Condition Monitoring and Control of a Process System in Distributed Control Mode

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Nowadays, in process industries, commonly used process Controllers/Systems are Supervisory control and data acquisition (SCADA), Programmable logic controllersand distributed control systems. Used of any of the Controller/System particularly dependent upon the type of Input/Output, response time, cost, complexity of the process, process-oriented/data-gathering-oriented, Process state-driven/event-driven, etc. Process control refers to control the sequence of activities in a process plant according to the requirement of the final product in the most economical way. Using an Automatic control system, we can monitor and control the process in real-time, identify and rectify the problem, and adjust (program) according to the requirement. This paper gives insight into system hardware for Controller and Input/Outputs and hardware for Distributed Control System (SIEMENS-PCS7) workstation. This paper describes the logic and algorithms applied to control a plant with the help of languages such as Sequential Function Charts (SFC) and Continuous Function Charts (CFC). It discusses the display designed to control a plant by the operator in detail. Also, it includes the proportional–integral–derivative (PID) optimized control loops for temperature and level control.

Keywords: Process Control, Distributed Control System (DCS), Multiple Input Multiple Outputs, Continuous Flow Charts, Proportional Integral Derivative Controller.

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1 Introduction

Industries like petroleum[1],fertilizer and chemical[2], power generation[3,4], oil, and cement factory[5] normally has more no of I/O, Complex process and not easy to monitor and control the process, in this condition we try to monitor and control the process by using PLC/SCADA/DCS but a selection of these controller/systems particularly depend upon no of I/O, Level of complexity, the process is slow or fast, the process is state-driven, or the process is event-driven, process-oriented or data gathering-oriented, cost of the controller/system, support from the vendor, etc.

DCS is a unique design computerized control system used in a plant /process generally with a huge no. of control loops where an autonomous controller is distributed throughout the system, but with a central operator supervisory control. DCS consists of an Automation station, engineering station, and Operator station. Each station has some specific function like operator station (upper level) only able to see what is happening in the plant if some problem occurs or exist in sensor/transducer or transmitter or something is not working, then operator report to a higher level and according to the direction of higher-level, they rectified the problem. The middle level includes the engineering station used in developing logic, configuration as well as commissioning of all servers, controllers, and workstations. Field level includes field devices like control valves, actuator, transmitters, they communicate with the upper levels by field bus and process bus.

DCS response time is slow, i.e., it takes a significant amount of time to process the data, so when response time is considered, then DCS is not the right solution. In fact, for safety, shutdown or firing control requires a separate controller.

DCS can handle many thousand I/O, process enhancement, data integration, and adding new equipment is very easy. The process is complex and needs to change every instantthan DCS is more suitable. The cost of DCS is more than PLC, but it can monitor and control the entire plant; in other words, it can monitor and control many thousands of I/O's. DCS software cannot easily hack because it has one security license manager, which cannot be used on a different computer.

The objective of process control is to optimize [3] the Processes, increase productivity, decrease the cost of production, and eliminate or suppress the disturbance. In the process industries, process control means controlling the sequence of activities concerning end-product requirements. To obtain an accurate product, all processes should be controlled. Measurements of process variables are essential in control systems to controlling the process. Sensors and transducers are responsible for measuring the physical variable and transmitting this value to the control room.

This paper includes seven units. Unit 2 gives a brief description of the process and system requirements; unit 3 is about the control system, unit 4 gives insight about the hardware used in the system and I/O's, unit 5 is about the logical Part (Programming) of the application. In contrast, unit 6 gives the information about the operator display design, and unit 7 results and discussion. Finally, the conclusion is shown in unit 8.

2 Process Description and Requirements

Level control is essential in industries because it may lead to problems and harm the equipment if the level is lower than expected. High levels may lead to overflow and potentially cause problems related to safety and the environment. In industries, obtaining accurate level measurements will save cost and time and optimize the performance of the plant/system and its processes.

