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Using a Distributed Control System (DCS) for Distillation Column Control in an Undergraduate Unit Operations Laboratory

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***Abstract*—This paper presents the main advantages of using an industrial distributed control system (DCS) in the operation of a distillation column which is used in an undergraduate unit operations laboratory course at the University of Texas at Austin. Taking advantage of the resources of an industrial DCS (friendly display options, an alarm management system, historical data bases and advanced control tools), undergraduate students are able to operate a distillation column under automatic control. After training on the DCS system, students are able to evaluate the performance of the control loops as well as tune them in order to improve the operation of the column.**

I. Introduction

THE use of Distributed Control Systems (DCS) are becoming popular and useful to control complex process in the industry that involves multiple variables and control loops. There are many vendors who provide these DCS systems, such as Emerson, Yokogawa, Foxboro and Honeywell. The continued development of these DCS systems by manufacturers result in great advantages for the users of this kind of technology [1]: (1) flexible hardware architecture and software tools [2] which come with advanced algorithms of optimization, modeling and control; (2) robust communication systems between hardware components such as workstations, smart devices, sensors; (3) capabilities which manage alarms and abnormal events; (4) integrated diagnostic features in hardware, communications and control; (5) capacity to have redundancy in the design of the systems in both hardware and software levels; (6) ability to create historical data bases and efficient manipulation; (7) security by having limits on the access to the parts of the control system; (8) user-friendly graphic tools that are useful in manipulating the system.

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This paper focuses on demonstrating that DCS technology can be beneficially used in the academic environment. A Delta V DCS system [3] is used to operate a distillation column in a senior-level unit operations laboratory in the Chemical Engineering Department at the University of Texas at Austin.

Thanks to the user-friendly display options and alarm management alternatives in the DCS system, students are able to easily understand how to operate the column and to set up the different control loops. Furthermore, by taking advantage of the historical data bases, students can also analyze the trends of the main variables of this column such as the differential pressure of the whole column, temperatures of every tray, the steam flow rate, etc. Then, as a result of the assessment of the single variable trends, actions can be taken to re-tune the different control loops or to design advanced control strategies. This paper addresses the use of the Auto-tune tool to improve controller performance.

The paper is organized into five sections. After the introduction, the second section presents a brief description of the distillation column. The third section illustrates how the DCS display options and alarm management system can provide easy operation of the distillation column by senior undergraduate students. Next, in the fourth section, the Auto-tune tool is used and the performance of the main control loops of the distillation column are evaluated by taking advantage of the DCS's historical data base facilities. Finally, the conclusions of this paper are found in the fifth section.

II. Distillation Column Project

A. Brief description of the process

Figure 1 shows the P&ID diagram of the distillation column, the main pieces of equipment involved in the binary distillation process are a Xytel distillation column, reboiler, condenser, accumulator, and reflux pump.

To operate the column there are four control loops that need to be working simultaneously: (1) level of the accumulator, which is a cascade controller where the controllers involved are the master level control loop LIC-091 and the slave reflux flow control loop FIC-100; (2) steam flow rate control loop FIC-150; (3) pressure control loop PI-081, which maintains the pressure at the top of the column constant; (4) the cascade temperature controller TIC-093 keeps the temperature at the output of the condenser constant by defining the set point of the slave flow control loop FIC-152, which is the water cooling supply.

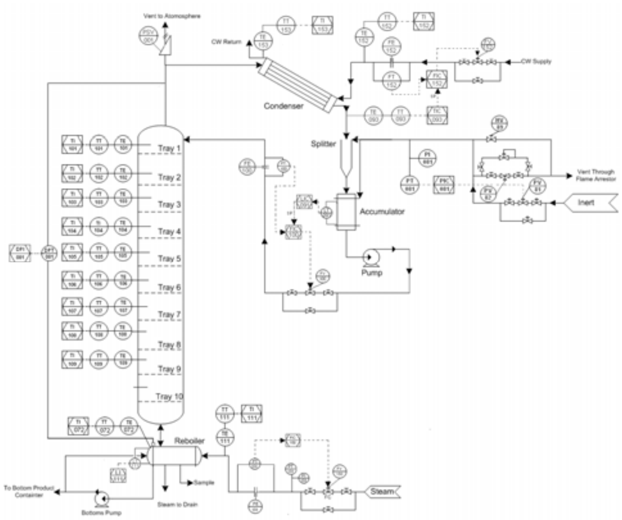

Fig. 1. P&ID of the distillation column

B. Project Objectives

This project has two main objectives: (1) to familiarize the student with the operation of an industrial DCS system and the control of the distillation column; (2) to perform field tests to assess the operational capacity of a column and to determine the column's flood point by theory and experimentation.

