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The Analysis of Network Models for the Design of Industrial and Fire Safety Systems for Oil Refineries

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Abstract. Tensor network models represent the processes and structure of complex systems, including dangerous technological objects of oil refineries. Complex systems tensor method research based on duality invariance. It is the sum constancy of the metric tensors dual networks whenever there is a change in structure. Dual subspaces closed and unclosed paths are responses to external and internal influences, which do not depend on each other. As an example of a network model is considered the atmospheric column oil-refining plant, which is used to organize the work of training stand. Thermal energy flows are presented in a mesh network, and massive flows of mechanical energy - in a junction network. The amount of mechanical and thermal energy flows allows you to determine the load on the nodes of the unit. The results are applied to predict dangerous situations on refining facilities to assess changes in restructuring processes and the risk of accidents. Calculations, such as heat and mass flow change if you change the control actions, disable installation elements and assess change critical settings.

1. Introduction

Dangerous events and emergencies at the facilities of the oil refining and petrochemical industries can occur when deviations from the routine maintenance of the technological process due to changes in the sources of influence [1-2], changes in the structure of connections (destruction of communications, disconnection of elements, subsystems). To analyze and predict dangerous events, it is necessary to study the consequences of changes in the structure of objects. In this paper, it is proposed to use network models to solve this problem.

In an electrical circuit, voltage sources in the branches are internal influences. Responses, currents arise in the circuits. Calculation of loop currents, and on them the calculation of currents and voltages in the branches, is the solution to the problem. Measurable currents in the branches of a connected circuit, $i^{\beta}{}_{c}$, according to the original sources e_{α}.

2. The features of working with the network model

In an electrical circuit, voltage sources in the branches are internal influences. Responses, currents arise in the circuits. Calculation of loop currents, and on them the calculation of currents and voltages in the branches, is the solution to the problem. Measurable currents in the branches of a connected circuit, $i^{\beta}{}_{c}$, according to the original sources e_{α}.

$$i^{\beta}{}_{c} = {}^{m}C_{\alpha`}{}^{\alpha}{}_{t}\, i^{\beta`} = {}^{m}C_{\alpha`}{}^{\alpha}{}_{t}\, ({}^{m}C_{\alpha`}{}^{\alpha}\, Z_{\alpha\beta}\, {}^{m}C_{\beta`}{}^{\beta}{}_{t})^{-1}\, {}^{m}C_{\alpha`}{}^{\alpha}\, e_{\alpha} \tag{1}$$

The expression in front of the vector e_{α}, we denote by Y_c, is the network solution matrix, which expresses the metric relations when the structure changes:

$$Y_c = {}^{m}C_{\alpha`}{}^{\alpha}{}_{t}\, ({}^{m}C_{\alpha`}{}^{\alpha}\, Z_{\alpha\beta}\, {}^{m}C_{\beta`}{}^{\beta}{}_{t})^{-1}\, {}^{m}C_{\alpha`}{}^{\alpha} \tag{2}$$

Multiplying it by e_{α} allows you to immediately receive responses in the branches of the $i^{\beta}{}_{c}$ network.

Current sources are external influences, they are located outside the circuit and act through the input and output nodes. Responses, voltages arise in open paths. Calculation of these stresses is the solution to the problem.

Stresses in the branches of the circuit, $E_{\alpha}{}^{c}$ according to the actions in the free branches I^{α}.

$$E_{\alpha}{}^{c} = {}^{j}A^{\alpha`}{}_{\alpha t}\, E_{\alpha`} = {}^{j}A^{\alpha`}{}_{\alpha t}\, ({}^{j}A^{\alpha`}{}_{\alpha}\, Y^{\alpha\beta}\, {}^{j}A_{\beta}^{\beta`}{}_{t})^{-1}\, {}^{j}A_{\beta}^{\beta`}\, I^{\beta} \tag{3}$$

The expression before I^{β} is denoted by Z_c, this is the matrix of the solution of the nodal network:

$$Z_c\, {}^{j}A^{\alpha`}{}_{\alpha t}\, ({}^{j}A^{\alpha`}{}_{\alpha}\, Y^{\alpha\beta}\, {}^{j}A_{\beta}^{\beta`}{}_{t})^{-1}\, {}^{j}A_{\beta}^{\beta`} \tag{4}$$

Multiplying it by I^{β} allows you to immediately get responses in the $E_{\alpha}{}^{c}$ branches.

