DOI https://doi.org/10.15407/usim.2020.02.055
UDC 621.311.2

V.V. OSYPENKO, DSc. (Eng.), Professor,
Kyiv National University of Technologies and Design,
2, Nemirovich-Danchenko str.,01011, Kyiv, Ukraine,
vvo7@ukr.net

V.V. KAPLUN, DSc. (Eng.), Professor,
National University of Life and Environmental Sciences of Ukraine,
15 Heroes of Defense Str., 03041, Kyiv, Ukraine,
wwwanten@gmail.com

M.O. VORONENKO, PhD (Eng.), Associate Professor,
Kherson National Technical University
24, Beryslavske Shose Str., 73008, Kherson, Ukraine,
mary_voronenko@i.ua

DYNAMIC VALUATION MODELLING OF COST AND ELECTRICITY CONSUMPTION OVER LOCAL OBJECTS WITH INTELLECTUAL GOVERNANCE

The work is devoted to the further development of the theory of intelligent electric power management systems construction for local objects with several heterogeneous (traditional and renewable) energy sources. The scientific idea is based on the use of modern information systems and technologies and is to improve the energy efficiency of the micro-energy networks of local objects based on the dynamic estimation of the real-time electricity cost and the transmission of this information to the user with the agreed discretion for matching the load schedule (or demand schedule). The method of dynamic planning of energy use in micro-energy systems and principles of building intelligent energy management systems of local objects are developed, on the basis of which the user will be able to control the load levels in real-time and optimize the energy costs, which in turn will lead to balancing of the microelectric network and increase the efficiency of its functioning. It is proved that the proposed solutions for the formation of control and technological functions can be used to improve the intelligent control systems in technologies smart microgrid, smart house, etc.

Keywords: *microenergy networks, local energy object, renewable energy sources, dynamic modeling of electricity cost, intelligent control system, dispatching-technological functions.*

Introduction

Traditionally cost-effective tools for managing electricity demand are differentiated tariffs, primarily in the daily and seasonal segments. In this case, the cost indicators of expected system effects are compared with the profitability of energy companies and the decline in demand during peak periods. However, there has been a recent increase in demand and, as a consequence, in electricity prices. This, in turn, contributes to the continuous growth of renewable sources share in the generation structure and creates the preconditions for the development of modern directions for improving the energy efficiency of individual objects network's operation through the optimal use of energy resources.

An example of such structural changes in the functioning of the distribution grids in Ukraine in recent years has been the widespread introduction of grid-based solar power plants, whose installed capacity does not exceed 30 kW, and is intended for partial power supply of local facilities and generation and electricity sale in the grid at a "green" tariff. During 2015–2017, the total number of registered home solar electrical stations (SES) has increased more than 14 times [1]. The National Renewable Energy Action Plan plans to increase solar power capacity by 2020 to 2 300 MW [4]. The emergence of such energy islands creates certain peculiarities regarding their optimal functioning. The peculiarity of the operation of local objects micro-energy networks (MENs) is caused by the connection to the low voltage network of distributed generation sources, energy storage, and consumer-controlled load. At the same time, an important feature of MEN is the ability to work in parallel with the main distribution network (power system), automatically switch to the isolated mode and resume synchronization with the network. The conditions for such switching can be technical reasons (mainly, emergencies, lower quality of electricity of the main grid, etc.) and reasons related to the cost indicators of local power supply (differentiated daily tariffs availability of the main network, use of renewable sources and energy storage and etc.). One of the important features of intensively introduced smart grid technologies is the operation of the grid through the close interaction between centralized and distributed (decentralized) generating capacities, forming integrated distribution networks that will become participants in the electricity and power market. [5, 9].

It is obvious that the monitoring and regulation of MEN in real-time will provide information exchange and allow management of energy balance between sources to be worked out within a certain time interval, and consumers, in this case, will have the opportunity to adjust their demand through scheduling real-time load based on cost criterion (current electricity price). Smart grids will effectively cover growing consumer demand by increasing electricity generation from distributed generation. In doing so, power management of such local facilities must be based on new principles that combine intelligent algorithms with integrated communications infrastructure to generate optimum real-time balance both on the demand side and on the generation side.

Problem setting

As practice shows, the use of a "green" tariff most encourages investors to install solar power plants. It is important not only to adopt mechanisms at the national level to stimulate the use of green energy by the domestic housing complex but also to develop appropriate instruments for their efficient use. Generation of solar power plants is limited by natural factors (the level of intensity of solar radiation depends on weather conditions, time of day, etc.). However, a scientifically sound and well-designed system for reconciling real-time electricity generation and consumption schedules can be quite promising. Especially for maneuvering power generation in peak and half-peak hour. The principles of managing the electricity consumption of local objects should determine the dynamic price of electricity, taking into account different time lags. This will optimize the operation of MEN in the efficient use of electricity and reduce the payback period of the SES.

