Assessment of the Charging Policy in Energy Efficiency of the Enterprise

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Abstract. The forecasting problem for energy facilities with a power exceeding 670 kW is currently one of the main. In connection with rules of the retail electricity market such customers also pay for actual energy consumption deviations from plan value. In compliance with the hierarchical stages of the electricity market a guaranteeing supplier is to respect the interests of distribution and generation companies that require load leveling. The answer to this question for industrial enterprise is possible only within technological process through implementation of energy-efficient processing chains with the adaptive function and forecasting tool. In such a circumstance the primary objective of a forecasting is reduce the energy consumption costs by taking account of the energy cost correlation for 24 hours for forming of pumping unit work schedule. The pumping unit virtual model with the variable frequency drive is considered. The forecasting tool and the optimizer are integrated into typical control circuit. Economic assessment of the optimization method was estimated.

1. Introduction

The question of rational use of energy, as well as looking for ways to reduce the cost of acquisition is the most relevant for today. Steadily rising prices of energy sources [1] led to the fact that the energy part production expenses became disproportionately large part. As a result, a lot of industrial enterprises faced the challenge of energy- and resource intensity reducing of output product and services, i.e. the problem of energy saving. Energy resources consumption analysis at many enterprises shows that the problem solving has two directions: organizational-technical measures for eliminating the useless energy resource consumption, and the adoption of energy-efficient technologies and energy conservation equipment allowing to perform the same work content with less electrical energy consumption.

The choice of the most optimal tariff (price category) may act as organizational-technical measures for industrial enterprises. Within the Enactment of the Government of the Russian Federation 442, dated 04 May 2012, "On the retail electricity market performance, full and/or partial limitation of electrical energy use conditions" the customer depending on the usable maximum power at the point of balance sheet delineation is obliged to choose the most appropriate price category [1].

2. Formulation of the problem

The problem of choice is currently acute for the customers with the maximum power more than 670 kW. Since 01 July 2013 these customers can choose only PT with hourly energy accounting or price category with hourly energy accounting and planning, namely from third to sixth price category [1].

The price category should be chosen based on minimum electrical energy purchase costs that in turn depends on load curve and peak power. One of the most significant factor when choosing the PT is the willingness to planify of hourly energy for day-ahead market.

The lowest values of the unregulated price are formed for the fifth and sixth but when these price categories are chosen a customer is obliged to provide to the energy service company plan values of energy consumption for the next month with an hourly breakdown. The customer tariff includes the deviation cost of the planned energy consumption from the real value and the value of such deviations can be significant. For that reason for the water facility, which purchases electrical energy at the fifth and sixth price category, it is very important to have an accurate forecast of energy consumption.

About 90% of the electric power consumption by water facilities is required for pumping equipment work, speaking about Water Supply Company it is about 2 million kWh per month. In this regard, along with the economic dimension of such problem as decrease of cash expenditures, for Water Supply Company there is a perceived problem with the low energy efficiency of operation of pump units associated with the use of water flow control via valve throttling. It is known that replacing valve control with variable frequency drive control allows to obtain energy savings up to 60% in similar systems [2]. Such authors as Bose, K. Bimal, B.S. Leznov [3], I.A. Syromyatnikov, C. U.Brunner, V. B. Vozdvizhenskiy, Siskind, S. Charles, Spear Mike, Novak Peter dealt with the issues for energy consumption optimization by using of the variable frequency drive.

3. Experimental part

In practice the effectiveness of technological process is analyzed separately and the improvement of production effectiveness is considered separately. The goal of this work is joint considering of the energy efficiency indicators of technological process and the level of business processes. The use of classical algorithm of vector control of frequency drive may act as the instrument to achieve the result at the level of technological process. It is offered to use supervisory control and data acquisition (SCADA) system as the element of process visualization. This system will be available for the upper hierarchical structure of management. A classic variation of a frequency converter structure is the use of a vector or adaptive control the pump unit rate. In this way, both the adjustment control area and the controller's parameters or the controller structure variation are secured. It depends on the change of the process parameters or external disturbances acting on the control object.

Figure 1 shows the electricity load curve, which is characterized the pronounced nonlinearity, the presence of typical peaks and lows of the load.
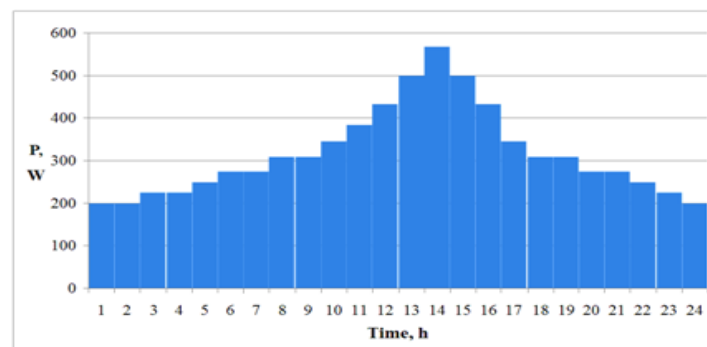

Figure 1. Power load diagram of the ventilation equipment.

