Energy Consumption Forecast Procedure for an Industrial Facility

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Abstract—We regard forecasting of energy consumption by private production areas of a large industrial facility as well as by the facility itself. As for production areas, the forecast is made based on empirical dependencies of the specific energy consumption and the production output. As for the facility itself, implementation of the task to minimize the energy consumption forecasting error is based on adjustment of the facility's actual energy consumption values evaluated with the metering device and the total design energy consumption of separate production areas of the facility. The suggested procedure of optimal energy consumption was tested based on the actual data of core product output and energy consumption by a group of workshops and power plants of the large iron and steel facility. Test results show that implementation of this procedure gives the mean accuracy of energy consumption forecasting for winter 2014 of 0.11% for the group of workshops and 0.137% for the power plants.

Keywords—Energy consumption, energy consumption forecasting error, energy efficiency, forecasting accuracy, forecasting.

I. INTRODUCTION

CURRENT electric load forecast procedures are usually based on statistical analysis of temporary periods of energy consumption. The problem is that only external factors with influence on energy consumption are being analyzed for a consumer [1]-[6], [8], [9]. These are ambient temperature, clouds, day length, weekday, extraordinary events, planned energy-intensive production on/off etc. Such approach gives relatively accurate results as to large consumers, for example, industrial sector, housing and utilities service, illumination load etc. The accuracy of this approach is not so high for a single consumer. Exact energy consumption forecast for the industrial facility demands analysis of the internal production.

Energy consumption rate setting and forecasting shall be implemented by detailed analysis of energy consumption by private production areas as well as by energy consumption rate setting and forecasting procedures of the facility as a whole. Thereunder, this work contains the procedure of error minimization as to energy consumption rate setting and forecasting based on the implementation of two following tasks [10], [15]-[17].

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II. ENERGY CONSUMPTION FORECASTING FOR PRODUCTION AREAS OF THE FACILITY

Industrial facilities usually have data on the results over the recording period (e.g., month) regarding production output and actual energy consumption for every type of products in accordance with the adopted energy accounting structure for production areas. Based on this data we can make rate setting of specific energy consumption using [7]:

$$w_{it} = \frac{W_{it}}{\Pi_{it}}, \quad i \in [1; N_p], \quad t \in [1; N_t],$$

where, w_{it} – specific energy consumption of the i-th production area for the t-th period of time; W_{it} – total energy consumption by the i-th area; P_{it} – production output made by the i-th area; N_p, N_t – number of production areas and periods of time, respectively.

There is an empirical connection between the specific energy consumption and the production output made by the facility's production area. The general equation is as:

$$w_i = f(\Pi_i).$$

The analysis of statistics on production outputs and relevant specific energy consumptions revealed that the following exponential relation most accurately shows the real connection between production outputs and specific energy consumptions [16]:

$$w_i = \exp(a_{i0} + a_{i1}\Pi_i), \tag{1}$$

where, a_{i0}, a_{i1} – coefficients determined for every relation (for every facility's production area).

Empirical dependencies (1) can be made, for example, by the least square method.

Seasonality should be taken into account to improve accuracy (1). Thus, it is enough for our geographic area to separate winter (the 1st and the 4th quarters) and summer (the 2nd and the 3rd quarters) periods. Then, regarding production areas, energy consumption for terminal point T can be forecasted based on the received dependencies (1) as:

$$W_{iT}^{\text{exp}} = w_i p_{iT}^{pl},$$

where W_{iT}^{exp} - expected energy consumption; p_{iT}^{pl} - planned production.

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III. OPTIMAL ENERGY CONSUMPTION FORECASTING FOR THE WHOLE FACILITY

Optimal energy consumption forecasting for a large industrial facility as a whole should be considered as the task to minimize general error in energy consumption forecasting [13], [14].

Regarding the large industrial facility as a whole the mentioned task can be implemented based on adjustment of the actual total energy consumption values by the facility W_0^{act} determined upon readings of the metering device and total estimate energy consumption W_0^{rat} of separate production areas of the facility.