Therefore, dynamic energy flow management is an innovative approach to managing on-demand energy consumption. It incorporates the traditional principles of energy management in combination with demand response, taking into account the technical capability of generating distributed SRs, integrated into a united structure, making it possible to make real-time decisions on-demand adjustment (especially in peak and half-peak time periods) based on the present value of electricity. This is achieved through the creation and implementation of integrated intelligent control systems, which will include high-tech communications and distributed generation controls and "smart" end devices to monitor power levels and make management decisions to dynamically control the entire electrical system.

The direction of such systems development is combined by the step-by-step expansion of the range of optimization tasks, suitable for real-time implementation (with small monitoring and forecast intervals), taking into account the regimes and defining the constraints, analyzing the generation and demand volumes, their dynamic refinement and forming recommendations for users, creating software for their practical implementation. Operations staff (user) maintains an information-based model of the control object by implementing dispatching technological functions in an environment-higher adaptive software, which reflects the state of the object, the current controlled parameter, and the possible choice of control effects (choice of modes or scenarios, setting up automatic control circuits, etc.). In the general case, the task of managing a local facility's power supply in normal modes is to reduce the peak load with a maximum redistribution of part of it to another time interval (primarily during a period of sufficient generation by renewable sources), or a corresponding change in demand (redistribution of the electricity schedule). At the same time, systematic justification of the demand management of such consumers-regulators should be performed, taking into account the additional capital and operating costs on the consumer side, necessary to change the existing electricity consumption schedule and to save the costs of electricity supply through the optimal use of generating capacities of the sources and network capacities at designated time periods.

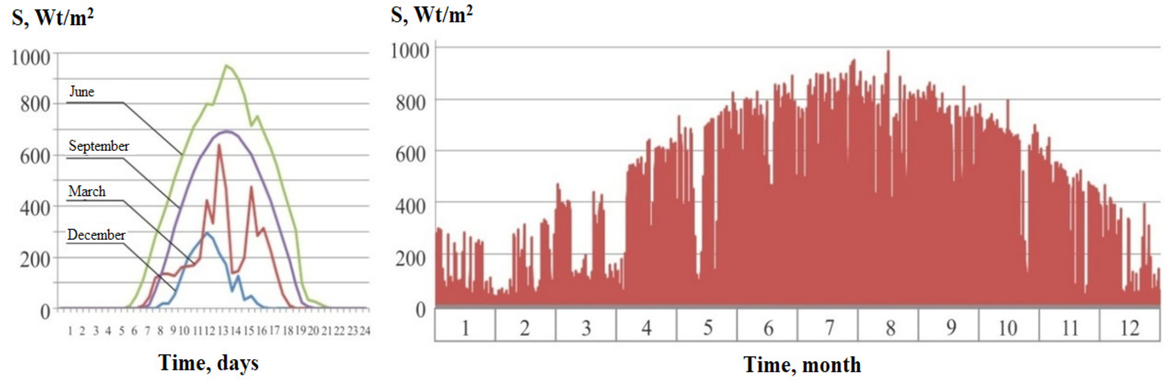
Purpose of the study

The aim is to develop a method of decentralized dynamic energy use planning and to justify the principles of building intelligent energy management systems for local facilities by optimally matching demand (power schedules) and dynamically changing real-time electricity costs to improve energy efficiency of micro-energy systems. The achievement of the goal is based on the use of modern information-analytical technologies, their software and technical implementation to create an automated system for forecasting, planning and scheduling the operation of MEN in online (day), medium-term (month-quarter) and long-term (year) modes.

Analysis of recent publications by research topic

Well-known studies concerning the optimization of the functioning of intellectual networks are presented in [6,8]. Thanks to the exchange of information in real-time, consumers can directly formulate (adjust) the schedule of their current receivers to change the price for electricity. Elastic supply of electricity prices through the introduction of intelligent algorithms for automated power management is defined as a function of demand. In [7, 10, 16], models of technical means and algorithms for their management for power consumption planning of selected current receivers are proposed, taking into account the amount of energy consumed and the time interval at which they are used in order to minimize the electricity supply total costs. The response to demand for electricity based on the price of electricity should be consistent with optimal energy use (supply) at specified intervals.

The publication [11] presents the results of real-time electricity pricing modelling that provide quantitative and qualitative characteristics of economic and environmental benefits by providing end-users with the ability to reduce electricity costs by responding to fluctuations in time of day. Studies [6,7] have shown that users' lack of knowledge about how to respond to price changes, as well as the lack of effective automation systems for such processes, have become major barriers to harnessing the potential benefits of real-time electricity billing. To solve this problem, it is proposed to introduce an automatic electricity consumption planning system to achieve the desired compromise between minimizing electricity billing and minimizing the receiver's standby time when prices are known in real-time. [17] proposed a model for the optimal planning of electricity consumption using an elastic distribution of power generation to minimize the price of electricity. A new approach to dynamic pricing in renewable energy islands was proposed. The concept of the conditional dynamic tariff as a criterion for the efficiency of local operations and the results of analytical studies of MEN management was introduced. In [5], these principles have been substantially expanded and further developed.



a *b*

***Fig.* 1**

As noted above, the planning of electricity production and its harmonization with the electricity consumption schedule is one of the main tasks of intelligent MEN control systems and the basic condition for their design. This paper is focused on the development of this idea, taking into account the results of the research presented in [17]. The principles of energy efficiency management using smart systems are exemplified by the MEN of a local facility using the SES. Although general approaches are also valid for any other structure of heterogeneous energy sources.

