Information and Analytical System for Monitoring the Energy Resources of the Enterprise

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***Abstract*—The issues of creation and functioning of the Ekoflex Information Monitoring System intended for accounting and forecasting values the consumption of energy resources of the enterprise, have been considered. A description of the system architecture and its software content has been given. A common digital network for centralized data collection and processing has been developed. The energy consumption of the enterprise can be monitored from any device anywhere in the world through a cloud web interface and a mobile interface. The gas (flow) consumption forecasting module takes into account several external factors (exogenous variables) and the structural specifics of the enterprise.**

Keywords*—*information system, forecasting, modeling, data collection and processing, software content

I. Introduction

The efficiency of the functioning of an industrial enterprise directly depends on the resources available to it, first of all, energy carriers: gas, water, electricity, chemicals, etc. The transition to energy markets and the dependence of the resulting cost of energy resources not only on the volumes of their consumption, but also on the difference between the declared (planned/predicted) and actual volumes of their consumption at a given time interval [0,T] led to the fact that the task of monitoring (control, accounting, analysis, and forecasting) the costs of energy resources of the enterprise is becoming extremely relevant. A systematic solution to this problem by creating an information and analytical system for monitoring the energy resources of an enterprise (IASMERE) allows not only to reduce direct costs for energy resources, but also to control parameters, such as the equipment operability, its shock-absorber characteristics, frequency of its renewal and modernization, environmental and hygienic indicators, the product quality, etc.

II. Research objective

The problems of control and accounting of energy resources of the enterprise are solved by technical means of control and accounting of energy resources, while the analysis of current and forecasting of future volumes of energy consumption is possible only on the basis of methods of mathematical statistics and mathematical models of interconnected non-stationary random processes. It is known [1, 2] that the processes of energy consumption are random processes with a complex correlation structure, depending on the type of an enterprise and three main groups of factors:

• chronological (time-of-year, month, day of the week, hours of the day);

• meteorological (ambient temperature, wind speed and direction, air humidity, etc.);

• organizational (scheduled switching on/off of technological equipment, etc.).

The complex influence of these factors on the processes of energy resource consumption and the random nature of a number of these factors led to the fact that, as a rule, these processes are non-uniform non-stationary random processes.

The influence of chronological factors on energy consumption processes result in the appearance of polyharmonic trends in them, the nature of which is determined by the cycling of technological processes.

The influence of the ambient temperature, as well as the speed and direction of the wind, led to the appearance of polynomial trends in the processes of energy consumption, caused by changes in meteorological conditions. Changes in consumption volumes, for example, of natural gas in relation to changes in meteorological conditions always occur with a certain time delay due to the inertia of the heat exchange processes of the heated buildings and structures of the enterprise with the environment.

The influence of organizational factors on the processes of consumption of energy resources result in a violation of the homogeneity of these processes and a sharp change in the dynamic properties of these processes.

The complex influence of unobservable and uncontrolled factors on the energy consumption processes gives rise to the appearance of stochastic trends in them.

III. Results

Developed by Ekoflex IASMERE solves the problems of monitoring the consumption of energy resources, carries out their automated collection, accounting, storage, and provides analytical information both for the entire enterprise and for its individual divisions.

IASMERE provides the integration of all enterprise resource meters into a common digital network for centralized data collection and processing. The ability to control the energy consumption of the enterprise from any device anywhere in the world is provided through a cloud web interface and a mobile interface—it is enough to have an Internet connection and to be a registered user in the system with the appropriate access to the archive of data on resource consumption at the enterprise with varying degrees of detail.

Data from all flow meters are collected in a single storage—in a database installed on the server. The system collects and processes data around the clock. Average and current indicators are available to users for viewing via the Internet at any time of the day. The server performs the function of notification when the instantaneous consumption of a resource exceeds the threshold set. In such situations, the users specified in the system will receive an email. During normal operation, no manual action is required by the operating personnel.

