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Distillation Column Hierarchical Control Using DeltaV Distributed Control System

Marian Popescu

Petroleum-Gas University of Ploiesti, Bd. București 39, Ploiești
e-mail: mpopescu@upg-ploiesti.ro

Abstract

The paper presents a study regarding hierarchical control of a distillation column. A two level hierarchical system is proposed for the propylene-propane separation column. The first level is represented by the LB control structure and the second level consists of a feedforward control system. At the second level is used the DeltaV distributed system which is configured and programed in order to implement the feedforward control algorithm. The hierarchical system is analyzed using a connection between the simulated process (in SIMULINK environment) and the DeltaV system.

Key words: *distillation column, hierarchical control, DeltaV distributed system, feedforward control*

Introduction

Distillation process is probably one of the most studied processes of chemical engineering in terms of its control. Because of the process complexity, its dimensions and objectives, the control of distillation processes is quite difficult. The evolution of the process, the targets to be achieved in its operation, but also the development of automation equipment allowed the use of hierarchical and distributed systems for distillation processes control.

Binary distillation is characterized, in general, by a feed mixture stream which is separated into two fractions: a top product (distillate) and a bottom product. The control of a binary distillation process refers mainly to composition control of the separated products. The propylene-propane separation process studied in this paper usually has as objectives a fixed value for the top specification (propylene concentration in distillate) and a range of variation for the bottom specification (propylene concentration in bottom product).

Propylene-propane Distillation Column

In this paper, the propylene-propane distillation column has the *LB* structure [8], which means that the top concentration (x_D) is controlled using the reflux flow rate and the bottom concentration (x_B) is controlled by manipulating the bottom product flow rate. The structure is presented in figure 1. Basically, the column can be considered a multivariable system with two inputs (*L* and *B*) and two outputs (x_D and x_B). The disturbances of this system are the feed flow rate (*F*) and the concentration of propylene in feed (x_F).

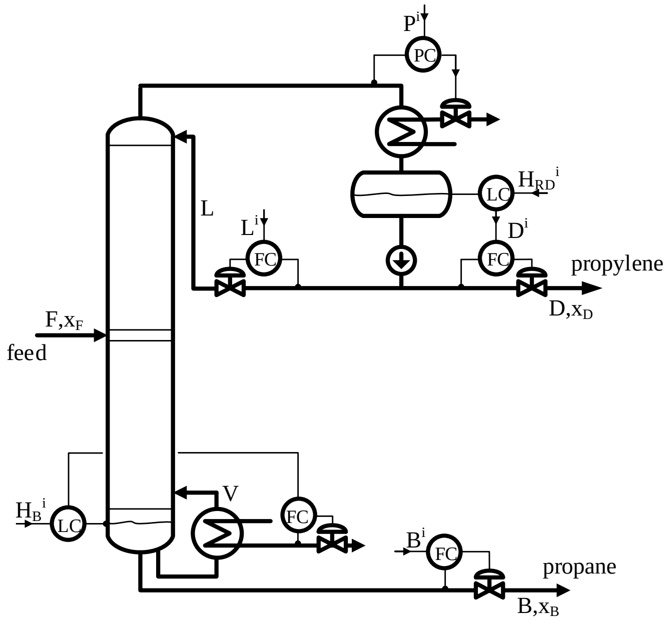

Fig. 1. Propylene-propane distillation column.

In order to study this process a simulator was developed in SIMULINK. The simulator is built around a nonlinear mathematical model [9, 10, 11] which is based on material balances (total and component), equilibrium equations, and hydraulic delays associated to the transport phenomena of vapor and liquid streams. The model considers: constant pressure, constant relative volatility, total condensation, negligible vapor holdup, constant molar flows etc.

From the simulations of the column it was observed that the two disturbances have an important effect on the concentrations of the separated products [4]. This implies that the control system for this column should be a feedforward control system.

Proposed Hierarchical Control System

The proposed control system is a hierarchical one with two levels as it can be seen in Figure 2.

At the first hierarchical level is the column with the conventional automation (*LB* structure) and the second hierarchical level is represented by the feedforward control system.

The feedforward controller (FFC) has as inputs the values of the two disturbances (*F* and x_F), the values of the set-points for x_D and x_B, and as outputs the set-points for the reflux and bottom product flow rates control systems.