The main results of the study and their justification

The widespread introduction of modern energy management tools for local entities in their relationship with external energy sources has necessitated the development of fundamentally new optimal management tools. The most promising today are the intelligent systems with the ability to implement dispatch and technological functions, created using methods of mathematical modelling of situations. We are currently reviewing the control and technological management of a local renewable site facility for five-time lags, including daily (30-minute discretion) monitoring of weather depending on the season, climatic zone, geographical location, and more. (the average monthly indicator relative to the season during the day, Fig. 1, *a*, in the weekly, seasonal, annual (annual data sets, Fig. 1, *b* and long-term time intervals (Fig. 2). For the day-to-day management level, our system provides moments of change in the direction of energy flows between MEN sources and the overall network, and also predicts times when the cost of electricity for consumers of a local entity will change. Let's call these moments "in-out", which will mean "purchase and sale" of electricity for the user.

In order to develop and apply the algorithm of an intelligent control system within a day, it is necessary to have forecasts for at least the following real-time time parameters:

- the moment t_{pa} of transition of the solar power system from the active state to the passive one due to the decrease in the intensity or absence of solar radiation;
- the moment t_{pa} of transition of the solar power system from the passive state to the active one due to the increase of the intensity of the solar radiation;
- the length of time $[t_{ap}, t_{pa}]$ between the specified transition times from one state to another.

The procedures for modelling the processes of dynamic estimation of the cost and electricity consumption of local energy objects in order to optimize them are as follows.

1. Real-time prediction of the following time parameters, that is, the daily control level with 30-minute sampling:

- the moment t_{ap} of transition of the solar power system from the active state to the passive one due

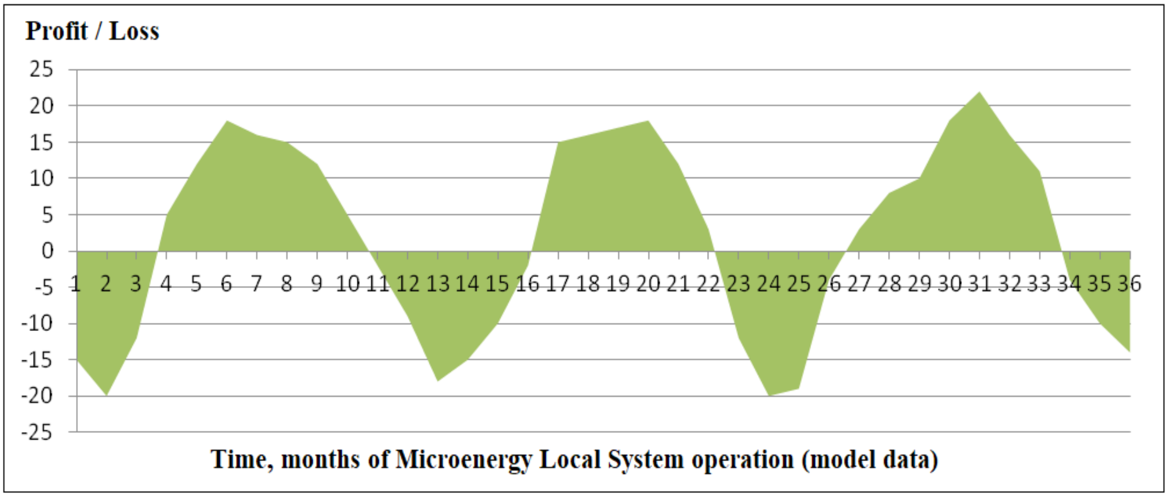


Fig. 2

to the decrease in the intensity or absence of solar radiation;

▪ the moment t_{pa} of transition of the solar power system from the passive state to the active one due to the increase of the intensity of the solar radiation;

▪ the length of time $[t_{ap}, t_{pa}]$ between the specified transition times from one state to another.

2. Building an intelligent technology for recognizing and constructing a decisive rule for the affiliation of the current situation to one of the previously trained clusters, the centers of which are the cost of electricity produced or consumed.

It is obvious that these moments do not occur instantaneously and such phenomena do not have a pronounced cyclicality. To do this, there are certain prerequisites that need to be linked systematically, and which change in "in the ensemble" may cause one or another switching moments t_{ap} or t_{ap}. Moreover, since for different MEN can be previously unknown relevant factors that actually influence the moments t_{ap} or t_{ap}, in order to solve the prediction problem, it is advisable to use inductive the group method of data handling (GMDH) algorithms [2,13–15]. A general approach to solving this problem was presented in [17].