It is possible to add additional data acquisition devices working with different parameters. The system allows generating reports, in accordance with certain specified criteria and the ability to automatically send them to responsible persons. IASMERE is geo-referenced with the ability to view the enterprise plan with applied equipment and meters at the installation sites, which provides additional information for various enterprise services about metering points, communications and allows to more efficiently building the energy balance in the context of workshops, sections, equipment units that are displayed on map. One can also carry out an online search for objects on the map, solving the direct and inverse problem of GIS systems. Moreover, IASMERE provides the possibility of operational control and further analysis of resource costs for certain production operations (both regular and irregular), the ability to obtain various types of reports that allow analysis and identification of the most resource-intensive production areas and/or technological operations in order to further optimization.

For data collection, special pulse counting devices are used. Up to 8 flow meters can be connected to one such collecting device and remote collecting devices will be connected by the RS-485 serial bus (fig. 1).

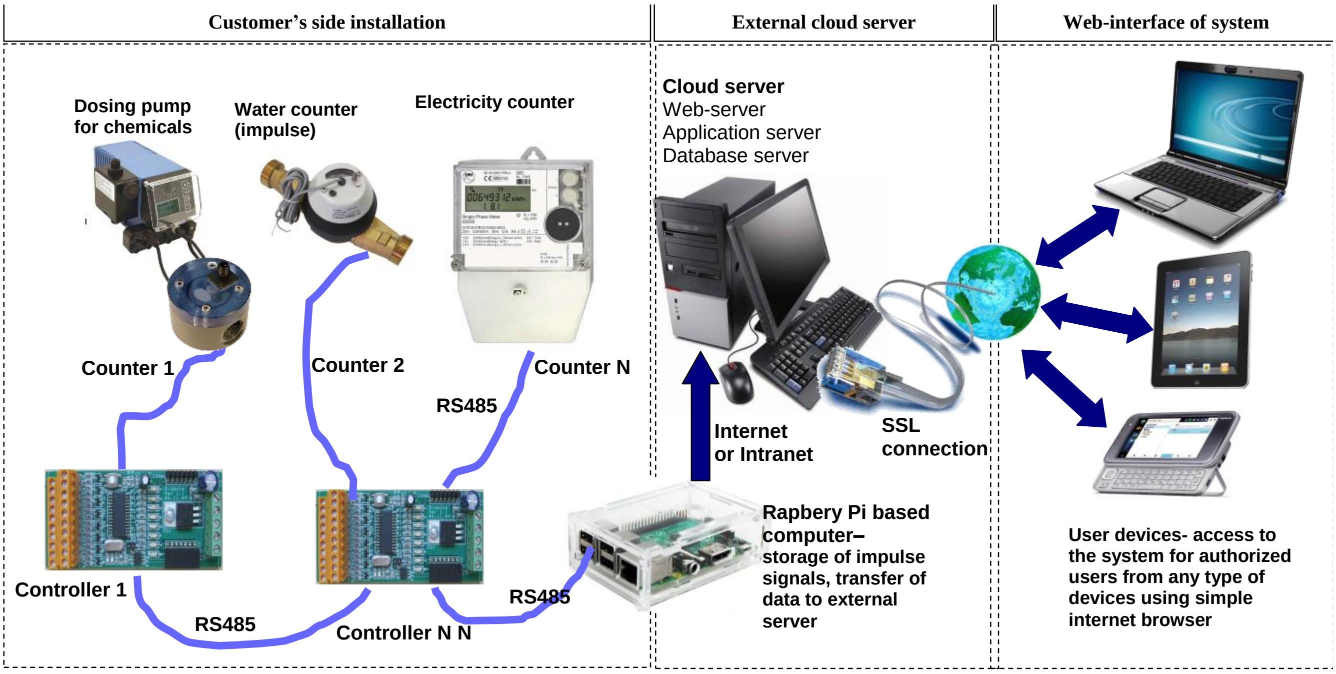

Fig. 1. Common structure of monitoring system "Ecoflex"

The data collectors are connected to the server via the same serial line. A specially developed program is constantly running on the server, which constantly inquires all collection devices and stores the data in the storage. The data collector itself does not store data but transmits it to the server for processing.