TABLE I
OPERATING POINTS OF THE DISTILLATION COLUMN

Control Loop Tag Number	Operation points	Units
LIC-091	18	cm
FIC-100	0-1.875	Liters/min
FIC-150	0.35 0.45 0.55 0.65 0.75 0.85	Kg/min
PI-081	101	kpa
TIC-093	57	˚C
FIC-152	0-13	Liters/min

To achieve the first objective, students receive training on how to manipulate the DCS system. To accomplish the second objective, the column has to be operated at different operating points. Table 1 shows the operating points of all control loops for the entire experiment, for instance the level of the accumulator must be held constant during the entire length of the experiment. These requirements imply that it is imperative to evaluate the performance of the control loops before determining the flood point of the column. In conclusion, the evaluation and improvement of the column control loops are the main important point and focus of this paper.

C. Safety Hazards

Another important point is the safe operation of the column. The most common problems are located in the level of the accumulator where two possible situations can occur. The first situation is to have a leak in the tank of the accumulator while the second is to have a low level in the accumulator, where it is possible to cause damage in the reflux pump. The next section will present how these hazards can easily be addressed by designing interlocks in the DCS system.

III. HUMAN MACHINE INTERFACE (HMI) OF THE DCS SYSTEM

The use of the DCS graphics interface results in easier operation of the distillation column for students. The HMI has three main functions [1]: (1) to provide visualization of process parameters; (2) to enable interaction with the process; (3) to provide alarms and event notification to the operator about any abnormal situations in the plant. Detailed information about these three functions is included in this section.

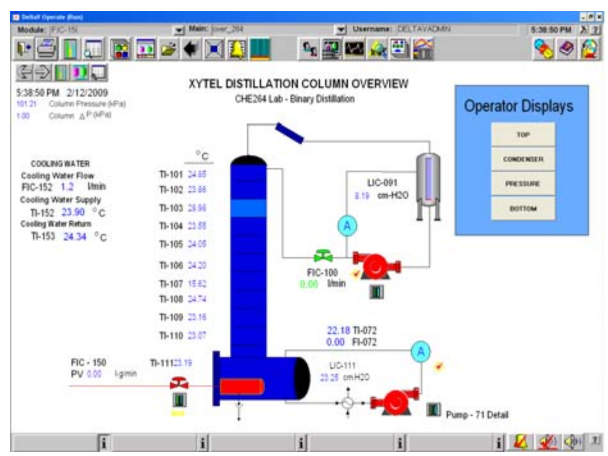

Fig. 2. Distillation column graphic display

Figure 2 shows the overview graphic display of the distillation column, which provides a representation of the process and makes it easier for operators to visualize what is happening. Through this overview display, it is possible to monitor the main variables of the column, check the conditions of the most important control loops, and identify the on/off status of the discrete components which are operating in the process. For instance, the temperature in every tray of the column can be monitored by checking the tag numbers TI-101 to TI-110 in Figure 2. Moreover, the key variables of the control loops FIC-150 and LIC-091 can be viewed. Finally, the pump status, which belongs to the control loop LIC-091, is identified by its color (green means that the pump is on while red means that the pump is off).