General quadratic criterion is as:

$$Q_E = (1-\alpha)E_0^2 + \alpha\sum_{i=0}^{Np}\left(a_i - a_i^n\right)^2 \to \min \quad (2)$$

$$E_0^2 = M_t\left\{\left(W_{0t}^{act} - \sum_{i=0}^{Np} a_i W_{it}^{rat}\right)^2\right\}, \; W_{it}^{rat} = 1 \text{ at } i = 0, \quad (3)$$

where, E_0 - general error; a_i - correction coefficient; a_i^n - rated values of correction coefficients: $a_0^n = 0$, $a_i^n = 1$; $a \in [0; 1]$ - regulating factor; $M_t\{\cdot\}$ - mathematical expectation; W_{it}^{rat} - rated value of energy consumption by the i-th production area.

The task (2) can be implemented by the following combined equations:

$$(1-\alpha)\sum_{j=0}^{Np} c_{ij}a_j + \alpha a_i = (1-\alpha)d_i + \alpha a_i^n, \; i\in\left[0; \; N_p\right] \quad (4)$$

where

$$c_{ij} = M_t\left\{W_{it}^{rat}W_{jt}^{rat}\right\};$$
$$d_i = M_t\left\{W_{0t}^{act}W_{it}^{rat}\right\}.$$

Combined equations (4) can be solved, for example, by Gauss method. The result of the solution of the combined equations (4) includes the values of a_i correction coefficients for every i-th production area.

The expected energy consumption by the whole facility W_{0T}^{exp} for terminal point T can be determined using the following a_i correction coefficients in accordance with:

$$W_{0T}^{exp} = \sum_{i=0}^{N_p} a_i W_{iT}^{exp}$$

where W_{iT}^{exp} - expected value of energy consumption by the i-th production area for terminal point T.

IV. DATA SELECTION WHEN MAKING FACTOR RELATIONSHIPS

Statistic data, got not through the active experiment under control but under industrial conditions determined by sizable fluctuations in production output, other production factors different by intensity, go through mathematical processing to make facility's energy consumption forecasting. Thus, to get a_i correction coefficients by the following factor dependency:

$$W_{0t}^{act} = \sum_{i=0}^{Np} a_i W_{it}^{rat} \quad (5)$$

Data should be initially selected from total statistics.

Data is selected to find out the most relevant data subsystem where the forecasting error σ_{pr} is the minimum at the accepted value of the restoration error E_0.

Factor dependency generation aspects are considered in details in the texts, for example, by [11], [12].

V. TEST CALCULATIONS FOR THE GROUP OF WORKSHOPS OF THE IRON AND STEEL FACILITY

The designed procedure of optimal energy consumption forecasting was tested based on the actual statistics of the following workshops of the iron and steel facility: blast-furnace workshop (BFW), casting, and rolling workshop (CRW) and coke and by-product processing workshop (CBPPW) for the winter period over January 2014 – December 2014.

Data include numerical values of the actual production output of: cast iron (BFW), hot-rolled products (CRW), coke (CBPPW), including actual and estimated specific energy consumption for production of the mentioned items based on the connections between the specific energy consumption and the production output.

When making factor dependencies data should be selected from total statistics. The values of energy consumption forecasting errors and restoration errors were recorded when selecting data on production output and energy consumption by the group of workshops (BFW, CRW, CBPPW). The dependency diagrams of the energy consumption forecasting error σ_{pr} for winter 2014 and the restoration error E_0 for the winter p energy consumption forecasting error σ_{pr} period 2014 are given in Fig. 1.

The numerical values of a_i correction coefficients for every forecasted month of the winter period January 2014 – December 2014. got at the minimum value of the forecasting error σ_{pr} are given in Table I.

