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THE COMPLEX ENERGY EFFICIENCY ESTIMATION OF INDUSTRIAL POWER SUPPLY SYSTEMS

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Abstract- In this paper the approach for estimation and comparison of power supply systems of the industrial enterprises from the criterion of energy efficiency is offered (regarding electric energy) and the description of this system and its basic features is shown. The example of comparison of three power supply systems is presented. This system is especially actual for analysis of industrial enterprises activity in the field of energy-saving and optimization of their power supply systems.

Keywords: Power Supply Systems, Energy Efficiency, Energy Savings.

I. INTRODUCTION

Now many industrial enterprises of our country continue to work on extremely out-of-date electrical and technological equipment. However modernization of the enterprises and also their power supply systems is interfered by a number of the economic, organizational and technical factors existing on the majority of the domestic industrial enterprises.

Except external bases, there is a set of the internal reasons of low energy efficiency of power supply systems which the management of the enterprises can actively influence for the purpose of decrease in their negative influence to a minimum.

The energy efficiency of power supply system is influenced by the variety of the reasons which can be divided on two basic categories:
- the technical reasons - low level of the technical status of the power supply system's equipment and also technological equipment and processes of industrial enterprise;
- the organizational reasons - inefficient management of the power supply systems, low level of the electrical personnel skill, absence of interest to increase the power supply system energy efficiency.

Within the limits of complex influence on the given factors the application of energy management is necessary. Energy management system of the enterprise just also represents set of the technical and organizational actions directed to increase the efficiency of the power resources, thus being a part of the general structure of the enterprise. As one of the important elements of energy management system in this paper the estimation of enterprise activity in the field of energy saving, similar presented in [3, 4] is offered.

II. PROPOSED METHODOLOGY

The given approach can be used as for estimation of the only enterprise activity in the field of energy-saving in dynamics, and for comparison of the different enterprises by criterion of energy efficiency. Results of such comparison can be used both for current activity (for example, for making the reasonable solution for personnel stimulation), and for prospective work (for development and specification of actions programs, for parameters planning, etc.).

Thus one of the complicated questions is to form the set of criteria for the complex estimation of the enterprise activity. The analysis of standards and normative documents allows allocating following set of factors:
- the technical status of electrical equipment of power supply system;
- the status of metering system;
- the application of automated systems for measuring and control;
- the application of VAR sources for reactive power control;
- the application of automated voltage regulators;
- the optimization of the electric network structure, optimal loading of the substation transformers and etc.;
- the energy savings in technological and other equipment;
- the personnel skill level (qualification).

The offered approach considers many of the mentioned factors and (Table 1) consists of ten criteria. All criteria can be divided into three groups conditionally: criteria of the first group (No 1-4) characterize a technical status and the level of special equipment application, criteria of the second group (No 5-7) consider economic benefit of the spent energy-saving actions, and the third group of criteria (No 8-10) allows considering skill of the personnel.

In this paper Multiple Attribute Decision Making (MADM) method is used to assist decision-makers in decision of power supply system's estimation by proposed criterion of energy efficiency. Well known

MADM methods comprise the simple additive weighting method (SAW) also known as weighted sum model (WSM), the weighted product model (WPM), Analytic Hierarchy Process (AHP), Revised Analytic Hierarchy Process (RAHP), Multiplicative Analytic Hierarchy Process (MAHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). For such a problem formulation SAW method is considered as the simplest and widest used MADM method. In this method the overall suitability of each alternative is calculated by averaging the score of each alternative with respect to every attribute with a corresponding importance weighting. Also if all the elements of the decision table are normalized, then SAW can be used for any type and any number of attributes [5].

Each of the presented criteria with the weight factor enters into the total cumulative rating of power supply system energy-efficiency (*R*)

$$R = \sum_{i=1}^{n} \alpha_i \cdot k_i \tag{1}$$

where α_i - weight factor of i-th criterion, p.u.; k_i - value of i-th criterion, p.u.; n - number of criteria.

Values of weight factors are defined by means of expert estimations method and can change depending on the specificity of the compared objects.

Each of the involved experts puts down to each criterion a mark (on a scale from 10 to 1 with step 1) depending on its importance for power supply system energy efficiency. Then estimations of experts by each criterion are averaged, setting thereby weight factors (α_i).

Table 1. Criteria for the energy efficiency estimation

No	Criterion	Description
1	Electric power consumption	The part of electric power cost in total production cost
2	Technical status of electrical equipment	The part of out-of-date electrical equipment in total amount
3	Status of the metering system	The part of electric power measured not by metering devices in total amount
4	Automated systems	The ratio of savings after application of automated systems for current time period to previous
5	Optimization in electrical networks	The ratio of electric power losses in electrical networks for current time period to previous
6	Energy-savings in technological equipment	The ratio of electric power consumption in technological equipment for current time period to previous
7	Energy-savings in auxiliary systems (lighting, ventilation, etc.)	The ratio of electric power consumption in auxiliary systems for current time period to previous
8	Personnel skill level	The part of personnel without necessary professional skill in total amount
9	Personnel training	The part of trained personnel in total amount
10	Personnel stimulation	The part of savings set for personnel stimulation in total amount

The values of criteria, irrespective of their nature, are defined in relative expression in p.u. The values of some criteria (in considered system it is criteria 9 and 10) are defined by subtraction from 1. It is caused by that fact that for the specified criteria growth of the value is desirable.

