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Efficiency Assessment of the Power Supply System of an Industrial Enterprise Through the Assessment of the Modes of Electric Power Consumption

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Abstract. The paper reviews the terms of the rational consumption and distribution of the energy resources at an enterprise. The authors analyze the significance and the effect of the change of the profile of the energy consumption per hour by the enterprise. The text explores the factors influencing the discipline of the planned electricity and power consumption. The authors present a calculation of the weighted average deviations for consumers and the terms of their assessment. The authors make conclusions concerning the rationality of the means of defining the energy efficiency system through the assessment of the modes of electric energy consumption of an industrial enterprise.

1. Introduction
In 2009–2010, the energy consumption of the world economy increased because of the effect of the economic crisis of 2008. The countries that suffered from the crisis most were Russia, Japan and the EU states where the crisis lead to the increase of the energy consumption in the economies. The energy efficiency of India and African states suffered less. Starting from 2011 the impact of the factors of the crisis of 2008 has been going down and the rates of the decrease of the energy consumption of the world economy have been demonstrating positive dynamics: in 2011 the decrease of the energy consumption of world gross product was 1.3%, in 2012 – 1.0%, in 2013 – 0.6%. In 2012–2013, it was only in the USA that the GDP energy consumption increased largely due to the increase in 2013 of the heating season degree-day by 23% as well as due to the structural changes of the US economy, which resulted in the increase of the power consuming industries.

In case of absence of the due planning of the production based on minimizing energy consumption, there might occur in the activity of the enterprise a possibility of unfavorable situations and consequences, financial losses and losses of potential benefit, i.e. the possibility of risks. Energy risks are a mixed type of risks including industrial, economical, commercial, resource and organizational types of risks. Energy risks should be managed through the continuous monitoring and the use of statistical methods in the energy input management system (EIMS). As a result, the possibility of risk is decreased (or eliminated) in three cases: if the event (factor of risk) takes place, if the result of this event is made predictable and if the risk factor is eliminated. Efficient risk management should solve a range of problems from defining and monitoring the risk to its cost estimate.

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2. Assessment of the modes of electric power consumption

The rational consumption and distribution of the power resources at an enterprise depends on the external and internal conditions of resource supply. The external conditions of power supply include the requirements defined in the regulatory documents that concern resource circulation. The internal conditions include the reliability of the enterprise power supply comprising the factors of power limitations / power outages due to external causes, emergency cases and the breakdown of resource-receiving and resource-transmitting equipment, as well as the management of power consumption.

Power consumption uniformity of an enterprise defines the profile of consumption per hour. The consumption per hour profile is defined by the characteristics of the electric energy and power price formation on the wholesale power market (WPM) and on the retail power market (RPM) in the Russian Federation [1-5]. On these markets, the kWh weighted average price is defined by the consumption per hour and the prices at this time, according to the price bracket calculation method [2]. Thus, power consumption per hour uniformity helps to minimize overcosting in the conditions of the volatility of the electric energy prices on WPM.

The consumption per hour profile has economical, technical and technological significance. The profile of consumption per hour reflects the quality of planning as well as the following energy (power) consumption at the enterprise. An increasingly even graph of consumption per hour (with minimized consumption peaks) results in a more efficient energy use regardless the situation on WPM and RPM (there occurs an effect of consumption peaks smoothing). At the same time, the current Russian legislation in the field of electric energy (power) circulation increases the significance of this index through the process of the overall price-formation, as well as the cost of the electric energy (power) paid for by the consumer.

It is worth mentioning that the decrease of the power consumption per hour does not contradict but is a co-directional vector in the direction of the increase of the efficient power use. Both indexes serve as variables in the function of energy consumption of an enterprise. That is why it is worthwhile using them separately in the course of energy efficiency assessment.

To assess energy consumption per hour, a calculation of contracted power utilization time (CPUT) is made on the basis of the consumption per hour data for the last calendar year given by the consumer. For the 3rd-6th price category (PC) consumers [2], WPM consumers or consumers who have contracts with independent electric distribution companies (EDCs) the contracted power utilization time is calculated using specified methods (1) [6-7].

\[
\text{CPUT} = \frac{V_{\text{act}}}{P_{\text{max}}}
\]

where \(V_{\text{act}}\) stands for the actual contracted electric energy consumption at the enterprise in the preceding regulatory period in kilowatt-hours (kWh);

\(P_{\text{max}}\) – the actual (contracted) maximum power consumption in kilowatts (kW).