From the two disturbances (*F* and x_F), the feed flow rate presents higher variance and with greater frequency than the concentration x_F. Taking this into consideration, in the following study will be analyzed the system behavior only to changes of *F*.

At the second hierarchical level is implemented an algorithm which uses Fenske-Underwood-Gilliland (FUG) relations [1, 2, 3, 12]:

$$B = F \cdot \frac{x_D^i - x_F}{x_D^i - x_B^i}; \tag{1}$$

$$\theta = \frac{\alpha}{x_F(\alpha - 1) + 1}; \tag{2}$$

$$N_{min} = \frac{ln\left(\frac{x_D^i}{1-x_D^i}\cdot\frac{1-x_B^i}{x_B^i}\right)}{ln\ \alpha}; \tag{3}$$

$$R_{min} = \frac{\alpha x_D^i}{\alpha-\theta} + \frac{1-x_D^i}{1-\theta} - 1; \tag{4}$$

$$A = \left(1 - 1{,}333\cdot\frac{N-N_{min}}{N+1}\right)^{1.7587}; \tag{5}$$

$$R = \frac{A+R_{min}}{1-A}; \tag{6}$$

$$L = R(F-B), \tag{7}$$

where: θ – parameter in the Underwood relation; α is the relative volatility; N_{min} – minimum number of theoretical stages; R_{min} – minimum reflux ratio; A – parameter in the Eduljee relation; N – number of theoretical stages; R – reflux ratio.

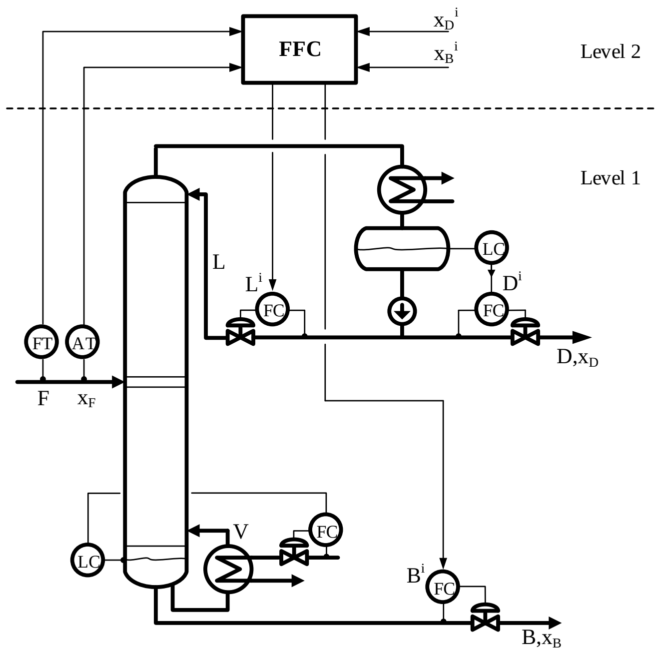

Fig. 2. Two-level hierarchical system.

Hierarchical System Implementation Using DeltaV Distributed System

In the control structure from figure 2 the feedforward controller from the second hierarchical level is implemented using the DeltaV distributed control system [5, 14] from Emerson Process Management.

In this case, a connection between the simulated process (in SIMULINK) and the DeltaV system is proposed, as it can be seen in figure 3.

The DeltaV system has as input the value of the disturbance *F* acquired from the process, and as outputs the values of the set-points for *L* and *B* control systems.