3. Refinery atmospheric column network model

We consider a network model of an oil refining plant (atmospheric column). The input stream is crude oil, which is separated into high-boiling (HB) and low-boiling (LB) fractions during the rectification process. The outlet streams are fractions: gas, gasoline, kerosene and fuel oil. Superheated steam is fed into the unit, which facilitates the separation of fractions.

The danger is caused by the presence of explosive and fire hazardous oil products, as well as substances hazardous to the environment. The rectification process and transportation of hazardous substances through pipelines under pressure and at high temperatures creates the danger of depressurization of the system from overpressure and under the influence of high temperatures [3]. The corrosive activity of oil products also creates the danger of depressurization of the system, violations of the structure of its design. Deviations from the routine operation of the equipment can lead to a sharp increase in pressure, depressurization of the system [4]. The subsequent spill of oil products and gas contamination can cause an explosion and fire, affecting people.

The diagram of the atmospheric distillation column in Fig. 1 shows the main components and assemblies of the installation. This allows you to create a simple 12-branch network model for the main processes in a given installation. The unit model includes an input stream of raw material, heated oil, and the output of the HB fraction, i.e. fuel oil, fractions 290-350°C, as well as two circulating irrigation circuits, which provide the separation of two fractions (kerosene and gasoline), with the withdrawal of the steam-gas fraction. There is also a superheated steam circulation loop for stripping

HB at the bottom of the column. In figure 2 we can see a network model of a distillation column, created using analogies between oil product flows and values in the network. The power of the pumps (pressure) is represented by the voltage sources. The responses are massive flows of petroleum products. Heating from a furnace and cooling in refrigerators, which regulate the flow of thermal energy, are represented by nodal currents. Thermal energy flows are the responses [5]. Node K is considered as a common node in which all flows are balanced, which corresponds to the "grounding" node in the network. Through it, the input stream of oil enters the installation, and the fractions (oil products) separated during the rectification process are returned to it and removed for processing.

