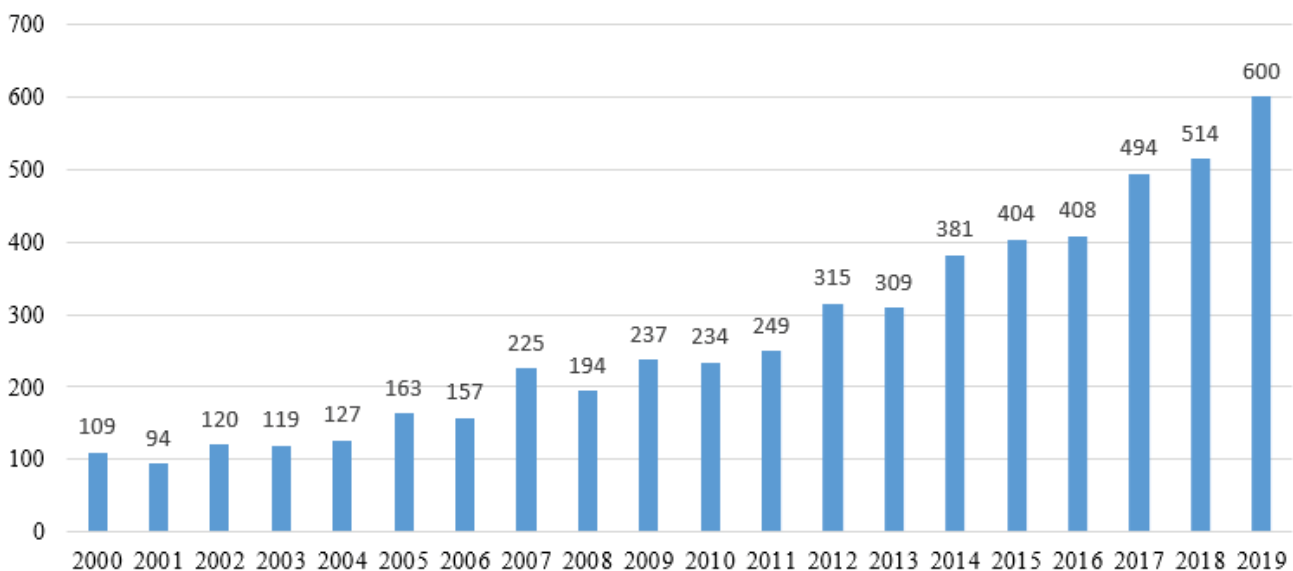
Two distinctive features of non-intrusive load monitoring technology follow from the definition analysis:

Non-intrusiveness. In contrast to the current intrusive load monitoring implemented using direct-on counters, Wi-Fi sockets, and GSM sockets, the NILM sensor measures current and voltage at one point in the building's electrical distribution network and does not require direct connection to the network [Cox, 2006]. At the same time, the NILM sensor provides the necessary measurement accuracy at a significantly lower cost of connection resources: only one meter per building is needed, and its installation and disassembly do not cause difficulties [Naghibi, Deilami, 2014].

Disaggregation of data. To get the load profiles of each device in a building, an intrusive metering device must be installed at the input of each device. The NILM sensor solves this problem by decomposing aggregated energy consumption data obtained at a single measurement point into different device consumption profiles. Significant cost savings on building equipment are already achieved at the household level [Naghibi, Deilami, 2014].

In large buildings, as well as in factories with a large amount of equipment, the installation and subsequent

Fig. 1. Number of publications for the "Non-Intrusive Load Monitoring" query included in the ScienceDirect database, pcs.



maintenance of traditional metering devices become critically expensive, since the number of meters will be directly proportional to the number of equipment at production. Thus, the high cost of solutions based on intrusive metering tools also encourages the development of non-intrusive load monitoring technologies [Cox et al., 2007].

A schematic diagram of load disaggregation is shown in Fig. 2.

First, the sensor collects data at a given frequency in order to form a total load profile. Following the data collection, the primary information is sent to the NILM data processing center (DPC), where it is pre-processed. Then, by changing the signal profile, an event that occurred due to turning the device on or off in the building is detected. Using cloud computing and big data analysis technologies, NILM analyzes an event and identifies a single device with

further highlighting its power consumption profile (Fig. 3) [Bergman et al., 2011]. The collected information (either from one or several sensors) is systematized by the data processing center and presented to the user in the form they need (for example, on an online platform or in a mobile app).