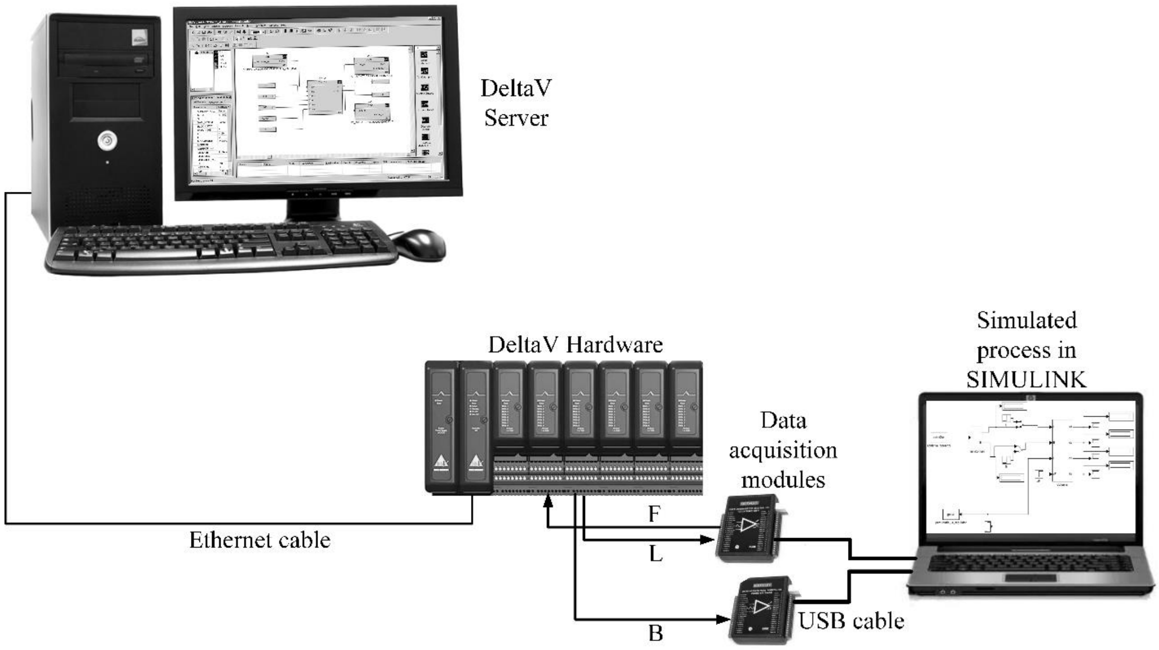

Fig. 3. Connection between DeltaV and the simulated process.

Configuration and Programming of the DeltaV System

The DeltaV system used in this study consists of a hardware infrastructure and a DeltaV server.

The DeltaV hardware infrastructure contains the following elements:

- power supply;
- controller;
- 1 Fieldbus H1 card;
- 2 analog input cards with 8 channels - 4-20mA;
- 1 analog output card with 8 channels - 4-20mA;
- 1 discrete input card with 8 channels - 24V d.c.;
- 1 discrete output card with 8 channels - 24V d.c..

In the application from this paper, from the input-output subsystem there were used:

- an analog input, to acquire the value of the disturbance feed flowrate (F) from the process;
- two analog outputs, to transmit to the process the values of the control signals (set-points for L and B control systems).

The configuration of the channels associated to the mentioned analog input and outputs is made using *DeltaV Explorer* application and consists in enabling the channel, choosing the channel type, and setting a tag and a description for the channel (figure 4).

The module which implements the feedforward controller was configured using *Control Studio* application, and can be seen in Figure 5.

Within the module presented in figure 5 the following function blocks are used:

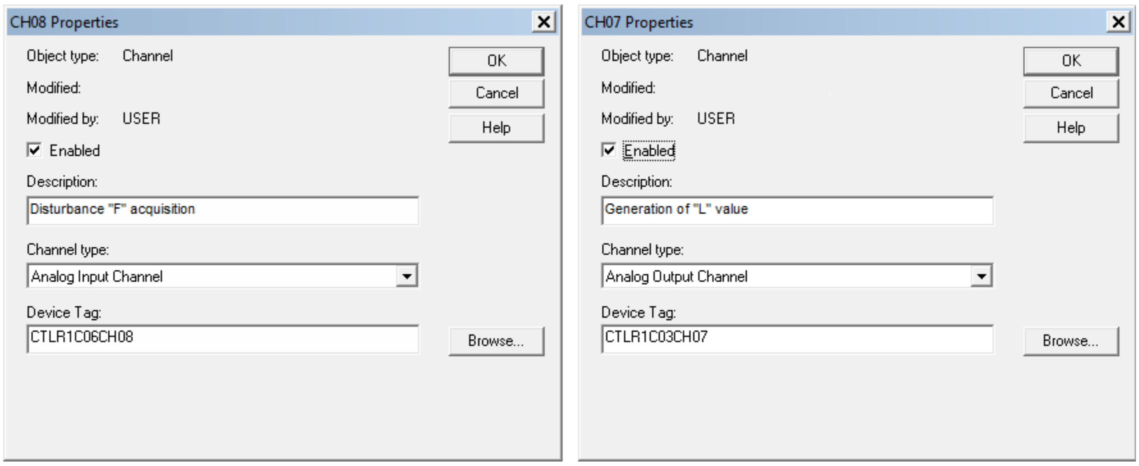

Fig. 4. Configuration of analog input and output channels properties.