To solve problem 1, we use a modified and improved inductive algorithm for predicting so-called "rare events" [14]. By a rare event x_i, we will mean exactly the moments t_{ap} or t_{pa}, that is, the beginning of periods of energy sales or purchases from the network.

The formulation of the problem of prediction of moments t_{ap} or t_{pa} formally can be described as follows.

Let that if the results of monitoring the parameters of a system on the interval $T_{obs} = [t_0, t_k]$ have an event that occurred n times x_i, $i = 1, 2, ..., n$. Let also that a sufficient amount of statistical material is recorded such that the interval T_{obs} can be divided into n intervals: $T_{obs} = [t_0, t_{s_1}, \ldots, t_{s_{i-1}}, t_{s_i}, \ldots, t_{s_{n-1}}, t_{s_n}]$, where t_{s_i} is the moment of occurrence of the i-th event. Such a breakdown is logical, given the assumptions that for the $[t_{s_{i-1}}, t_{s_i}]$ interval the event x_i occurred only once. Further, each interval $[t_{s_{i-1}}, t_{s_i}]$ is divided into l even narrower intervals $\Delta t' = [t'_{j-1}, t'_j] = \text{const}$, $j = 1, 2, ..., l$ and its nodes control the parameters of the factors acting on the object and measure the parameters of the current state of the object. Thus, in our case we have a set of n moments of occurrence of events x_i, $i = 1, 2, ..., n$. The purpose of this stage of modelling is to predict the $(n + 1)$-th time moment at which an event $x_{(n+1)}$ may occur, which is precisely the moment of switching moments t_{ap} or t_{ap}.

Algorithm for predicting switching moments t_{ap} or t_{ap}.

The following problem can be described using the regression equation as follows [14]:

$$\begin{aligned} y_f &= f\{x_{1(0)}, x_{1(-1)}, \ldots, x_{1(-\tau_1)}, \\ & x_{2(0)}, x_{2(-1)}, \ldots, x_{2(-\tau_2)}, \\ & \ldots \\ & x_{m(0)}, x_{m(-1)}, \ldots, x_{m(-\tau_m)}, \theta_f\} , \end{aligned} \quad (1)$$

where y_f is the original (predictive) value, x_i, $i = 1, 2, \ldots, m$ are the arguments, τ_m is the "delay" of each argument taken into account, θ_f is the vector of the estimated parameters.

A more compact representation of model (1) could be:

$$f(\cdot) = y_f = (X, \theta_f). \quad (2)$$

The important differences between this approach and traditional forecasting procedures are:

- there are no delayed output arguments y_f among the function arguments $f(\cdot)$;
- the initial value is the time between the last observation (control measurement) and the onset of the "rare event".

The times t_{ap} or t_{ap} are either closely related and dependent on the current weather situation and time to day. From here, it is necessary to constantly monitor the environmental parameters that were included in model (1) for this particular site. This will allow us to build an in-out transition rule for any local energy island participant. Recall briefly the procedure for forming a decisive rule in recognizing a new situation in order to determine the monetary equivalent of the decision.

Let the current situation $\omega_l^* \in \Omega$, where $\omega_{ij} \in \Omega$, $i = 1, \ldots, n, j = 1, \ldots, m$ corresponds to the optimum according to (1) the moment of switching t_{ap} or t_{ap} . Let's also assume that the completed educational stage and the database already have the results of inductive clustering [3] and received K clusters with m centers that are monetary equivalents of switching results and represented in place $\mathbb{R}^n$.

The current situation for this local object belongs to the k-th cluster if:

$$d(\omega_l^*, m_k) < d(\omega_l^*, m_s), \;\; k,s = 1,\ldots,K, \;\; k \neq s. \quad (3)$$

Considering that the calculation (3) should be performed only on the axis x_0 of the target features [14], the resultant centers of clusters from place $\mathbb{R}^n$ are projected into place $\mathbb{R}^1$ and expression (3) becomes:

$$d(x_{0l}^*, \dot{m}_k) < d(x_{0l}^*, \dot{m}_s), \; k,s = 1,\ldots,K, \;\; k \neq s \quad (4)$$

where m_k, $k = 1, \ldots, K$ are the centers of the clusters on the axis x_0 , that is, the monetary equivalent of the switch result.

The minimum recognition error criterion $\Delta^2(\Omega_\Delta)$ can be written as [4]:

$$\Delta^2(\Omega_\Delta) = \sum_{\Omega_\Delta} \delta_l^2 \to \min, \quad (5)$$

$$\delta_l = \begin{cases} 1, \; d(x_{0l}^*, \dot{m}_{k(l)}) > d(x_{0l}^*, \dot{m}_{s(l)}) \\ 0, \; d(x_{0l}^*, \dot{m}_{k(l)}) < d(x_{0l}^*, \dot{m}_{s(l)}) \end{cases}, \quad (6)$$

where:

$k \neq s$, $k, s = 1, \ldots, K$, $\omega_l^* \in R_k$,

or:

$$\delta_l = [x_{0l}^* - \dot{m}_{k(l)}], \;\; \omega_l^* \in \Omega_\Delta , \quad (7)$$

where x_{0l}^* is a value of the target, that is, the cost of electricity saved for its own consumption or sold by a specific producer / consumer.