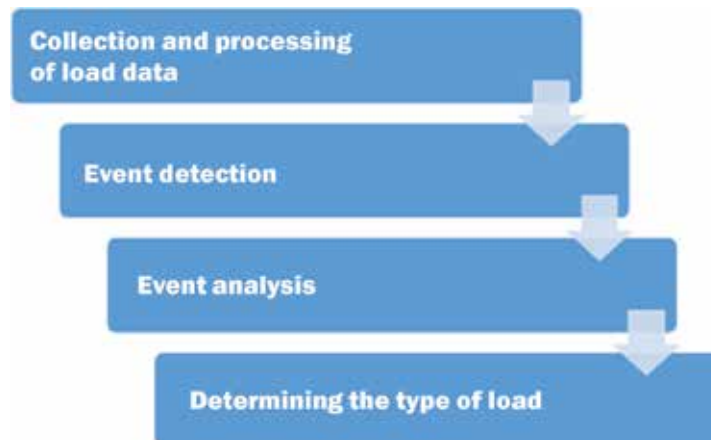
Thus, NILM is a promising method to identify individual devices, determine their power consumption and work schedules. Tabulation 2 shows the main types of devices that can be recognized using NILM:

The information collected by the NILM sensor has a wide range of applications in the field of electric power, including the provision of the detailed report to the consumer on the use of electricity and the contributions of various devices to total energy consumption, as well as generating electricity bills broken down by consumer devices; measuring and verifying the energy efficiency of buildings; improved forecasting of

Tabulation 1
Definition of the "non-intrusive load monitoring" term

Term definition	Source
Non-Intrusive Load Monitoring (NILM) is a system designed to monitor an electrical circuit that contains multiple devices that turn on and off independently from each other. Complex analysis of current and voltage signals of total NILM load is used to evaluate the number and type of individual loads, their individual energy consumption, and other relevant statistics.	[Hart, 1992]
Non-Intrusive load monitoring (NILM) is a method for analyzing aggregative electrical load data together with load profile data in order to break down the total load into a family of consumer devices that form the total power consumption	[Bergman et al., 2011a]
Non-Intrusive load monitoring (NILM) is a set of algorithms aimed at using smart meter statistics to extract information that is more useful. NILM includes the disaggregation of the electrical load in terms of individual energy consumption by devices	[Azaza, Wallin, 2017]
Non-Intrusive load monitoring (NILM) is the process of identifying enabled appliances in a household by single or multiple measurements taken at the input point of the total load, without connecting any sensors to each of the devices	[Welikalaa et al., 2019]
Non-Intrusive load monitoring (NILM) is a method aimed at decomposing of aggregated energy consumption data obtained at a single measurement point into different consumption profiles of devices operating in the electrical system under study	[Bonfigli, Squartini, 2020]
Non-intrusive load monitoring (NILM) is a system that uses aggregative data on power consumption only from one meter installed in the switchboard, and an disaggregating algorithm for data on power consumption by devices	[Biansoongnern, Plungklang, 2016]

Fig. 2. Schematic diagram of load disaggregation



demand profiles; developing programs for cost-dependent demand management; collecting data for building digital duplicates and models. Behavior patterns of the NILM sensor owner, including occupation, sleep mode, and other elements of daily life, can also be obtained from data, collected when using the sensor [McKenna et al., 2012].

3. KEY FUNCTIONS OF THE NILM SYSTEM

The accuracy of total load measurement with the NILM sensor is second to none in traditional power metering systems. In turn, the accuracy of load disaggregation continues to improve permanently, but to date it has not reached 100%. However, there is no significant difference for potential users whether the accuracy is 95% or 98%. More significant are innovative ways to use the data obtained, as well as previously non-existent business models based on them. Examples of practical implementation can include both the development of personalized demand management strategies based on energy consumption data, and the

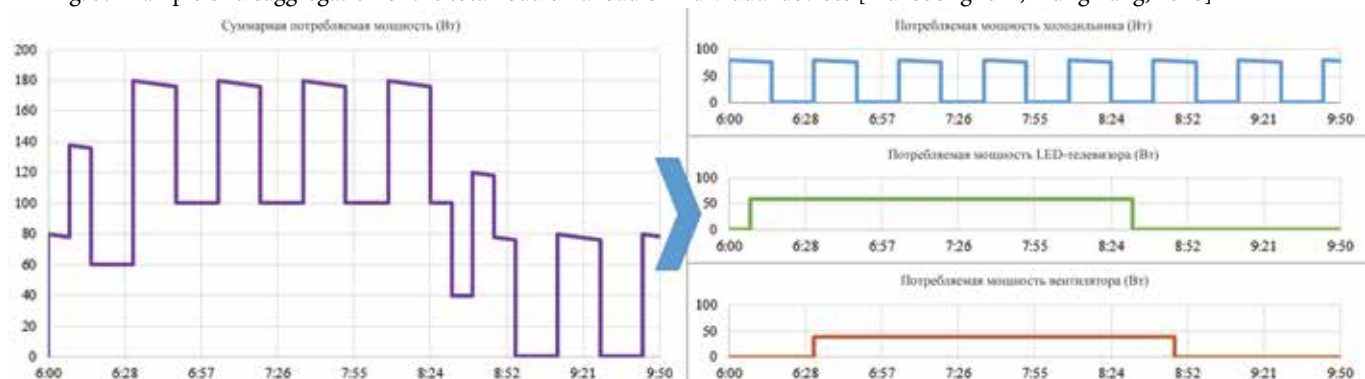
formation of energy consumption forecasts at the scale of large power systems [Zhuang et al., 2018]. Some promising applications of NILM will be discussed later.