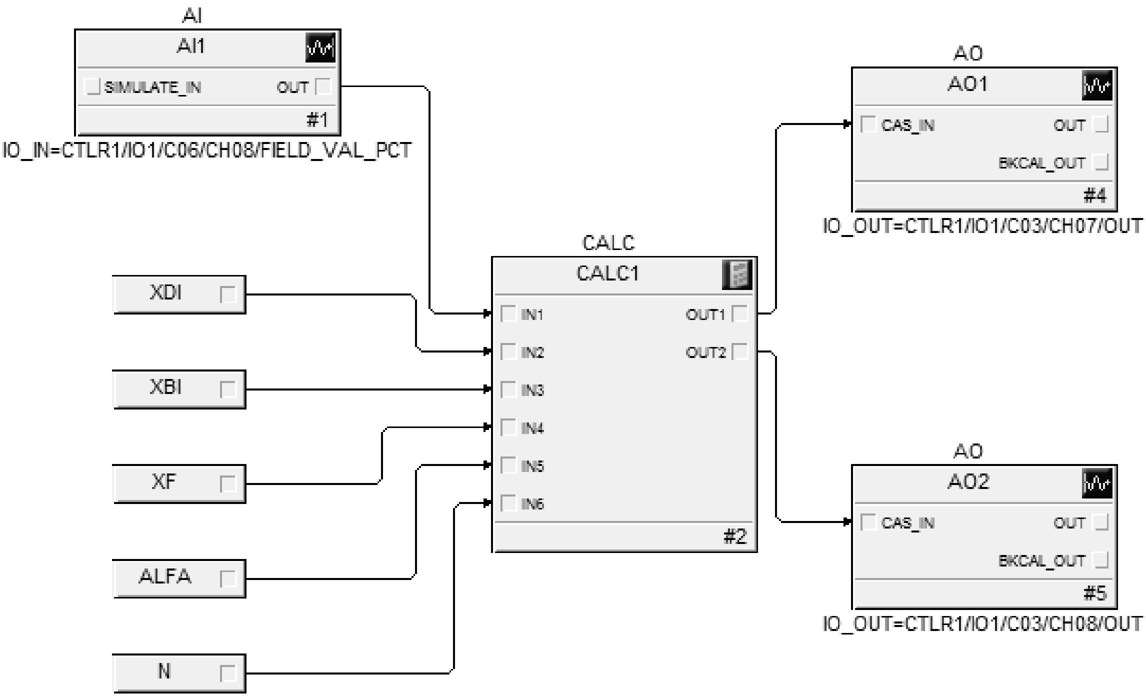

Fig. 5. The DeltaV module which implements FUG algorithm.

- an *AI* (Analog Input) block, used for the acquisition of the disturbance *F* value from the previously configured analog input channel;
- two *AO* (Analog Output) blocks, used for the generation of control signals to the process, through the analog output channels;
- *Input Parameter* blocks for the parameters x_D^i, x_B^i, x_F, *alfa* and *N* from Fenske-Underwood-Gilliland algorithm;
- a *Calculator* block through which the Fenske-Underwood-Gilliland algorithm is implemented.

The assignment of the *AI* function block with the analog input channel involves the configuration of *IO_IN* parameter (fig. 6) by setting the corresponding input channel device tag which was set previously (fig. 4).

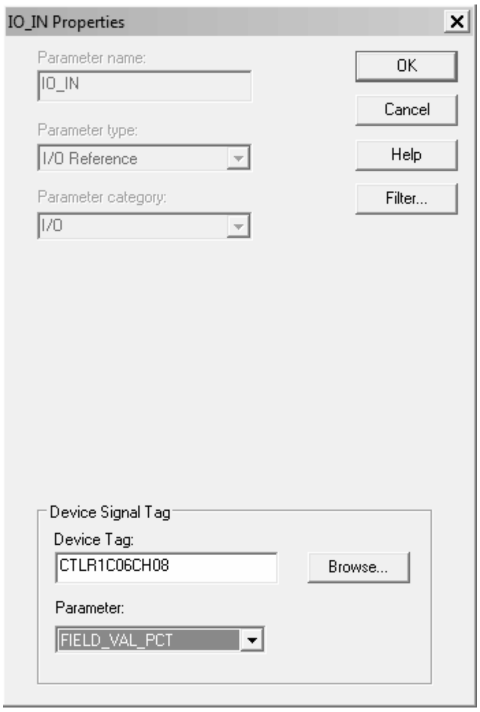

Fig. 6. The assignment of AI block with the analog input channel.

