Power consumption analysis of pump station control systems based on fuzzy controllers with discrete terms in iThink software

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Abstract. In this article, power consumption of pumping station control systems is discussed. To study the issue, two simulation models of oil level control in the iThink software have been developed, using a frequency converter only and using a frequency converter and a fuzzy controller. A simulation of the oil-level control was carried out in a graphic form, and plots of pumps power consumption were obtained. Based on the initial and obtained data, the efficiency of the considered control systems has been compared, and also the power consumption of the systems was shown graphically using a frequency converter only and using a frequency converter and a fuzzy controller.
The models analysis has shown that it is more economical and safe to use a control circuit with a frequency converter and a fuzzy controller.

1. Introduction

Research of pumping station control systems at real objects will require large investments, it will be quite long in time, may lead to undesirable consequences, and also interfere with the existing production. For these reasons, a simulation modeling was used for a comparative analysis of pumping station control systems using a frequency converter only and a frequency converter and a fuzzy controller. To develop the simulation model, iThink software by High Performance Systems was used.

The authors set the goal to develop two simulation models of the oil level control system with the presentation of the control process and power consumption in a graphic form, to compare their power consumption and choose the most economical. Also in the model, it is possible to compare control systems by a sharp increase in the amount of oil supplied.

Oil-level control process data and controlled asynchronous electric drive data were used for the model development. The following input data were used: the amount of oil supplied, the initial oil level, the mainline voltage, the functional dependencies of the frequency converter and the asynchronous pump drive (AD).

In the developed model, a comparative analysis of the two control systems behaviour was carried out under identical initial conditions by the sharp increase in the amount of oil supplied and in the pumps power consumption in both cases.

2. Modelling of pump station controlling process

Simulation modelling allows one to apply an abstract model that possesses necessary qualities of the studied original system. Such model does not require as much investment as a real object, can be created much faster, and also reduces the time costs.
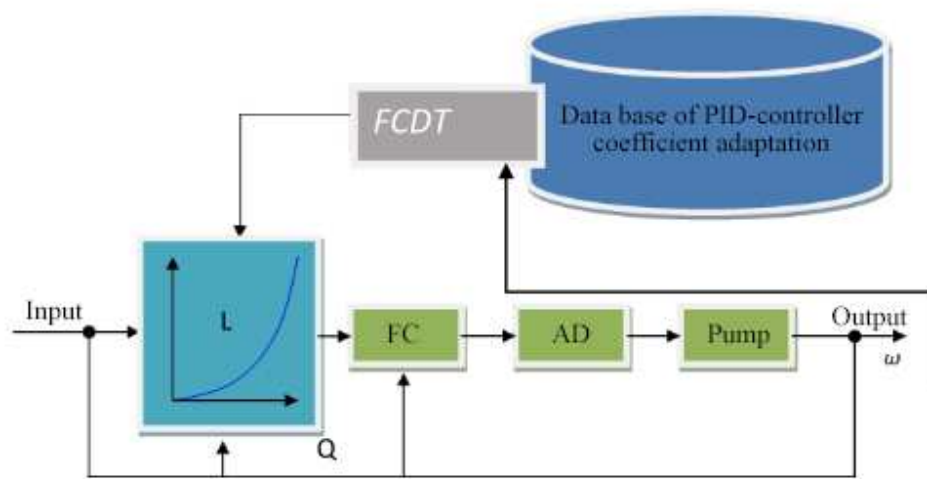

Figure 1. Flow chart of the frequency-controlled asynchronous electric drive with the linearization
unit "Input-output":
FCDT – fuzzy controller with discrete terms, L – oil level, Q – oil consumption.

Figure 1 shows the flow chart of a frequency-controlled asynchronous electric drive (FCED) with a linearization block "Input-output" [1-6]. Linearization is carried out according to the system of production rules.

The adjustable parameters of the pump station (PS) are the level in tank L and the flow rate in the output pipelines of the pumps. The level in the PS tank should be maintained at a level of 2.5 meters (tank height - 5 m, length – 10.2 m and volume 200 m^3) that corresponds to 100 m^3.