Disaggregation of total energy consumption and visualization. Users can determine the energy consumption of each device using the NILM sensor. The analysis result can be presented in the user application or in the personal account of the online system in the form of interactive infographics. The amount of useful information can be significantly increased by installing several sensors (for example, to get the distribution of energy consumption by floors in a high-rise building or data on the loading of machines in various workshops of a large enterprise).

Detection of abnormal operating modes of devices and prevention of breakdowns. Sensors collect real-time statistics on the device's operating modes. Specialized machine learning algorithms are able to recognize changes in the operating mode and notify the user of a failure in a timely manner.

Splitting the invoice for electricity consumed. Load disaggregation allows to divide the electricity bill by the main sources of consumption. If the cost of electricity is different for different times of day, it is possible to compose

Fig. 3. Example of disaggregation of the total load on a load of individual devices [Biansoongnern, Plungklang, 2016]



Источник: [Biansoongnern, Plungklang, 2016].

Tabulation 2
The main types of detected devices [Zoha et al., 2012]

Source	Example
Devices that are in two modes: "on/off"	Toaster, incandescent lamp
Devices that are in multiple states but have a recurring on/off model	Stovetop, laundry washer, dishwasher
Devices with variable mode of operation	Variable power lamp, drill
Devices that are active for a long period of time	Landline phone, smoke detector, Wi-Fi router

Source: [Zoha et al., 2012].

a report on the operating cost of the device at a certain time interval. This function opens up a wide range of opportunities for optimizing energy costs and generating schedules for efficient energy consumption.

Integration with third-party products. Load disaggregation is one of the key features of NILM. Its advantages can also be implemented using third-party electricity meter producers. The hardware component can be integrated into counters, vending machines, and third-party sensors to send data to the NILM data processing center and then process the information.

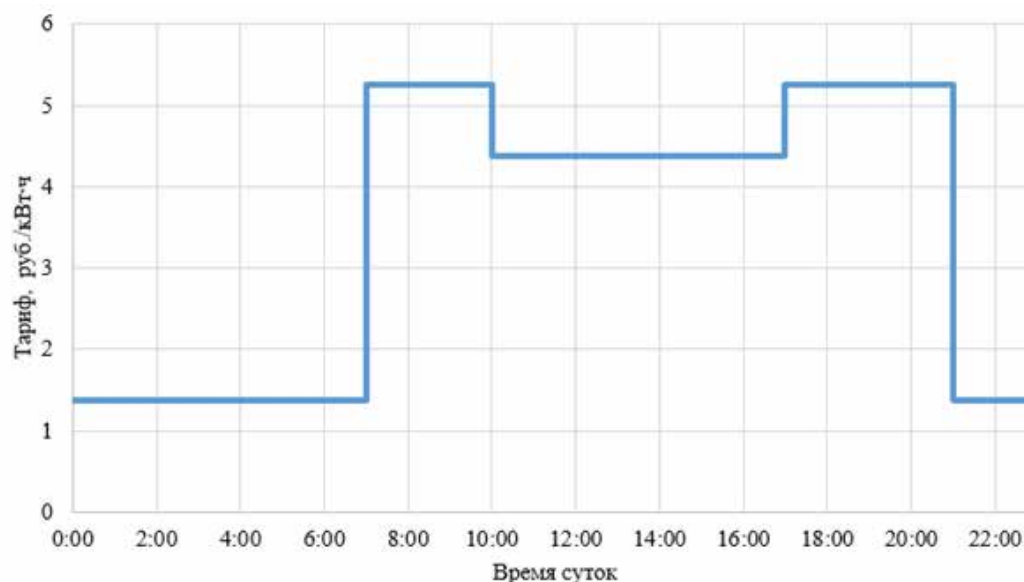
Sending alerts and notifications. Using the online service, the NILM system is able to notify the user about critical situations that have occurred or on completion of user's set conditions (for example, if the power consumption exceeds the set value or if the refrigerator door was left open).

4. EFFECTS OF NILM TECHNOLOGIES IN THE CONTEXT OF CONSUMERS

The introduction of technological innovations is considered effective if they lead to a positive economic effect [Transformation..., 2018]. Analysis of sources from the list of NILM Wiki has shown that the integrated implementation of NILM technology can provide a significant economic effect [NILM Wiki..., [no date]]. In addition, data from ATS JSC, analytical reports from the Centre for strategic studies, and materials from Mosenergosbyt JSC were used to assess the effects on the Russian electricity market.

