DEVELOPMENT OF LOGICAL SYSTEM FOR COMPRESSOR STATION CRITICAL SAFETY OPERATION

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DEVELOPMENT OF LOGICAL SYSTEM FOR COMPRESSOR STATION CRITICAL SAFETY OPERATION

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CERTIFICATE

This is to certify that the work contained in this thesis titled ***"Development of Logical System for Compressor Station Critical Safety Operation"*** has been carried out by ***Puranjan Giri*** under my/our supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

An acknowledged need exists within the gas transmission industry for a new generation Compressor Station. The characteristics desired for this new compression system include: minimal maintenance requirements; capability of starting and stopping several times per day; easy installation and minimal environmental detriments. Several factors driving this need include- the increasing demand for natural gas; stringent environmental regulations; maintenance requirements of gas-fired equipment; and the age of the installed pipeline infrastructure.

Considering the current configurations of commercially available Compressor Station systems, a logical control system could be designed for compressor station critical safety operation to meet the challenges facing the gas industry.

For the last few decades there is an extensive work development in Control of electromechanical machines and its peripherals by using conventional transducer sensor along with hardware based PID controller and actuators in close loop system. In this conventional system, the system non-linearity are either avoided by using system delay or considered approximate linear zone which creates lot of dissimilarities in actual performance of the system and its theoretical optimal behavior. In recent techniques developed in mechatronics the above problem of non-linearity can be avoided by using special software & hardware combination such as

1. smart transducer & sensor
2. Proximity switches with microprobes
3. Adaptive modeling of the system
4. System power interface by using online PLC.
5. System Supervision & monitoring by using tool 1 to 4.

In nut-shell the above problem can be solved by developing a logical control system for compressor station critical safety operation using tools like PLC & SCADA.

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A thesis is a product of experience and that goes a long way in shaping up a person in his respective profession. And he is forever indebted to a lot of people who helped him get through this long journey, for their timely help and guidance without which the project success wouldn't have materialized.

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ACRONYMS/ ABBREVIATIONS

A/D	*Analog to Digital*
AI/ AO	*Analog Input/ Analog Output*
CPU	*Central Processing Unit*
DAS	*Data Acquisition System*
DCS	*Distributed Control System*
DDC	*Direct Digital Control*
DI/DO	*Digital Input/ Digital Output*
D-MUX	*De-Multiplexing*
ESD	*Emergency Shut Down*
HDT	*High Discharge Temperature*
HDP	*High Discharge Pressure*
I/O	*Input/ Output*
LCV	*Low Control Voltage*
LSP	*Low Suction Pressure*
MIMO	*Multi Input Multi Output*
MIS	*Management Information System*
MMI/HMI	*Man Machine Interface/ Human Machine Interface*
OS	*Operating System*
PB	*Push Button*
PLC	*Programmable Logic Controller*
RTU	*Remote Terminal Unit*
S BD V	*Station Blow Down Valve*
SBV	*Station Block valve*
SCADA	*Supervisory Control And Data Acquisition*
SDV	*Station Discharge Valve*
S/H	*Sampling and Hold*
SISO	*Single Input Single Output*
SP	*Set Point*
SSDL	*Station Shutdown Lockout*
SSDR	*Station Shutdown Restartable*
SSHDP	*Station Scrubber High Discharge Pressure*
SSHLL	*Station Scrubber High Liquid Level*
SRV	*Input/ Output*
SSV	*Station Suction Valve*
T&S	*Transducer & Sensor*
UDV	*Unit Discharge valve*
URV	*Unit Recycle Valve*
USF	*Unit Seal Failure*
USV	*Unit Suction Valve*
UVF to C	*Unit Valve Fail to Close*
VF	*Valve Fault*
WINCC	*Windows Control System*
μ P/ μ C	*Micro Processor/ Micro Controller*

CHAPTER 1

INTRODUCTION

1.1 PREAMBLE

Logical systems for compressor stations are designed and engineered to allow natural gas pipeline operators to safely, efficiently and intelligently control prime mover and compressors. These systems make pre-programmed decisions based upon operator-entered set points, field inputs and other outside influences. Systems are typically engineered to monitor and control station safety through quickly responding to shutdown conditions when necessary by maintaining a set point for temperature discharge pressure or product flow. Systems also accumulate data, provide a station overview, develop real-time and historical trending information and generate reports.

On a larger scope, the local station system can be integrated with other company systems, such as a supervisory control and data acquisition (SCADA) system to manage an entire pipeline, with provisions for regulatory reporting, pipeline modeling and economic decision analysis.

Logical systems are made up of two primary components – hardware and software. These two components are directly linked, impacting each other's cost, delivery and performance. Hardware can be further defined by a host of end devices, valves and control elements. These devices would normally include sensors, transmitters and switches for temperature control, a variety of meters to monitor process flow, multiple instruments for monitoring liquid levels and switches to monitor unit vibration. Software is categorized by the programmable logic controller/remote terminal unit (PLC/RTU) manufacturer and the control application for which it is intended. Software is designed for operating each compressor unit, as well as for station operation and eventual transmission to a central control location tying in complete information and data for the entire pipeline. These systems have reliably and accurately controlled running parameters of the units, thereby extending the mechanical life of prime mover and compressor components.

Specialist engineering and integration firms focusing on compressor station critical safety operation through logical control which can offer the natural gas pipeline industry clients a means of customizing systems to fit an existing automation plan or work with the operator to embark on a new automation philosophy to facilitate system growth.

1.2 OBJECTIVE

Development of Logical control system for Gas Compressor Station by

1. Monitoring flow, temperature, density, pressure, speed, vibration through RTUs,
2. Generate pre-programmed decisions (Logic) based upon operator-entered set points, field inputs and other outside influences through PLC.
3. Create a SCADA program to developed PC based Graphical User Interfaces which will give runtime information pertaining to alarms, events, processes and shutdown conditions.

1.3 TYPICAL FUNCTION OF LOGICAL SYSTEM

1. Start-up and shut-down sequencing
2. Compressor/motor protection
3. Vibration protection and condition monitoring
4. Alarming/safety checking/interlocks
5. Loading/unloading
6. Communications to the central SCADA system

1.4 METHODOLOGY

1. As the subject concentrates on the logical system development of compressor station, so identify and study of its equipment and layout is the first step.
2. Assess the status of the unit. The unit can be in one of several modes including starting, stopping or running. A status of "available" indicates the unit is ready to be started and is free of malfunctions, whereas an "unavailable" status indicates there is a condition that needs to be addressed before the unit should be started.
3. Input/output (I/O) data acquisition is a task needed for processing the data from the field devices by the Data Acquisition System. The task provides

devices. This task will map input points and identify any such point that is out of range.

4. Development of a Ladder Logic Diagram for controlling compressor station critical safety operation.
5. A simple SCADA program is developed for automation of compressor station. Successful test builds the workflow of thesis to proceed, and forms better foundations are performed from the model, and the data.

1.5 UTILITY OF PROJECT

1. Logical system would help the compressor station running uninterruptedly.
2. The concept can be well applied for remote diagnostics by minimizing downtime and product loss in the event of system failure.
3. This will results in quicker starts, decreased fuel consumption, more speed range, decreased air pollution and quicker detection of problems.
4. Sophisticated HMI software programs give the operator a window into the control system, allow in station level and unit level monitoring and control in the control room using a standard PC

CHAPTER 2

LITERATURE REVIEW

Roberto Camoirano, Giuseppe Dellepiane [4] explains about Power-electric variable frequency drive can be well applied to a wide range of industrial process, which provides reliable and cost efficient solution to ensure precise control of torque and speed using electrically driven rotating machine.

Charles M. Mitchell, Kevin Williams [5] gives the clear idea about performance of PLC in emergency shutdown system and its failure rate in worst case.

Dardo Marqués, Manfred Morari [3] explains operating policies for compressor station in the face of varying demand are established by trial and error using simulators and energy saving by this.