The basic model flowchart contains two submodels (frames) with and without a fuzzy controller. The connector links between them reflect the impact of each submodel on the other.

In the "Model" tab, mathematical connections between the blocks are constructed. In this window, there is a flow chart of the model from the built-in blocks, between which interconnections are established by arrow-connectors.

Figure 2 shows the equivalent of the functional structure of the control system of the pumping station electric drives in two ways, created in the iThink software.

The general view of the model contains the input streams «Oil supply», «Oil supply 2» and output streams «Pumps» and «Pumps 2». Flows «Oil supply» and «Oil supply 2» show the total oil flows. «Pumps» and «Pumps 2» are output flows, and discharge out of the tank is carried out with their help. Also in Figure 2 are shown: Tanks «Tank» and «Tank 2»; functional blocks «Amount of oil supplied», «Amount of oil supplied 2», «Power grid», «Power grid 2», «FC», «FC 2», «AD», «AD 2», «Power consumption», «Power consumption 2» and «Fuzzy controller». Functional blocks «Amount of oil supplied», «Amount of oil supplied 2», «Power grid», «Power grid 2» designate previously known production characteristics, «Fuzzy controller» means oil supply control using fuzzy controllers with

discrete terms. The functional blocks «FC», «FC 2», «AD» «AD 2» are a frequency converter and a pumps asynchronous electric drive.

In each block, the parameter values and mathematical formulas of the functional dependence of each element in the given model are prescribed. Formulas and parameter values are set using the standard dialog boxes in the iThink software.
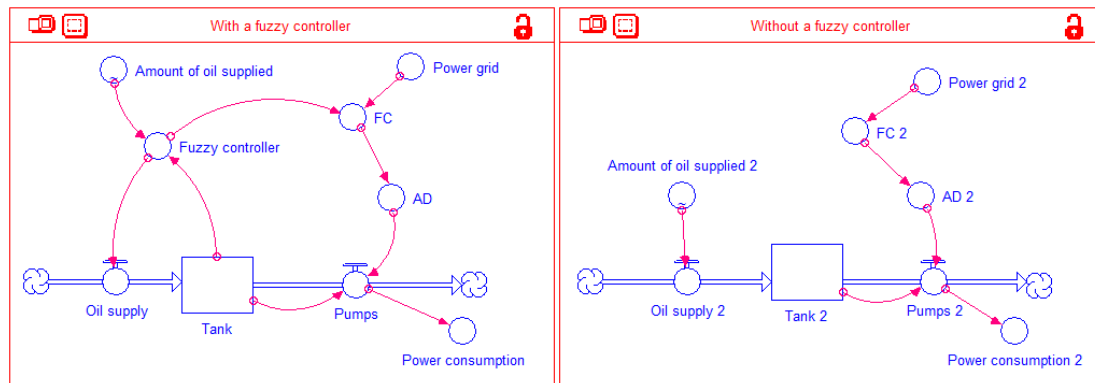

Figure 2. A general view of the two ways model of the pump station control process in the "Model" tab.
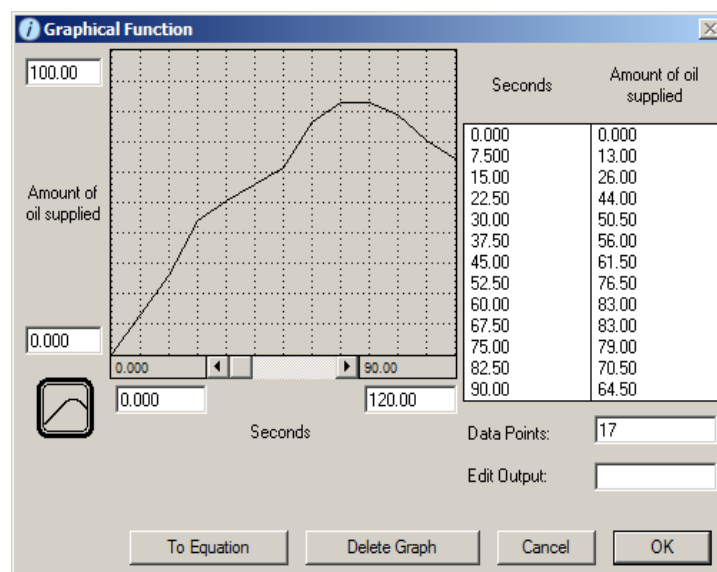

Figure 3. Setting the amount of oil supplied in the Graphical Function window.