Effect on households. Load disaggregation will allow to study in detail the power consumption of each device

Fig. 4. Tariff for electric energy, differentiated by zones of the day, for consumers in Moscow with electric stoves [Mosenergosbyt JSC, [no date]]



Source: [Mosenergosbyt JSC, [no date]]

Tabulation 3
Price categories of unregulated prices for electric energy (capacity)

Pricing tier	Principle of electricity metering
First	Consumed electricity is accounted generally for billing period
Second	Consumed electricity is accounted for by time-of-day calculation period
Third	During the billing period, hourly accounting is carried out, but the hourly planning is not performed, and the cost of services for the transmission of electric energy is determined by the tariff for services of the electric energy transmission in the one-part equation
Fourth	During the billing period, hourly accounting is carried out, but the hourly planning is not performed, and the cost of services for the transmission of electric energy is determined by the tariff for services of the electric energy transmission in the two-part equation
Fifth	During the billing period, hourly planning and accounting are carried out, and the cost of services for the transmission of electric energy is determined by the tariff for services of the electric energy transmission in the one-part equation
Sixth	During the billing period, hourly planning and accounting are carried out, and the cost of services for the transmission of electric energy is determined by the tariff for services of the electric energy transmission in the one-part equation

Source: [Mosenergosbyt JSC, [no date]]

available in the house. For those who want to save money, it becomes possible to identify the devices that make the greatest contribution to the final energy consumption: this information can help the user to make a decision about replacing inefficient electrical appliances.

If the user pays for electricity using a tariff differentiated by time zones, it is possible to optimize the energy consumption plan and reduce the monthly bill (Fig. 4).

The fault monitoring system is able to assess the condition of the devices in real time and issue alerts in case of a fault. Preventive repairs can be significantly cheaper than purchasing new equipment in the case of a breakdown.

Also, by means of disaggregation, it is possible to easily identify the facts of extraneous interference in the distribution board of the house and prevent non-contractual consumption.

Using an online service or a user app, the sensor owner can choose which notifications they want to receive. Approximate list of notifications:

- about atypical operation of appliances (refrigerator door is not closed, problems with the pump of the dishwasher, etc.);
- about exceeding the value of operation time set by the user (the owner forgot to turn off the stove, iron, etc.);
- about the fact of switching on of any device (house monitoring while the user is absent, as well as an ability to detect unlawful entry into the house).

The notification system also allows to organize parental control and monitoring of elderly relatives.

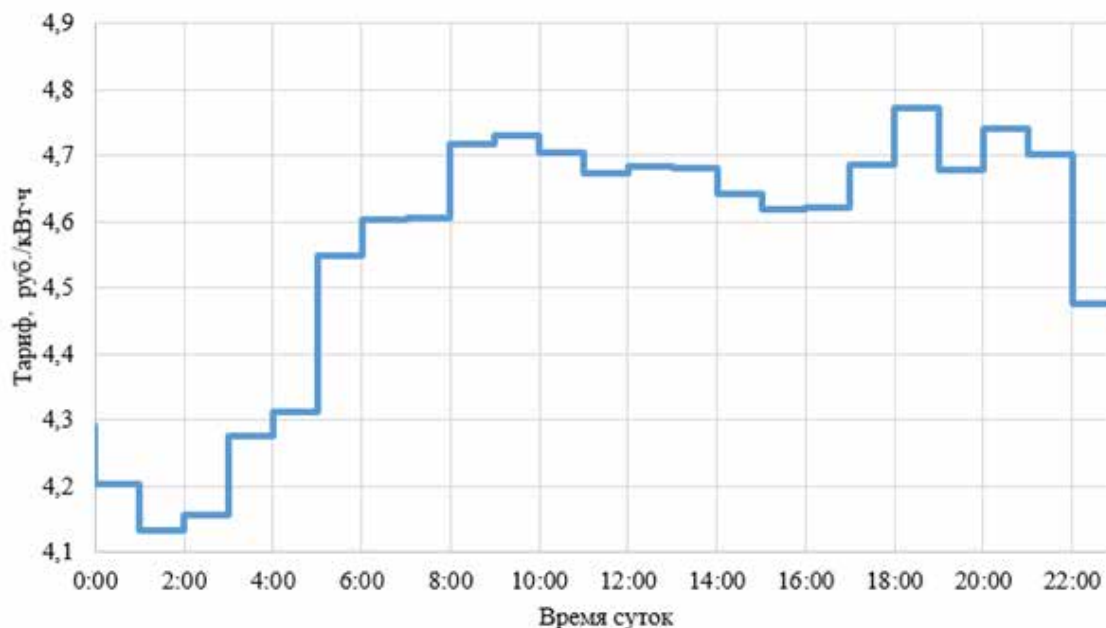
These effects can engage the user in monitoring and analyzing their load, as well as contribute to the rationalization of energy consumption by the population.