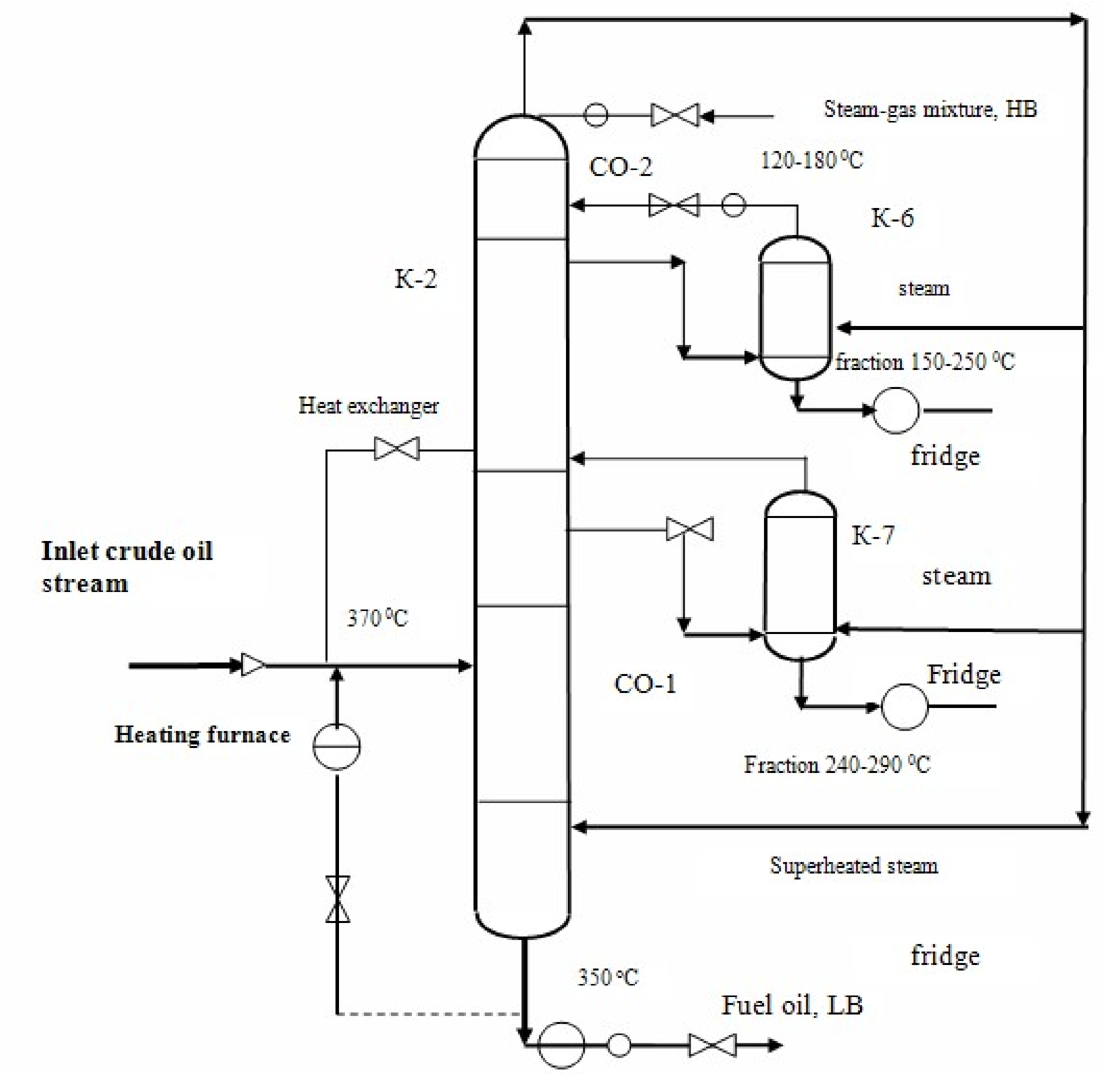

Figure 1. Distillation column diagram. The diagram shows: K2 - distillation column; columns K6 and K7; CO-1 and CO-2 - circulating irrigation.

The structure of the network model in figure 2 contains a superheated steam circuit, as well as two circulating irrigation circuits. Closed and open paths are shown by dotted lines, their numbers are given by numbers with dashes.

The network model of the atmospheric column for primary oil refining is used to analyze potentially dangerous situations associated with outages of parts of the unit; including, for the work of the training stand. It is assumed that with an increase in pressure, the flow of the liquid fraction increases, and with an increase in the heater temperature, the flow of thermal energy increases.

First, the calculation of the operation of the installation in the standard mode is carried out. For this, matrices C and A, solution matrices (2) and (4) are used. The submatrix C defining the contours in the connected network, ^{m}C, is (figure 3).

It provides the calculation of the contour network using the solution matrix (2). In accordance with this formula, we obtain the solution matrix Yc in the form (figure 4).