The maximum power consumption (\(P_{\text{max}}\)) is calculated on the basis of the power consumption per hour data according to the current rules of the retail power market [2]. In the absence of the consumption per hour data or in case of impossibility to directly calculate maximum power consumption, the following methods are used for the calculation (given in descending order of usage priority):

- hourly measurement of power in the winter / summer in operating day (24 hours);
- hourly measurement of power during 24 hours in 2 or more regulatory periods (months);
- definition of maximum power consumption according to the Certificate of Delineation of Balance Sheet Attribution (CDBSA);
- according to the typical daily load curve for the consumer on the working days and days-off.

For the 1st-2nd PC consumers, the CPUT used is equal to the calculation value of the default provider guaranteeing energy supply in the region of the consumer.

The discipline of the planned energy and power consumption of an enterprise is characterized by the deviation of the actual energy (power) consumption from the planned consumption. The deviation of the actual energy (power) consumption per hour from the planned consumption per hour is the
second most significant factor of the increase of the energy (power) resulting costs in the conditions of the current WPM and RPM regulations [1-5]. Consumption deviations result in the risks of overspending on energy and power on the WPM and RPM, the creation of transition modes of the local power generation (the increase of specific consumption of the fluid), as well as the wearing of the basic and auxiliary facility.

In order to assess the index characterizing the discipline of the planned energy and power consumption, the deviation of the actual consumption per hour from the planned consumption per hour is calculated on the basis of the data of the interval metering system (IMS) of the enterprise. For the enterprises that are supplied by a default provider, this calculation is done as for the 3rd-6th PC consumers. For the 1st-2nd PC consumers, the deviation value is 5% because of the relaying of costs of the default provider from the WPM to the RPM [2-3]. In the absence of the interval metering devices and (or) in the absence of the planned hourly energy (power) consumption value, the deviation value is considered to be 5%. The calculation of the weighted average deviation value (Δ) for consumers with the interval measuring and planned consumption is performed according to the formula (2):

$$\Delta = \sum_{t=1}^{T} \frac{abs(N_{\text{fact}}^t - N_{\text{plan}}^t)}{N_{\text{plan}}^t}$$  \hspace{1cm} (2)

where $N_{\text{fact}}^t$ is the actual power consumption during an hour t (kW); $N_{\text{plan}}^t$ – the planned power consumption during an hour t (kW); T – the sum of hours in the annual amount of working days.

The assessment of the average deviation value is based on the data on the planned and actual consumption during the year preceding the assessment or on the data from the records of the enterprise for the previous 2 years. For the consumers of the WPM, the calculation of the balance value is done according to the WPM regulations.

For the enterprises with the local power generation, the deviation assessment value is based on the analysis of the fluctuations of the specific fuel consumption for the generation of 1 kWh. To carry out the comparative assessment, the identical periods are selected for comparison, the most significant factors being the season of the year, the production plan of the enterprise, the quality of the fluid as well as the unscheduled shutdown of the generation equipment. No less than three identical periods are selected for assessment.

3. The assessment of deviations (profile) in energy (power) consumption

For the assessment of deviations (profile) in energy (power) consumption it is necessary to define the quality index that shows the specific deviations of the actual from the planned energy (power) consumption per hour at the enterprise $\eta(\Delta)^{1-2}$.

The index characterizes the discipline of the planned energy and power consumption. The deviation of the actual energy (power) consumption per hour from the planned consumption per hour is the second most significant factor of the increase of the energy (power) resulting costs in the conditions of the current WPM and RPM regulations. Consumption deviations result in the risks of overspending on energy and power on the WPM and RPM, the creation of transition modes of the local power generation (the increase of specific consumption of the fluid), as well as the wearing of the basic and auxiliary facility.

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For the enterprises that are supplied by a default provider, this calculation is done as for the 3rd-6th PC consumers. For the 1st-2nd PC consumers, the deviation value is 5% because of the relaying of costs of the default provider from the WPM to the RPM [2 - 3]. In the absence of the interval metering devices and (or) in the absence of the planned hourly energy (power) consumption value, the deviation value is considered to be 5%.

