Modeling of power consumption by nonlinear inertial production

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***Abstract*—It is impossible to determine the optimal operating conditions without any scientific substantiation for some nonlinear productions described as slow-response, nonlinear and closed. The simplified dynamic model of production which is able to evaluate the capacity of energy consumption as at static as well as at transitional conditions has been introduced. Some recommendations to solve problems of leveling traffics of electric load have been given for this kind of industry.**

Keywords— modeling, alumina production, power consumption, planning, electric load.

I. INTRODUCTION

In power industry there are two serious problems in connection with functioning of power-consuming industries: the first problem is definition of its power consumption, the second one is a choice of its functioning mode for the purpose of ensuring uniformity of the production schedule of a power supply system as a whole. It is obvious that the solution of these tasks requires development of the tools based on the knowledge base about production, being a load center, and on modern information technologies[1,2]. Production power consumption entirely depends on its character and an operating mode[3,4,5].

For the linear discrete productions electricity consumption of which is in direct ratio to production, and output to be defined by a ratio:

$$W = \sum_{i=1}^{n} K_i \cdot F_i ,$$

(i – number of an output product, n- quantity of an output product types, Ki – factor of energy consumption for an unit of i-production (КWt·hour), Fi - the volume of i-product) it isn't required to develop difficult models for the solution of power consumption planning problem.

II. MODELING

Absolutely different situation develops for a number of the nonlinear inertial closed productions. In this case even skilled technologists often aren't able to predict, transients of what material flow power and duration can arise upon transition to other modes caused, for example, by change of raw materials factors and how power consumption will change. The energy-intensive alumina production by Bayer method has such features.

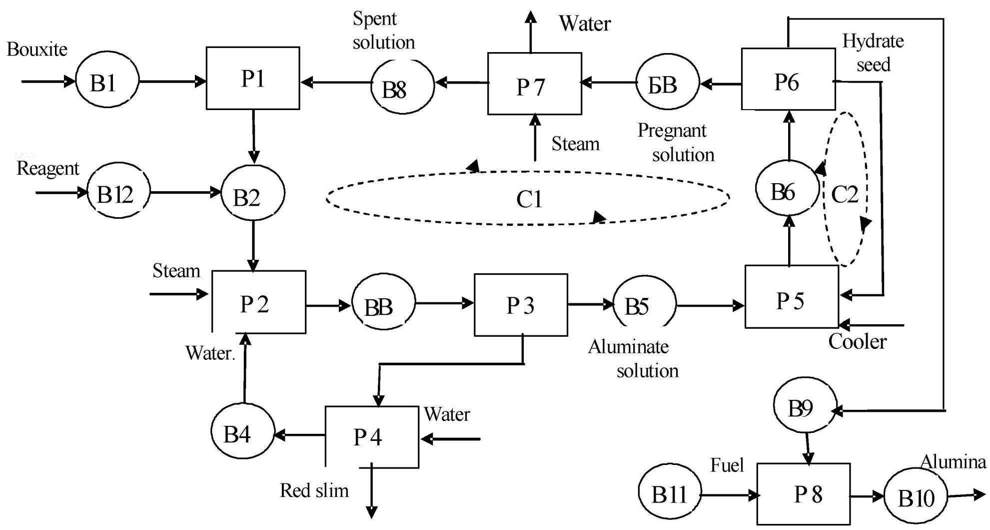

Fig.1. Scheme of aluminous production.

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Alumina is technical aluminum oxide (raw material for electrolytic receiving of aluminum) received on large-capacity continuous productions by the most widespread – Bayer method. The structure of the main transformations of raw materials to a finished product is represented in figure 1. Initial ore is bauxites. In section P1 they are grinded in the presence of reagent (caustic soda). The main stream of reagent arrives with spent liquor.

The obtained bauxite suspension (slurry) is leached by direct steam at high temperature in the section P2. The section P3 the finished slurry is separated into liquid part (aluminate solution) and into solid part (red mud). The red mud is flushed by water in the series of washers (the section P4) and then it is sent into a dump. The rich Al_2O_3 solution comes to the sections P5-P8 for the inverse process: aluminium oxide's exsolution. The counterreaction of the solution decomposition in line of sequentially connected reactors (the section P5) is carried out at cooling of solution with catalyst: small crystals of return seed aluminium hydroxide $Al(OH)_3$. The obtained hydrate slurry is separated into tree parts: pregnant solution, fine seed hydrate, and coarse production hydrate. Pregnant solution, which is relatively poor in aluminium oxide, is evaporated to the required condition in the evaporating stations (the section P7). The production hydrate is baked in furnaces in the final section P8.