Similarly, the assignment of the *AO* function blocks with the analog outputs channels consists in the configuration of *IO_OUT* parameter, as it can be seen in figure 7, by setting the corresponding device tag of the considered output channel.

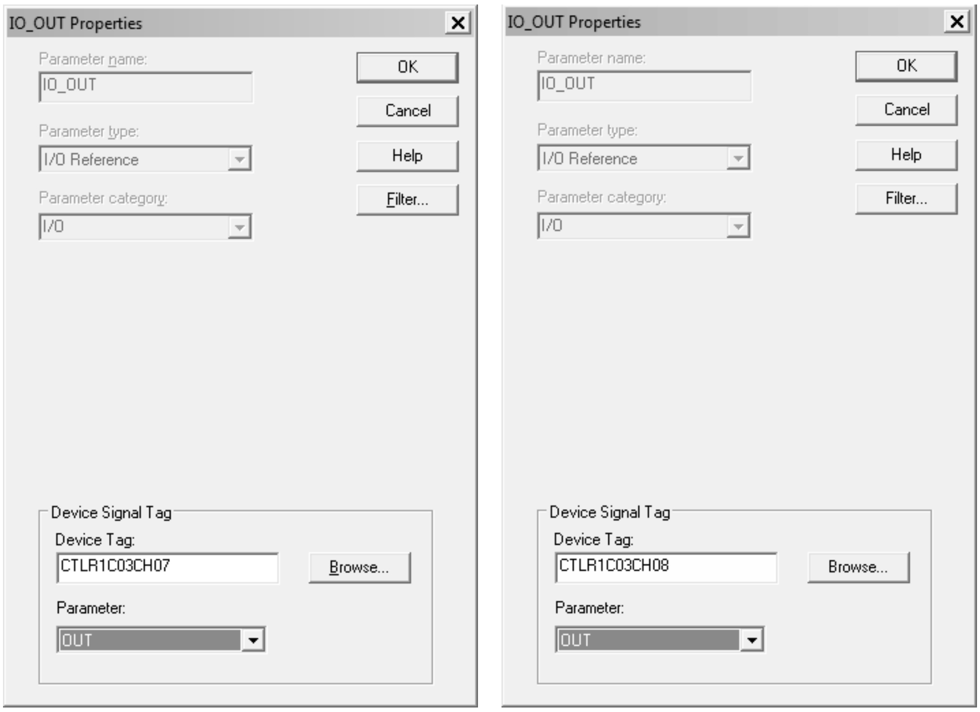

Fig. 7. The assignment of AO blocks with the analog output channels.

In figure 8 is presented the content of the *Calculator* function block which implements the Fenske-Underwood-Gilliland control algorithm.