The controller is a microprocessor-based circuit that performs two main functions—counting pulses from meters and communication via a digital line [3].

Ekoflex IASMERE allows:

– to shape the balance of energy resources of the enterprise in real time;

– to analyze the specific cost of energy resources per unit of production for individual structural divisions of the enterprise (workshops, areas, pieces of equipment, etc.);

– to maintain constant data of certain resources in critical areas of production (for example, on humidity and temperature in cold stores);

– to analyze the depreciation of the equipment (for example, engine hours) and to inform about the need for its modernization and replacement;

– to create and to integrate local control systems into a single "cloud" information space for the purposes of accounting for consumption and distribution of resources (for example, electricity, steam, gas, humidity temperature, equipment operating time, etc.);

– to provide online access to information on energy consumption for various categories of users and to instantly inform about deviations from the set limits of resource consumption and values of temperature, humidity, as well as the need for maintenance of one or another equipment connected to the system.

One of the main tasks solved in Ekoflex IASMERE [4] is the task of predicting the consumption of all types of energy resources of the enterprise based on data collected for previous periods and predicted data on changes in external factors (manufacturing parameters, temperature and humidity in the premises of the enterprise, during the external environment, etc.).

The results of the system analysis of modern methods of forecasting energy resources, the study of physical characteristics and the nature of their relationships with external factors have shown that the most adequate models of energy consumption processes can be obtained in the class of linear discrete stochastic models of the form:

$$Y_t = \sum_{i \in M} V_i(B) F_{it} + V_{m+1}(B) a_t, \qquad (1)$$

where Y_t – the value of the consumption process of the analyzed type of energy resource at time t ($t = 1, 2, \ldots$); $V_i(B)$, $i \in M$ – the operator of a linear discrete transfer function, connecting the process of energy resource consumption Y_t with the *i*-th meteorological or organizational factor F_{it}; $M = (1, 2, \ldots, m)$ – a variety of meteorological and organizational factors F_{it}, influencing the process Y_t; $V_{m+1}(B)$ – an operator of a linear discrete transfer function, linking the process Y_t with chronological factors; a_t – the residual model error.

In order to take into account the relation of energy resources with meteorological and organizational factors, it is most expedient to use the class of linear discrete transfer functions with a rational structure of the form:

$$y_{it} = V_i(B) F_{it} = \delta_i^{-1}(B) \omega_i(B) B^{b_i} F_{it}, \quad i \in M, \qquad (2)$$

where Y_t – the component of the process Y_t associated with the *i*-th meteorological or organizational factor, $\omega_i(B) = (\omega_{0i} - \omega_{1i}B - \ldots - \omega_{c_i i}B^{c_i})$, $\delta_i(B) = (1 - \delta_{1i}B - \ldots \delta_{r_i i}B^{r_i})$ – polynomials in B degrees r_i, c_i; B – backward shift operator $B^{b_i} F_{it} = F_{it} - b_i$; b_i – the delay factor y_{it} and F_{it}, which can take values $0, 1, 2, \ldots$.

If the influence of all meteorological and organizational factors on the process is eliminated, then the process determined by the equation

$$y_{m+1,t} = Y_t = \sum_{i \in M} \delta_i^{-1}(B) \omega_i(B) B^{b_i} F_{it} \qquad (3)$$

is associated only with chronological factors. The nature of the influence of chronological factors on the volume of energy consumption is much more complicated. The influence of these factors leads to the appearance of periodic components with random parameters, as well as deterministic or stochastic trends, reflecting the general trend of increasing (decreasing) natural gas consumption, in the processes under consideration.

