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Engineering

A HANDS-ON LABORATORY INDUSTRIAL PROCESS CONTROL SYSTEMS AND ADVANCED AUTOMATION USED BY DCS

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ABSTRACT This paper aim to provide Training Techniques in the field of Control Education, by applying advanced practical experiment approaches using the Feedback Distribution Control System trainer (DCS), and improve the skills in the area of real time control system. The experimental approach was taken under consideration to verify the varieties of Control technique in industrial control field using DCS technology. Coupling the software and hardware to create a useful control system experiment that can give a strong effect in training process. Understanding and Programming the DCS was the challenge to run the industrial plant processes available in the Trainer DCS System. The sequential control method was implemented the experiment. Besides creating different control scenarios for controlling the processes.

Moreover this paper, we will explain how we can utilize the DCS controller in training and control education programs of the Industrial Control Systems for real-time control systems and design the training programs to meet the goals of professional training

KEYWORDS : Control education, Distributed control system, real-time control systems, automation, software development, Industrial control systems

1. INTRODUCTION:

The need to find different ways of teaching technique in control education for different specialty of control system maintenance and operation technician. The variety of skills that technical students should master is also increasing. This paper describes pedagogical methods that have been adopted as a response to these needs and to the desires of both students, trainers and lecturers to achieve better learning and training results.[1]

And in particular, due to the increasing demands on having skilled trained kuwaiti technicians with knowledge of Distributed Control Systems to join both of governmental and industrial sectors, mainly in instrumentation maintenance and industrial process control fields, the lecturer in the institute of "Higher Institute of Energy" motivated to find an experimental methods to follow the technological aspects and to fulfil Institute Vision.

The field of process control comprises a wide set of functions through all levels of the automation system pyramid. To give students a glance of the complexity of process control it is important to provide the possibility to try as much functionality as possible at own hand. That is why the practice on industrial relevant hardware- and software should be an important part of control education. Beside theoretical basics given in lectures, study trips to industrial plants and deepening loop-control-laboratories a laboratory along the levels of the automation pyramid, a plant give the students the big picture of process automation. [2]

This paper presents the challenges of design new automated process control experiment using DCS Trainer by applying sequential control method joining multi processes to get the desired output response. The control system is integrated with DCS process management package called Delta-V and process training Rigs. Where the Industrial processes comprise Rig's for Temperature, Pressure and Level processes. The paper concentrate of how to create a basic close loop control of the devices to obtain the desired output values of Level and Temperature with the DCS controller and within the allowed constraints. In general the DCS Trainer is used to monitoring and control from display (which is by default) but in this paper we add a close loop control for automatic control mode Fig.(1) by making the necessary modification in the software of DeltaV Which is possible if you create new strategies and scenario of operation of the process.

At this level of design and modify the software of DCS ,The students should be previously experienced with measurements (sensors) and control devices (actuators) and able to carry out the open and close loops control systems used in the industrial process, besides the theoretical information in modeling and using block diagrams and system stability.

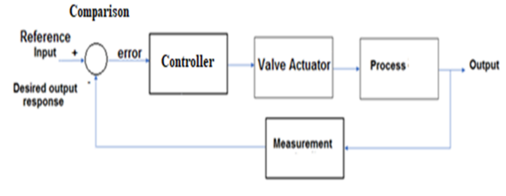


Fig. (1): close loop control system

1.1 Brief information about the DCS system hardware

The Feedback Distributed Control System trainer, 38-009, is a complete DCS training solution Fig.(2). It integrates a commercial DCS process management package, Delta V, with a selection of proprietary process training rigs that offer a range of target processes:

1. Level and Flow
2. Temperature
3. Pressure

The rigs may be operated in combination to produce a multi-process, multi-loop system. [3]

1.2 Brief information about DCS Controller software

1.2.1 DeltaV Explorer, similar in appearance to the Windows Explorer, is an application that lets you define system components (such as areas, nodes, modules, and alarms) and view the overall structure and layout of your system. Fig.(3) shows a typical DeltaV Explorer window. You can do many things with this application, including creating, copying or moving modules, configuring system hardware, and defining types and priorities of alarms.[3]

1.2.2 DeltaV Operating modes

The DeltaV Operate application functions in two modes. In configure mode, it is used to build high resolution, real-time process graphics. In run mode, control system operators use these graphics in the daily monitoring and maintenance of the process.[3]

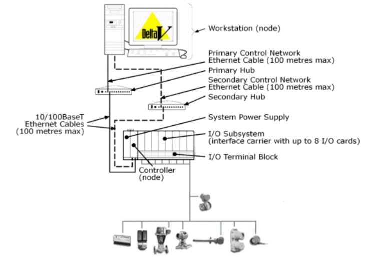


Fig.(2): DCS Structure

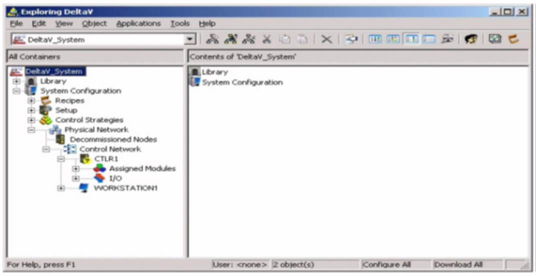


Fig. (3): DeltaV Explorer

1.2.3 Tips on DeltaV software used in DCS

Equipment Hierarchy

DeltaV supports a logical hierarchy which includes the following:

1. Area – logical division of a process control system. Areas typically represent plant locations or main processing functions.
2. Process Cell – may be class-based (available to Batch Executive) or non-class based. The process cell can be used to organize units and modules.
3. Unit Module – allows you to take advantage of advanced alarming techniques. Units are also key to a Batch Hierarchy.
4. Equipment Module – a grouping of equipment that performs a minor task like a totalizer or header. Allows you take advantage of advanced alarming techniques.
5. Control Module – links I/O, algorithms, conditions displays and other parameters to the equipment. Modules typically control a single entity like a motor or flow loop.

A typical hierarchical structure is shown in Fig.(4)A DeltaV system may use any, but not necessarily all, of these levels. For example, the DCS trainer uses only Area and Control Module levels.[3]

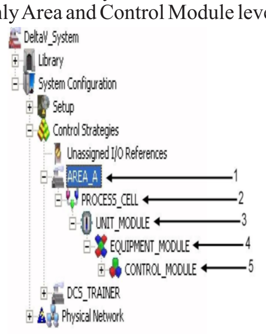


Fig. (4): Equipment Hierarchy

it is preferable when creating new modules to put them in new plant areas and leave AREA_A for system operations and functions only.

2. METHODS:

The method used to create an automatic control system divided into five stages.

1- Understanding the DCS hardware and software needed in this application
2- Proposal of control loops conditions need to be applied by using DCS
3- Creating the scenario of operation.
4- Programming stage by apply the expressions in the command boxes of Delta-V software
5- Running the process and monitor the results by DCS output Display

2.1 Stage 1: Understanding the DCS hardware and software needed in this application

DCS system part:

2.1 .1 Hardware

2.1.1.1 Controller Part:

The trainer is supplied complete with the computer, software, controller, I/O modules and cables necessary to monitor and control the process rigs. A Control Cabinet houses the components that provide the interface between the computer and the rigs. The computer, rigs and Control Cabinet are easy to interconnect using the supplied cables.

DCS produce outgoing signals in the range 4–20 mA and used to control the process. Typically, direct current (dc) pulses were used to drive electromechanical counters, and 24 V dc.

The valves, transducers and transmitters associated with the training equipment are standard industrial components that operate using either 4–20 mA current loop control or 24 V dc control. [1]

2.1.1.2 Process Rigs Part:

Temperature and Level rigs - Input /Output Devices:
38-100-Level process Rig compromise of

1- Manual valves (MV1,MV2,MV3,MV4)
2- Reservoir
3- Process Tank
4- Water pump. Digital output (0,1)
5- Solenoid valves (SV1, SV2, and Sv3). Digital Output
6- Servo Valve. Analogue Output
7- Float Level. Analogue input
8- Flow sensor. Analogue input
9- Float switch. Digital input

Remarks: Digital output (0, 1) which represent (0V, 24V), Digital input (0, 1) represents (4mA, 20mA), Analogue input (0% to 100%) represent (4mA to 20mA) and Analogue Output (0% to 100%) represent (4mA to 20mA)

Figure no. (5) show us how Temperature process Rig monitored from HMI Display

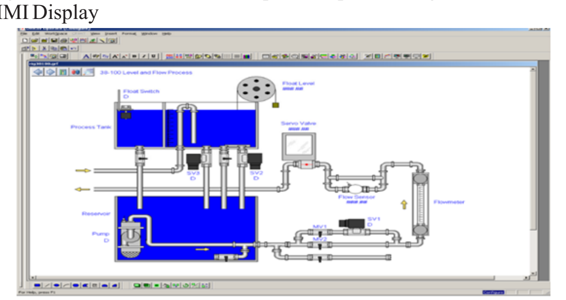


Fig. (5): Temperature process Rig monitored from HMI Display

38-600-Temperature process Rig compromise of:

1- Manual valves (MV1,MV2)
2- Reservoir (Boiler)
3- Heat Exchanger
4- Heating Element. Digital Output
5- Water pump. Digital output (0,1)
6- Fan. Digital Output
7- Servo Valve. Analogue Output
8- Flow sensor. Analogue input
9- Temperature sensors. (T1,T2,T3,T4,T5) Analogue input

Remarks: Digital output (0, 1) which represent (0V, 24V), Digital input (0, 1) represents (4mA, 20mA), Analogue input (0% to 100%) represent (4mA to 20mA) and Analogue Output (0% to 100%) represent (4mA to 20mA)