Thus, based on the obtained solution, it is possible to determine the value of the initial value x_0^* for the current situation ω_l^*, which, of course, did not participate in the training:

$$\min_K d[(m_k, \omega^*) / S^*(X^*)] \to x_0^* . \quad (8)$$

As shown by the results of modelling, coordination of energy planning and use of the filter of current prices for electricity (including on the basis of the forecast), it leads to a significant reduction of costs for electricity supply to consumers, allows to optimize scenarios of "generation-demand" processes taking into account peak and half-peak periods. Consolidated statistical arrays of observations of solar radiation intensity were used as the baseline data for the functioning of the heterogeneous sources used in the adopted model (according to "Avante " LLC, Kyiv). For each month, electricity generation volumes were

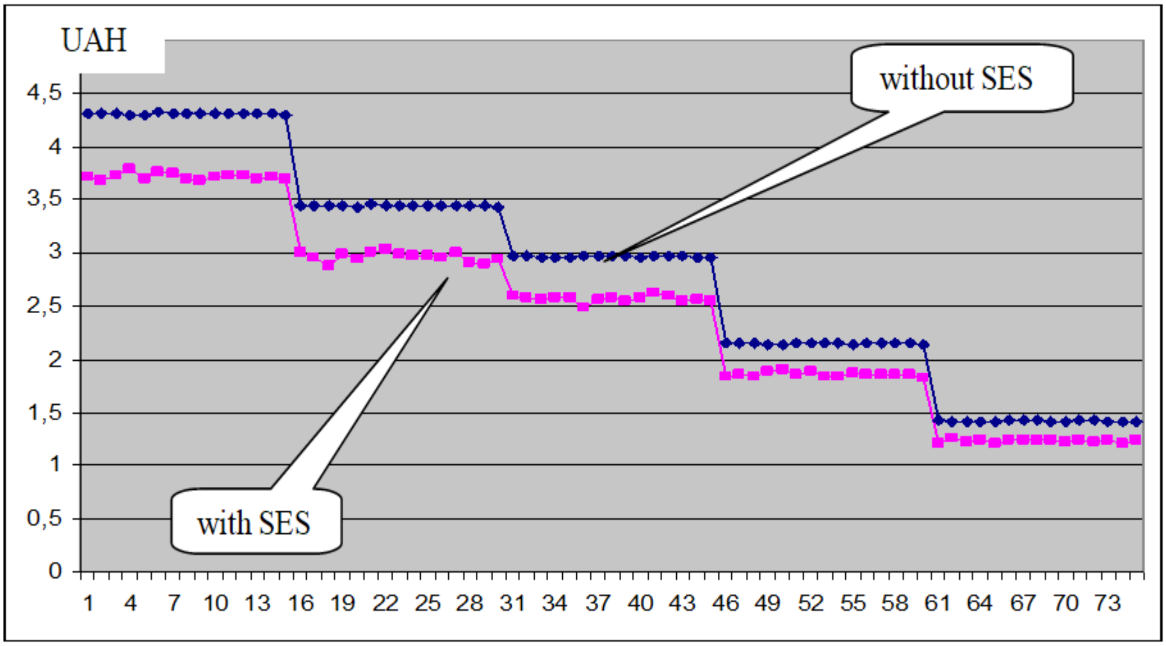


***Fig.* 3**

calculated based on the intensity of solar radiation over the selected time interval. As a result of modelling, the dependencies of the present value of electricity for 75 studied variants of the source composition system with and without SES for the Kyiv region are shown (Fig. 3).

As can be seen, the increase in the efficiency of the MEN operation for the calendar year (reduction of the unit cost of electricity under comparable conditions) reaches an average of 13,9%. The range of change of the present value of electricity of a local object in the billing period is from 1,25 to 3,7 UAH.

Conclusion

The optimal design of heterogeneous power supply systems is complicated by the indefinite generation of stochastic renewable energy generation and the time-varying demand for electricity. Obviously, the structural configuration and efficient management of multiple-source MENs must be based on real-time demand-side matching and dynamic energy planning. In order to make effective use of renewable and traditional sources, this paper proposes an approach to solve the problem of managing electricity consumption on the basis of reconciliation of its own electricity production and demand at the level of the micro-energy system, which creates the preconditions for the implementation of practical principles of local objects energy management.