The sections are separated by buffer tanks B1-B8. The B1 and B9-B12 are storages. The technological cycles of alkali containing (C1) and seed hydrate (C2) are shown by dashed ovals on the flow diagram.

Production model development is based on the following facts: the hydrochemical production itself by Bayer method has a number of features – this production has a strong non-linear, inertia and the closed nature (reversible flows are ten times bigger than direct once, buffer tanks are small). Therefore experience of model development based on regression analysis is not applicable in this case. The task of modeling was solved by using a simplified deterministic production model based on the equations of stationary material balance.

Under modeling the whole production process (fig. 1) was divided in eight units I-VIII (fig. 2). Modeling of units I-IV, VI-VII is based on nonlinear algebraic equations of material balance:

$$\sum_{i=1}^{16} L_{ij} A_i G_i F_i = 0$$

$$\sum_{i=1}^{16} N_{ij} B_i G_i F_i = 0 \quad \sum_{i=1}^{16} H_{ij} G_i F_i = 0 \quad \sum_{i=1}^{16} I_{ij} F_i = 0$$

$$\sum_{i=1}^{16} I_{ij} D_i F_i = 0$$

$$M_i = 1.645 \frac{B_i}{A_i},$$

where Fi- material flows in volume units of measurement, Gi – content of solid phase in the flows, Ai – concentration of liquid phase of Al_2O_3, B_i – concentration of caustic soda (Na_2O_k), D – flux density, M – so-called caustic ratio of the solution, Lij, Nij, Hij, Iij – show specific nonlinear transformations for each of i-th flow at the inlet (output) of j-th unit, including the sign (positive for the input and negative for the output stream).

The V unit shows the sequence of N units, which imitate the dynamics of solution decomposition in decomposers. The dynamics of decomposition was modeled under the assumption of ideal mixing process of hydrate slurry in decomposer. *So* the volume V_D of the each n-th ideal device and their number N_D in circuit became parameters for model identification: to achieve the same duration and form of transient processes derived by model and observed by experts in practice in sum on the output of multiple parallel lines of consistently working decomposers. Practice existing regularities of temperature change along the devices lines were approximated by quadratic dependences.

As a result the model of each n-th device looks like this:

$$G_n^* = 1 - \frac{G_n}{2.43}$$

$$F_{n-1} = F_n + 0.53 \cdot V_D \cdot V_{Vn} \cdot G_n^*$$

$$V_D \frac{d}{dt} \cdot G_n = F_{n-1} \cdot G_{n-1} - F_n \cdot G_n + 1.53 \cdot V_D \cdot V_{Vn} \cdot G_n^*$$

$$V_D \frac{d}{dt} \cdot G_n^* \cdot A_n = F_{n-1} \cdot G_{n-1}^* \cdot A_{n-1} - F_n \cdot G_n^* \cdot A_n - V_D \cdot V_{Vn} \cdot G_n^*$$

$$V_D \frac{d}{dt} \cdot G_n^* \cdot B_n = F_{n-1} \cdot G_{n-1}^* \cdot B_{n-1} - F_n \cdot G_n^* \cdot B_n$$

$$V_{Vn} = -U_D K_1(B_n, T_n) K_2(X_{30}, S_{30}) \frac{(A_n - A_E(B_n, T_n))^2}{A_E(B_n, T_n)^2},$$

where F_n – the consumption of hydrate slurry at the output of the n-th device, G_n - the its content of solid hydrate, A_n – the content in liquid phase Al_2O_3, B_n – content in liquid phase Na_2O_k, V_{Vn} – rate of solution decomposition in device, K_1, K_2 – non-linear functions, taking into account the dependence of the V_{Vn} from concentration of the reagent Bn and the temperature Tn in device, the content X_{3o} and surface S_{3o} of seed hydrate particles, A_E – equilibrium concentration Al_2O_3 - nonlinear function Bn und Tn.

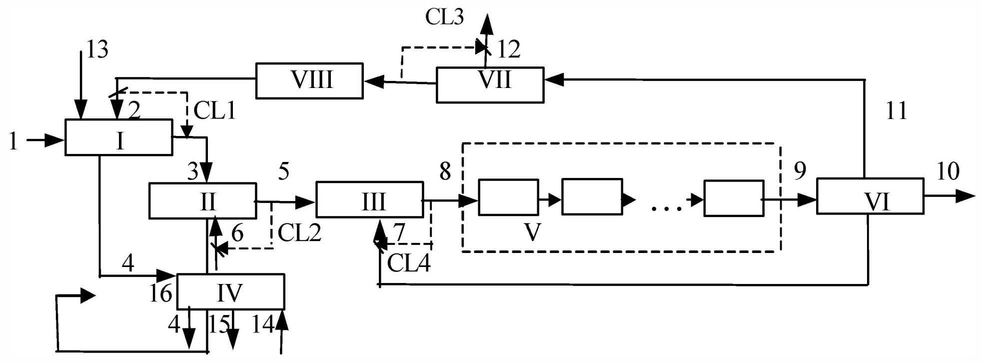

Fig. 2. Structure of power consumption model of alumina production

The unit VIII describes the work of the generalized buffer tank. In alumina production the largest holding capacity has buffer tank of spent liquor, that's why it was modeled as a generalized one:

$$\frac{dV_8(t)}{dt} = F_{11}(t) - F_2(t)$$

As the derived model includes system of nonlinear algebraic and differential equations, which were solved with the help of numerical methods, the error estimation of the model was made. The global solution error was 2.9%, when modeling in period of 100 hours.

The model has the ability to automatically identify under various technological regimes. The specific criterion has been developed for this, which minimization provides the identification of the model:

$$J = \frac{(B_{6*} - B_6)^2}{D[B_6]} + \frac{(M_{5*} - M_5)^2}{D[M_5]} + 5\frac{(M_{2*} - M_2)^2}{D[M_2]},$$

where D[]- variance of the main operational parameters, identifying the model. Index «*» means the parameter value in the extremum point.

The calculation of power consumption is found by using the ratio:

$$W = Ke \cdot \sum_{i=1}^{16} Kei \cdot F_i ,$$

where *Kei* – distribution coefficients of power consumption along the hydrochemical ring (KWt·h/units *F*), their values are determined by the capacity of the drives, pumps, agitators, etc. *Ke* – the correction coefficient, which reflects the share of unaccounted power consumption.

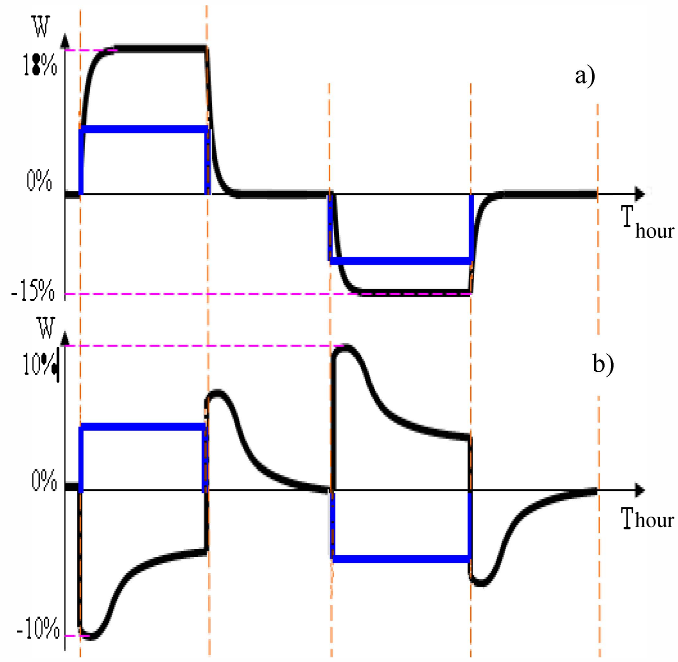

Fig. 3. The reaction of power consumption change W of alumina production at sudden change of technical parameters (the blue chart) regarding the nominal values: M3 (a), content of seed hydrate (b). Division value of the x-axis is 120 hours.

On the fig. 3 there is dynamic impact on the power consumption of production W at sudden change of parameter M3 from +6% to -6%(fig. 3a), the content of seed hydrate from +8% to -8% (fig. 3b). In reality such leaps of parameters change are not observed, it can be explained by the inertia of the ACS, carrying out the technological process. Switch to the other modes is realized by smoother, steady steps.

It is obvious, that for continuous inertial production the task of balance the load of the power system can be solved only for the case of switch to another production mode. Considering the nature of daily (typical curve is characterized by night dips) and weekly load curves (there is gradual increase of the basic and peak power consumption in the energy system by Thursday, and then sharp decline in the weekend), it is recommended to switch to the mode, which requires increasing the load, on Friday night with the idea to fill the fall of curve on the weekend.

Switch to technological mode, resulting in a reduction of the load, is recommended to perform in the middle of the week, thereby reducing irregularity of the weekly load curve. More direct recommendations for leveling load curve can be obtained with the help of proposed model with the definition of actual values of technological parameters.

III. CONCLUSION

The developed model of nonlinear inertial production can serve as the basis of specialized software packages, designed to predict power consumption of such productions.

The proposed method can solve the problems of equalization of electric load for nonlinear production, possessing the properties of the inertia and reticence

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