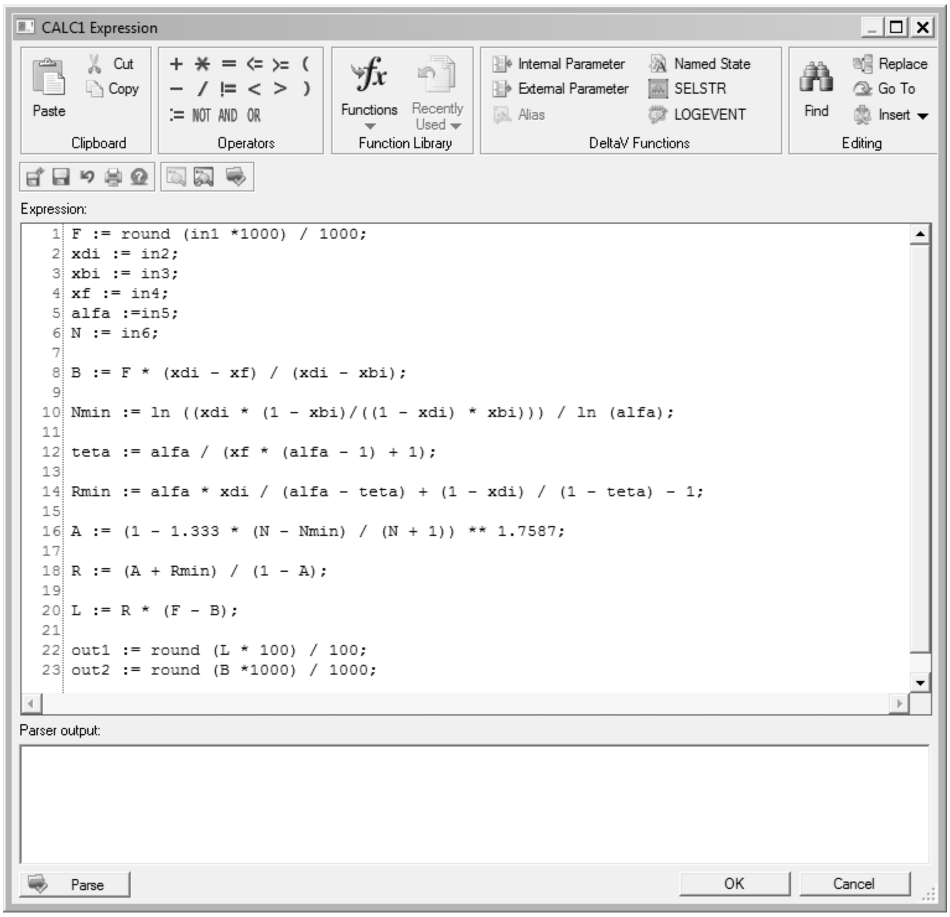

Fig. 8. Implementation of FUG algorithm within Calculator block.

Based on the disturbance *F* value obtained through the *AI* function block, and on the input parameters x_D^i, x_B^i, x_F, $alfa$ and N, the algorithm calculates the values of the *L* and *B* control signals which are the outputs of the *Calculator* block. These last two values will be connected to the *AO* function blocks (as seen in figure 5) in order to be transmitted to the process through the analog outputs of the DeltaV system.

Simulation of the Hierarchical System with Two Levels Using the Connection SIMULINK-DeltaV

The actual connection between the DeltaV system and the computer with the simulated process is made by using KUSB-3100 data acquisition modules [13]. Thus, on an analog output channel of a data acquisition module is generated (from the simulated process in SIMULINK) the value of the disturbance *F* to DeltaV system, and on two analog input channels are acquired the two control signals generated by the feedforward control system implemented in DeltaV.

In order to simulate the control system of the propylene-propane separation column, the SIMULINK model from Figure 9 is used.

In Figure 9 it can be observed the presence of two functions (*generation* and *acquisition*), necessary to transmit the value of the disturbance to the DeltaV equipment, and to acquire the values of the control signals from DeltaV respectively.

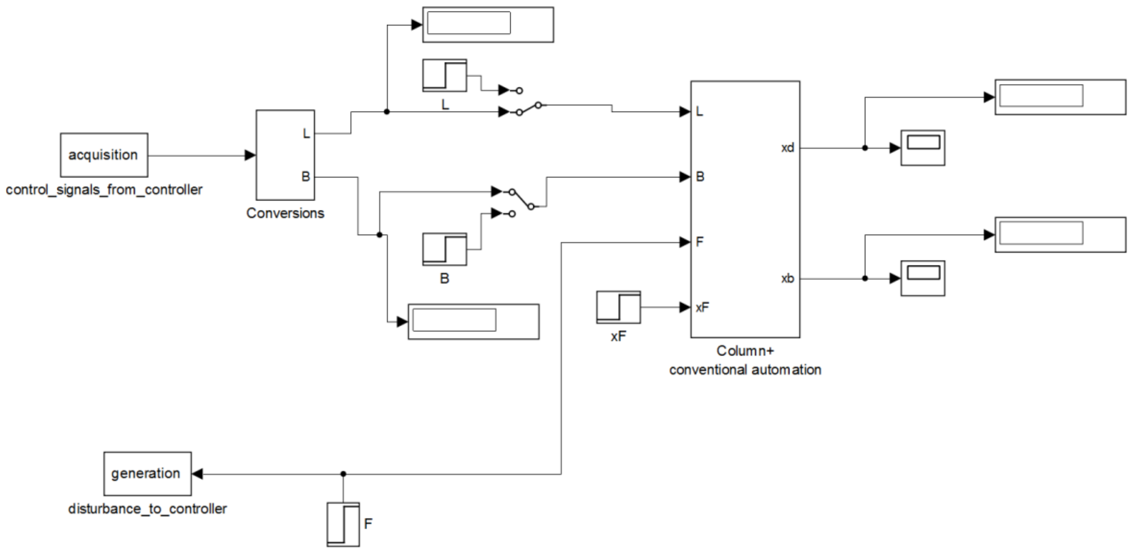

Fig. 9. Simulation model associated to the SIMULINK-DeltaV connection.