The amount of oil supplied is graphically set in the Graphical Function window. The amount of oil supplied plot is shown in Figure 3.

The fuzzy controller selects the degree of pump valve opening on the oil supply line, depending on the amount of oil supplied and the Tank level (Figure 4). The oil supply is set depending on the output signal of the fuzzy controller.

The main power consumer of the pumping station is the electrical drive «AD». The voltage in the power grid as a function of time is given as follows:

Power_grid_2=RANDOM(215,225,1).

The electrical power that comes from the power grid must be converted before the pump's electric drive. This is done using a frequency converter («FC»). The transformation of the electrical power is expressed by the functional dependence:

(Power_grid/8.7)+(Fuzzy_controller^0.9).

The pump operates from an asynchronous electric drive, electric power is supplied to it from the frequency converter. This dependency is specified using the Converter window.
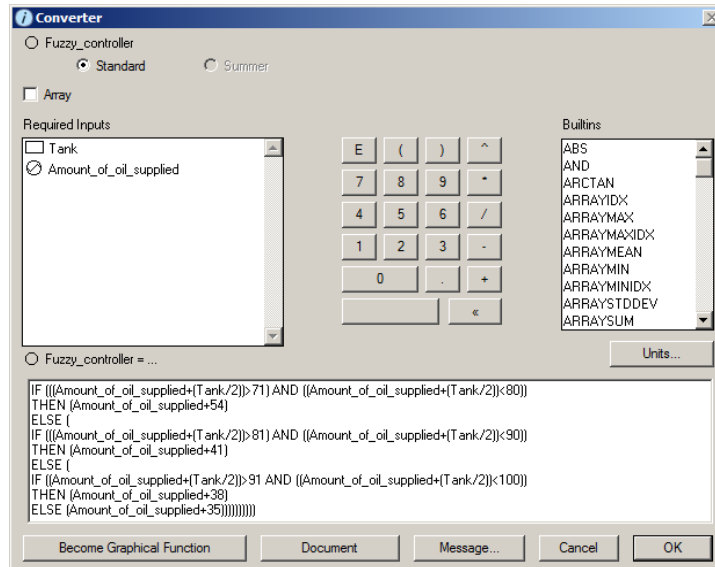

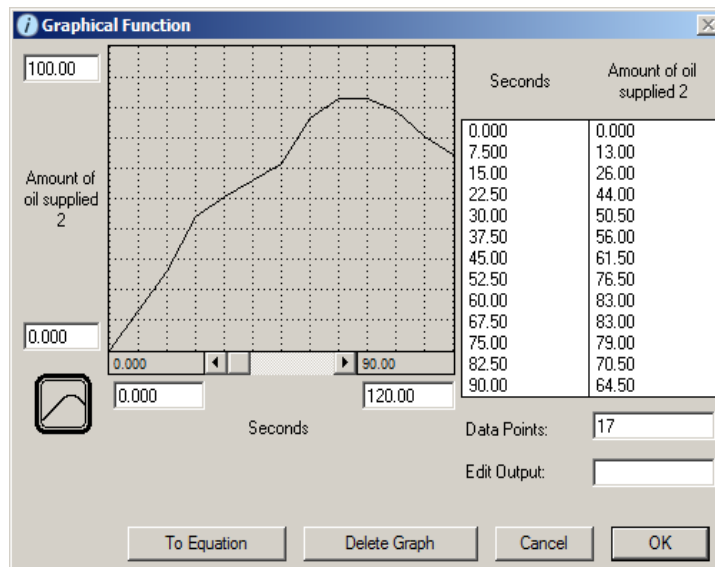**Figure 4.** Setting the fuzzy controller in the Converter window.