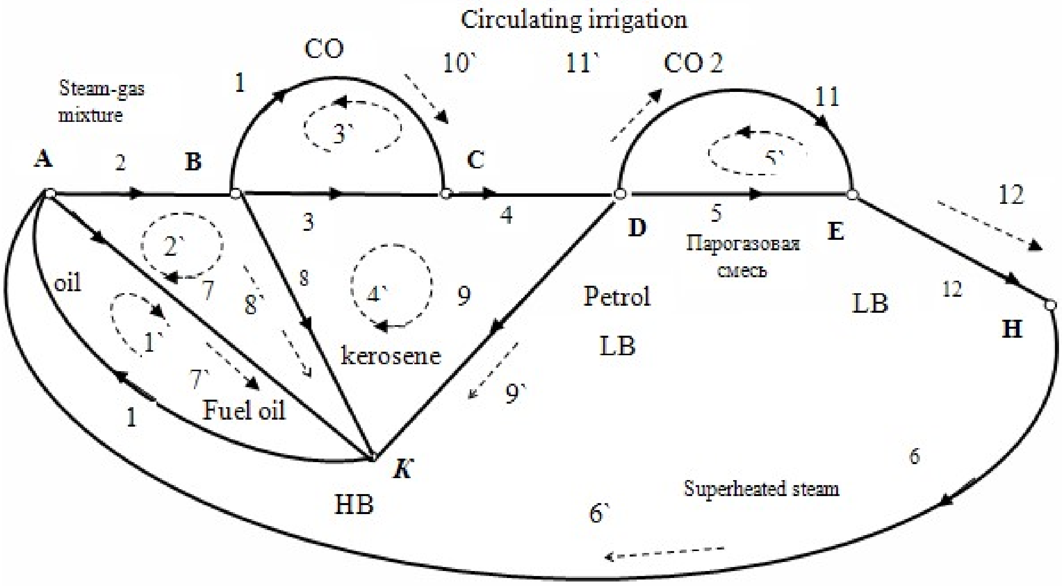

Figure 2. Network model implemented at the stand. Installation of a distillation column with circuits for withdrawing the HB (fuel oil) and LB fractions, as well as two circulating refluxes, a superheated steam cycle. Balancing flows, "grounding", in node K.

	1	2	3	4	5	6	7	8	9	10	11	12	
1`	1	0	0	0	0	0	1	0	0	0	0	0	m
2`	0	1	0	0	0	0	-1	1	0	0	0	0	m
^{m}C = 3`	0	0	1	0	0	0	0	0	0	-1	0	0	m
4`	0	0	1	1	0	0	0	-1	1	0	0	0	m
5`	0	0	0	0	1	0	0	0	0	0	-1	0	m
6`	0	1	1	1	1	1	0	0	0	0	0	1	m

Figure 3. Submatrix *C* defining contours in a connected network, ^{m}C.

	1	2	3	4	5	6	7	8	9	10	11	12	
1	137	41	3	6	-10	-20	76	35	26	3	-10	-20	
2	41	104	18	36	11	22	-41	68	14	18	11	22	
3	3	18	126	39	6	12	-3	-21	27	-87	6	12	1/213
4	6	36	39	78	12	24	-6	-42	54	39	12	24	
5	-10	11	6	12	122	31	10	-1	-19	6	-91	31	
6	-20	22	12	24	31	62	20	-2	-38	12	31	62	

Figure 4. Form of the decision matrix Yc.

The values of the matrix elements should be divided by the determinant value equal to 213. The matrix is symmetric, therefore the first 6 rows are shown.

In the network model used at the stand, the influences are sources of EMF, their counterparts in the installation are pumps that create pressure [6]. The responses are loop currents, currents and voltages on the branches. In a real system, these are flows of oil and oil products in liquid, gas, or vapor-gas phases. Multiplying the solution matrix by the EMF vector, e_α, gives responses, currents $i^\beta{}_c$.

As an example, let's set the vector of sources, multiply the matrix Y_c by it - we get the currents $i^\beta{}_c$. Let the EMF sources have the following meanings (figure 5):

	1	2	3	4	5	6	7	8	9	10	11	12
e_α=	200	0	0	0	0	100	20	40	50	-30	-20	10

Figure 5. The values of EMF souces.

Then the responses, currents $i^\alpha{}_c$ and voltages $e_\alpha{}^c$ in the connected network will become (figure 6):

	1	2	3	4	5	6	7	8	9	10	11	12
$i^\alpha{}_c$ =	138,6	58,5	22,82	15,63	10,61	1,22	81,36	42,86	14,41	-7,18	-9,39	1,22

Figure 6. The values of the currents in the circuit.