The following Fig. (6) show us how Temperature process Rig monitored from HMI Display

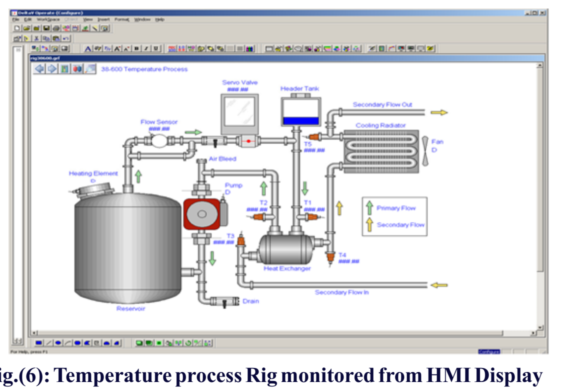


Fig.(6): Temperature process Rig monitored from HMI Display

2.1 .2 Software

Brief information about DeltaV software used in DCS- Equipment Hierarchy.

DeltaV supports a logical hierarchy which includes the following:
1. Area – logical division of a process control system. Areas typically represent plant locations or main processing functions.
2. Process Cell. – The process cell can be used to organize units and modules.
3. Unit Module – allows you to take advantage of advanced alarming techniques. Units are also key to a Batch Hierarchy.
4. Equipment Module – a grouping of equipment that performs a minor task like a totalizer or header. Allows you take advantage of advanced alarming techniques.
5. Control Module – links I/O, algorithms, conditions displays and other parameters to the equipment. Modules typically control a single entity like a motor or flow loop.

A typical hierarchical structure is shown in Fig. (7).A DeltaV system may use any, but not necessarily all, of these levels. For example, the DCS trainer uses only Area and Control Module levels. [3]

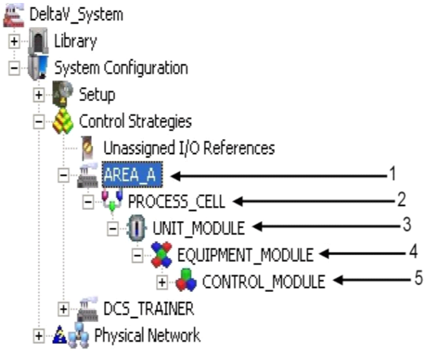


Fig. (7) :DeltaV system hierarchical structure

it is preferable when creating new modules to put them in new plant areas and leave AREA_A for system operations and functions only.[3]

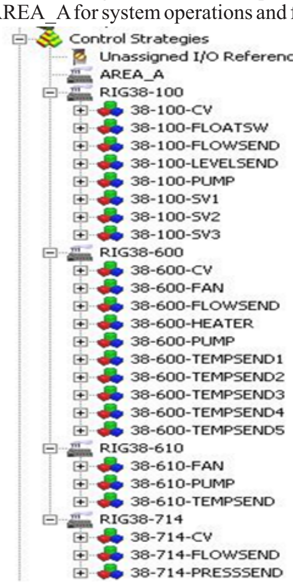


Fig. (8): A Strategies hierarchical structure

2.2 Stage 2: Proposal of control loops conditions need to be applied by using DCS

The idea was to create an automatic control system by using DCS system to maintain the level and temperature at certain pre-defined values with certain conditions.

The following conditions were proposed for system operation which was applied in Temperature and Level Processes rigs:-
1- Create close loop control system using sequential control
2- Maintain the water level in the process tank within the range (60% and 80%)
3- If water level reach close to 100% then the float switch will send a signal to trip the pump (switch off) automatically
4- Heating up the water till 35 degree centigrade
5- Switch off the heater element if temperature reach 60 degree
6- Maintain the protection of pumps during circulating of the water (Servo and solenoid valves in open position)

2.3 Stage 3: Creating the scenario of operation.
Describing the scenario of the process operation after running the system, which can be summarized by the following statements:

2.3.1 LEVEL PROCESS PART
1- In the beginning we have to open both Servo valves manually to 100% which is not included in this automatic control scheme
2- The control system will start running directly after switching on the heater element from mimic board (display) consequently the two pumps in both Temperature and Level process rigs will start running automatically.
3- The solenoid valve No.1 will be opened simultaneously after the pump running, which mean that has a direct relation to the pump condition.
4- The Solenoid valve 2 will be opened when the water level in the process tank reach 70% or above, to start drain the water to reservoir.
5- The Solenoid valve 3 will operated with inverse relation to the pump state. Therefor SV3 will be opened when the pump OFF at a level 80% and keep opening till the pump switched ON again at a level of 60%.
6- There was protection from water flood by Float switch which send command to switch OFF the pump at a level of 90% or above.
7- Once the water level reach below 60% the process will be repeated again several times.