In this case, the structure with two hierarchical levels contains at level 1 the column with the conventional automation simulated in SIMULINK, and the DeltaV equipment at level 2 as feedforward controller.

Using the connection presented in figure 9 simulations were performed to capture the system behavior to changes of disturbance F, the results being presented in figures 10-13.

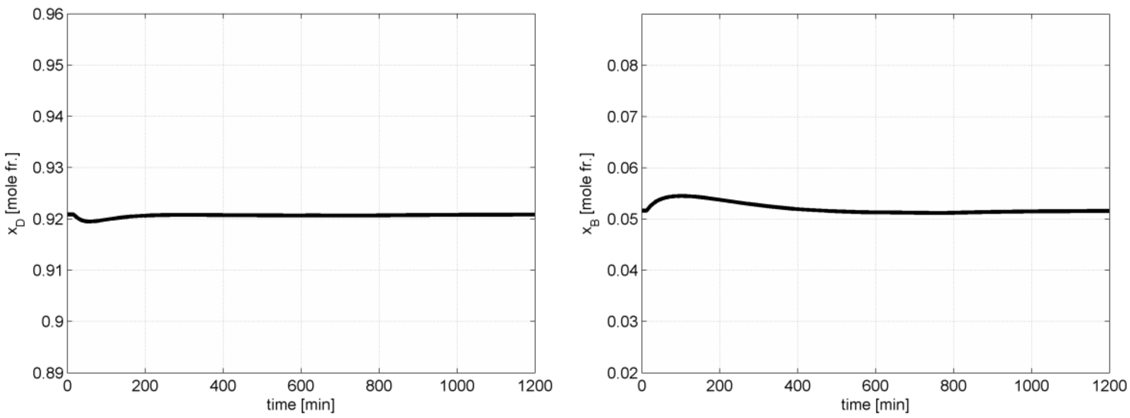

Fig. 10. Concentrations x_D and x_B evolutions to a 2.5% increase of F.

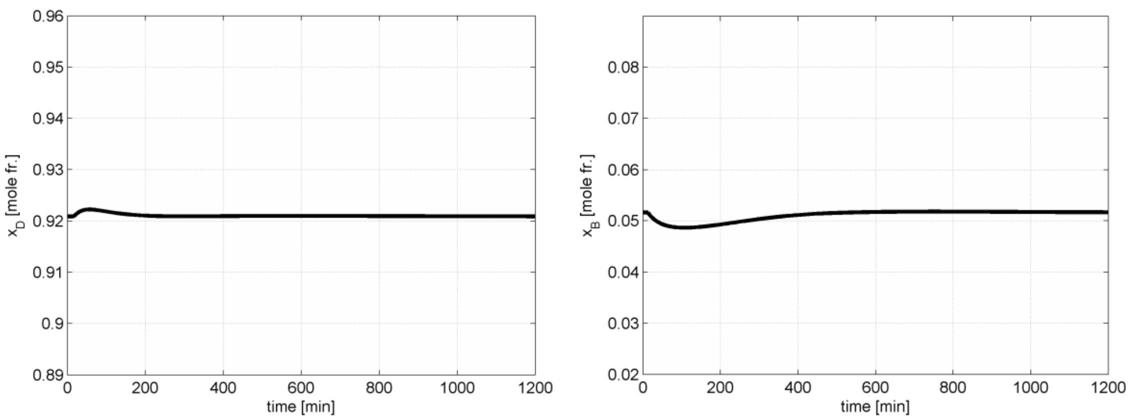

Fig. 11. Concentrations x_D and x_B evolutions to a 2.5% decrease of F.