Temperature control is a slow and time-varying process. It is vital since it gives a critical condition not only for combustion, chemical reactions, and fermentation but also for concentration, drying, distillation, crystallization, extrusion, and air conditioning. Controlling temperature poorly may lead to significant problems related to quality, safety, cost, and productivity.

Three numbers of pumps are provided for liquid to circulate from the storage tank; two numbers of motorized control valves are provided to control the flow of liquid in pipeline, to drive the heater power a powerful thyristor power controller is used to control the temperature of liquid in pipeline, for the flow of liquid two flow transmitter (DPT) are provided, three no of RTD Sensor are provided to measure the temperature at various stages, five numbers of the level transmitter are used to sense the level of each tank, Digital panel meters are provided to indicate the output of each sensor/transducer, to study the response of four tank system four acrylic tank are used, An industrial type liquid heater is used as a heat Source.

Figure 1. Describes the process or plant that is required to be monitored and controlled.

Fig. 1. MIMO Process Control System

In our laboratories, we have four tank systems that have the following equipment/device.

The abbreviation instruments and equipment used are as shown in TABLE 1.

Table 1. ABBREVIATIONS AND INSTRUMENTS

S. No.	Abbreviation	Description
1	MCV	Motorized control valve
2	FT	Flow transmitter
3	HV	Hand valve
4	R	Rotameter
5	LT	Level transmitter
6	TT	Temperature transmitter
7	TPC	Temperature power transmitter
8	CT	Current transmitter
9	RT	Reservoir tank
10	PUMP	Centrifugal
11	OHT	Over Head tank

The objective of the project is to condition monitoring and control the level of the four-tank system and temperature of the liquid in the pipeline by using (SIEMENS) distributed control system.

The number and types of inputs/outputs such as analog/digital for the system are shown in TABLE 2.

Table 2. Number and types of inputs/outputs

S.No.	I/O type	Nos
1	Analog input	8
2	Analog output	3

The sequence shown below is to run each operation:

For Level Control: -

1. Electrical connections should be given as per the manual

2. Interfacing connection should be given as per the manual

3. Position of the Hand valve (This HV position is for level control of tank1 and similarly, some changes in HV position will result in control of other tanks also)

NO - HV2, HV6

NC - HV3, HV4, HV5, HV19, HV20, HV8

Partially open – HV1, HV7

4. Switch on the VMPA-701 and varying the speed of the pump

5. Open the SIMATIC Manager software

6. Open Station Configuration Editor, select IE General, WinCC Appl, and click ok

6. Go to SIMATIC Manager> Open the file MIMO_NIT

7. Go to SIMATIC Manager>Choose options>select configure Network>Select SIMATIC 400(1), IE General, WinCC Appl>download the selected station

8. Go To SIMATIC Manager>open WinCC Appl >select OS(1), take right-click choose PLC and download again Select OS(1), Take right click compile

9. Open WinCC Appl> select OS (1) and open object>activate

For Temperature control: -

1. HV position change to

NO – HV3, HV4, HV6, HV8

NC – HV2, HV5, HV19, HV20, HV7

Partially open – HVI

2. Switch On the heaterand vary the pump speed

3 Control System

The complete control system shown in fig 2, consists of field station and master station. The master station has both engineering and automation stations. The lower-end computer uses the SIMATIC ET200PA SMART processor as the core, the local control uses the SIMATIC HMI touch screen, and the industrial computer (host computer) takes over centralized monitoring and management.Industrial Ethernet (SIMATIC NET) is used by the host computer to connect each local control to the upper-end computer.The lower-end computer is connected via RS-232 point-to-point communication. Field instrument/equipment, sensors or actuators, pumps, valves, etc., connected via PROFIBUS DP and PROFIBUS PA.

The control system topology is as shown in Figure 2.