The decision matrix can be used to calculate responses to different options for actions by multiplying it by a new vector. For example, the pressure of one of the pumps has increased, it is necessary to calculate how the flows will change, and assess the danger of exceeding the maximum [7] permissible values (MPV). Then assess the accumulation of deviations over time, with an increase in the risk of a dangerous situation leading to an accident (rupture of pipelines, depressurization, product leakage, explosion, fire, etc.).

Similarly, using the solution matrix (4), the nodal currents are calculated as heat fluxes in the branches of the network model [8-9].

To analyze potential threats, it is necessary to consider the integral energy flow, consisting of a combination of mechanical and thermal energy. To monitor the state of the installation, it is necessary to place pressure sensors, temperature sensors, etc. The number of sensors placed is determined by the structure of the network. The reference paths define the locations of the sensors for monitoring the mass and heat flows in the plant nodes. This is necessary to assess the state of the installation in different accidents. The deviations of flows in case of an emergency change in the structure from the values of flows in the standard mode reduces the possibility of flows passing through the structure of the installation. Having received the deviations of the new flows [10-11] from the standard values, it is possible to calculate the rate of accumulation of excess volumes of thermal and mechanical energy, as well as their total values, and determine the period of time during which these values will exceed the MPV and the strength characteristics of the installation units, which is dangerous (figure 7).

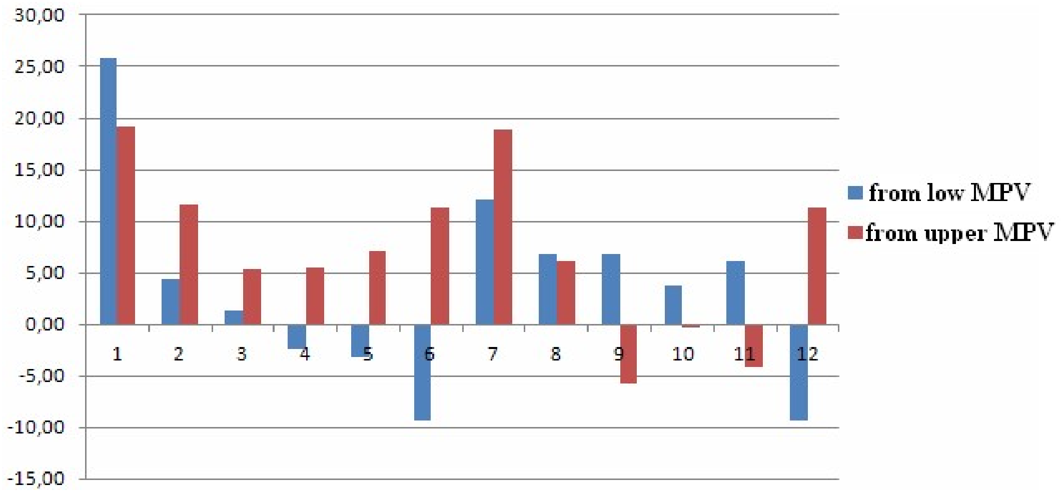

Figure. 7. Deviations of mass fluxes in the sections of the network model (installation) from MPV when the circuit breaks 6` Below the axis - going beyond the MPV, red - dangerous excess of the MPV.

The diagram shows deviations of mass fluxes from MPV (lower ones - in blue, upper ones - in red), which arose as a result of an emergency rupture of circuit 6` (superheated steam) under constant influences.

The diagram clearly shows in which areas there was a deviation from the MPV in the initial period of time, leading to the triggering of the alarm sensors.

The risk of destruction increases over time. The calculation of the standard values of impacts and responses, values for the destruction of node H, an increase in the accumulated difference over time is carried out. The data obtained are summarized in tables that show an increase in deviations from the regulatory values, an increase in the risk of destruction of the installation.

4. Conclusion

The paper demonstrates the possibility of using network models for the design of industrial and fire safety systems for oil refineries. The modeling of the atmospheric column of the oil refining plant, which is used to organize the work of the training stand, has been carried out. The results are applied to predict fire hazardous situations at oil refining facilities.

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