TABLE I
CORRECTION COEFFICIENTS

Coefficients	January 2014	February 2014	March 2014	October 2014	November, 2014	December 2014
a_0	-73950	-228359	-73950	-73950	-1691697	-1099147
a_1	0,845	0,829	0,845	0,845	0,834	1,058
a_2	0,994	0,997	0,994	0,994	0,995	1,000
a_3	1,035	1,040	1,035	1,035	1,039	1,036

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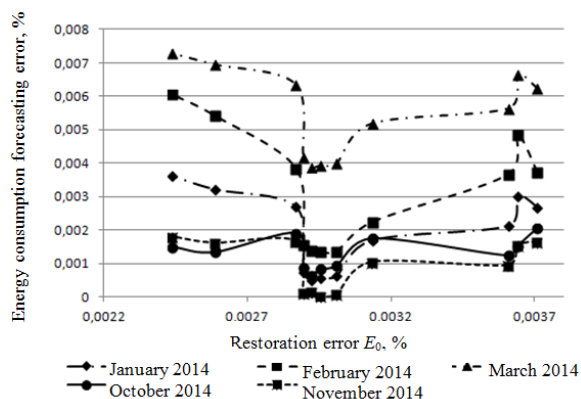International Journal of Economics and Management Engineering
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Fig. 1 Dependency diagrams of the energy consumption forecasting error σ_{pr} and the restoration error E_0

The forecast accuracy of energy consumption E should be determined using:

$$E = \frac{|W_0^{act} - W_0^{exp}|}{W_0^{exp}} \qquad (6)$$

Numerical values of the actual W_0^{act} and the expected W_0^{exp} energy consumption, as well as the forecasting accuracy E for the group of workshops (BFW, CBPPW, CBPPW) for the winter period of 2014 are given in Table II.

TABLE II
ENERGY CONSUMPTION FORECAST ACCURACY FOR THE GROUP OF WORKSHOPS

Value	January 2014	February 2014	March 2014	October 2014	November, 2014	December 2014
W_{0t}^{act}	66239125	62639900	65886029	67776157	66599444	65147179
W_{0t}^{exp}	66272201	62724482	66141253	67819960	66598437	65128805
E	0,00050	0,00135	0,00386	0,00065	0,00002	0,00028

The mean accuracy E_{mean} for winter 2014 of the energy consumption forecasting is determined using:

$$E_{mean} = \frac{\sum_{t=1}^{m} E_0}{m}, \qquad (7)$$

where m – number of months.
After we insert values from Table II into (7), we get:

$$E_{mean} = \frac{0,00665}{6} = 0,0011.$$

The results show that when we use the optimal forecast procedure developed by the authors, the mean accuracy of the energy consumption forecasting for the group of workshops (BFW, CBPPW, CBPPW) of the iron and steel facility for winter 2014 is 0.11% that is enough for practical use.

VI. TEST CALCULATIONS FOR POWER PLANTS OF THE IRON AND STEEL FACILITY

The designed procedure of optimal energy consumption forecasting was also tested based on the actual statistics of the power plants of the iron and steel facility; these are: combined heat and power plant (CHPP), central power plant (CPP) and steam power plant (SPP) for the winter period over January 2014 – December 2014.

Data include numerical values of the actual production of: electric energy, heat with main stream, heat with hot water, for chemical water treatment, and estimated energy consumption for production of the mentioned items based on the dependencies of the specific energy consumption and the production output.

The values of energy consumption forecasting errors and restoration errors were recorded when selecting data on production output and energy consumption by the power plants (CHPP, CPP, SPP). The dependency diagrams of the energy consumption forecasting error σ_{pr} for winter 2014 and the restoration error E_0 for the winter period 2014 are given in Fig. 2.
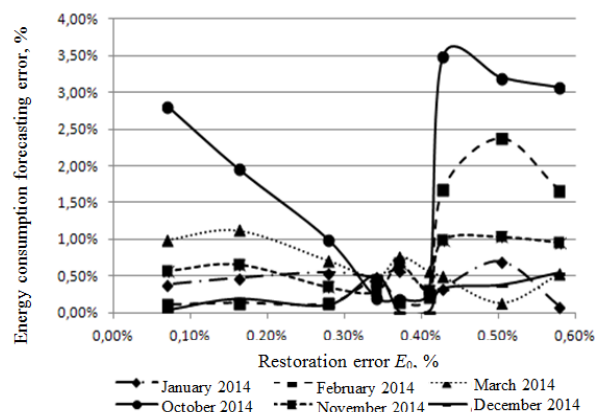

Fig. 2 Dependency diagrams of the energy consumption forecasting error σ_{pr} and the restoration error E_0

The numerical values of a_i correction coefficients for every forecasted month of winter period 2014 got at the minimum value of the forecasting error σ_{pr} are given in Table III.