Industrial enterprises and large commercial buildings. For industry and large commercial buildings, the division of energy consumption has a significantly greater economic effect than for households. The above advantages of disaggregating and data analysis on consumption profiles become even more relevant due to the wider range of pricing (table 3, figure 5).

Statistical data collected by the NILM sensor allows us to determine the most effective energy consumption plan and reasonably choose the pricing tier that will be the most profitable for the consumer.

It should be noted that for most large buildings, significant load management potential is contained in the climate and lighting equipment, which is a significant part of the total load. Many shopping centers and offices make a practice of reducing the power of lighting during peak consumption hours. It is also possible to configure the cycles for turning climate equipment on and off so that the operating period does not coincide with peak consumption hours. Climate characteristics have a significant inertia, which allows them to be particularly flexible in optimizing the energy consumption mode.

Fig. 5. Tariff for low-voltage electric energy for the third pricing tier as of October 1, 2019



Source: [Mosenergosbyt JSC, [no date]]

The installation of several sensors, united with a single online system, will allow allocating of energy consumption by floors, rooms, or groups of equipment, depending on the power supply scheme of the building. For large property owners, this will make possible to charge reasonable electricity fees to tenants. Tenants, in turn, can also optimize the cost of electricity supply. For industrial enterprises, it becomes possible to analyze the workload of equipment and workshop premises in order to further improve the operational efficiency of the enterprise.

The ability of NILM to monitor equipment operation and perform preventative accounting is important for factories. Businesses can save significant amounts of money with low costs for preventive monitoring, avoiding failures. For example, there is a possibility to identify the damage of cable winding in electric motors [Das et al., 2014]. The works [Cox, 2007; Nation, 2017] demonstrate an example of using the NILM system for monitoring the operating modes of gas turbine engines and generators.

The function of preventive monitoring is particularly important for continuous production cycle enterprises, where the production stoppage due to unforeseen breakdowns can lead to the loss of fixed assets.

Management companies and housing and communal services. The data generated by the NILM online system will allow to analyze the cost of general household needs by type of load and make the house more energy efficient.

The implementation of NILM will also make it much easier to detect illegal connections to the networks of general household needs and counteract theft of electricity.

5. EFFECTS OF NILM TECHNOLOGY IN THE CONTEXT OF ELECTRIC POWER COMPANIES

The previous paragraphs described small NILM sensor systems - from one (in the case of a population) to a dozen (in the case of an enterprise or commercial building). Companies in the power industry are able to integrate NILM sensors into large systems that are united into statistical data exchange platforms. Big data of this kind can be widely used in a number of energy companies.

Electric grid company. The implementation of the NILM system in the activities of power grid companies opens up opportunities for predictive informing about equipment failures.

Automated data collection will simplify the reconciliation of energy balances, increase the effectiveness of counteracting unaccounted consumption, and reduce the volume of commercial and technological losses.

Power supply companies. The big data of the NILM system will allow us to predict with greater efficiency the load generated by consumers, which will increase the efficiency of power supply companies in the wholesale electricity and capacity market.

Data analysis from a large sample of consumers will allow to develop recommendations on optimization of the intra-day load schedule for each consumer, helping them to achieve maximum savings.

Authorities and regulators. For industry authority bodies and regulators the analysis of NILM large data will optimize the decision-making concerning the future development of the electricity sector through investment programmes in matters of pricing and tariff, as well as the formation of energy efficiency programs.

6. INFLUENCE OF NILM TECHNOLOGY ON THE FORMATION OF NEW ORGANIZATIONAL AND BUSINESS MODELS

In addition to improving the efficiency of electric power companies in their current paradigm, the NILM technology can serve as a powerful tool for implementing completely new concepts.

Building an smart grid. NILM technology can become one of the key technologies at implementing smart grids. Smart grid energy management is the basis for implementing demand management, integrating stochastic generators using renewable energy sources, and storage systems. However, modern concepts of smart grids emphasize the management of stochastic generation and storage, while underestimating the potential for flexibility on the consumer side. NILM technology is able to provide all the required volume of information to manage generating and consumption modes within the intelligent network. The work [Zaidi et al., 2010] shows that the NILM system can automatically detect the pattern of load behavior and use it to set the optimal operation mode of intelligent network elements. The NILM technology can be used to obtain information of required accuracy in order to control the operating modes of devices in a hybrid DC and AC network [Huang et al., 2016]. The work [Zhang

et al., 2011] examines the adaptation of NILM technology to identify the charging of an electric vehicle accumulator in the intelligent network.

Demand management. Demand management is an incentive system for end-users to voluntarily change the schedule of electricity consumption without additional regulation by the subject of operational dispatch management and for savings resulting from such a reduction in consumption. In addition to maneuverable generating, demand management is a significant source of flexibility in the power system, i.e. the ability to maintain a power balance in the conditions of rapidly changing consumption power and stochastic generation power.