See Mapping of input output devices for processes control programming in appendix Table no. (1)

2.3.2 Heating process Part
1- 1- Once the Heater Element is set to ON position (equal to 1) and start heating the primary water in the reservoir (boiler) the pump will be switched On automatically and the water start to flow in the pipes through the Heat Exchanger
2- The Temperature sensors measuring the process temperature from both Primary side and secondary side, and the heater and pumps will be switched off automatically if Temperate T5 =35°C. The End of process

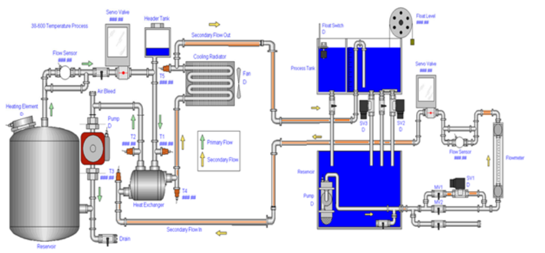


Fig. (9): Combined Rigs for Temperature and control

2.3.3 Brief Description on the process loops and devices used in each loop in the combination of both Rigs see Fig. (9).

We have two loops of water flow related to heater exchanger:
1- Primary Loop of Heat Exchanger (hot water from boiler)
2- Secondary Loop of Heat Exchanger (process water Level)

PRIMARY LOOP Input /Output devices (Temperature Rigs) consist of:
1- Manual valves (Mv1)
2- Reservoir (Boiler)
3- Heat Exchanger
4- Heating Element. Digital Output
5- Water pump. Digital output (0,1)
6- Servo Valve. Analogue Output
7- Float Level Analogue input
8- Temperature sensors. (T1,T2)Analogue input

SECONDARY LOOP Input /Output devices (Level & Temperature Rigs) consist of:
1- Manual valves (MV1,MV2,MV3,MV4)
2- Reservoir
3- Process Tank
4- Water pump. Digital output (0,1)

5- Solenoid valves (SV1, SV2, and Sv3). Digital Output
6- Servo Valve. Analogue Output
7- Heat Exchanger
8- Float Level. Analogue input
9- Flow sensor. Analogue input
10- Float switch. Digital input
11- Fan. Digital Output
12- Temperature sensors. (T3,T4,T5)Analogue input

2.4 Stage 4: Programming stage by apply the expressions in the command boxes of Delta-V software Programming the control strategies by writing the proper Expressions in CND to Devices Control Studio in the Control Module:

RIG38-600
TEMRATURE RIG
1- [RIG38-600/38-600-HEATER]-Control Studio Heater Element
AND 1
CND 1 Expression: '//38-600-TEMPSEND5/AI1/OUT.CV'<35;
CND 2 Expression: '//38-600-CV/AO1/OUT.CV'>60;
CND 3 Expression: '//38-600-TEMPSEND1/AI1/OUT.CV'<50;
DO1: IO_OUT=DCS_CONTOLLER/DI/CO7/CH07/OUT_D Heater Element

2- [RIG38-600/38-600-PUMP]-Control Studio PUMP
CND 1 Expression: '//38-600-HEATER/DO1/OUT_D.CV'=true;
DO1: IO_OUT=DCS_CONTOLLER/DI/CO7/CH06/OUT_D PUMP
RIG38-100 LEVEL PROCESS RIG

1- [RIG38-100/38-100-PUMP]-Control Studio PUMP
AND 1
CND 1 Expression: '//38-100-LEVELSEND/AI1/PV.CV'>80;
CND 2 Expression: '//38-100- LEVELSEND/AI1/PV.CV'<60;
CND 3 Expression:'//38-100-FLOATSW/DI1/PV_D.CV'=false;
CND 4 Expression: '//38-600-HEATER/D01/OUT_D.CV'=true;
CND 5 Expression: '//38-600-CV/AO1/OUT.CV'>80;
DO1: IO_OUT=DCS_CONTOLLER/DI/CO7/CH01/OUT_D -------- PUMP

2- [RIG38-100/38-100-SV1]-Control Studio ----------Solenoid Valve 1
CND1 Expression: '//38-100-PUMP/DO1/OUT_D.CV'=true;
DO1: IO_OUT=DCS_CONTOLLER/IO1/CO7/CH02/OUT_D

3- [RIG38-100/38-100-SV2]-Control Studio ---------- Solenoid Valve 3
CND1 Expression: '//38-100-LEVELSEND/AI1/PV.CV'>70;
DO1: IO_OUT=DCS_CONTOLLER/IO1/CO7/CH03/OUT_D

4- [RIG38-100/38-100-SV3]-Control Studio ---------- Solenoid Valve 2
CND1 Expression: '//38-100-PUMP/DO1/OUT_D.CV'=false;
DO1: IO_OUT=DCS_CONTOLLER/IO1/CO7/CH04/OUT_D

An example of the navigation between widows in DEltaV to program the control studio commands of SV3 and SV1 were explained in appendix Figures no (1,2,3,4,5,6).