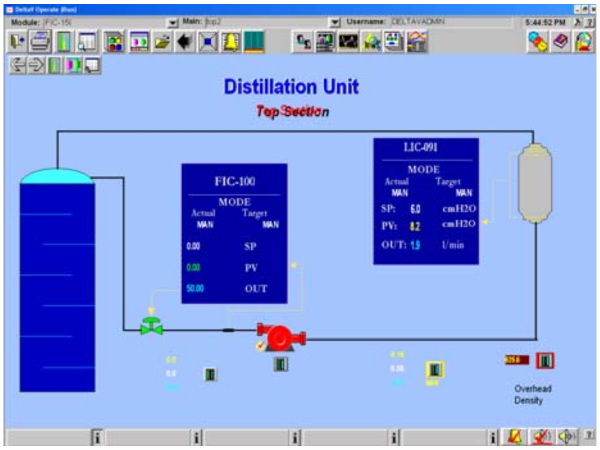

Fig. 3. Detail display of the Accumulator control loop

To interact with the process, detailed displays, which contain specific control functions to operate the column, can be used. Figure 3 shows one of the four detailed displays available in the distillation column. With this detailed display, it is possible to control the level of the accumulator by setting up a cascade control loop. The operator has the choice to configure these two controllers (FIC-100 and LIC-091) in three modes [4]. For manual mode (MAN), shown in Figure 3, the operator manipulates the final control element directly. In Figure 3, the operator is able to manipulate the opening of the valve of the control loop FIC-100, which determines the reflux flow to the column. In automatic mode (AUTO), the final control element is manipulated automatically through a PID controller and the set point for the control loop is entered by the operator. For the detailed display of Figure 3, both control loops FIC-100 and LIC-091 are able to set up in the automatic mode, but the LIC-091 control loop does not have any control element to manipulate. In cascade mode (CAS) [2], where two master and slave controllers are operating, the master controller sets the set point for the slave controller and the set point for the master controller is set by the operator. In order to set up the cascade control strategy in Figure 3, the mode of the controller FIC-100 is set to CAS mode and the mode of the controller LIC-091 is set to AUTO mode.

On the other hand, with the idea of having specific information about the separate loops that are operating in the distillation column, Figure 4 illustrates a typical faceplate display. This faceplate corresponds to steam flow rate control loop FIC-150. Usually, the faceplate display shows the controlled process variable and the output of the control loop. Furthermore, the set point, and the operating mode of the control loop can be changed. Additionally, detailed information is available related to both the parameters of the steam flow PID controller and the different alarms that can be authorized in this control loop with its respective values of activation.

To obtain a better understanding of the plant, trends of the key variables of the process can be visualized and analyzed. Figure 5 shows the trend display of the key variables of the column over a period of time such as the differential pressure of the column DPI-081 (blue line), reflux flow (light red line), accumulator level (purple line), steam flow (green line), etc.

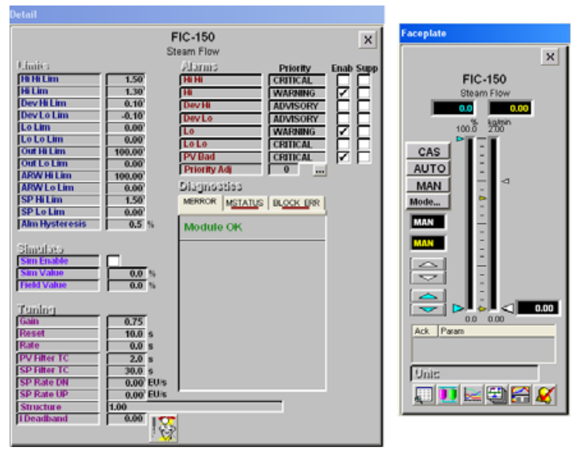

Fig. 4. Faceplate used to control the steam flow rate of the distillation column

Based on these trends, the set point values as well as the mode of the different controllers of the column can be changed with the purpose of improving the performance of the plant. In addition, by using the historical databases accumulated throughout the semester, new control strategies can be created, controller parameters can be customized, and abnormal situations can be detected. The evaluation and tuning of the control loops are presented in the next section.

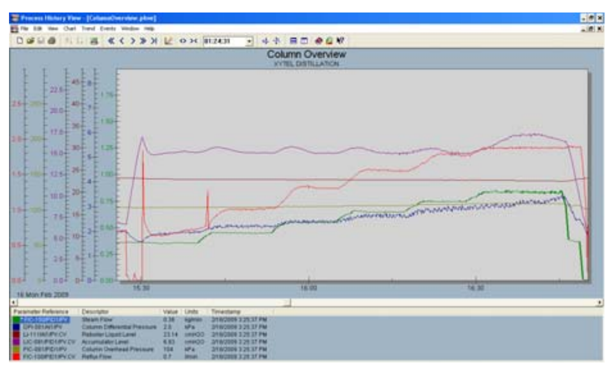

Fig. 5. Trend display of the column

Finally, Figure 6 shows the list of alarms which are assigned to the level sensors and level control loops that are present in the column. In this list of alarms, each sensor or control loop is associated to a traditional process alarm such as high alarm (HI_ALM), low alarm (LO_ALM), high high alarm (HI-HI_ALM), low low alarm (LO-LO_ALM), process variable bad (PVBAD), etc. These process alarms have been associated with a priority parameter like warming, advisory or critical alarm. For example, the control loop LIC-091 has enabled three different alarms: HI_ALM, LO_ALM and

PVBAD. With the following priority for each alarm: warming, warming and critical respectively. At the moment that an alarm has been detected, a report message is created. The alarm is maintained active in the system and it is shown in the bottom part of displays of Figures 2 and 3 until there is confirmation about the receipt of the notification, or confirmation of acknowledgment, which means that the alert has been processed. Then, by using these alarms over the level of the accumulator, the safe operation of the process is increased by alerting students to any abnormal situation.