However, currently there are not sufficiently accurate models to assess the potential for demand management. By analyzing user load profiles, the NILM system can identify devices with high potential as part of demand management.

In recent years, an increasing number of researchers have devoted themselves to the study of demand response based on NILM. High-precision comparative analysis of demand management participants allows us to build new price models based on determining prices for each group of consumers involved in demand management, thereby maximizing their benefits [Lin, Wang, 2011]. Incentive demand management programs allow the subject of operational dispatch management to involve new participants, and NILM, in turn, significantly simplifies the verification of load reduction, which is especially important for monitoring the performance of demand management responsibilities in the private sector [Bergman, 2011].

Significant demand management potential is concentrated in the hands of medium and small consumers in the retail market, as well as in the private sector. The low cost, ease of installation and intuitive understandability of user app of the NILM sensor will help to popularize demand management among consumers and involve them in it.

Tabulation 4
Estimation of p and q parameters for the NILM technology

Technology	Innovation coefficient p	Imitation coefficient q
Cloud platform for video surveillance	0.026	0.325
Service of collecting contact information of clients	0.014	0, 219
Personal and corporate data protection product for mobile devices used for work in the office and at home	0.029	0.374
"Smart home" systems	0.020	0.270
Weighted average for NILM technology	0.022	0.323

Source: [Churkin, 2013]

Energy consulting. The wide range of functions of the NILM sensor extends such activities as energy consulting. Due to non-intrusiveness, NILM sensors can be easily installed on the power supply system of the object under study, and after data is being collected they can be also easily dismantled. The collected data will allow to:

- disaggregate the load and identify the devices that make the main contribution to energy consumption;
- make a division of the monthly bill by devices that are sources of expenses;
- develop a strategy to optimize the daily consumption schedule;
- detect unauthorized use of equipment by company employees;
- detect the fact of illegal connection to the object's networks.

The list shows the main directions of data collected by the sensor. The NILM technology is quite flexible and can be adapted to non-standard situations and requirements of the energy audit customer.

Commercial use of data. As has already been stated, the NILM sensor owner's daily routine, including occupation, sleep mode, and other elements of daily life, can also be obtained from data, collected when using the sensor [McKenna et al., 2012].

This information can be applied in non-energy-related areas, such as commercial services (customer profiling, targeted marketing), legal services (curfew monitoring), and remote health care (monitoring of elderly people living at home) [Devlin et al., 2018].

Thus, a completely new type of business opens up for an electric power company using NILM technology – the use of data for commercial purposes.

7. FORECASTING THE RATE OF NILM DISTRIBUTION

The process of spreading innovation through market and non-market channels among different consumers over time is called "diffusion of innovation" [Oslo Manual..., 2006].

In this article, the diffusion model proposed by F. Bass [Bass, 1969] will be used to predict the rate of distribution of NILM technology among private users.

The Bass model, as well as its subsequent modifications, is based on taking into account both "innovators" who accept the innovation independently and influence potential buyers in the future, and "imitators" who accept the innovation under the influence of innovators who are already using the technology [Trachuk, Linder, 2017].

The Bass model allows us to describe a wide range of products - from highly specialized technological solutions to everyday household goods such as washing machines, dishwashers, and cell phones. This model is also able to characterize completely different industries [Bass et al., 1994].

This model is widely used in forecasting, especially in predicting the introduction of new products and technologies to the market, the actual distribution data of which has not

Tabulation 5
Forecast of the NILM technology distribution

Year	Percentage of consumers who accepted the innovation, %	Percentage of consumers who accepted the innovation during the year, %	Innovators share, %	Imitators share, %
0	2.23	24.3	24.3	0.0
1	5.10	31.4	23.7	7.7
2	8.78	40.1	23.0	17.1
3	13.40	50.3	22.1	28.2
4	19.07	61.9	21.0	40.9
5	25.85	74.0	19.6	54.4
6	33.70	85.5	18.0	67.5
7	42.39	94.8	16.1	78.7
8	51.56	100.0	14.0	86.0
9	60.70	99.7	11.8	88.0
10	69.28	93.6	9.5	84.0
11	76.84	82.4	7.5	75.0
12	83.10	68.3	5.6	62.7
13	88.01	53.6	4.1	49.5
14	91.69	40.1	2.9	37.2
15	94.33	28.9	2.0	26.8
16	96.19	20.2	1.4	18.8
17	97.46	13.8	0.9	12.9
18	98.31	9.3	0.6	8.7
19	98.89	6.2	0.4	5.8
20	99.27	4.1	0.3	3.9
21	99.52	2.7	0.2	2.6
22	99.68	1.8	0.1	1.7
23	99.79	1.2	0.1	1.1
24	99.86	0.8	0.1	0.7
25	99.91	0.5	0.0	0.5

yet been collected. To evaluate the model parameters, we use information about products that are already sold on the market and have a number of characteristics similar to the product under study.