2.5 Stage 5: Running the process and monitor the results by DCS output Display.

Before running the control system the analogue and digital input devices were calibrated for accurate process control, In the meanwhile the level output response of the system was adjusted by manual valves (open and close) to meet the system constraints see appendix figure (1).

The sequential process control system was tested, in the meantime an automatic control system was verified to maintain a closed loop control according to the proposed scenario. The big challenge in this research was how to put your hands on the system to run a close loop system and view the desired results. It took several working hours to be acquainted with DCS system including implementing your proposed control scenario by joining the software and hardware parts of the DCS system.

The designing and the application stages of a control scenario were compared step by step and the combination of temperature and Level process was tested to have a stable control system.

1.1. RESULTS: The experimental results of close loop system was implemented to control both water temperature and level in the same steps designed for. Where in the beginning the Heater was switched on to start the sequential operation to get started, pumps started to run and solenoid valve SV1was opened automatically to let water flow in the pipe lines to fill the process tank to a level of 80%.see Fig(10)

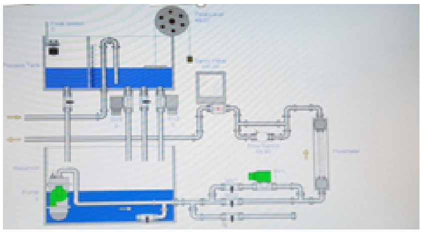


Fig.(10): SV1 opened & pump (ON)

While water level increasing and reach 70% the SV3 opened see fig. (11).

When the level reach 80% the system switched off the pump and closed SV1 and SV3 opened with SV2 to drain the water to the reservoir see fig. (12). When the level reached 70% or less SV3 closed and the water continued to drain by SV2 till 60% see fig. (13). and the same control loop will be repeated again to maintain the level between 60% and 80%.

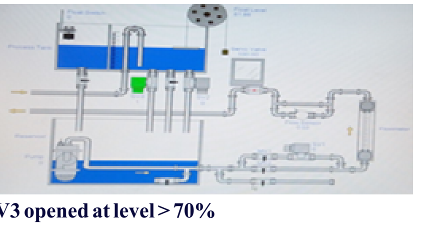


Fig.(11): SV3 opened at level > 70%

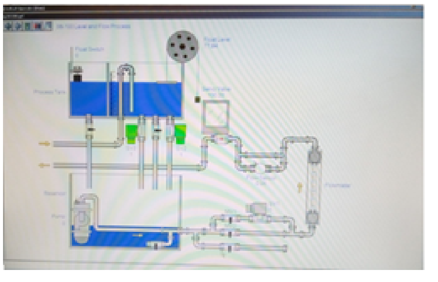


Fig.(12): SV3 and SV2 opened at level = 80%

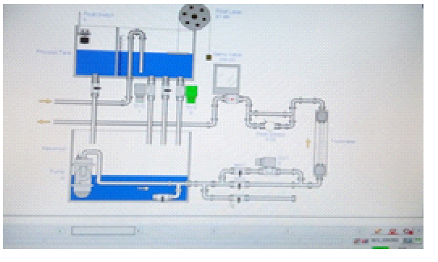


Fig.(13): SV3 closed SV2 opened at level < 70%

See appendix Fig. (1): *Time response for the level process* For the temperature process stages

Once the Heater Element switched ON and start heating the water in the reservoir (boiler) used for primary loop of Heat Exchanger, the two pumps switched ON automatically and the water start to flow in the pipes through the Heat Exchanger in Primary and Secondary loops.

The Temperature sensors measuring the process temperature from both Primary side and secondary side, and the heater and pumps will be switched off automatically if Temperate T5 =35°C.

The End of process

4-DISCUSSION:
The practice on industrial relevant hard- and software should be an

important part of control education. Beside theoretical basics given in lectures, study trips to industrial plants and deepening loop-control-laboratories a laboratory along the levels of the automation pyramid as well as along the life-cycle of a plant give the students the big picture of process automation.[2]

This research concentrated on a practical experimental approach that enrich the educational means of training toward the industrial plants. And a combination of multi processes in one control systems to produce a useful products is part of educational goals. The table (1) in the appendix showed how to design your control system by mapping input /output devices together in the software side to get an Automatic Control System. The knowledge gained from the execution procedure of this practical experiment is helpful to give the new trainees with a practical and theoretical methods through programming and controlling techniques.

The major consideration in industrial processes control are summarized in:

1- Sequential control of output devices actuators to maintain the desired output response.
2- Calibration of input sensors
3- Calibration of output devices
4- Minimize the errors by using different techniques.
5- Safety operation of process in case of malfunction appear.
6- Alarm need to be provided for warning hazards
7- Data logger for tracing the history of problems in small and large scale systems.
8- Maintain the automation control with system stability.