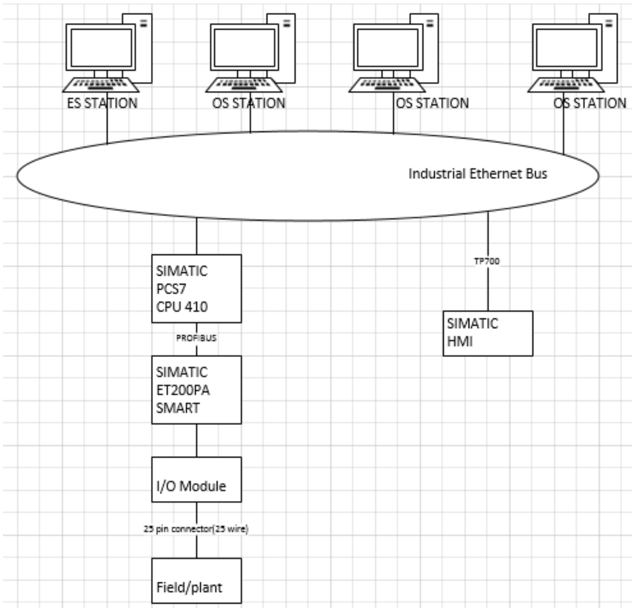

Fig. 2. Control system topology

4 System Hardware and Software

HARDWARE

System hardware shown in fig. 3, consists of SIMATIC PCS7 CPU 410, SIMATIC NET, Operator Station or HMI, ET200PA SMART.

Fig. 3. SIEMENS DCS Hardware

I. SIMATIC PCS7 CPU 410: It is robust, high-performance hardware; the CPU 410-5H covers the entire Performance spectrum of the AS 412 to 417 systems. The performance range of the CPU 410-5H can be extended according to the size and type of PCS7 applications. The CPU can multi-task, it means that several programs can run both Basic Process Control Applications (BPCS) and safety-oriented applications simultaneously.

II. SIMATIC NET: Communication is one of the very important for any process industries reason being the distance between field and control room is long sometimes it may be more than 5km and these wire from far away equipment is messy. SIMATIC NET is one of the solutions for the process industries which handling all kinds of communication either between field or automation systems. SIMATIC NET is of three levels, i.e., management level, cell level, and field level.

Field level: Sensors, actuators, field equipment such as pumps, valves, motors, small area controllers, etc., thousands of these are located throughout the plant, away from the main control room. Some actuators have their tiny control computers. One of the problems now industries are facing is wiring and cost. For this level, PROFIBUS DP and the AS-Interface are offered by SIMATIC NET. At the same time, 126 devices are allowed to be connected by the RS485 balanced transmission used in PROFIBUS DP; but with the help of hubs or repeaters, more devices can be connected, or the network expanded.

Cell level: The collected process data is further distributed to various automation systems for an operator to monitor and control. For this level, SIMATIC NET offers industrial Ethernet and PROFIBUS, which are used for communication.

Measurement level: For future use, collected process data is saved, further processed, or used for design and analysis. This is a high-level function that is handled by high-level management. For such purposes, the use of Industrial Ethernet is followed for communication networks.

III. Operator Station or HMI is used for displaying and operating all the plant parameters graphically and logging this data in the plant database systems. Trend Display provides practical and easy monitoring of the various process parameters. Some station is used for monitoring only processparameters; others for only displaying trends, data logging, scheduling the plant as well as alarming requirements.

IV. ET200PA SMART: ET 200PA SMART has the technical setup of the S7-300 automation system and is made up of the IM 650 interface module and special ET 200PA SMART I/O modules. ET 200PA SMART can only communicate with DP master of S7-400 PA CPU (CPU 410-5H). PROFIBUS DP is either co-axial electrical wire (RS485) or optical fiber cable (FOC).

Distributed I/O devices are the ideal solution when inputs and outputs are distributed throughout the plant, and the control CPU is in a central location. The DP master connects the control CPU and the distributed I/O's. The DP master helps in data exchange between PROFIBUS DP and distributed I/O's and monitors PROFIBUS DP. The distributed I/O's (DP slaves) help prepare the encoder data and the actuators on-site such that the PROFIBUS DP can transmit them to the control CPU.