Mokhatab, Saeid, Santos, Sidney P., Cleveland [6] explains about design and control of compressor station ad related overhaul cost. The controlling of station will provide video and print data recording of all key station parameters. The operating stations and units remotely from central dispatch stations and the station control systems will report to the central station via a Supervisory Control and Data Acquisition

Siemens Automation and Drives [7] has expanded the functionality of its visualization system, Simatic WinCC, in the new version 7.0 provide plant personnel with optical responses about possible or required inputs. Such elements are, for example, animated GIFs or displays highlighted by hover and glass effects. Using the hover effect, operable fields change color when they are touched by the cursor, whilst the glass effect enables the fields to be displayed semi transparently. In the alarm and trend display, the controls were completely revised and functionally adapted.

Ernest O Doebelin, Dhanesh N Manik [2] explains about various measuring device like force, torque, shaft power, pressure, flow, temperature etc. Manipulation and transmission of recorded data. Data transmission and instrument connectivity.

Hinz Automation [8] has explained about various problem related to compressor station automatic control and also suggested the solution of those problem.

CHAPTER 3

STUDY OF COMPRESSOR STATION

3.1 INTRODUCTION

Compressor stations are the "engine" that powers an interstate natural gas pipeline. As the name implies, the compressor station compresses the natural gas, (increasing its pressure) to push the gas through the pipeline.

Pipeline companies install compressor stations along their pipelines, typically one every 40 to 100 miles. The size and the number of compressors vary, based on the diameter of the pipe and the volume of gas to be moved. Nevertheless, the basic components of a station are similar.

3.2 COMPONENTS OF COMPRESSOR STATION

- Compressor
- Prime Mover
- Scrubber or Inlet Separator
- Gas Cooler
- Valves
- Data Acquisition System
- Fire & Gas Detection System
- Compressed Air System etc.

3.3 NORMAL OPERATION OF COMPRESSOR STATION

When the natural gas enters the compressor station, it flows through separators (Scrubber) used to remove solids and liquids from the natural gas in the pipeline. These separators are provided mainly to protect the compressor from any small debris that has gotten into the pipeline during construction and water from integrity testing. It should be noted that except for the small amount of debris and liquids captured to protect the compressors, all the natural gas that enters a compressor station leaves it again through the pipeline.

After going through the separators the natural gas is then compressed by a centrifugal or reciprocating compressor. Simplistically a centrifugal compressor works like a fan, each fan is called an impeller and there may be one or several impellers in series depending on how much pressure is needed. A reciprocating compressor on the other hand is made up of one or several pistons configured much like an engine block. Deciding between which type of compressor to use is based on the flow rate through the compressor as well as the amount of pressure that is needed.

The compressor is driven by either a gas turbine, electric motor, or reciprocating engine. A gas turbine is very similar to a jet engine found on an airplane except that instead of using the thrust to push the airplane, the jet turns a large fan to spin or rotate the compressor. An electric motor is a larger version of the electric motors you see every day just as the reciprocating engine is similar to car engine just larger. The gas turbine and reciprocating engines typically use natural gas from the pipeline, where the electric motor uses power from an electric transmission line.

Selection of this piece of equipment is based on air quality, available power, and the type of compressor selected. Typically electric motors are used when air quality is an issue. Gas turbines are used when electric power is not readily available. Reciprocating engines are used when smaller compressors are needed.

Most compressor stations are automated so that the compressors can be started, controlled and stopped from a central control location regardless of the weather conditions, time of day, or day of the week. The logical system also acts to protect the equipment, facility, and surrounding area in the event that the equipment is not operating as it was intended. The operators of the system continuously monitor and adjust the mix of compressors that are running to maximize efficiency as well as keeping detailed operating data on each compressor station. The control center also can remotely operate shut-off valves along the pipeline system.

3.4 CRITICAL PARAMETERS FOR SAFE OPERATION

- Gas Flow Rate in Pipeline
- Inlet & Outlet Temperature
- Inlet & Outlet Pressure
- Speed of Prime Mover
- Lube Oil Level & Temperature
- Bearing Temperature
- Valve Condition

- Fire
- Gas Leak
- Vibration
- Lower Explosive Limit
- Scrubber Liquid Level & Differential Pressure
- Control Voltage & Current
- Unbalancing of Prime Mover.

3.5 ACTION NEEDED AT DIFFERENT SITUATION

The compressor station control system consists of a computer network with separate control computer of the station (overall) control and each individual unit that is interconnected by a computer network.

The station control system provides the overall control of the facility. It handles control in the station that is common to all units (i.e., station compressed air, etc.). The control system of driver and driven equipment are integrated with the station control system. For multiunit stations, load sharing and efficiency programs may control which unit run and how their load is divided. The station control system is responsible to station valves required for emergency shutdown of the station and blow down of piping for compressor stations.

As a central control hub for the station, most normal operator control functions are carried out using this system. An important design constraints of this system is that it must be possible to continue to operate the compressor units (in manual mode) if the station control system is non-operational.

The station control system is responsible for:

- Station process control
- Shut down control
- Auxiliaries control and monitoring

There is often an emergency shutdown (ESD) controller, which is a simple dedicated controller split from the main controller to reduce false emergency shutdowns. The main controller has the potential for outages due to failures or maintenance, so it is appropriate to have dedicated hardware for the ESD system to control valves sequencing and respond to fire and gas detection.

A. AT STATION PROCESS CONTROL CONDITION

The station control system is responsible for the pipeline process control of the station. This control may be one of:

- Suction pressure control
- Discharge pressure control
- Flow control

This control is done in the from of a gain plus integral loop controller set in the unit speed to achieve the desired set- point. Often their may be overrides acting on the primary control loop. If the remote link to the central SCADA site goes down, the station controls maintain the last valid set-point. In order to change this value, an operator has to take local control of the station and enter a new set-point.

B. AT STATION SHUTDOWN CONTROL CONDITION

An important part of a station control is managing the shutdown of units and control of station valves in response to different situations.

Station Shutdown Restartable (SSDR) Mode

This shutdown mode is triggered by one of the following transient process condition

- High discharge pressure
- Low suction pressure
- High discharge temperature

On detection of one of these conditions, a normal stop is send on to the units. As seen in **figure 5.1,** valve return to a normal shutdown position with no change in station main valve position. Units can be restarted remotely when desired. The unit valves stay open and the compressor is pressurized for a certain time period.

Station shutdown Lockout (SSDL) Mode

This shutdown condition triggered by any of the following nontransient conditions:

- Valve fault
- Station scrubber high liquid level shutdown
- Station scrubber high differential pressure shutdown

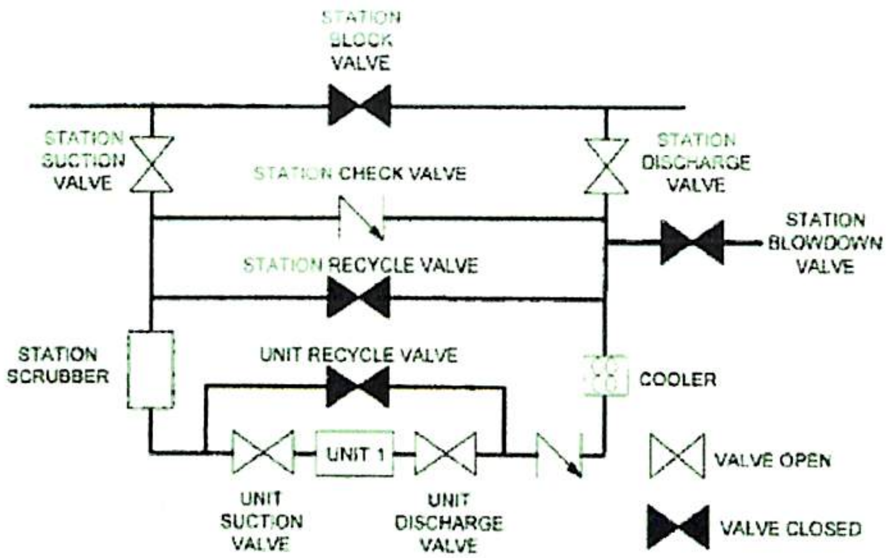


Fig. 3.1: Station Shutdown Restartable

On detection of any of these conditions, a hard-wired emergency stop is issued to the units and the station suction and discharge valves signaled to close. As soon as the differential pressure across the station block vale is at a low enough value to permit safe opening of the block valve, it is signaled to open (**see figure 3.2**). The condition has to be cleared before the station can be brought back into service.