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The resulting deviation value is a sum of deviation indices ($\Delta g$) divided by the volume of the actual consumption (generation) of electric energy ($V_g$) in the given identical periods (g):

$$\Delta = \frac{\sum \Delta g \times V_g}{\sum V_g}$$  \hspace{1cm} (3)

4. The manageability of energy resources consumption

The manageability of energy resources consumption is an index characterizing the manageability of the natural and cost indices of energy resources consumption. A complex of interrelated documents regulating the accounting, planning and energy (power) consumption discipline united into a system allows to speak about the management of energy consumption as well as the guaranteeing of its efficient use.

The level of the manageability and the efficient use of energy resources depends on: the existence of the energy consumption management system (ECMS), the introduction and the updating of the ECMS so that it corresponds to the Russian National Standard ISO 50001-2012 “Systems of energy management. Requirements and application guidelines”, the certification of the system as well as its meeting the requirements and the special features of the energy circulation according to the Russian Federation regulations.

Systemic control and the integral management of energy resources, including the cases of the low rating of the index of specific consumption for each produced item, nonetheless, is a positive trend and serves as a basis for the sustainable development and growth of energy efficiency.

In order to assess the index of manageability of energy resources consumption the enterprise (organization) is to provide the data on the current state of things in the field of energy management in the form of a questionnaire. The state of the energy management system is defined by the existence and the level of development of the following elements:

- Energy survey (energy budgeting) or the updating of data on the consumption of each of the energy resources (in a declaration or by means of internal audit);
- Registration, accounting and analysis of data on the consumption of each of the energy resources;
- Energy consumption planning, analysis and monitoring of the consumption discipline of each of the energy resources;
- Competence and number of specialists involved in energy management (the management of each of the energy resources);
- Efficiency indices of each of the energy resources use at the enterprise (organization) and the existence of the measurable target results in what concerns the achievement of these indices;
- Paperwork management, information (data) exchange, standardizing and choosing those in charge from the staff;
- The existence of a policy in the field of energy efficiency meeting the requirements of the energy accounting and circulation regulations of the Russian Federation and the requirements of the Russian National Standard ISO 50001-2012;
A certificate of the Russian National Standard ISO 50001-2012, an energy performance certificate (declaration), a rank in the rating of energy efficiency.
Each element is given a mark in the range 1-11 for each type of the energy resources. The ECMS is then assessed for each type of the energy resources by means of expert review.

5. Resource supply reliability
Reliable energy supply is the factor of efficient and continuous use of energy resources. Its absence can lead to production (operation activity) stoppage and result in the increase of production costs and economic losses. Breaks in energy supply, whether caused by accidents, off-schedule repairs, power limitations or power outages as a result of overdue payment to the resource supplier, lead to transition modes of consumption or emergency power supply. At this can have a negative impact on the rational (efficient) use of energy resources.

In order to assess this index, the major aspects of reliability (events / incidents) for each type of the energy resources are analyzed:
- Electric energy (power) - \( \eta (\rho_2) \);  
- Energy supply stoppage as a result of contract breach by the consumer according to the requirements of the energy (power) supply regulations [1 - 7];  
- Emergency stoppage of energy supply because of external / internal factors;  
- Off-schedule repairs of electric mains and / or of the consuming equipment of the enterprise (organization);  
- The use of back-up power sources as a result of the maximum power consumption exceedance.

The events are characterized by the frequency of occurrence and the graveness of the economic and technical consequences for the consumer. The economic consequences result from a large number of factors of the operation activity of the enterprise. In fact, defining the possibility of the event and its consequences means defining a risk.

In order to assess the index, a maximum-permissible possibility of an event is set, which can lead to the economic consequences, the growth of expenses for the energy resource or its back-ups as well as the operation activity and production costs. In the assessment of the index it is hypothetically assumed that the events in question are not taking place simultaneously and are independent. On the basis of the questionnaire of the enterprise (organization), an analysis is carried out of events that took place during the last 2-3 years that lead to the risk of unreliable energy supply in a month during the analyzed period. The resulting value is averaged either over the events or arithmetically (in the absence of data on the losses) or is calculated with respect to the other factors in the total sum of the economic losses if there is a value of losses resulting from these events.

6. Conclusions
Having defined electric energy (power) consumption uniformity and having calculated the weighted average deviation value, we can assess the modes of electric power consumption of an industrial enterprise and compare them to the consumption modes of the competitors. This will make it possible to assess the energy efficiency of the enterprise and to define the domains of power consumption that require special attention during the energy audit.

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