SOFTWARE

I. SIMATIC MANAGER: SIMATIC Manager is the starting point for creating your entire project. There are four phases of creating the automation project. The first phase is planning and configuring the plant, 2nd phase is implementation and module testing, 3rd phase is testing and commissioning, and the last phase is operation and maintenance.

II. SIMATIC WinCC (v7.4): Archiving, Compressing, and analyzing process data. Configuration of process data in the (compressed) archives, archiving process data in the compressed archives, analysis utilizing a trend view, ruler view, and manual changing of archive data.

Process industries have become much more complex in relation to ever-increasing quality requirements, rapid product changes as well as frequent modifications.Also, to ensure the highest possible productivity, there is a need to make quick and target-oriented decisions against process optimization at all levels of the company. This requires an integrated information flow at each operational level and location. SIMATIC WinCC helps provide us with greater transparency and a foundation to optimize the process.

III. Automation License Manager: As a precautionary measure against cyber-attacks in plants, systems, networks, and machines, it is necessary to implement and at the same time maintain a holistic, state-of-the-art industrial security concept. Siemen's products are based on license keys, and these keys are supplied by USB stick. License keys are only associated with a special handling program on the product data carrier and are installed by default with the Software.

5 Programming and Logic Design

DCS supports various programming languages like sequential function charts,Continuous function charts, ladder diagrams, functional block diagrams, instruction lists, structured texts, etc., among which SIEMENS DCS supports both CFC and SFC.

CFC: It is used to create the entire software structure of the CPU by using pre-configured blocks or newly created blocks. The editor caninsertblocks into function charts assign each block parameter by given some specific name and interconnect blocks. Interconnecting means that values can be transferred from one output or input to another one or more inputs or output during communication between the blocks.

Drag and drop pre-configured blocks or newly created blocks from the pool of blocks to the chart using mouse click. The chart is a "drawing board" where we interconnect the Block inputs and outputs via a mouse click. Here we need not consider details like algorithms or assignment of machine resources; in other words, we can fully concentrate on the technological aspects of our configuration. After creating all functions, we can generate the executable machine code using a mouse click, download the code to the target system (CPU) and debug it using the CFC debugger.

SFC: Sequential Function Chart helps in graphical configuration and commissioning of sequential control systems. Transfer of sequential control systems (e.g., batch process) to an automation system and execution is done. Based on sequencers, a sequential control system helps in the state-driven (event-driven) execution of production processes. Sequential control systems can be used for describing product manufacturing specifications into state-driven processes or event-driven, for example. The sequential control system helps control the CFC-created essential automation functions by operating and state changes and then selective processing.

The CFC program of the MIMO process control system shown in fig 4 consists of four parts or sections, which are carried out at the engineering station. The Process Automation Library in Siemens PCS7 software has ready-made blocks for various processes and equipment. Configuration of CFC Blocks is done in the plant and the programming of CFC Charts is done in the SIMATIC Manager.

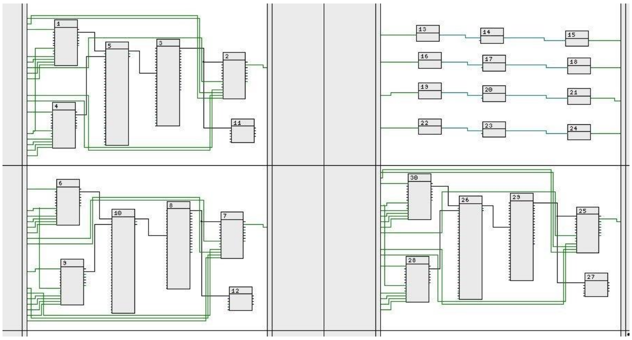

Fig. 4. CFC Program for MIMO System

The CFC Program of the MIMO Process control system is shown in Figure 4.

No. of I/O for Level Control

INPUT

Level of tank1 “IW512”

Level of tank2 “IW514”

Level of tank3 “IW516”

Level of tank4 “IW518”

OUTPUT

Motorized control valve 1 "QW512."