An adequate description of such a process structure is possible in the class of multiplicative autoregression models—an integrated moving average (ARIMA) of the form:

$$\begin{aligned} &\Phi^1_{p_1}(B^{S_1}) \Phi^2_{p_2}(B^{S_2}) \ldots \Phi^j_{p_j}(B^{S_j}) \ldots \Phi^n_{p_n}(B^{S_n}) \nabla^{D_1}_{S_1} \nabla^{D_2}_{S_2} \ldots \nabla^{D_j}_{S_j} \ldots \nabla^{D_n}_{S_n} y_{m+1,t} = \\ &= \theta_0 + \theta^1_{q_1}(B^{S_1}) \theta^2_{q_2}(B^{S_2}) \ldots \theta^j_{q_j}(B^{S_j}) \ldots \theta^n_{q_n}(B^{S_n}) a_t, \end{aligned} \qquad (4)$$

where $j \in N$, $N = \{1, 2, ..., n\}$ – a set of periodic process components $y_{m+1,t}$; S_j – the period of the j-th periodic component and $S_1 = 1$; ∇_{S_j} – simplifying operator defined as $\nabla_{S_j}^{D_j} = (1 - B^{S_j})^{D_j}$; D_j – the order of taking the j-th difference;

$$\Phi_{p_j}^j(B^{S_j}) = (1 - \Phi_1^j B^{S_j} - \Phi_2^j B^{2S_j} - ... - \Phi_{p_j}^j B^{p_j S_j}) \quad (5)$$

– polynomials B^{S_j} in degrees p_j, determining the autoregressive component S_j of the periodic component;

$$\theta_{q_j}^j(B^{S_j}) = (1 - \theta_1^j B^{S_j} - \theta_2^j B^{2S_j} - ... - \theta_{q_j}^j B^{q_j S_j}) \quad (6)$$

– polynomials B^{S_j} in degrees q_j, which correspond to the S_j moving average components of the periodic component;
a_t – the residual model error; θ_0 – a common constant.

If $\forall j \in N$, $D_j = 0$, then model (4) describes the class of linear stationary processes. If $\exists k \in N$ such as $D_k \neq 0$, then model (4) allows one to obtain an adequate description of homogeneous non-stationary processes, for which taking all $D_k \neq 0$ differences transforms them into a stationary reversible process. If $D_1 > 0$, then model (4) describes a non-stationary process containing a polynomial trend of the degree $D_1 - 1$.

If $\theta_0 = 0$, then model (4) allows describing random processes with stochastic trends, i.e. with a random level or slope. If $\theta_0 \neq 0$, then model (4) corresponds to the processes containing deterministic trends.

The mathematical model (1), which adequately describes the real processes of consumption of various types of energy resources of the enterprise, is obtained by solving the problems of structural identification, rough and accurate estimation of the model parameters, followed by checking the correlation value of the residual model errors a_t. For an adequate model, the values of the residual model errors are practically not correlated with each other and with the values $F_{it}, i \in M$.

Model (1) allows us to calculate the forecast of future volumes of energy consumption with a given lead in the form of a conditional mathematical expectation. Moreover, for each forecast value, its upper and lower confidence limits of the forecast, in which, with a given probability, the actual value of the volume of consumption of the predicted type of energy resource will be located, are calculated. The use of model (1) makes it possible to adequately describe almost all types of energy resources of the enterprise, and the variance of forecast errors approaches a practically achievable minimum within the framework of the correlation theory of random processes.

IV. Conclusions

Developed Ekoflex IASMERE allows for centralized data collection in a cloud architecture, automatic data processing, and provision of results of both direct data collection (in digital, tabular, and graphical form) and forecasting data—with the possibility of further data export to other external systems (MSExcel, XML, 1C).

Ekoflex IASMERE with this forecasting module can be used at many enterprises to estimate and to predict energy costs and, as a result, it can be one of the important tools in the complex of the enterprise energy efficiency.

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