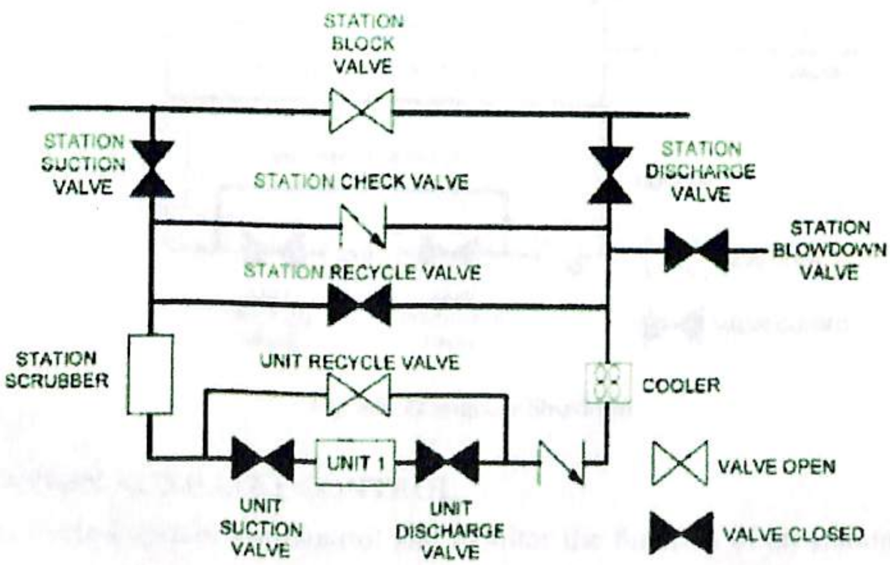


Fig. 3.2: Station Shutdown Lockout

Emergency Shutdown (ESD) Mode

This shutdown condition is triggered by a nontransient condition during which it is unsafe to have piping pressurized. Any of the following can triggered an ESD.

- Fire
- High gas level(gas leak)
- Unit seal failure
- Unit valves fail to close
- Low control voltage
- Manual ESD via push button

On detection of any of these conditions, the following occurs

A station shutdown lockout is issued, causing the unit to stop, the suction and discharge valve to close, and block valve to open.

When the station suction and discharge valve are both fully closed the station blow down valve opens, venting all gas within the station to the atmosphere.

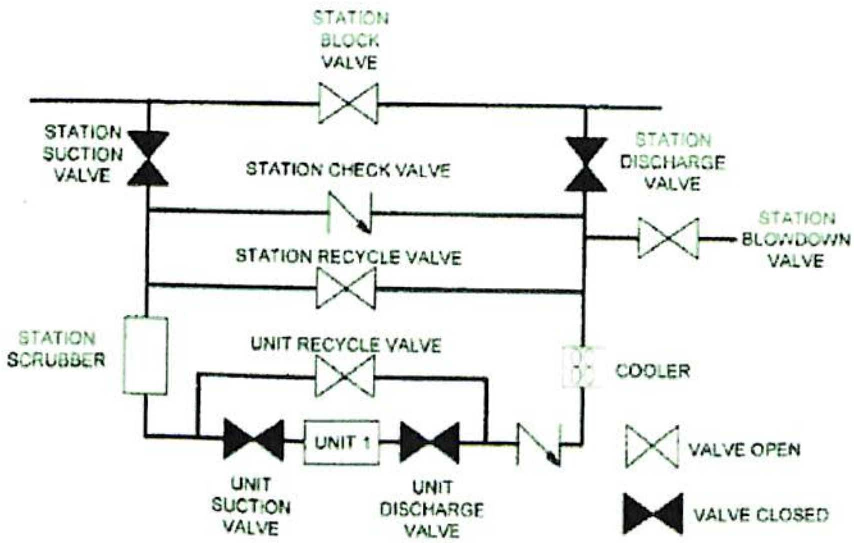


Fig. 3.3: Emergency Shutdown

C. AT STATION AUXILIARY CONTROL

The station control system also control and monitor the function of all station auxiliary system common to the operation of all units. These systems include:

- Auxiliary (emergency) generator
- Battery charger(s) & Inverter
- Security system
- Air- conditioning
- Commercial AC power monitor
- Ground fault detection
- Air compressor(s)
- Mainline scrubber & Fuel gas scrubber
- Vent fan & louver
- Central lube oil cooler
- Fire & gas detection system

Depending on the installation and complexity of the system, it may be controlled from the station main controller or by its won dedicated controller. In either case, an alarm/ status summary for the system is shown on the station control system operator interface.

CHAPTER 4

STUDY OF CONTROL SYSTEM

4.1 INTRODUCTION

A control system is a device or set of devices to manage, command, direct or regulate the behavior of other devices or systems. There are two common classes of control systems, logic or sequential controls, and feedback or linear controls.

An automatic sequential control system may trigger a series of mechanical actuators in the correct sequence to perform a task. For example various electric and pneumatic transducers may fold and glue a cardboard box, fill it with product and then seal it in an automatic packaging machine.

In the case of linear feedback systems, a control loop, including sensors, control algorithms and actuators, is arranged in such a fashion as to try to regulate a variable at a setpoint or reference value. An example of this may increase the fuel supply to a furnace when a measured temperature drops. PID controllers are common and effective in cases such as this. Control systems that include some sensing of the results they are trying to achieve are making use of feedback and so can, to some extent, adapt to varying circumstances.

4.2 CONTROL SYSTEM ARCHITECTURE

In modern control systems, the control functions of the driver and driven equipment are performed in a specialized computer. Measured parameter of system (measured by various transducer/ sensor T1, T2, ...Tn) is comes through a Multiplexer(passes one signal at a time depending on clock pulse) and given to Sampling & Hold Block, the signal is further send to the Analog to Digital (A/D) conversion block. A/D conversion block start converting the signal based on the start conversion direction form the Micro Controller/ Micro Processor(μ P/μ C), and after converting in gives a signal (end of conversion) to the μ P/μ C. then the converted signal comes to μ P/μ C.

In μ P/μ C operating system, math tool, mathematical model, plc, supervisory controller, measurement loop, application program is present. Set point can be feed in to the μ P/μ C, which is checked by μ P/μ C through simulation loop.

Based on Set Point and measured signal μ P/μ C find the error signal and feed the error signal in simulation loop, then it generate control signal. The control signal is send to De-

Multiplexer after checking in simulation loop, and from De- Multiplexer it send to Actuator, which actuate the system based on corrective action generated by the µ P/µ C. If the system is not controlled within prescribed time then it generates an Alarm/ Shutdown Action.