Figure 5. Setting the amount of oil supplied in the Graphical Function window.

The initial value of the tank level is set using the Stock window and is zero. The level is controlled and maintained by the fuzzy controller based on the equation, by pumps on inlet pipelines.

The functional dependence of the model element «Pumps» is as follows:

IF (Tank>0 AND Tank<20) THEN (AD-50)
ELSE (IF (Tank>21 AND Tank<40) THEN (AD-35)
ELSE (IF (Tank>41 AND Tank<60) THEN (AD-20)
ELSE (IF (Tank>61 AND Tank<80) THEN (AD-5)
ELSE (IF (Tank>81 AND Tank<100) THEN (AD+5)
ELSE (IF (Tank>101 AND Tank<120)THEN (AD+25)
ELSE (IF (Tank>121 AND Tank<200) THEN (AD+45)

ELSE (IF (Tank>201 AND Tank<300) THEN (AD+90)

ELSE (IF (Tank>301 AND Tank<500) THEN (AD+150)

ELSE (IF (Tank>501) THEN (AD+300)

ELSE ((AD-90))))))))))))

The parameters of the control system using only the frequency converter are shown in Figure 5 and also in the description below.

Data for the flow «Oil supply 2» are taken directly from the «Amount of oil supplied 2» plot: Oil_supply_2=Amount_of_oil_supplied_2.

The initial level in tank 2 is set to zero. The level is controlled and maintained by means of flows «Oil supply 2» and «Pumps 2» for which functional dependencies are defined.

The parameters of the block «Power grid 2» are similar to the «Power grid»: Power_grid_2=RANDOM(215,225,1).

Electric power coming from the grid is converted using a frequency converter «FC 2» according to the following functional dependence:

FC_2=(Power_grid_2/8,7).

The mathematical dependence describing the operation of the asynchronous drive «AD 2» repeats the formula for the asynchronous drive «AD» and is equal to the «FC»: AD_2=FC_2.

The functional dependence of the model element «Pumps 2» is as follows:

Pumps_2 = IF (Tank_2>0 AND Tank_2<20) THEN (AD_2-50) ELSE (

IF (Tank_2>21 AND Tank_2<40) THEN (AD_2-35) ELSE (

IF (Tank_2>41 AND Tank_2<60) THEN (AD_2-20) ELSE (

IF (Tank_2>61 AND Tank_2<80) THEN (AD_2-5) ELSE (

IF (Tank_2>81 AND Tank_2<100) THEN (AD_2+5) ELSE (

IF (Tank_2>101 AND Tank_2<120) THEN (AD_2+25) ELSE (

IF (Tank_2>121 AND Tank_2<200) THEN (AD_2+45) ELSE (

IF (Tank_2>201 AND Tank_2<300) THEN (AD_2+90) ELSE (

IF (Tank_2>301 AND Tank_2<500) THEN (AD_2+150) ELSE (

IF (Tank_2>501) THEN (AD_2+300) ELSE ((AD_2-90))))))))))))

The Equation tab shows all the values of the specified parameters for all function blocks, functional dependencies and other customized parameters.

3. Analysis of the model obtained

Let us carry out a comparative analysis of the developed simulation models. To do this, let us use 4 graphics.