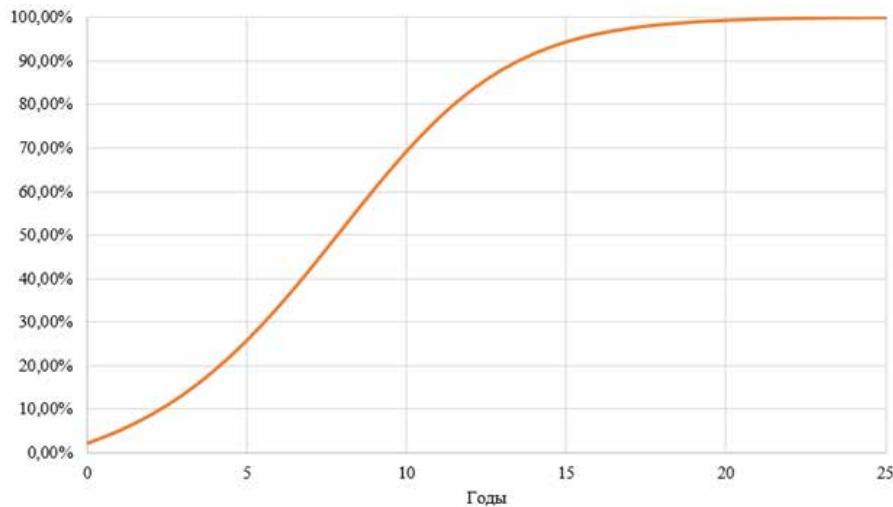
It should be noted that, despite the effectiveness of the model for predicting the diffusion of durable products (air conditioners, televisions, video surveillance systems, smart home equipment, etc.) [Bass, 2004; Bass et al., 1994], the Bass model does not exclude possible errors and uncertainties due to the use of evaluative dimensions in the construction.

The Bass model in discrete form shall be formulated as:

$$n(t) = p(M - N(t-1)) + q \frac{N(t-1)}{M} (M - N(t-1)) = n(t)_{\text{inn}} + n(t)_{\text{im}}, \quad (1)$$

where $n(t)$ – the number of consumers who accepted the innovation at the time t ; $N(t-1)$ – the total number of consumers who accepted the innovation during the previous period $(t-1)$; M – market potential; p – innovation coefficient;

Fig. 6. Total number of consumers who accepted the innovation



q – simulation coefficient; $n(t)_{\text{инн}}$ – the number of innovators who accepted the innovation at a time t ; $n(t)_{\text{им}}$ – the number of imitators who accepted the innovation at a time t .

The first term in formula (1) corresponds to the contribution of innovators to the number of purchases at a given time t and is proportional to the number of users who have not yet purchased the innovation, i.e. the multiplier $(M - N(t - 1))$. In turn, the contribution of imitators is proportional to both the number of consumers who have not yet made a purchase, and the share of users who have already purchased the innovation – $\frac{N(t-1)}{M}(M - N(t-1))$.

In discrete form, the total number of consumers who have accepted the innovation is expressed by the formula:

$$N(t) = N(t-1) + n(t), \quad (2)$$

where $N(t)$ is the total number of consumers who accepted the innovation.

For convenience of further calculations, expression (1) is converted to the form:

$$n(t) = (p + q \frac{N(t-1)}{M})(M - N(t-1)). \quad (3)$$

The Bass mathematical model can also be represented in continuous form:

$$n(t) = \frac{dN(t)}{dt} = (p + q \frac{N(t)}{M})(M - N(t)). \quad (4)$$

The solution of the differential equation (4) allows us to express a number of useful relations [Bass, 1969]:

$$N(t) = M \left[\frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p} e^{-(p+q)t}} \right], \quad (5)$$

$$n(t) = M \left[\frac{p(p+q)^2 \cdot e^{-(p+q)t}}{(p+q \cdot e^{-(p+q)t})^2} \right]. \quad (6)$$

In the case of $p < q$ the curve $N(t)$ has a S-shape with an inflection point T^* , defined by the ratio:

$$T^* = \left[\frac{1}{p+q} \right] \cdot \ln \left(\frac{q}{p} \right). \quad (7)$$

It is important to note that the point T^* in the case of $p < q$ is defined as the extreme point of the curve $n(t)$, that is, it is the point of the sales peak.