Motorized control valve 2 "QW514."

Chart1

LT2 and LT3 level control programming includes 2-Pcs7AnIn, 1-selA16In, PID controller, Pcs7AnOu and MonAnl. These blocks are interconnected together to form two close loops that easily monitor and control the level of tank2 and tank3.

Pcs7AnIn (2 no): Each of the channel-specific signal functions of the analog input module is cyclically processed by the block. From the process image (partition), a raw analog (4-20mA) value is read and converted to a physical value, or a percentage value is calculated, or a percentage value based on raw value is calculated.

SelA16In: selecting one of 16 analog values and switching it through to the output.

PID Controller-This block takes error (difference between input and output) and gives manipulated value as an output.

Pcs7AnOu: signal processing of an analog output value from S7-300/400 analog output groups

MonAnl: Monitoring an analog process value and monitoring of the grading of an analog process value.

Chart2

Scaling the analog value: The level of a tank with a capacity of 500 liters is to be measured. The transducer measures a voltage of 0V with an empty tank and a voltage of +10V with a full tank.The analog module converts the voltage range from 0 V to +10 V into the value range 0to +27648 and converts this range into the original quantity of 0 to 500 liters with Scale program block.

This scaling programming consists of three blocks:

1st block is a converter that converts 4-20mA into integers, i.e., 4-20mA to 0-27648

2nd block is a division that converts the 0-27648 range to 0 to 100 by dividing each value by 100.

3rd block converts an integer to a word, i.e., from 0 to 100 value to 4-20mA.

The other two charts (one chart for level control of tank1 and tank4 another chart for temperature control) are similarly programmed.

6 Operator Display (Graphic) Design

Graphics Designer is an editor in WinCC Explorer that creates process drawings outside the plant. The operator can draft these drawings and work with them in process mode using the "drawing by the name." The standard library for WinCC provides several ready-made objects to be used when creating process diagrams. In a library, you will find a different type of object, which is further classified into static and dynamic objects. The purpose of a stationary object is only to draw a picture. A pipeline, circle, etc are the example of the static object. Dynamic objects are updated either through a connection to a tag or through a function. Through this, the process values shown here are always up to date at runtime. Process input, process output, field or status display are examples of dynamic standard objects.There are several options for dynamic updating of objects in a process diagram (Tag Connection, Dynamic Dialog Box, Direct Link, C Action, VBS Action, etc.). The tag selection dialog allows us to tie objects, e.g., process input/output fields or faceplates that we implanted in a process diagram in the Graphics Designer, with the corresponding connection of a block instance in the Continuous Flow chart. In-process mode, these objects read the current values of the connection from the AS and display the values to the OS. During the configuration process, we can choose between two tag sources, either ES tags or WinCC tags. Depend upon the requirement, Channels, Logical connections, Process tags, Internal tags, Tag groups, etc., can be managed at the "tag management" editor by double-clicking in the tree view of the WinCC Explorer.

The Graphics Designer or Operator display design of the MIMO process control systemis shown in fig 5.

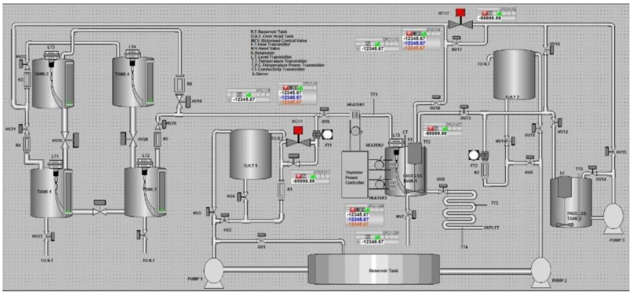

Fig. 5. Operator Display of MIMO process control System

7 Results and Discussion

Trend Display provides practical and easy monitoring of various process parameters. While some PCs are used only for monitoring process parameters, others are used for displaying trends, data logging, plant scheduling and hazard requirements.