Measure data are also display in the computer monitor, showing some indication in the indicator, printed by a printer, send to 2nd Data Acquisition System, 2nd Distributed Control System, SCADA network, or to the Management Information Service for taking Managerial decision. µ P/µ C also provide authentic accessing of measure data

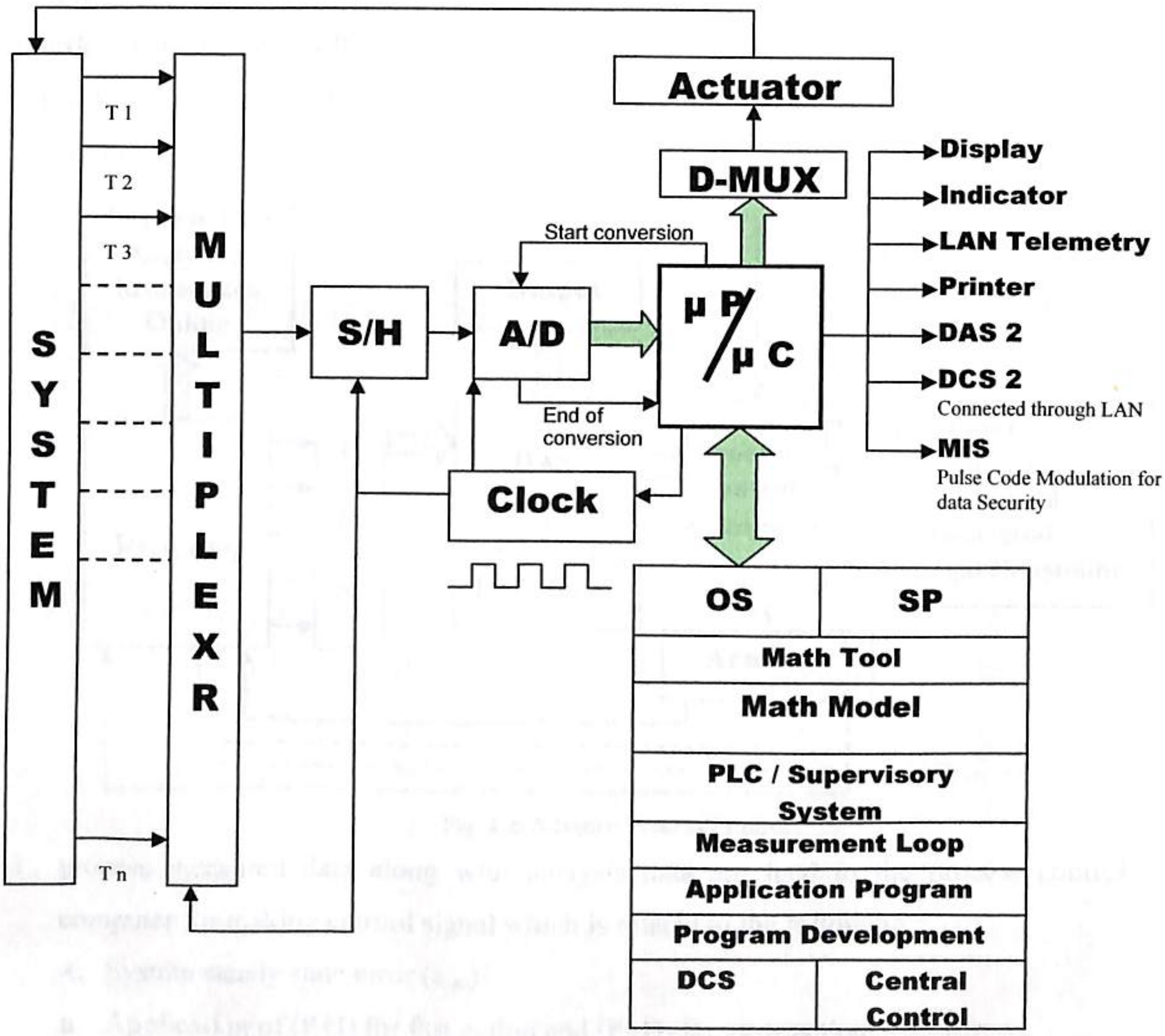


Fig. 4.1: Centralized/ Distributed Control System architecture

4.3 ADVANCE PROCESS CONTROL

During process control we have to map the process into process control software by using transducer & sensor, such as pressure temperature flow-rate etc. which may not be sufficient to express the process in details, so another side of instrumentation is called analytical instrumentation by which some process parameter are sensed in online basis and use for process analysis means its chemical structure & composition, total heat contain (enthalpy), entropy etc.

However in modern techniques we are sensing the process radiation characteristics, absorption & emission , change in magnetic & electrical properties by using some physical laws related to RAMAN EFFECT, ZEEMAN EFFECT & FARAD EFFECT, VILLARY EFFECT, HALL EFFET- this will help to reduce the sensing time, which makes the controller fast.

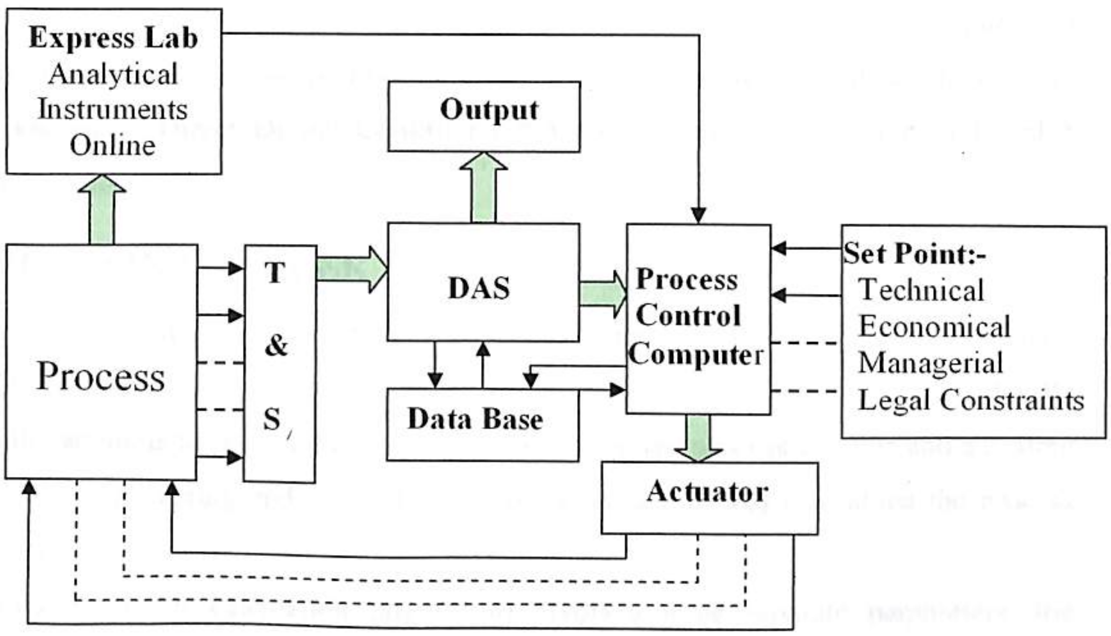


Fig. 4.2: Advance Process Control

1. process measured data along with analysis data are feed to the process control computer for making control signal which is related to the following :
   - A. System steady state error (e_{ss})
   - B. Application of (P+I) for fast action and (P+D) for slow action
   - C. Complete adjustment of PID parameter (online)
   - D. Online checking of system stability based on technical, economical and other constraints aspects.

E. Automatic fault finding and system diagnostics using suitable software (MATLAB DIGILAB etc)

F. Online system adaptive modeling – in modern process control we are not directly feeding back the control signal to the process, due to the probability of system malfunction etc. in practice the controller output signal or the control signal is fed to the process mathematical model and check its performance if found satisfactory then the signal goes to the process. So it is necessary to update the process continuously based on measured and analysis value of the process parameters.

2. Set Point- in conventional control system we use Single Input Single Output called SISO System. But in practice all physical process are basically Multi Input Multi Output (MIMO) system, which need a set of system set point, known as optimal control technique. The theory involved in this practice is "State Variable Analysis". In modern practice Digital Control Software are available which is capable to determine the optimal set point of the process by using input output data. The concept is known as Direct Digital Control (DDC), this techniques are using in Level 5 Automation.

4.4 PID CONTROLLER

A **proportional–integral–derivative controller (PID controller)** is a generic control loop feedback mechanism widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then taking a corrective action that can adjust the process accordingly.

The PID controller calculation (algorithm) involves three separate parameters; the Proportional, the Integral and Derivative values. The Proportional value determines the reaction to the current error, the Integral determines the reaction based on the sum of recent errors and the Derivative determines the reaction to the rate at which the error has been changing. Some applications may require using only one or two modes to provide the appropriate system control. This is achieved by setting the gain of undesired control outputs to zero.