In the experiment the study subject is the low pressure radial fan. The drive mechanism of the fan is the induction motor (IM) with a capacity of 0.55 [kW]. The installation also includes such units as

the frequency converter, the radial ventilator, the programmable logic controller, current and pressure sensors, an electrical power unit of the frequency converter, a bank of solid-state relay. The superordinate control level is a TRACE MODE SCADA system. Multiwindow interface of the system allowed to present mnemonic scheme of the technological process along with the monitor and control nodes, and form control procedure trends for the experimental unit. The mnemonic scheme is shown in Figure 2. It also shows the visualization example of the regulating characteristic taken from the experimental unit.
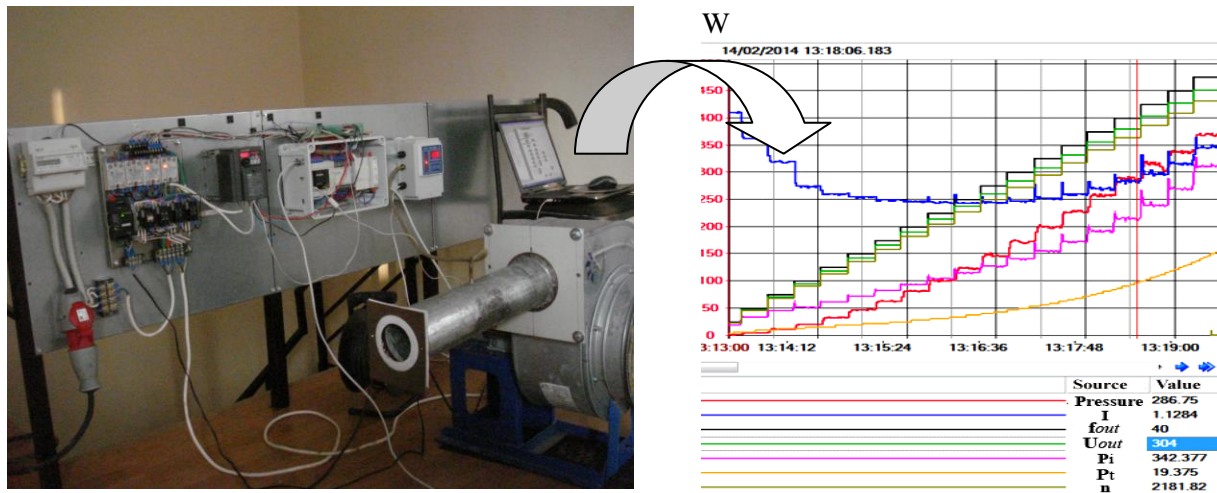

Figure 2. An experimental unit with characteristics of the fan operation.

Since output characteristics and the fan capacity are known, the experimental data sufficiency allow avoiding the use of analytic expressions, and the unit performance evaluation can be determined according to the database of the experiment. For the load curve (Figure 1) using pressure and power experimental loads, the pressure level in the system and energy consumption was determined for each day hour (Table 1).

Table 1. Calculated value for the load curve

Time	Power, [W]	Pressure, [Pa]	Energy consumption, [kWh]
00:00	200	142.31	200
01:00	200	142.31	200
02:00	224	171.35	224
03:00	224	171.35	224
04:00	248	198.31	248
05:00	274	228.33	274
		......	
23:00	200	142.31	200
Total sum			7601 [W]

The use of the variable frequency drive eliminates the inefficiency of the airflow control by means of the pneumo-latch throttling. At the implementation of the variable frequency drive, the pressure of 400 Pa is maintained in the system by means of rotation frequency varying of the driving unit. It leads to fan delivery change, that provides a constant pressure in the system when the air flow is changed. In percentage terms the efficiency of such approach is 79%.

4. Forecasting and optimization results

The introduction of the load forecasting tool and the optimization mechanism of the target function are therefore proposed. The goal of the optimization task is to reduce expenditures connected with electrical energy of the 3rd elevation pumping station taking into account the water intake curve, current tariff rates and process requirements (presence a reservoir) are made to the water pipe of the pumping and filtration station (PFS) – peak back–up boilerhouse (PBB).
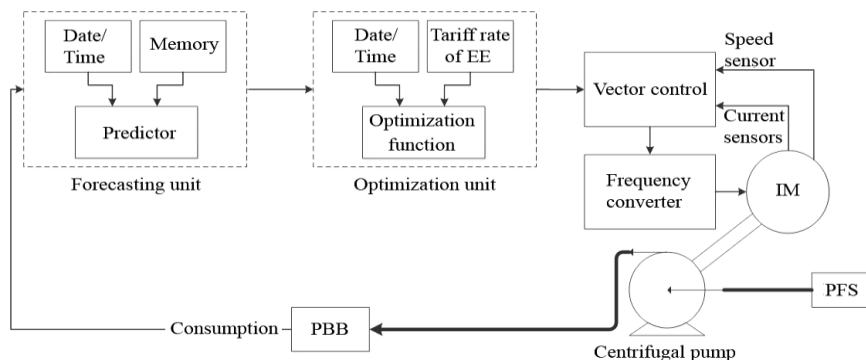

Figure 3. Flow-chart of the pumping station operation.