Using Parameter display, we can monitor level and temperature and change the level and temperature according to the requirement. An operator can change the set-point according to the requirement varying the PID parameter (K_p , K_i , K_d,T_i, T_d).

PID parameters without Optimization

When the gain of PID (K_p , K_i , K_d,T_i, T_d) is not optimized, the graph of set-point and process value are different or does not coincide.The Trend display for level control is shown in Fig 6. The error (SP-PV) is always present, and the controller tries to eliminate/minimize this error, but it is taking longer.

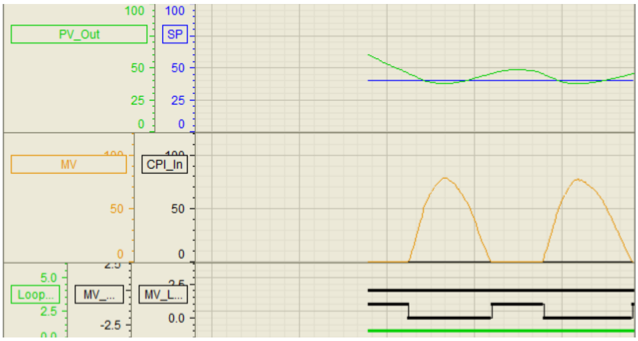

Fig. 6. Trend display of level control before PID optimization.

The value of the PID-parameteris shown in TABLE 3 before PID optimization

TABLE 3. PID-parameter

Process parameter	K_p	K_i	K_d	T_i	T_d
Level	1.5	0.2	1	0.1	0.01
Temperature	8	0.8	5	0.1	0.01

PID parameter after optimization

When the gain of PID (K_p , K_i , K_d, T_i, T_d) is optimized, the graph of the set-point and the process value is either identical or coincident. The PID optimization is shown in fig. 7.The Trend display for level control is shown in Fig 8 after optimization. The error (sp-pv) does not exist, and therefore no action is taken from the controller to the system.

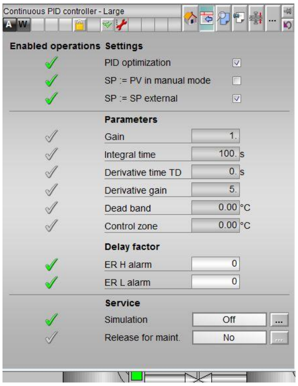

Figure.7. PID parameter after PID optimization

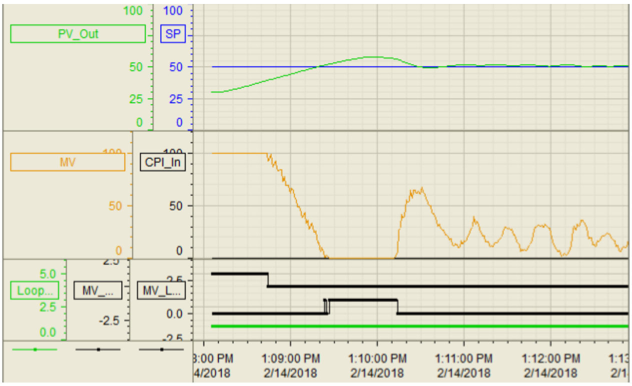

Fig. 8. Trend display of level control after PID optimization [3]

When the gain of PID (K_p , K_i , K_d, T_i, T_d) is optimized, the graph of the set-point and the process value is either identical or coincident. The error (SP-PV) does not exist, and therefore no action is taken from the controller to the system.

The value of the PID-parameter is shown in TABLE 4.

TABLE 4. PID-parameter

Process parameter	K_p	K_i	K_d	T_i	T_d
Level	10	8	0	5	0
Temperature	12	1	8	2	1

8 Conclusion

MIMO process control System was implemented on SIEMENS DCS (PCS7) System. On this system, continuous and batch processes can be implemented. Here, Continuous Flow Chart Blocks reduced the time required for design and development. Created chat can be modified whenever required. Operator displays or graphic design for monitoring and control the processes for small plants, or large plants are very informative and interactive in this SIMATIC DCS (PCS7).

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