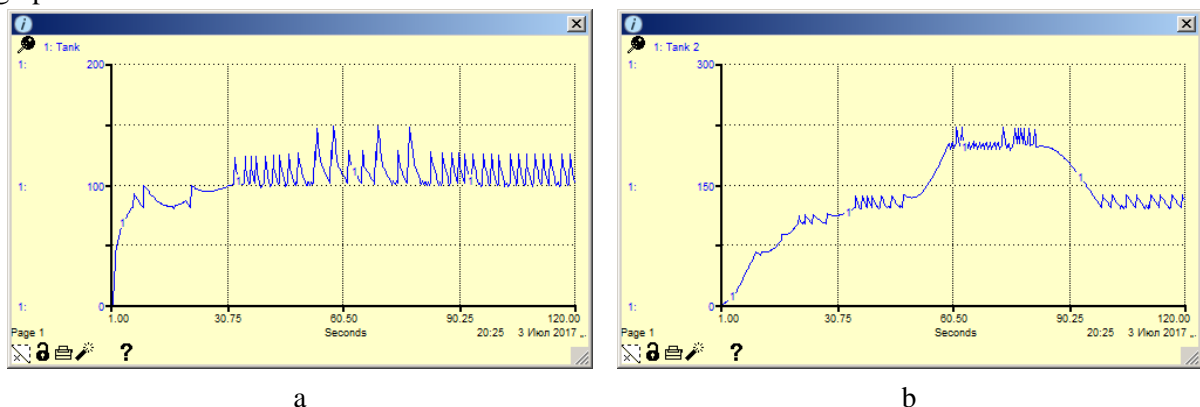a   b

Figure 6. The plot of the oil level versus simulation time: a –using the FC; b - without using the FC.

The plots of the tank level versus simulation time using the fuzzy controller and without using the FC are shown in Figure 6, the level is controlled and maintained at a value of 100 m^3, which corresponds to a height of 2.5 meters of the tank (tank parameters are described above).

The plot in Figure 6, b shows that in a case of sharp increase in the oil supplied to the tank, there is a threat of overflow, as the level reaches a critical value. If the FC is used, levelling is carried out faster, and a sharp increase in the amount of oil supplied does not lead to a critical level values.

Let's compare the power consumption in the circuit with and without the FC, these plots are shown in Figure 7. Power consumption with the FC is lower by an average of 20% compared to the control without the FC. With a sharp increase in the amount of oil supplied to the tank, the power consumption in the circuit with the FC slightly increases, and in the circuit without the FC there is a jump in power consumption.
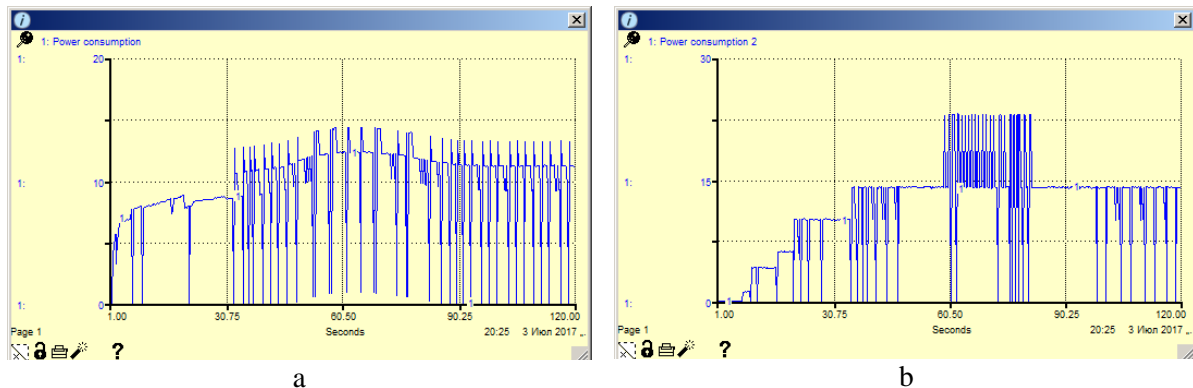

a   b

Figure 7. Plot of power consumption: a – without fuzzy controller; b – with fuzzy controller.

4. Conclusion

The model of the pumping station developed in this work reflects the processes that occur when the oil level is controlled. Two circuits of oil level control and maintenance are considered, using frequency converter only and a frequency converter and a fuzzy controller.

In a system without the fuzzy controller, all other things being equal, a sharp increase in the amount of oil supplied leads to a threat of liquid overflow from a tank. The energy consumption of such system is somewhat higher since for maintaining the level in the tank by pumps on the tank discharge, more energy is expended and a jump in energy consumption occurs.

In case of using the fuzzy controller, the levelling in the tank is much faster, a sharp increase in the amount of oil supplied does not lead to a critical level, with an average power consumption of 20% less than in a system without the fuzzy controller.

Simulation of power consumption has shown that it is more economical and safe to use a control circuit with a frequency converter and a fuzzy controller.

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