Different experimental strategies are examined to capture all economical, operational and environmental aspects of the problem.[4] The results of this experiment can be easily explained from the figure (1) in appendix. The time response curve of the level process showed that sequential control of the valves and pump create automated close control system. And if we concentrate more deeply on the slope of each part of the curve with respect to time we realize that:

1- The time needed to fill tank till 70% was depended on flow rate of water in the pipes which depended on pump rate and opening% of servo valve
2- The level from 70% 80% the filling was slow compare the previous case due to SV3 was opened.
3- While from 80% to 70% the draining rate was depend on may three devices SV2 mSV3 and manual valve opening percentage

By execution of this practical control system the technical trainees will have the access to DCS world and programming and gain more self-confidence in modifying and control of processes scheme.

5.CONCLUSION:

By using one of the advanced Distribution Control System (DCS) in training process, we enrich the Maintenance of Measuring and Control Equipment training program with the advanced technology and great knowledge of how to operate and maintain the control systems using different types of processes and controller devices.

In the DCS system, we can tailor different training courses under the control programs such as operation of control systems (monitoring and control), maintenance of DCS equipment and Process devices and how to trace/repair faults and finally how to create control strategy, program the control system criteria and modify the software program.

The table in appendix can be used as a template to create new scenario of operation for the process adding different types of control technique such as PID control.

Mapping of input/ ouput devices relating to process control scenario

				Level and Temperature Processes Rigs Input /Output Devices status																									
				38-100 Level Process Rig												38-600 Temprature Process Rig													
				Analog Input		Digital Input	Analog Output	Digital Output								Analog Input						Digital Input	Analog Output	Digital Output					
			Location	C02CH01	C02CH0	C06CH01	C04CH01	C07CH01		C07CH02		C07CH03		C07CH04		C02CH03	C03CH01	C03CH02	C03CH03	C03CH04	C03CH05	NIL	C04CH02	C07CH0		C07CH0		C07CH0	
			SIGNAL	LEVELSEND	FLOWSEND	FLOATSW	Control Valve %	PUMP (ON)	PUMP (OFF)	Solenoid Valve 1 (ON)	Solenoid Valve 1 (OFF)	Solenoid Valve 2 (ON)	Solenoid Valve 2 (OFF)	Solenoid Valve 3 (ON)	Solenoid Valve 3 (OFF)	FLOWSEND	TEMPSEND 1	TEMPSEND 2	TEMPSEND 3	TEMPSEND 4	TEMPSEND 5	NIL	Control Valve %	FAN (ON)	FAN (OFF)	PUMP (ON)	PUMP (OFF)	HEATER (ON)	HEATER (OFF)
38-600 Temperature Process Rig	38-100 Level Process Rig	Digital Output	PUMP	>80 OFF		>90% OFF	>80																					ON	
				<60 ON																									
			Solenoid Valve 1					ON																					
			Solenoid Valve 2				> 70																						
			Solenoid Valve 3						ON																				
			Solenoid Valve 4																										
		Analog Output	Control Valve																										
	38-600 Temprature Process Rig	Digital Output	FAN																										
			PUMP																									ON	
			HEATER														<50				<35		>60%						
		Analog Output	Control Valve																										

Table no. ***(1): Mapping of input output devices for processes control programming purposes***

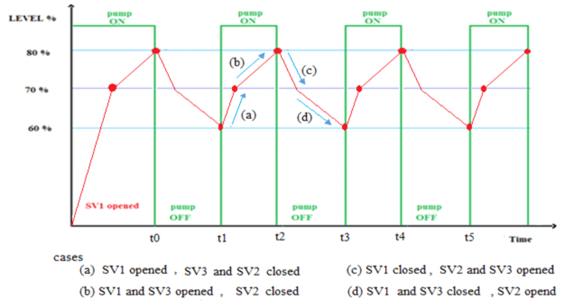
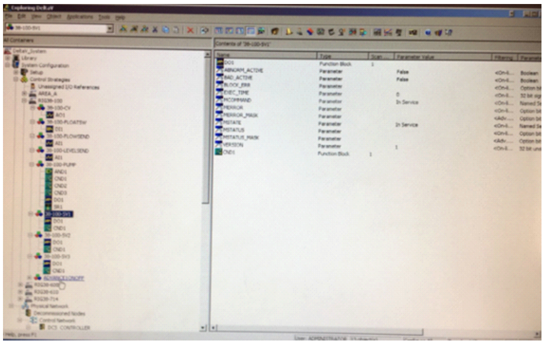
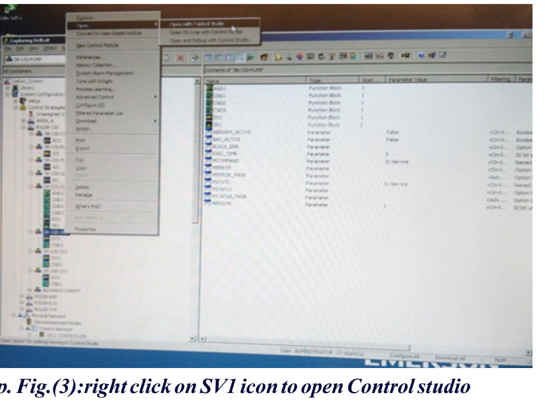