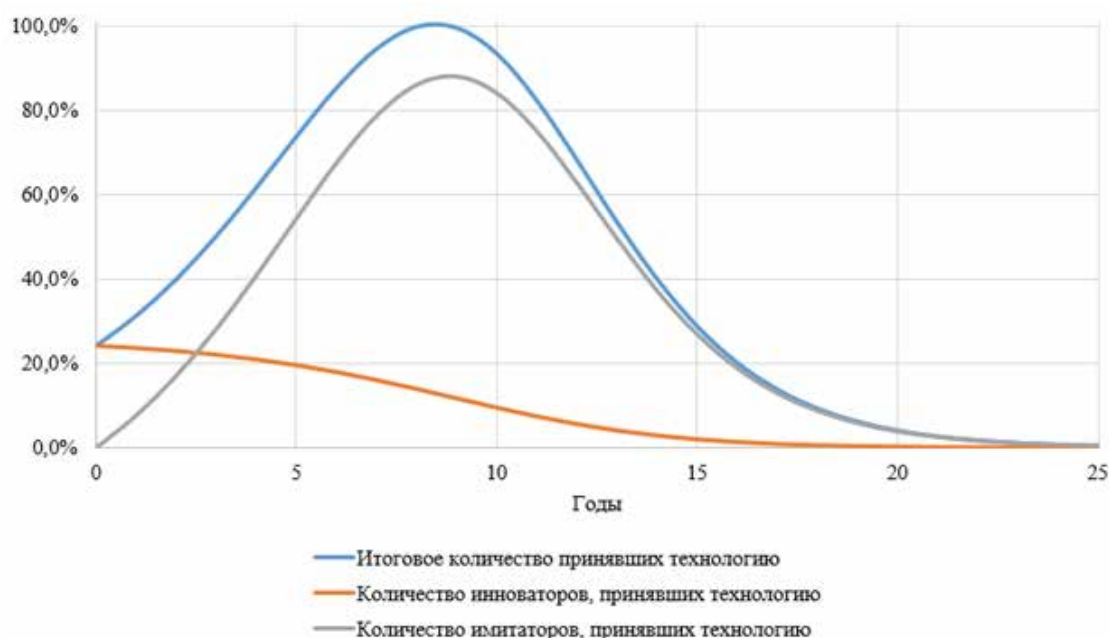
The definition of the parameters M , p and q . NILM technology has a wide range of applications: from households and office buildings to industrial production. In this regard, it was decided to normalize the market potential M to 100% in order to describe the process of technology distribution.

Since the model is often used to describe the distribution process of a product that has not yet been released to the market, there is no actual data on p and for q the NILM technology. In this regard, it was decided to use the parameters of other products with similar market characteristics, whose coefficients p and q are known.

The following digital solutions were selected to evaluate the coefficients p and q of NILM technology: a cloud platform for video surveillance, a service for collecting customer contact information, a product for protecting personal and corporate data for mobile devices used for work in the office and at home, and a smart home system. For the NILM technology, the weighted average value $p = 0,022$, $q = 0,323$ (table 4).

Calculation result. The spread of NILM technology was predicted using (1) and (2) formulas. In Fig. 6, 7 and from table 5 it can be seen that the speed of the NILM technology distribution increases in the first eight years, after which it begins to decrease. A significant amount of market potential will be exhausted by the fifteenth year after the start of sales.

Innovation coefficient p is lower than simulation coefficient q . In this case, the graph of the dependence of the consumers number who accepted the innovation at time t , from time will have a maximum point corresponding to the sales peak. According to the calculation, the peak of sales will come in the eighth year.

Fig. 7. Number of consumers who accepted the innovation at a given time t 

Calculations have shown that the speed of distribution of the NILM technology is low. Eight years before the peak of sales is a significant period in the era of the fourth industrial revolution, when the pace of technological evolution is quite high and continues to grow. Technology corridors can significantly accelerate the spread of NILM technology.

In Russia, the term "technological corridor" usually refers to a number of requirements and restrictions imposed by the state on the technical parameters of applied technologies, consumer products and services.

Technology corridors have significant potential to accelerate the spread of technologies, stimulate research and development, and displace outdated technologies [Stepuro, 2017].

Electric power companies can also help accelerate the spread of NILM technology by systematically introduction of NILM sensors. For example, new buildings may be equipped with them, or if NILM sensors are installed during the replacement of electricity meters in already built buildings.

8. CONCLUSION

The article considers the concept and various ways of using non-Intrusive load monitoring technology. Despite the consensus in the interpretation of the key elements and functions of NILM, due to the flexibility and ease of scaling, researchers identify a wide range of activities that affect energy consumption in one way or another, where the technology can be used.

Key ways of applying NILM in practice were formed and potential effects from implementation were identified. Non-intrusive load monitoring can bring benefits to end-

users, improve the efficiency of companies in the power industry, and serve as a powerful driver for the development of completely new patterns in the power industry.

The pace of distribution of NILM technology predicted using the Bass model indicates the need to use technological corridors and systematic implementation of the technology by energy companies to accelerate its adoption and approach the peak of sales.

As a further study of NILM, it is interesting to study more deeply each direction of implementing non-intrusive monitoring, as well as the formation and evaluation of effects for various participants in the electricity market. Another promising area of research is the integration of NILM sensors with "non-electrical" sensors (such as temperature, humidity, light, etc.) and actuators.

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