As a result of the study, regularities of the current cost influence of MEN electricity on the formation of the local object load schedule by coordinating the generation of heterogeneous sources and planning of energy consumption by using the filter of the electricity cost dynamic estimation. This leads to a significant reduction of the costs for electricity supply and allows to optimize “generation-demand” scenarios, taking into account, first and foremost, peak and half-peak periods. Information on the determined dynamic cost of electricity for the selected time interval and the implementation of the relevant dispatching and technological functions will allow making the automated intelligent system operational decisions taking into account the belonging to a certain price cluster of the model and will provide the user with current control over the formation of its own load schedule. This, in turn, will increase the user's motivation for such optimization, since MEN's energy balancing will lead to a significant reduction in the cost of supplying the local facility. It is proved that the widespread introduction of MEN with heterogeneous (traditional and renewable) sources requires a comprehensive optimization approach based on the real-time cost of electricity. The validity and certainty of the results, conclusions, and recommendations for a particular local entity must be based on the correct use of the data obtained through statistical modelling. Implementation of the research results will provide a comprehensive solution to the problems of the optimal power supply of local objects, reducing energy and resource costs.

REFERENCES

1. *State Statistics Service of Ukraine*. [online] Available at: <http://www.ukrstat.gov.ua/>. [Accessed 06 Dec. 2010]. (in Ukrainian).
2. *Kaplun, V.V.*, 2016. "Derzhavna sluzhba statystyky Ukrayiny"., Visnyk KNUTD, 3 (98), pp. 52–58. (in Ukrainian).
3. *Osypenko, V.V.*, 2014. "Two approaches to solving the problem of broad-based clustering from inductive modeling positions"., Byuleten NUBiP Ukrayiny Ser. Enerhetyka ta avtomatyka, elektronne fakhove vydannya, 1, pp. 83–97, http://nbuv.gov.ua/j-pdf/eia_2014_1_11.pdf. (in Ukrainian).
4. *Solar energy is one of the promising directions* for the development of renewable energy in Ukraine. Government portal. [online] Available at: <http://www.kmu.gov.ua/control/publish/article?art_id=248970577>. (in Ukrainian).
5. *Strukturno-parametrychnyy syntez kombinovanykh* system elektrozhyvlennya, kolektyvnamonohrafiya, prof. Kaplun V.V. (ed.), 2017. KNUTD, Kyiv, 189 p. (in Ukrainian).
6. *Kim, B.-G., Zhang, Y., van der Schaar, Lee, J.-W.,* 2014. "Dynamic pricing for smart grid with reinforcement learning", IEEE CCSES (IEEE NFOCOM Workshop).
7. B*orenstein, S., Jaske, M., Rosenfeld, A.,* "Dynamic pricing, advanced metering, and demand response in electricity markets", Center for the Study of Energy Markets. [online] Available at: <https://escholarship.org/uc/item/11w8d6m4>. [Accessed 21 Sept. 2016].
8. D*ang, T., Ringland, K*., 2012. "Optimal load scheduling for residential renewable energy integration", IEEE 3rd International Conference on Smart Grid Communications, Smart Grid Comm., pp. 516–521. DOI: 10.1109/SmartGridComm.2012.6486037.
9. *Dupont, B., Jeroen, T., Ronnie, B.*, 2012. "Automated residential demand response based on dynamic pricing", 2012 3rd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies (ISGT Europe), Berlin, pp. 1–7.
10. *Faruqui, A., Sergici, S., Akaba, L.,* 2014. "The impact of dynamic pricing on residential and small commercial and industrial usage: New experimental evidence from Connecticut", The Energy Journal, 35 (1), 137–160.
11. *Holtschneider, T., Erlich,* I., 2013. "Optimization of electricity pricing considering neural network based model of consumers' demand response", 2013 IEEE Symposium on Computational Intelligence Applications in Smart Grid (CIASG), Singapore, pp. 154–160.
12. *Ivakhnenko, A.G., Madala, R.,* 1994. Inductive learning algorithms for complex systems modelling, CRC Press, Boca Raton, 350 p.
13. *Ivakhnenko, A.G.*, 1987. "Objective Computer Clusterisation Based on Self-Organisation Theory", Soviet Automatic Control, 20 (6), pp. 1–7.
14. *Ivakhnenko, A.G., Osypenko, V.V.*, 1984. "Prediction of Rare Events on the Basis of the GMDH Algorithm", Scripta Technica Inc., U.S.A, Soviet Automatic Control, 5 (17), pp. 6–10.
15. *Lee, J.-W., Lee, D.-H.*, 2011. "Residential electricity load scheduling for multi-class appliances with time-of-use pricing", IEEE GLOBECOM Workshops.
16. *Mohsenian-Rad, H., Leon-Garcia, A.*, 2010. "Optimal residential load control with price prediction in real-time electricity pricing environments", IEEE Transactions on Smart Grid., 1 (2), pp. 120–133.
17. *Osypenko, V., Kaplun, V.*, 2017. "About the intelligent decision making system for dynamic electricity pricing on renewable microgrids", Proc. of the XII IEEE Int. Conf. CSIT-2017 & Int. Workshop on Inductive Modelling, September 05–08, 2017, Lviv, Ukraine, Vezha&Co, Lviv, pp. 348–350.

18. *Thimmapuram, P.R., Kim J.*, 2013. “Consumers’ price elasticity of demand modelling with economic effects on electricity markets using an agent-based model”, IEEE Transactions on Smart Grid, 4 (1), pp. 390–397.