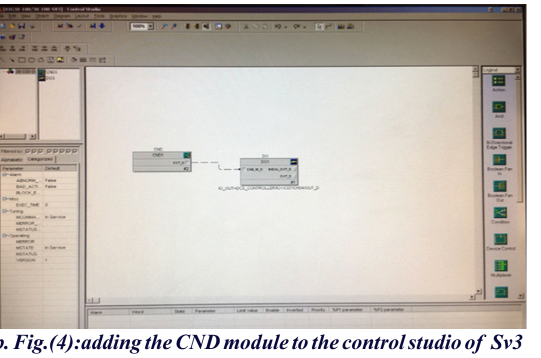
Fig. (1): Time response curve for the level process



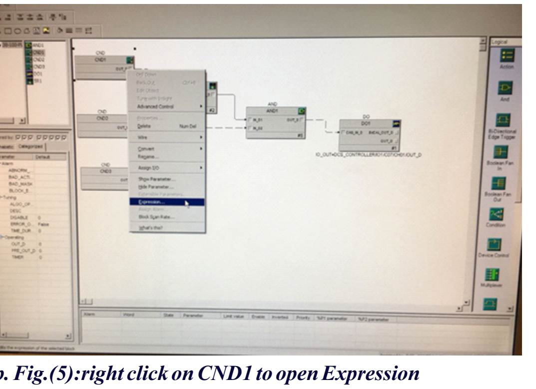
App. Fig.(2):Exploring DeltaV and module unit 38-100-SV!



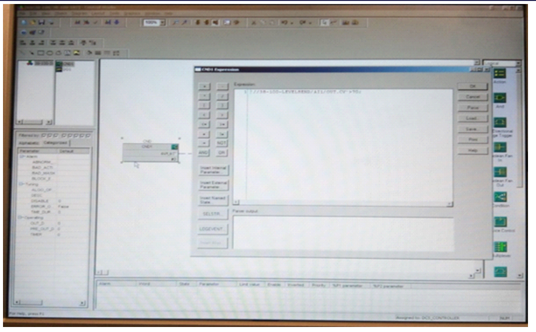
App. Fig.(3):right click on SV1 icon to open Control studio



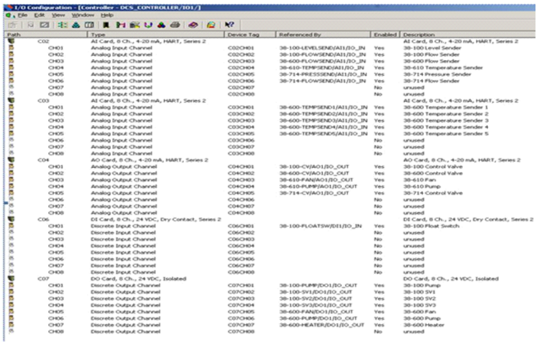
App. Fig.(4):adding the CND module to the control studio of Sv3



App. Fig.(5):right click on CND1 to open Expression



App. Fig.(6):CND1 Expression



I/O Configuration - [Controller - DCS_CONTROLLER/IO1/]