Organizational–technical measures leading to the elimination of the useless expenditure of power resources (the level of production control) are aimed at using the forecasting tool in the current performance of the enterprise. Such interpretation is conditioned by the electricity market. The forecast is a tool of the electricity market performance. The forecasting problem is highlighted, for example, in the works of the following authors: Nagasaka K, Mamun M. A., Hobbs N. J., Kim B. H., Lee K. Y., Mao H., Zeng X., Leng G., Zhai Y., Keane J.

The load curve of a water facility is characterized by stable cycles with the typical changes of energy consumption during the day (morning and evening peaks and the night minimum demand) and also during the week (the load decrease during the weekend due to the absence of water consumption).

The first step of any forecasting is the source data analysis. The signal noiseness and random components, that have no value for formation forecast model, are excluded by special prepare the source data. It can be wavelet-analysis method, which is currently one of the most advanced data analysis technology. Figure 4 shows the result of the wavelet decomposition. The fundamentals and the possibility of use wavelets for the times series forecasting are given in the papers of the following authors: Yao S.J., Song Y.H., Zhang L.Z., Cheng X.Y., Smolentsev N.K, Yakovlev A.N., K. Blatter, Daubechies, Mallat S., Vorobyev V.I., Gribunin V.G.

The results of Ljung-Box Q-test indicate that the source data is not random variables and the energy consumption forecasting is possible. The method of neural networks with the exposure into a neural network logical basis was chosen as the forecasting method [4–8]. The time frame was provisionally divided into 3 equal sequences to make independent forecasting. Thus, the range of valid values is formed, where the forecast value is determined by laws of the fuzzy logic [9].

The network structure is the three-layer neural network with the following parameters: $v=3$ is each value of the fuzzy variables, $n=v \cdot w=12$ is the number of the first layer neurons, $m=9$ is the number of the second layer neurons, $k=v=3$ is the number of the third layer neurons, 67 is the number of stages for the model adaptation [10].

Figure 5 shows the result of forecasting with the precision up to 0.55%.

When the enterprise operating at the sixth price category, the obtained accuracy of forecast save 1426 rubles a month, which is 0.1% of the total value of the payment.

The most efficient instrument to reduce the energy charge for an enterprise is a joint accounting of energy efficiency of both the technological process level and the production control level.

Water supply organizations are characterized by a steady load profile of water draw-off which is well correlated with the energy consumption curve. The reduction of correlation, including the reduction of the power demand during peak hours in the region is achieved by using the forecasting tool. The energy consumption reduction is efficient, when the medium-term forecasting characteristic of water draw-off is known and the electric drive of the pump operates without taking account the received perturbation influence by the sensor of the water supply system and chooses the optimal control trajectory of the reservoir filling point.
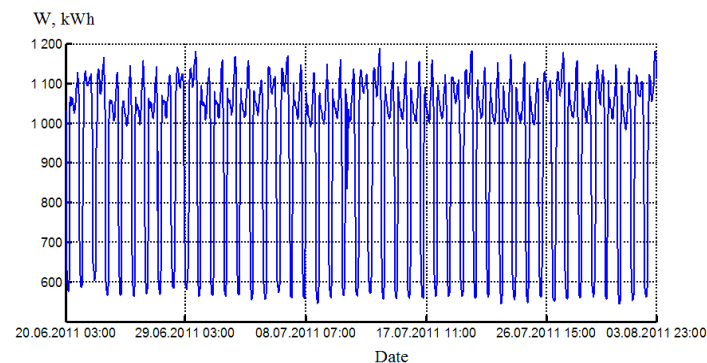

Figure 4. The reconstructed time frame of the load curve of the 3rd elevation pumping station