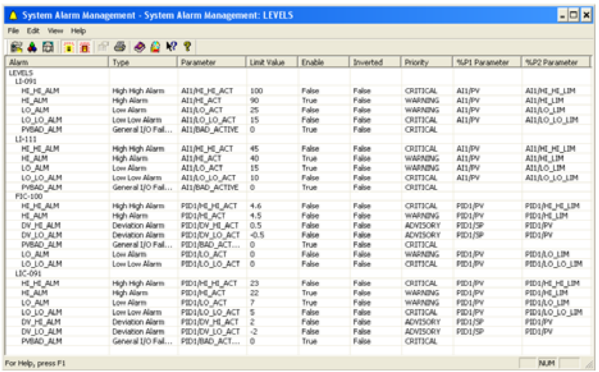

Fig. 6. Alarm management system of the level components

On top of this complete alarm information provided by the DCS system, it is also possible to create interlocks which are discrete algorithms used to prevent damages in equipment. For example, if the level of accumulator drops to lower than 6 cm, an alarm is activated (LO_ALM) and the reflux pump is turned off automatically with the intention of protecting the equipment from any damage.

IV. DCS Control Evaluation And Tuning Capabilities

This section presents two topics. The first part focuses on the Auto-tuning feature, which is used to tune the control loops of the distillation column, while the second part evaluates and analyzes the main control loops of the column.

A. *Auto-tuning options feature*

The Auto-tuning method available in the Delta V system is a patented closed loop tuning method based on the work of Astrom and Hagglund [5]. By inserting a relay as a controller into the feedback control loop, the controlled variable will typically oscillate with small amplitude. From these oscillations, the ultimate gain and frequency are identified. Then, in order to obtain the values of the PID parameters, the classic Ziegler-Nichols tuning rules are applied.

Figure 7 shows the toolbox software where the level control loop LIC-091 was tuned and the steam flow rate was fixed to 0.55 Kg/min. The sustained oscillation which is the output of the controller (green line) is generated such that the output of the controller (red line) oscillates around the set point (dark blue line). Before tuning, two important parameters have to be defined: the speed of response, which was selected normal, and the kind of controller, which was selected PI standard, where its equation is shown in equation (1).

$$Out(s) = GAIN\left(1 + \frac{1}{T_r s}\right) \bullet E(s) \qquad (1)$$

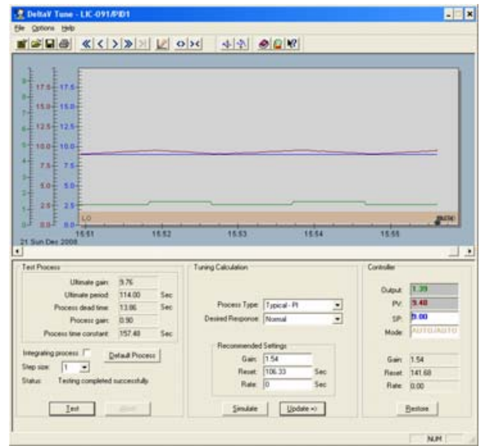

Fig. 7. Auto-Tuning DCS Tool

Finally, the parameters obtained for the PI controller were: GAIN=1.54 and Tr=106.3.

B. *Performance Evaluation*

To evaluate the performance of the control loops, the DCS's historical data base is utilized. By using an Excel add in, data from the DCS data base can be migrated to an Excel file with purposes of manipulating data.

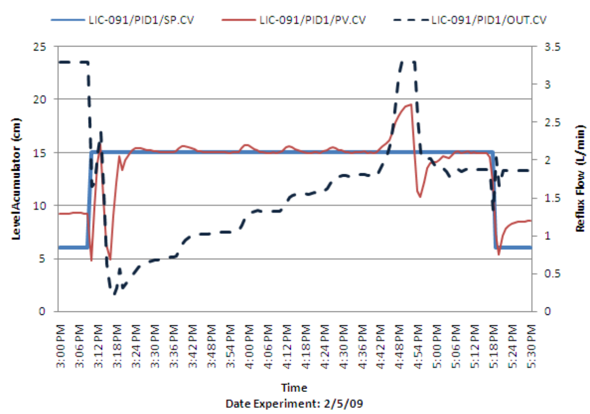

Fig. 8. Trajectories Level Control Loop LIC-091

Figures 8-10 show the trajectories of the control loops LIC-091, FIC-100 and FIC-150, in that specific order. During the first 14 minutes, the column is warming up; the reflux pump remains off and the steam flow set point is set at 0.7kg/min (see Figure 10). This situation is held constant until the level of the accumulator reaches an approximate level of 15cm.