Energy consumption forecasting accuracy should be determined with (6). Numerical values of the actual W_0^{act} and the expected W_0^{exp} energy consumption, as well as energy consumption forecasting accuracy E for the power plants (CHPP, CPP, SPP) over the winter period 2014 are given in Table IV.

The mean accuracy E_{mean} for winter 2014 of the energy consumption forecasting is determined using the (7). Inserting the numerical values from Table IV into (7), we get:

$$E_{mean} = \frac{0,00824}{6} = 0,00137.$$

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The results show that when we use the optimal forecast procedure developed by the authors, the mean accuracy of the energy consumption forecast for the power plants (CHPP, CPP, SPP) of the iron and steel facility for winter 2014 is 0.137% that is enough for practical use.

TABLE III
CORRECTION COEFFICIENTS

Coefficients	January 2014	February 2014	March 2014	October 2014	November, 2014	December 2014
a_0	3611352	7626642	4840511	3884406	4788999	3884406
a_1	0,78	0,77	0,71	1,23	0,91	1,23
a_2	3,35	0,85	3,59	1,42	0,84	1,42
a_3	1,25	0,90	1,22	1,18	0,96	1,18
a_4	-13,81	-13,68	-18,88	-16,26	-12,07	-16,26
a_5	1,18	2,52	1,22	1,91	1,61	1,91
a_6	2,06	1,52	1,88	1,38	1,57	1,38
a_7	1,11	1,53	0,98	1,02	1,05	1,02
a_8	-0,05	0,10	-0,25	-0,96	-0,63	-0,96
a_9	0,63	0,63	2,59	-2,34	-1,93	-2,34
a_{10}	2,55	2,43	2,48	2,10	2,25	2,10
a_{11}	-1,18	-0,74	-1,03	-0,19	0,34	-0,19
a_{12}	-1,40	-0,52	-1,12	-0,41	-0,02	-0,41
a_{13}	-4,62	0,32	-3,05	-1,09	2,67	-1,09

TABLE IV
ENERGY CONSUMPTION FORECASTING ACCURACY FOR THE POWER PLANTS

Value	January 2014	February 2014	March 2014	October 2014	November, 2014	December 2014
W_{0t}^{act}	57102442	52733380	54346738	53617004	53117158	56339097
W_{0t}^{exp}	57051796	52791472	54275303	53719231	52964369	56347535
E	0,00089	0,00110	0,00132	0,00190	0,00288	0,00015

VII. CONCLUSIONS

Energy consumption by private production areas of the industrial facility is forecasted based on the empirical dependencies of the specific energy consumption and the production output.

Energy consumption forecasting of a large industrial facility as a whole should be considered as the task to minimize the general energy consumption forecasting error. Implementation of this task is based on adjustment of the actual total energy consumption values determined with the metering device and the rated total energy consumption of separate production areas of the facility.

To make factor dependencies based on the actual statistics during energy consumption forecasting, data should be selected from the total statistics to find out the best relevant data subsystem where the forecasting error is the minimum at the accepted restoration error value.

The energy consumption forecasting procedure was tested based on the actual data on production of the main types of products and energy consumption by the group of workshops (BFW, CBPPW, CBPPW) and the power plants (CHPP, CPP, SPP) of the iron and steel facility. The test results show that the mean energy consumption forecasting error for the group of workshops is 0.11% over the winter period 2014, for the power plants – 0.137% that is enough for practical use of

energy resource forecasting.

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