Reseived 14.03.2020

ЛІТЕРАТУРА

1. *Державна служба статистики України*. URL: http://www.ukrstat.gov.ua/. (дата звернення: 06.12.2010).
2. *Каплун В.В.* Умовний динамічний тариф як критерій ефективності функціонування мікроенергетичних систем локальних об’єктів. Вісник КНУТД, №3 (98), 2016, с.52-58.
3. *Осипенко В.В.* Два підходи до розв’язання задачі кластеризації у широкому сенсі з позицій індуктивного моделювання, Бюлетень НУБіП України. Сер. Енергетика та автоматика [Електронне фахове видання], №1, 2014 р., с. 83–97, URL: http://nbuv.gov.ua/j-pdf/eia_2014_1_11.pdf.
4. *Сонячна енергетика* - один з перспективних напрямів розвитку відновлюваної енергетики в Україні. Урядовий портал. URL: http://www.kmu.gov.ua/control/publish/article?art_id=248970577.
5. *Структурно-параметричний синтез комбінованих систем електроживлення*: колективна монографія / кер. кол. авт. і наук. ред. проф. В.В. Каплун. К.: КНУТД, 2017. 189 с.
6. *Kim B.-G., Zhang Y., van der Schaar, Lee J.-W.* “Dynamic pricing for smart grid with reinforcement learning,” in IEEE CCSES (IEEE NFOCOM Workshop), 2014.
7. *Borenstein S, Jaske M, Rosenfeld A.* Dynamic pricing, advanced metering, and demand response in electricity markets. Center for the Study of Energy Markets. 2002. URL: https://escholarship.org/uc/item/11w8d6m4 (дата звернення: 21.09.2016).
8. *Dang T., Ringland K.* Optimal load scheduling for residential renewable energy integration. IEEE 3rd International Conference on Smart Grid Communications. Smart Grid Comm. 2012. P. 516–521. DOI: 10.1109/SmartGridComm.2012.6486037.
9. *Dupont B., Jeroen T., Ronnie B.* Automated residential demand response based on dynamic pricing. 2012 3rd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies (ISGT Europe). Berlin, 2012. pp. 1–7.
10. *Faruqui A, Sergici S, Akaba L.* The impact of dynamic pricing on residential and small commercial and industrial usage: New experimental evidence from Connecticut. The Energy Journal. 2014. № 35 (1). pp. 137–160.
11. *Holtschneider T., Erlich I.* Optimization of electricity pricing considering neural network based model of consumers’ demand response. 2013 IEEE Symposium on Computational Intelligence Applications in Smart Grid (CIASG). Singapore, 2013. pp. 154–160.
12. *Ivakhnenko A.G., Madala R.* Inductive learning algorithms for complex systems modelling. CRC Press, Boca Raton, 1994. 350 p.
13. *Ivakhnenko A. G.* Objective Computer Clusterisation Based on Self-Organisation Theory. Soviet Automatic Control. 1987. № 20 (6). pp. 1-7.
14. *Ivakhnenko A. G., Osypenko V. V.* Prediction of Rare Events on the Basis of the GMDH Algorithm / Scripta Technica Inc., U.S.A. Soviet Automatic Control. 1984. № 5 (17). pp. 6–10.
15. *Lee J.-W., Lee D.-H.* Residential electricity load scheduling for multi-class appliances with time-of-use pricing. IEEE GLOBECOM Workshops. 2011.
16. *Mohsenian-Rad A.-H., Leon-Garcia A.* Optimal residential load control with price prediction in real-time electricity pricing environments. IEEE Transactions on Smart Grid. 2010. № 1 (2). pp. 120–133.
17. *Osypenko V., Kaplun V.* About the intelligent decision making system for dynamic electricity pricing on renewable microgrids. Proc. of the XII IEEE Int. Conf. CSIT-2017 & Int. Workshop on Inductive Modelling, September 05–08, 2017, Lviv, Ukraine. Lviv : Vezha&Co, 2017. pp. 348–350.
18. *Thimmapuram P. R., Kim J.* Consumers’ price elasticity of demand modelling with economic effects on electricity markets using an agent-based model. IEEE Transactions on Smart Grid. 2013. № 4 (1). pp. 390–397.

Надійшло 14.03.2020

В.В. Осипенко, доктор технічних наук, професор,
директор Центру інформаційних технологій проектування,
Київський національний університет технологій та дизайну,
вул. Немировича-Данченка, 2, 01011, Київ, Україна,
vvo7@ukr.net

В.В. Каплун, доктор технічних наук, професор,
Національний університет біоресурсів та природокористування України,
вул. Героїв оборони, 15, 03041, Київ, Україна,
wwwanten@gmail.com

М.О. Вороненко, доктор філософії, доцент,
Херсонський національний технічний університет,
вул. Бериславське шосе, 24, 73008, Херсон, Україна,
mary_voronenko@i.ua