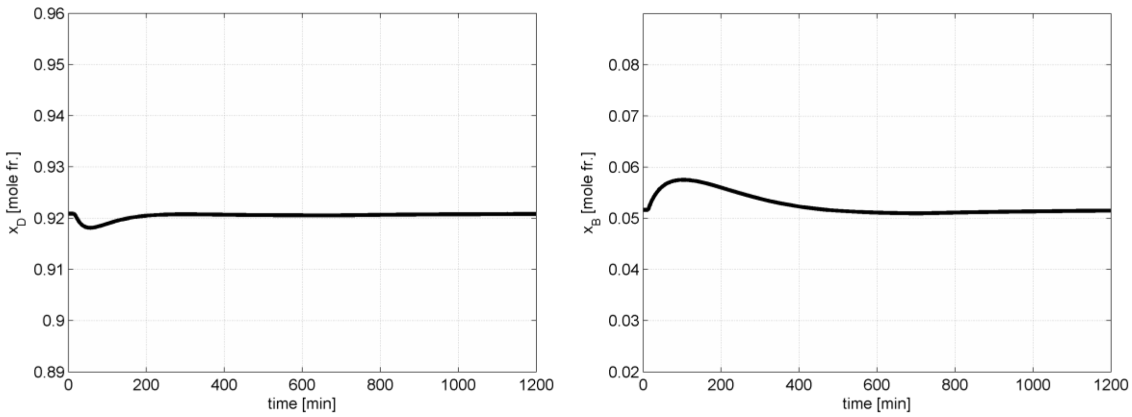

Fig. 12. Concentrations x_D and x_B evolutions to a 5% increase of *F*.

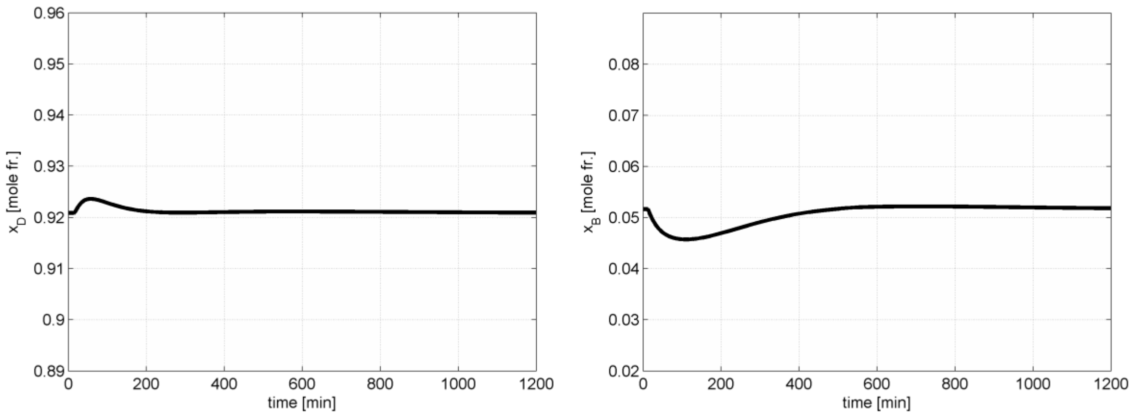

Fig. 13. Concentrations x_D and x_B evolutions to a 5% decrease of *F*.

From figures 10-13 it can be observed that the control system which has as central element the feedforward controller, manages to compensate the effects of the disturbance *F* on the two concentrations. This means that the connection *simulated process – industrial control equipment* is adequate to test automation solutions, this being confirmed also by [4, 6, 7].

Conclusions

The paper presented a study on the hierarchical control of a propylene-propane distillation column. The proposed hierarchical system has two levels: a conventional control level which is the *LB* control structure and an advanced control level represented by a feedforward control system. At the second hierarchical level the DeltaV distributed control system was used. This system was configured and programed in order to implement the Fenske-Underwood-Gilliland relations that compose the feedforward algorithm. The hierarchical control system was analyzed by simulation using a connection between the simulated process in SIMULINK and the DeltaV system. From the simulation results it was observed that the effects of the disturbance *F* on the concentrations x_D and x_B are compensated, thus demonstrating the viability of this type of connection.

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Conducerea ierarhică a unei coloane de fracționare utilizând sistemul distribuit DeltaV

Rezumat

Lucrarea prezintă un studiu privind conducerea ierarhică a unei coloane de fracționare. Este propus un sistem ierarhic cu două niveluri pentru coloana de separare propenă-propan. Primul nivel ierarhic este reprezentat de structura de reglare LB, iar nivelul doi constă dintr-un sistem de reglare după perturbație. La nivelul doi este utilizat sistemul distribuit DeltaV care este configurat și programat pentru a implementa algoritmul de reglare după perturbație. Sistemul ierarhic este analizat prin utilizarea unei conexiuni între procesul simulat (în mediul SIMULINK) și sistemul DeltaV.