Path	Type	Device Tag	Referenced By	Enabled	Description
C02	AI Card, 8 Ch., 4-20 mA, HART, Series 2				AI Card, 8 Ch., 4-20 mA, HART, Series 2
CH01	Analog Input Channel	C02CH01	38-100-LEVELSEND/AI1/IO_IN	Yes	38-100 Level Sender
CH02	Analog Input Channel	C02CH02	38-100-FLOWSEND/AI1/IO_IN	Yes	38-100 Flow Sender
CH03	Analog Input Channel	C02CH03	38-600-FLOWSEND/AI1/IO_IN	Yes	38-600 Flow Sender
CH04	Analog Input Channel	C02CH04	38-610-TEMPSEND/AI1/IO_IN	Yes	38-610 Temperature Sender
CH05	Analog Input Channel	C02CH05	38-714-PRESSSEND/AI1/IO_IN	Yes	38-714 Pressure Sender
CH06	Analog Input Channel	C02CH06	38-714-FLOWSEND/AI1/IO_IN	Yes	38-714 Flow Sender
CH07	Analog Input Channel	C02CH07		No	unused
CH08	Analog Input Channel	C02CH08		No	unused
C03	AI Card, 8 Ch., 4-20 mA, HART, Series 2				AI Card, 8 Ch., 4-20 mA, HART, Series 2
CH01	Analog Input Channel	C03CH01	38-600-TEMPSEND1/AI1/IO_IN	Yes	38-600 Temperature Sender 1
CH02	Analog Input Channel	C03CH02	38-600-TEMPSEND2/AI1/IO_IN	Yes	38-600 Temperature Sender 2
CH03	Analog Input Channel	C03CH03	38-600-TEMPSEND3/AI1/IO_IN	Yes	38-600 Temperature Sender 3
CH04	Analog Input Channel	C03CH04	38-600-TEMPSEND4/AI1/IO_IN	Yes	38-600 Temperature Sender 4
CH05	Analog Input Channel	C03CH05	38-600-TEMPSEND5/AI1/IO_IN	Yes	38-600 Temperature Sender 5
CH06	Analog Input Channel	C03CH06		No	unused
CH07	Analog Input Channel	C03CH07		No	unused
CH08	Analog Input Channel	C03CH08		No	unused
C04	AO Card, 8 Ch., 4-20 mA, HART, Series 2				AO Card, 8 Ch., 4-20 mA, HART, Series 2
CH01	Analog Output Channel	C04CH01	38-100-CV/AO1/IO_OUT	Yes	38-100 Control Valve
CH02	Analog Output Channel	C04CH02	38-600-CV/AO1/IO_OUT	Yes	38-600 Control Valve
CH03	Analog Output Channel	C04CH03	38-610-FAN/AO1/IO_OUT	Yes	38-610 Fan
CH04	Analog Output Channel	C04CH04	38-610-PUMP/AO1/IO_OUT	Yes	38-610 Pump
CH05	Analog Output Channel	C04CH05	38-714-CV/AO1/IO_OUT	Yes	38-714 Control Valve
CH06	Analog Output Channel	C04CH06		No	unused
CH07	Analog Output Channel	C04CH07		No	unused
CH08	Analog Output Channel	C04CH08		No	unused
C06	DI Card, 8 Ch., 24 VDC, Dry Contact, Series 2				DI Card, 8 Ch., 24 VDC, Dry Contact, Series 2
CH01	Discrete Input Channel	C06CH01	38-100-FLOATSW/DI1/IO_IN	Yes	38-100 Float Switch
CH02	Discrete Input Channel	C06CH02		No	unused
CH03	Discrete Input Channel	C06CH03		No	unused
CH04	Discrete Input Channel	C06CH04		No	unused
CH05	Discrete Input Channel	C06CH05		No	unused
CH06	Discrete Input Channel	C06CH06		No	unused
CH07	Discrete Input Channel	C06CH07		No	unused
CH08	Discrete Input Channel	C06CH08		No	unused
C07	DO Card, 8 Ch., 24 VDC, Isolated				DO Card, 8 Ch., 24 VDC, Isolated
CH01	Discrete Output Channel	C07CH01	38-100-PUMP/DO1/IO_OUT	Yes	38-100 Pump
CH02	Discrete Output Channel	C07CH02	38-100-SV1/DO1/IO_OUT	Yes	38-100 SV1
CH03	Discrete Output Channel	C07CH03	38-100-SV2/DO1/IO_OUT	Yes	38-100 SV2
CH04	Discrete Output Channel	C07CH04	38-100-SV3/DO1/IO_OUT	Yes	38-100 SV3
CH05	Discrete Output Channel	C07CH05	38-600-FAN/DO1/IO_OUT	Yes	38-600 Fan
CH06	Discrete Output Channel	C07CH06	38-600-PUMP/DO1/IO_OUT	Yes	38-600 Pump
CH07	Discrete Output Channel	C07CH07	38-600-HEATER/DO1/IO_OUT	Yes	38-600 Heater
CH08	Discrete Output Channel	C07CH08		No	unused

App. Fig. (7): Input / Output configuration

REFERENCES:

1- IEEE TRANSACTIONS ON EDUCATION, VOL. 51, NO. 4, NOVEMBER 2008 423 An Alternative Teaching Method for Electrical Engineering Courses Carina Savander-Ranne, Olli-Pekka Lundén

2- Proceedings of the 9th IFAC Symposium Advances in Control Education The International Federation of Automatic Control Nizhny Novgorod, Russia, June 19-21, 2012 A Hands-On Laboratory on Industrial Hardware, Process Control and Advanced Automation Tina Krausser, Lars Evertz, Ulrich Epple Chair of Process Control Engineering/ RTWH Aachen University, Aachen, 52064 Germany (e-mail: {t.krausser, l.evertz, u.epple}@plt.rwth-aachen.de). , and Samuli Kolari}

3- Feedback Instruments Ltd, Park Road, Crowborough, E. Sussex, TN6 2QR, UK. Telephone: +44 (0) 1892 653322, Fax: +44 (0) 1892 663719. email: feedback@feedback-instruments.com website: http://www.feedback-instruments.com Manual: 38-009 Ed05 01/07/11 Printed in England by Fl Ltd, Crowborough Feedback Part No. 1160–38009

4- IEEE TRANSACTIONS ON EDUCATION, VOL28, Issue NO. 4, NOVEMBER 2008 423 Multi-objective stochastic Distribution Feeder Reconfiguration in Systems with wind power Generators Fuel Cells using the pint estimated method