After this time, the reflux pump is turned on and the set point of the steam flow is changed to 0.35. From minute 14

(3:14pm), to minute 86 (4:40pm), the steam flow is changing from 0.35 to 0.75 (Figure 10) in step sizes that are shown in Table 1. In the same period of time, Figure 8 shows that the trajectory of the controlled variable (red line), which is the master control loop LIC-091, follows the set point trajectory (blue line) very well. However, as a result of increasing the steam flow rate, the LIC-091 output trajectory (dashed line), which is the reflux flow set point of the slave controller FIC-100, has an increasing trend. Furthermore, Figure 9 shows that the controlled variable (red line) is able to follow the set-point (blue line).

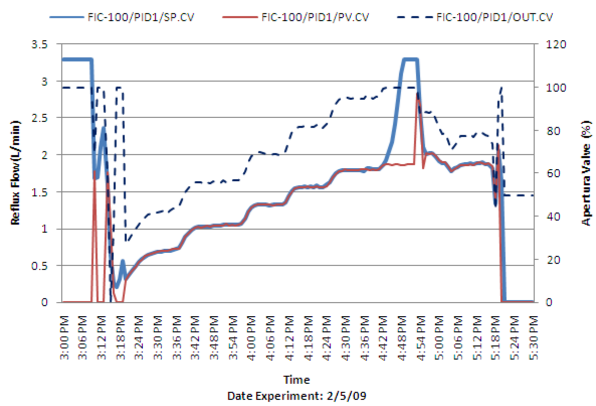

Fig. 9. Trajectories Flow Control Loop FIC-100

When the steam flow rate is changed to 0.85kg/min (see Figure 10 at 4:40pm), Figure 9 shows that the controlled variable is not able to follow the set point trajectory because the reflux flow has reached its maximum value of flow (around 1.85 L/min) when the valve is completely open 100% (dashed line). As a result of this, the level of the accumulator (Figure 8) starts to increase and to move away from the set point. At this operating point, the distillation column has reached its maximum capacity, which means that the flow coming in from the condenser is more than the flow coming out of the accumulator.

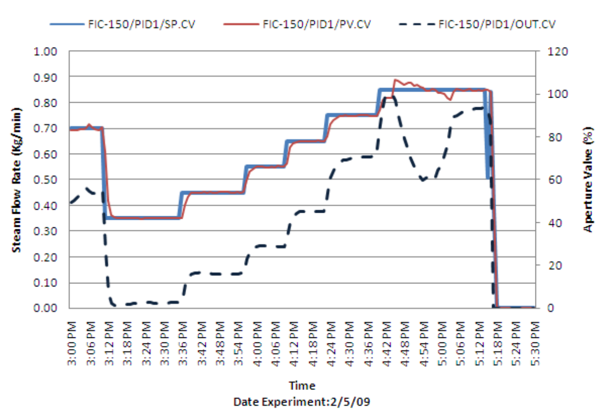

Fig. 10. Trajectories Level Control Loop FIC-152

In addition, Figure 10 shows that during the period of time from 4:42pm to 4:45pm the steam flow valve (dashed line) has reached its maximum value. Thus, in order to continue the operation of the column, bypass valves are opened in the steam and reflux flow paths (see Figure 1).

As a conclusion, the evaluation of these controllers show that the distillation column reaches its maximum capacity when the steam flow increases to more than 0.8 kg/min. No advanced control is needed since the performance of the main control loops are excellent.

V. Conclusions

The time required to guide students to operate the basic functions of the DCS system is minimal. Basically, the training is completed before the experiment begins. An overview on the multiple display options, such as faceplates, is illustrated to students. However, the main focus is to understand how to set up the modes of the different control loops that are operating in the column. On the other hand, to use advanced control techniques require more hours of training; in this case, special projects of longer duration are developed.

To use a DCS system in the academic environment allows students to have a large amount of data available to observe the current performance of the column or to see the trends of the previous experiments. Furthermore, there is flexibility to change standard control strategies in the process with the option of readjusting the controller parameters.

Acknowledgment

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