Operational changes of the pumping unit occur when the forecasting tool and optimizer are implemented in a typical control circuit with the variable frequency drive. But it depends on the cost of energy for every hour and under condition of keeping the customer load curve (in this case, peak standby boiler plant). It can be achieved through using a service water reservoir at the peak standby boiler plant, which storages water at minimum energy cost hours and yields it on the needs of a customer at maximum water draw-off hours.
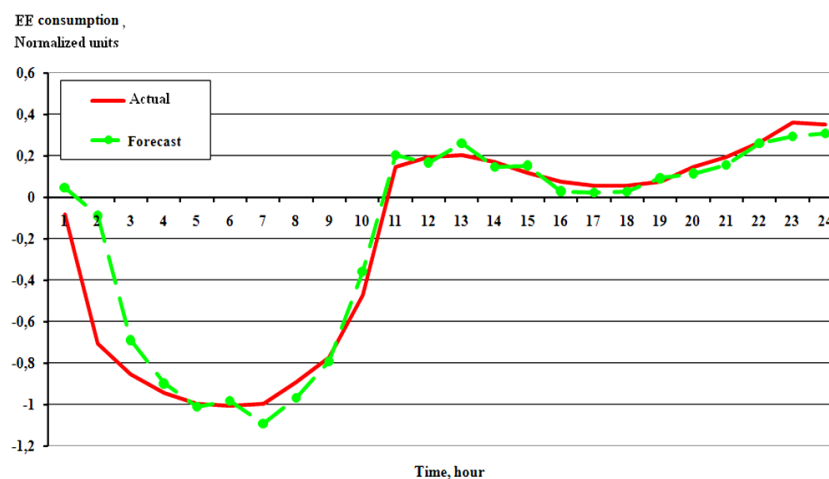

Figure 5. The result of the energy consumption forecasting by a method of the neural network.

As the result, the purchase amount of energy and power at maximum price decreases and the share of purchase at minimum price increases. The load change takes place by optimizer at maximum energy cost hours and peak value of capacity (08:00).

Optimization results depend on the control method of the pumping unit are shown in the Table 2. By the results of research, the conclusion that forecasting optimization of the 3rd elevation pumping station performance has resulted in the reduction of power costs, but at the same time power requirement is not decreased (406.37 kWh), but also decreased (411.2 kWh). There is no efficiency on

the technological process level, however, at the production level the efficiency of this regulation (the reduction of the energy purchase costs) is 26%.

Table 2. Electrical energy cost and consumption

Control method	Energy consumption per calendar day, [kWh]	Power costs per day, [rubles]
Varying the speed of a pump	406.37	1180.70
Varying the speed of a pump based on optimization function and consumption forecast	411.20	870.58

5. Conclusion

The results obtained attest to the forecast-optimization control in combination with the pricing policy allow to reach significant fund savings up to 60% in terms of peak power values and up to 12% in terms of the energy cost. Based on the experimental data it can be concluded, that the methods engineering of forecast-optimization control of water-supply engineering tract equipment including level-to-level relationship of control eliminates correlation between the load curve of the peak standby boiler plant and 3rd elevation pumping station and the methods engineering sets new relations between the change of the tariff rate and the pumping unit operating mode. The scope of application of forecast-optimization control is enterprises with a nonuniform load profile and a possibility of storing the product (water, gas) [11]. The time differentiation of energy rates is the necessary condition.

References

[1]   *About Functioning of the Retail Markets of Electric Energy, Full and (or) Partial Restriction of the Mode of Consumption of Electric Energy* (approved by the Government of the Russian Federation, an edition from 26/12/2016 No. 442) Retrieved from http://www.consultant.ru/document/cons_doc_LAW_130498/ (in Russian)

[2]   Bethoux O *et al* 2017 *Electric Power Systems Research* **142** 176–189 10.1016/j.epsr.2016.09.014

[3]   Leznov B S 2006 *Energy Saving and Controlled Drive in Pump Sand Blowing Machinery* (Moscow: Energoatomizdat) (in Russian)

[4]   Narayan S *and* Smyth R 2015 The financial econometrics of price discovery and predictability// *International Review of Financial Analysis* **42** Pages 380–393 DOI: 10.1016/j.irfa.2015.09.003

[5]   Lin C T *and* Lee C S G 1994 *Supervised and unsupervised learning with fuzzy similarity for neural-network-based fuzzy logic control systems* (New York: Van Nostrand Reinhold)

[6]   Homik K *et al* 1989 *Neural Networks* **2(5)** 359–366

[7]   Zadeh L A 1965 *Information and Control* **8(3)** 338–353 DOI: 10.1016/S0019-9958(65)90241-X

[8]   Costa T V *et al* 2009 *Computer Aided Chemical Engineering* **27** 1407–1412 DOI: 10.1016/S1570-7946(09)70625-X

[9]   Giuliani M *et al* 2016 *Environ Model Softw* **85** 293–298 DOI: 10.1016/j.envsoft.2016.08.015

[10] Babinovich D E *and* Shutov E A 2014 *WIT Transactions on Ecology and the Environment* **190** 501–510 DOI: 10.2495/EQ140481

[11] Sumarokova L *et al* 2016 *MATEC Web of Conferences* **92** 01025 DOI: 10.1051/matecconf/20179201025