МОДЕЛЮВАННЯ ДИНАМІЧНОГО ОЦІНЮВАННЯ ВАРТОСТІ І СПОЖИВАННЯ ЕЛЕКТРОЕНЕРГІЇ ЛОКАЛЬНИХ ОБ'ЄКТІВ З ІНТЕЛЕКТУАЛЬНИМ УПРАВЛІННЯМ

Вступ. Робота присвячена подальшому розвитку теорії побудови інтелектуальних систем управління локальними об'єктами з кількома різнорідними (традиційними і поновлюваними) джерелами енергії. Наукова ідея базується на використанні сучасних інформаційних систем і полягає в підвищенні енергоефективності мікроенергетичних мереж локальних об'єктів на основі динамічного оцінювання вартості електроенергії в реальному часі та передачі цієї інформації користувачеві з обумовленою дискретністю для узгодження графіка навантаження (графіка попиту).

Мета статті. Метою дослідження є розробка методу децентралізованого динамічного планування використання енергоресурсів та обґрунтування принципів побудови інтелектуальних систем управління енергоспоживанням локальних об'єктів шляхом оптимального узгодження між попитом (графіками електроспоживання) та динамічно змінюваною вартістю електроенергії у реальному часі для підвищення енергоефективності мікроенергетичних систем.

Методи. Системний підхід, системний аналіз, індуктивні технології моделювання, енергетичний менеджмент.

Результати. Розроблено метод децентралізованого динамічного планування використання енергоресурсів в мікроенергетичних системах і основні принципи побудови інтелектуальних систем управління енергоспоживанням локальних об'єктів, на основі яких користувач зможе контролювати рівень навантаження в реальному часі і оптимізувати витрати на електроенергію, що в свою чергу призведе до балансування мережі і підвищить енергоефективність її функціонування.

Висновки. Результати цього дослідження показують, що запропоновані принципи формування диспетчерсько-технологічних функцій можуть бути використані для удосконалення інтелектуальних систем управління в технологіях *smart microgrid* та ін.

Ключові слова: *мікроенергетичні мережі, локальний енергетичний об'єкт, поновлювальні джерела енергії, динамічне моделювання вартості електроенергії, інтелектуальна система управління, диспетчерсько-технологічні функції.*

В.В. Осипенко, доктор технических наук, профессор,
директор Центра информационных технологий проектирования,
Киевский национальный университет технологий и дизайна,
ул. Немировича-Данченко, 2, 01011, Киев, Украина,
vvo7@ukr.net

В.В. Каплун, доктор технических наук, профессор,
Национальный университет биоресурсов и природопользования Украины,
ул. Героев обороны, 15, 03041, Киев, Украина,
wwwanten@gmail.com

М.А. Вороненко, доктор философии, доцент,
Херсонский национальный технический университет,
ул. Бериславское шоссе, 24, 73008, Херсон, Украина,
mary_voronenko@i.ua

МОДЕЛИРОВАНИЕ ДИНАМИЧЕСКОГО ОЦЕНИВАНИЯ СТОИМОСТИ И ПОТРЕБЛЕНИЯ ЭЛЕКТРОЭНЕРГИИ ЛОКАЛЬНЫХ ОБЬЕКТОВ С ИНТЕЛЛЕКТУАЛЬНЫМ УПРАВЛЕНИЕМ

Введение. Работа посвящена дальнейшему развитию теории построения интеллектуальных систем управления локальными объектами с несколькими разнородными (традиционными и возобновляемыми) источниками энергии. Научная идея базируется на использовании современных информационных систем и заключается в повышении энергоэффективности микроэнергетических сетей локальных объектов на основе динамического оценивания стоимости электроэнергии в реальном времени и передачи этой информации пользователю с обусловленной дискретностью для согласования графика нагрузки (графика спроса).

Цель статьи. Целью исследования является разработка метода децентрализованного динамического планирования использования энергоресурсов и обоснование принципов построения интеллектуальных систем управления энергопотреблением локальных объектов путем оптимального согласования между спросом (графиками электропотребления) и динамично меняющейся стоимостью электроэнергии в реальном времени для повышения энергоэффективности микроэнергетических систем.

Методы. Системный подход, системный анализ, индуктивные технологии моделирования, энергетический менеджмент.

Результаты. Разработан метод децентрализованного динамического планирования использования энергоресурсов в микроэнергетичних системах и основные принципы построения интеллектуальных систем управления энергопотреблением локальных объектов, на основе которых пользователь сможет контролировать уровень нагрузки в реальном времени и оптимизировать затраты на электроэнергию, что в свою очередь приведет к балансированию сети и повысит энергоэффективность ее функционирования.

Выводы. Результаты этого исследования показывают, что предложенные принципы формирования диспетчерско-технологических функций могут быть использованы для усовершенствования интеллектуальных систем управления в технологиях *smart microgrid*.

Ключевые слова: *микроэнергетические сети, локальный энергетический объект, возобновляемые источники энергии, динамическое моделирование стоимости электроэнергии, интеллектуальная система управления, диспетчерско-технологические функции.*