A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are particularly common, since derivative action is very sensitive to measurement noise, and the absence of an integral value may prevent the system from reaching its target value due to the control action.

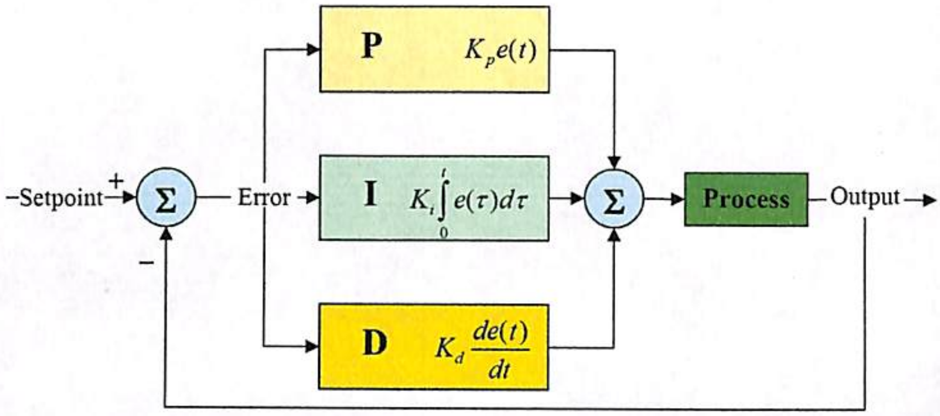


Fig. 4.3: A block diagram of a PID controller

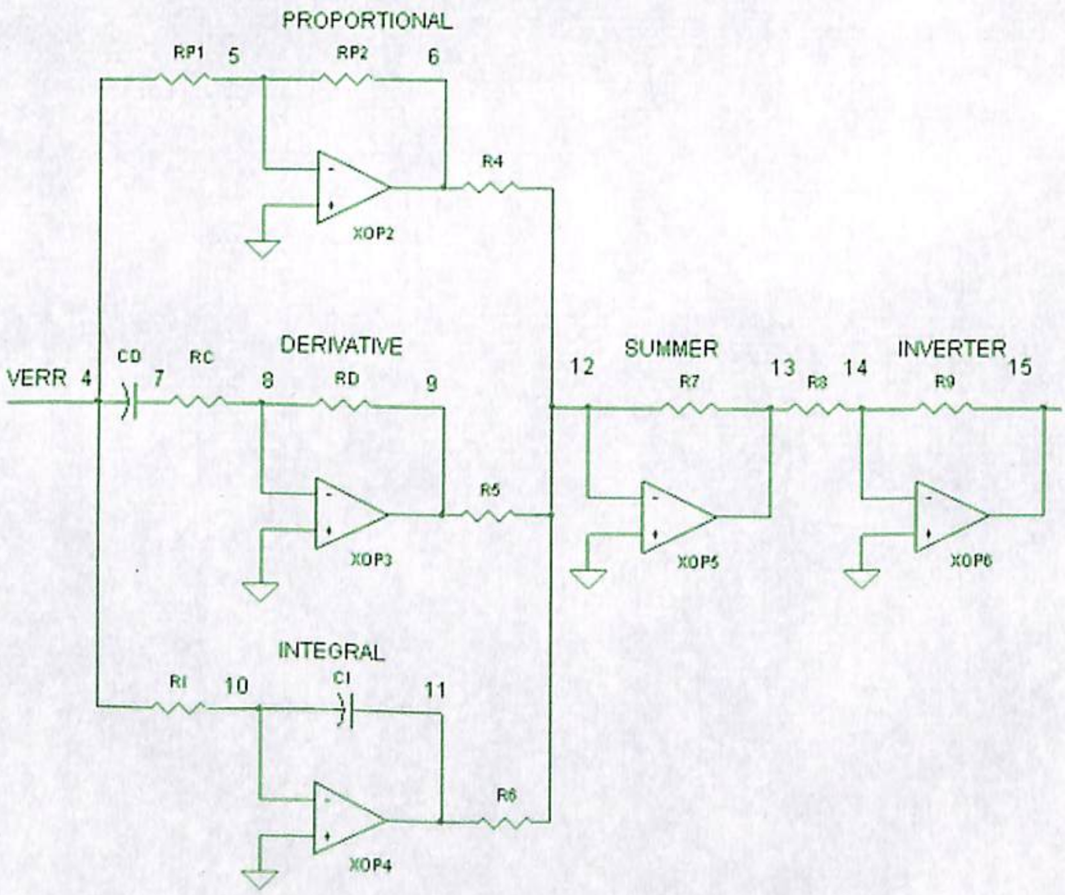


Fig. 4.4: Architectural diagram of a PID controller

PID CONTROLLER THEORY

A. Proportional term

The proportional term makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain. The proportional term is given by:

- P_{out} **Proportional output**
- K_p **Proportional Gain,** a tuning parameter
- E **Error** = $SP - PV$
- t **Time** or instantaneous time (the present)

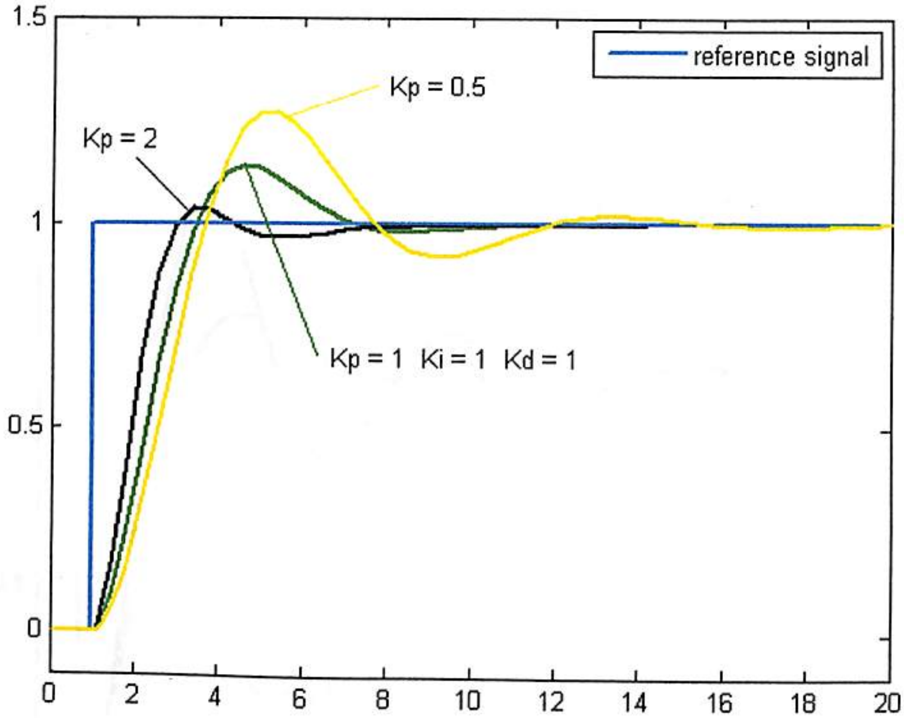


Fig. 4.5: Change of response for varying K_p

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable. In contrast, a small gain results in a small output response to a large input error, and a less responsive (or sensitive) controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances. In the absence of disturbances, pure proportional control will not settle at its target value, but will retain a steady state error that is a function of the proportional gain and the process gain.