The offered approach works with the following objective: the less the value of the total rating, the better. Therefore the maximum weight factor for criterion can be equal to 1, and minimum to 10. For other set of criteria the system can work with more widespread scheme: the more the rating, the better. Some of the criteria need to be considered in more details.

The first and main criterion is the power consumption of industrial enterprise. The application of this criterion is strictly specified by standards [1, 2]. The complex criterion for optimization in electrical networks includes such problems as reactive power planning, optimal load flows, optimal loading of substation transformers, etc. The criteria of the third group allow considering in expert system a role of so-called «the human factor» which cannot be underestimated. Because the final results of power supply system's modernization depends on how much skilled, qualified, trained and stimulated personnel is involved to the problem decision.

III. SIMULATION RESULTS

As the example of proposed approach application let's consider the comparison of three following enterprises. The companies presented in the example are the enterprises which produced the materials for building branch. The production is characterized by high level of power consumption (approximately 40-45% in production cost are the fuel and electric power cost).

A. The Enterprise No 1 (E1)

The electric power consumption of the enterprise is rather high. The part of electric power cost in total production cost is about 23%. At the same time the enterprise is characterized by high deterioration both the basic technological equipment and also electric networks (about 70%). After putting into operation the automated measuring system the expenses for the electric power have been reduced on 22 % because of more exact control and forecasting of the power consumption. The additional low-voltage capacitor placement has allowed reducing electric power losses in electric networks on 19%. The optimization of the electric motors loading has led to decrease in the expense of the electric power on 9 %. By a result of personnel certification it is revealed that about 12% of the personnel have insufficient qualification and for the current time period the part of trained personnel is only about 4%.

B. The Enterprises No 2 (E2) and No 3 (E3)

At the given enterprises much smaller attention from the enterprise management is paid to the problem of energy efficiency. The electric power consumption of the enterprise is also high. The part of electric power cost in total production cost is about 18-21%. The enterprises are also characterized by high deterioration both the basic technological equipment and also electric networks (more than 60%). The enterprises are not equipped by the automated measuring systems. Small decrease in electric power losses in electric networks (5-7%) is caused by the operation of available reactive power sources. As for personnel skill level the state is different for mentioned enterprises. For the enterprise No 3 only 3% of the personnel have no sufficient qualification and for the enterprise No 2 it is much more (about 15 %). Also for the current period improvement of professional skill was not spent. The values of criteria and weight factors for the considered example are presented in Table 2.

Table 2. The example of power supply system’s comparison by proposed expert system

No	Criterion	Value			Weight factor
		E1	E2	E3	
1	Electric power consumption	0.23	0.18	0.21	1
2	Technical status of electrical equipment	0.71	0.66	0.60	2
3	Status of the metering system	0.00	0.19	0.10	2
4	Automated systems	0.78	1.00	1.00	2
5	Optimization in electrical networks	0.81	0.95	0.93	2
6	Energy-savings in technological equipment	0.91	1.00	1.00	3
7	Energy-savings in auxiliary systems (lighting, ventilation, etc.)	0.95	1.00	0.98	4
8	Personnel skill level	0.12	0.15	0.03	3
9	Personnel training	0.04	0.00	0.02	5
10	Personnel stimulation	0.07	0.05	0.05	3
Total rating R		19.31	21.08	20.23	

So, it is simple to define the total rating for each enterprise. For example, for the enterprise №1 the total rating is calculated as following:

$$R = 1\cdot 0.23 + 2\cdot 0.71 + 2\cdot 0 + 2\cdot 0.78 + \\ +2\cdot 0.81 + 3\cdot 0.91 + 4\cdot 0.95 + 3\cdot 0.12 + \\ +5\cdot(1-0.04) + 3\cdot(1-0.07) = 19.31 \quad (2)$$

For the second enterprise the total rating is equal to 21.08, and for the third – 20.23. So, in the offered system the best by the criterion of power supply system’s energy efficiency is the enterprise No 1, and the worst - the enterprise No 2. The enterprise No 1, despite the greatest power consumption, has won because of the best metering system status, wide application of automated systems, reactive power sources placement for reactive power control and personnel professional training and stimulation.

IV. CONCLUSIONS

The approach considered in the paper is focused on the problem of the energy efficiency estimation of the industrial power supply systems. The development of similar expert systems for other fuel and energy resources (thermal energy, water supply, etc.) is also expedient. Besides, it is possible to expand considered approach by increase the number of criteria. It is also possible to complicate the process of total rating definition, for example, by the application of some powerful mathematical and optimization techniques.

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BIOGRAPHIES

Alexander Valerjevitch Mogilenko was born in Leninsk, Kazakhstan, USSR, 1976. He received his M.Sc. and Ph.D. degrees from Novosibirsk State Technical University in 1999 and 2003, respectively, all in Power Electrical Engineering. His careers were as teacher in Novosibirsk State Technical University, Novosibirsk, Russia (1999-2003), chief of power losses department (2003-2007) and main expert of power engineering department (2008) in open joint stock company Novosibirskenergo, Novosibirsk, Russia. He is the author about 90 publications and participated in 34 conferences. Dr. Mogilenko is the member of Swiss SEV Association for Electrical Engineering, Power and Information Technologies, Austrian Electrotechnical Association and Germany VDE Association, Germany.

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