B. Integral term

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. Summing the instantaneous error over time (integrating the error) gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output. The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain, K_i. The integral term is given by:

- I_{out} **Integral output**
- K_i **Integral Gain**, a tuning parameter
- e **Error** $= SP - PV$
- τ **Time** in the past contributing to the integral response

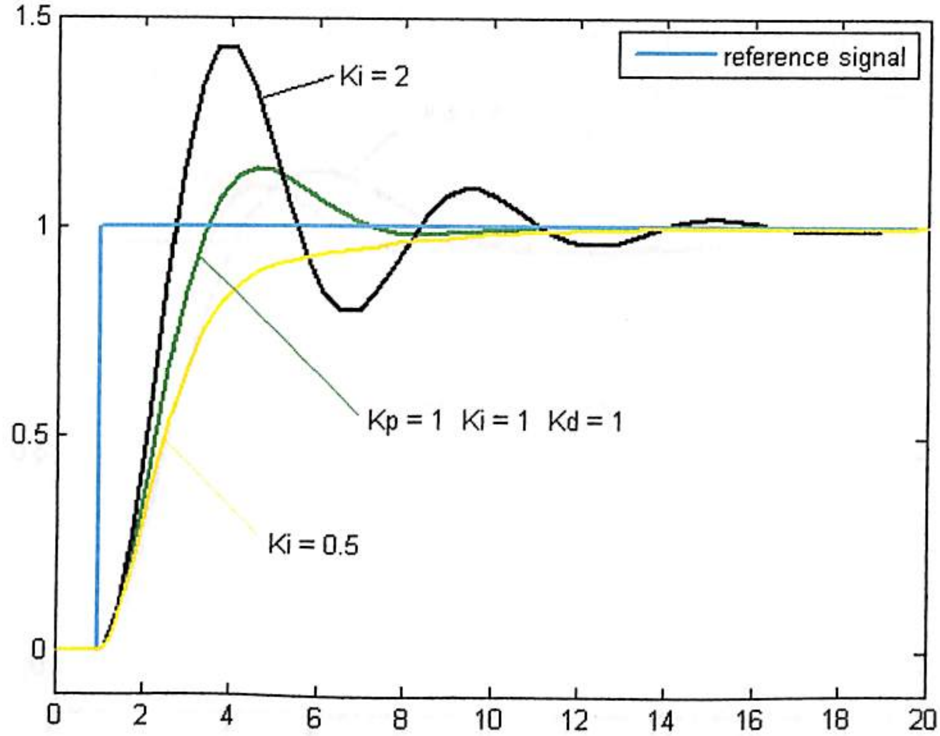


Fig. 4.6: Change of response for varying *K*

The integral term (when added to the proportional term) accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a proportional only controller. However, since the integral term is responding to accumulated errors from the past, it can cause the present value to **overshoot** the setpoint value.

C. Derivative term

The rate of change of the process error is calculated by determining the slope of the error over time (i.e. its first derivative with respect to time) and multiplying this rate of change by the derivative gain K_d. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, K_d. The derivative term is given by:

- D_{out} **Derivative output**
- K_d **Derivative Gain**, a tuning parameter
- e **Error** = $SP - PV$
- t **Time** or instantaneous time (the present)

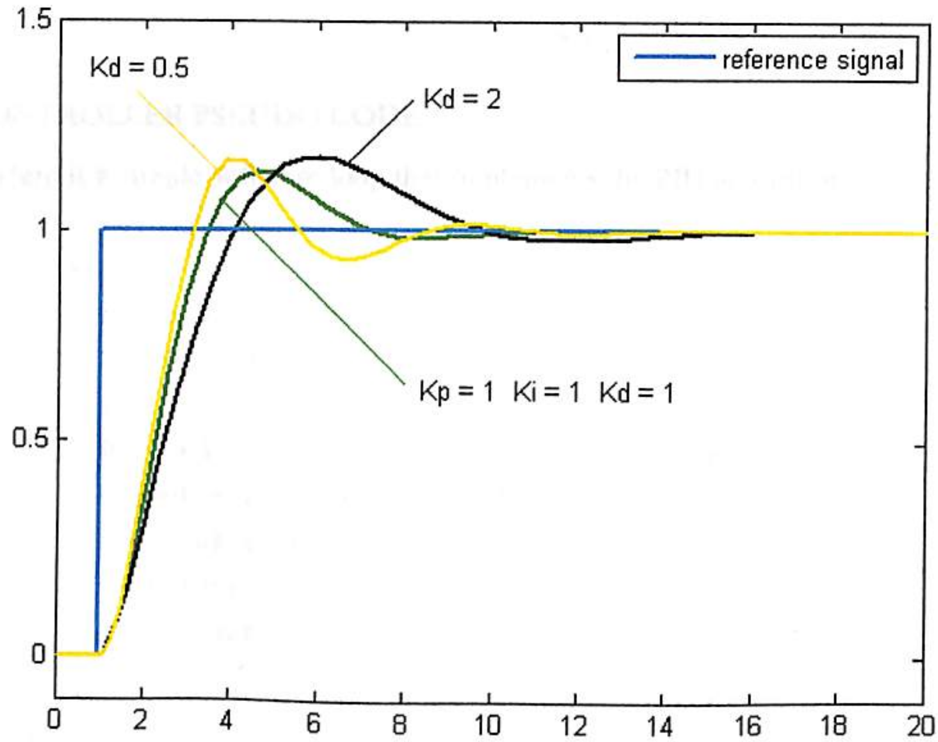


Fig. 4.7: Change of response for varying K_d

The derivative term slows the rate of change of the controller output and this effect is most noticeable close to the controller setpoint. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller-process stability. However, differentiation of a signal amplifies noise and thus this term in the controller is highly sensitive to noise in the error term, and can cause a process to become unstable if the noise and the derivative gain are sufficiently large.

Parameter	Rise Time	Overshoot	Settling Time	S.S. Error
K_p	Decrease	Increase	Small Change	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_d	Small Decrease	Decrease	Decrease	None

TABLE 4.1: Effect of Increasing Parameter

PID CONTROLLER PSEUDO CODE

Here is a simple software loop that implements the PID algorithm:

```
previous_error = 0
start:
  error = setpoint - actual_position
  P = Kp * error
  I = I + Ki * error * dt
  D = (Kd / dt) * (error - previous_error)
  output = P + I + D
  previous_error = error
  wait (dt)
  goto start
```

CHAPTER 5

STUDY OF PLC AND SCADA

5.1 WHY PLC SYSTEM

In the previous chapter from the control sequence we are in a position to keep the output parameter with in permissible limit, this conventional control is based on mostly hardware based controller (PID) & peripherals which are associated with propagation delay, non-linearity, simulation and lack of database system (history). The ultimate result is delay in control action and its accuracy.

In modern practice we are dividing entire control system in logical software part which is programmable & associate hardware part. This combination can immediately generate control action based on software and hardware output. A typical of such microcontroller (c) is known as PLC (Programmable Logic Controller).

A PLC is a hardware that is invented to replace the conventional relay logic circuit for machine and process control. This hardware can accept the real world inputs and can send the output command through its input/ output modules. The PLC operates by sensing its inputs and depending upon their conditions. The outputs are activated. The user write a program as per the application, usually via software, which then loaded and run in PLC, produces the desired result.

In the modern world of automation there is a need of PLC. In any process, if there are number of operations to be taken place simultaneously, involving large no of relays, timers, counters, etc, the involvement of PLC will ensure a reliable and cost effective management in performing the desired system operation.

5.2 INTRODUCTION TO PLC

Programmable Logic Controllers (PLC) are in the computer family. They are used in commercial and industrial applications. A PLC monitors inputs, makes decisions based on its program, and controls outputs to automate a process or machine. This course is meant to supply you with basic information on the functions and configurations of PLCs

PLC consists of input modules or points, a Central Processing Unit (CPU), and output modules or points. An input accepts a variety of digital or analog signals from various field devices (sensors) and converts them into a logic signal that can be used by the CPU. The CPU makes decisions and executes control instructions based on program instructions in memory. Output modules convert control instructions from the CPU into a digital or analog signal that can be used to control various field devices (actuators). A programming device is used to input the desired instructions. These instructions determine what the PLC will do for a specific input. An operator interface device allows process information to be displayed and new control parameters to be entered.

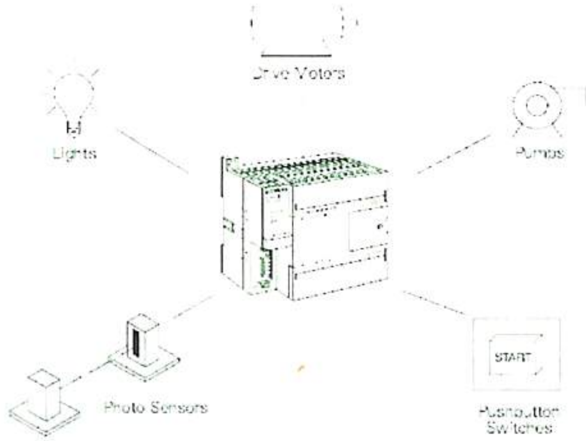


Fig. 5.1: Basic PLC Operation

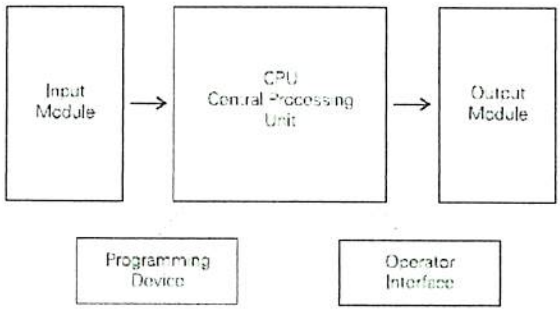


Fig. 5.2: Main Component of PLC

Pushbuttons (sensors), in this simple example, connected to PLC inputs, can be used to start and stop a motor connected to a PLC through a motor starter (actuator).

Hard-Wired Control: Prior to PLCs, many of these control tasks were solved with contactor or relay controls. This is often referred to as hardwired control. Circuit diagrams had to be designed, electrical components specified and installed, and wiring lists created. Electricians would then wire the components necessary to perform a specific task. If an error was made, the wires had to be reconnected correctly. A change in function or system expansion required extensive component changes and rewiring.

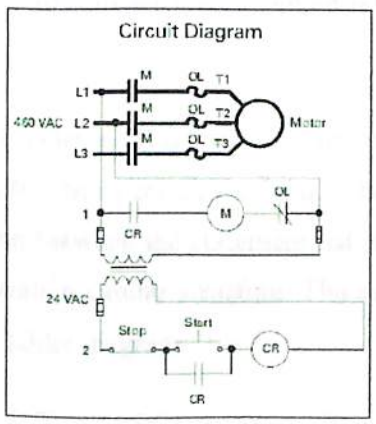


Fig.5.3: Hardware Control

5.3 PLC PROGRAMMING

A program consists of one or more instructions that accomplish a task. Programming a PLC is simply constructing a set of instructions. There are several ways to look at a program such as ladder logic, statement lists, or function block diagrams.

A. LADDER LOGIC DIAGRAM

Ladder logic (LAD) is one programming language used with PLCs. Ladder logic uses components that resemble elements used in a line diagram format to describe hard-wired control. The left vertical line of a ladder logic diagram represents the power or energized conductor. The output element or instruction represents the neutral or return path of the circuit. The right vertical line, which represents the return path on a hard-wired control line diagram, is omitted. Ladder logic diagrams are read from left-to-right, top-to-bottom. Rungs are sometimes referred to as networks. A network may have several control elements, but only one output coil.

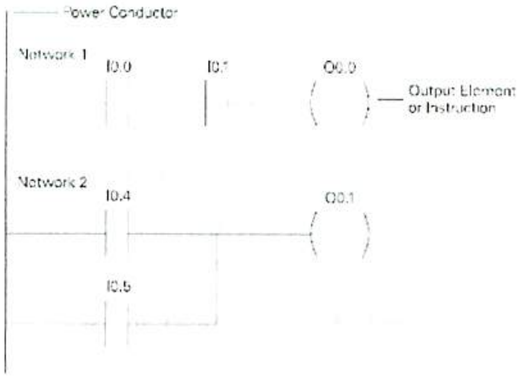


Fig. 5.4: Ladder Diagram

In the example program shown example I0.0, I0.1 and Q0.0 represent the first instruction combination. If inputs I0.0 and I0.1 are energized, output relay Q0.0 energizes. The inputs could be switches, pushbuttons, or contact closures. I0.4, I0.5, and Q1.1 represent the second instruction combination. If either input I0.4 or I0.5 are energized, output relay Q0.1 energizes.

B. STATEMENT LIST

A statement list (STL) provides another view of a set of instructions. The operation, what is to be done, is shown on the left. The operand, the item to be operated on by the operation, is shown on the right. A comparison between the statement list shown below, and the ladder logic shown on the previous page, reveals a similar structure. The set of instructions in this statement list perform the same task as the ladder diagram.

```
NETWORK 1
          LD        I0.0
          A         I0.1
          =         Q0.0
NETWORK 2
          LD        I0.4
          O         I0.5
          =         Q0.1
```

Fig. 5.5: Statement List

C. FUNCTION BLOCK DIAGRAMS

Function Block Diagrams (FBD) provides another view of a set of instructions. Each function has a name to designate its specific task. Functions are indicated by a rectangle. Inputs are shown on the left-hand side of the rectangle and outputs are shown on the right-hand side. The function block diagram shown below performs the same function as shown by the ladder diagram and statement list.

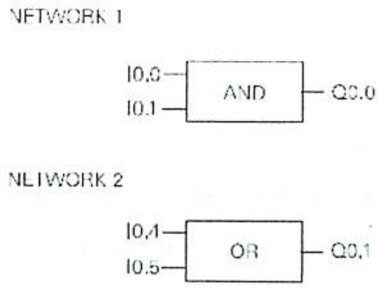


Fig. 5.6: Functional Block Diagram

5.4 PLC SAFETY RULES

- Use a fail-safe design.
- Make the program inaccessible to unauthorized persons.
- Use predictable, non-configurable programs.
- Use redundancy in hardware.
- Directly connect emergency stops to the PLC, or the main power supply.
- Check for system OK at start-up.
- Provide training for new users and engineers to reduce careless and uninformed mistakes.
- Use PLC built in functions for error and failure detection.

5.5 ADVANTAGES OF PLCs

The same, as well as more complex tasks can be done with a PLC. Wiring between devices and relay contacts is done in the PLC program. Hard-wiring, though still required to connect field devices, is less intensive. Modifying the application and correcting errors are easier to handle. It is easier to create and change a program in a PLC than it is to wire and re-wire a circuit. Following are just a few of the advantages of PLCs:

1. Smaller physical size than hard-wire solutions.
2. Easier and faster to make changes.
3. PLCs have integrated diagnostics and override functions.
4. Diagnostics are centrally available.
5. Applications can be immediately documented.
6. Applications can be duplicated faster and less expensively.

5.6 PLC TROUBLESHOOTING

1. Look at the process and see if it is in a normal state. i.e. no jammed actuators, broken parts, etc. If there are visible problems, fix them and restart the process.
2. Look at the PLC to see which error lights are on. Each PLC vendor will provide documents that indicate which problems correspond to the error lights. Common error lights are given below. If any off the warning lights are on, look for electrical supply problems to the PLC.

   HALT - something has stopped the CPU

   RUN - the PLC thinks it is OK (and probably is)

   ERROR - a physical problem has occurred with the PLC
3. Check indicator lights on I/O cards to see if they match the system. i.e., look at sensors that are on/off, and actuators on/off, check to see that the lights on the PLC I/O cards agree. If any of the light disagrees with the physical reality, then interface electronics/mechanics need inspection.
4. Turn the PLC off and on again. If this fixes the problem it could be a programming mistake, or a grounding problem. Programming mistakes often happen the same way each time. Grounding problems are often random, and have no pattern.
5. Consult the manuals or use software if available. If no obvious problems exist, the problem is not simple and requires a technically skilled approach.
6. If all else fails call the vendor (or the contractor) for help.

5.7 SCADA SYSTEMS CONCEPTS

SCADA is the abbreviation for ***Supervisory Control And Data Acquisition***. SCADA systems (A branch of instrumentation engineering, include input-output signal hardware, controllers, human-machine interfacing ("HMI"), networks, communications, databases, and software) are typically used to perform data collection and control at the supervisory level. The supervisory control system is a system that is placed on top of a real-time control system to control a process that is external to the SCADA system.

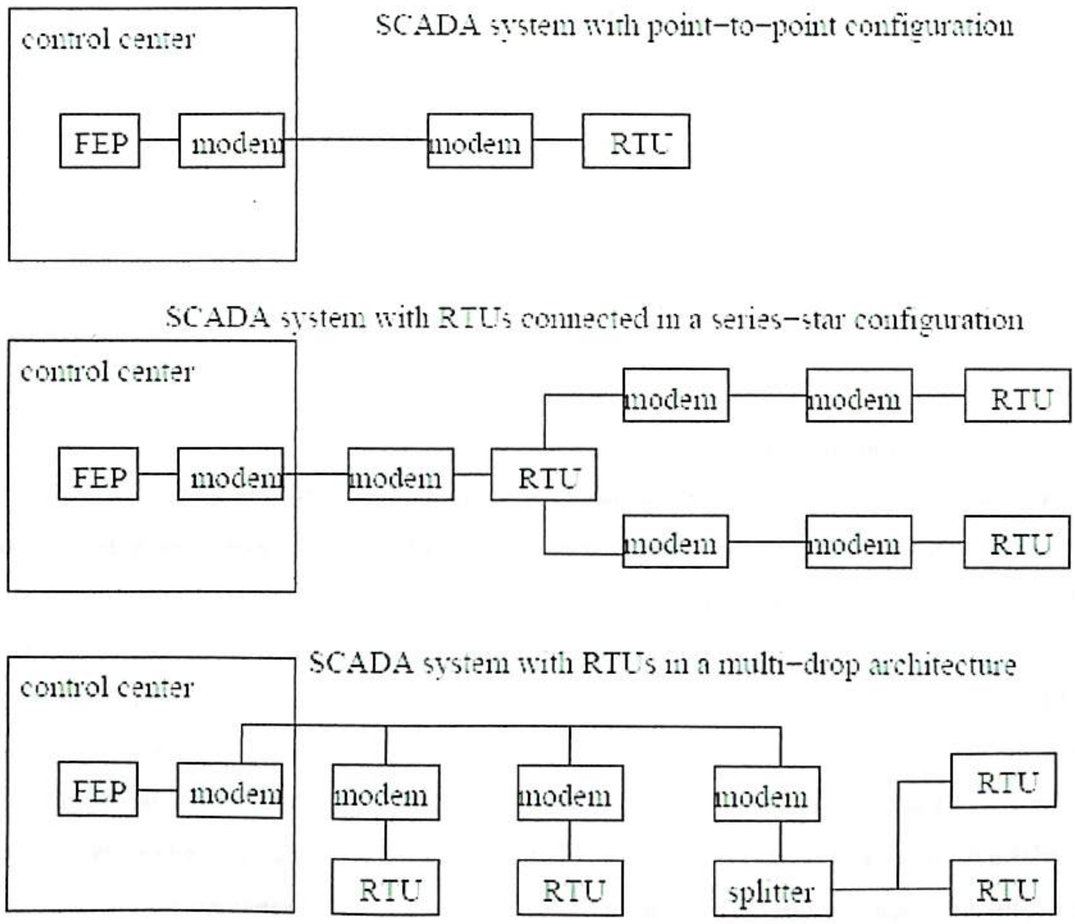


Fig.5.7: Typical SCADA system configuration

The term SCADA usually refers to centralized systems which monitor and control entire sites, or complexes of systems spread out over large areas (on the scale of kilometers or miles). Most site control is performed automatically by remote terminal units ("RTUs") or by programmable logic controllers ("PLCs"). Host control functions are usually restricted to basic site overriding or *supervisory* level intervention. SCADA system may allow operators to change the set points for the flow, and enable alarm conditions, such as loss of flow and high temperature, to be displayed and recorded. The feedback control loop passes through the RTU or PLC, while the SCADA system monitors the overall performance of the loop. Data acquisition begins at the RTU or PLC level and includes meter readings and equipment status reports that are communicated to SCADA as required. Data is then compiled and formatted in such a way that a control room operator using the HMI can make supervisory decisions to adjust or override normal RTU (PLC) controls. Data may also be fed to a Historian, often built on a commodity Database Management System, to allow trending and other analytical auditing.

Complete SCADA systems or Distributed Control Systems ("DCS") may be acquired from a single supplier, but they are more often assembled from hardware and software components available from ABB, Allen-Bradley, Direct LOGIC, GE Fanuc, Schneider Electric, Siemens PLCs, along with related HMI packages.

5.8 HUMAN MACHINE INTERFACE

The **user interface** (or *Human Machine Interface*) is the aggregate of means by which people—*the users*—interact with *the system*—a particular machine, device, computer program or other complex tools. The user interface provides means of:

- Input, allowing the users to manipulate a system
- Output, allowing the system to produce the effects of the users' manipulation.

A Human-Machine Interface or HMI is the apparatus which presents process data to a human operator, and through which the human operator controls the process. The HMI industry was essentially born out of a need for a standardized way to monitor and to control multiple remote controllers, PLC and other control devices. While a PLC does provide automated, pre-programmed control over a process, they are usually distributed across a plant, making it difficult to gather data from them manually. Historically PLCs had no standardized way to present information to an operator. The SCADA system gathers information from the PLCs and other controllers via some form of network, and combines and formats the information. An HMI may also be linked to a database, to provide trending, diagnostic data, and management information such as scheduled maintenance procedures, logistic information, detailed schematics for a particular sensor or machine, and expert-system troubleshooting guides.

The design of a user interface affects the amount of effort the user must expend to provide input for the system and to interpret the output of the system, and how much effort it takes to learn how to do this. **Usability** is the degree to which the design of a particular user interface takes into account the human psychology and physiology of the users, and makes the process of using the system effective, efficient and satisfying.

Currently the following types of user interface are the most common:

- **Graphical user interfaces** (GUI) accept input via devices such as computer keyboard and mouse and provide articulated graphical output on the computer monitor. There are at least two different principles widely used in GUI design: Object-oriented user interfaces (OOUIs) and application oriented interfaces
- **Web-based user interfaces** accept input and provide output by generating web pages which are transmitted via the Internet and viewed by the user using a web browser program. Newer implementations utilize Java, AJAX, Adobe Flex, Microsoft .NET, or similar technologies to provide real-time control in a separate program, eliminating the need to refresh a traditional HTML based web browser.

5.9 SYSTEM COMPONENTS

The three components of a SCADA system are:

1. Multiple Remote Terminal Units (also known as RTUs or Outstations).
2. Master Station and HMI Computer(s).
3. Communication infrastructure

A. REMOTE TERMINAL UNIT (RTU)

RTU, or **Remote Terminal Unit** is a microprocessor controlled electronic device which interfaces objects in the physical world to a distributed control system or SCADA system by transmitting telemetry data to the system and/or altering the state of connected objects based on control messages received from the system.

The RTU connects to physical equipment, and reads status data such as the open/closed status from a switch or a valve, reads measurements such as pressure, flow, voltage or current. By sending signals to equipment the RTU can control equipment, such as opening or closing a switch or a valve, or setting the speed of a pump. It can also read digital status data or analog measurement data, and send out digital commands or analog set points. Quality SCADA RTUs have these characteristics:

- Data Networking capability
- Data Reliability
- Data Security.

Architecture and Communications:

A typical RTU has a communications interface (usually serial (RS232, RS485, RS422), Ethernet, Modbus, proprietary, or any combination), a simple microprocessor, some form of non volatile memory, some environmental sensors, some override switches, and a bus which it uses to communicate with devices and/or interface boards. This bus is sometimes called a device bus or a field bus. Standards include the ISO Controller Area Network (ISO 11898), MODBUS, and others. Many vendors provide proprietary buses for their equipment; examples include Allen-Bradley's Data Highway and HSQ Technology's MISER net. Sometimes a device or field bus standard can be used to interconnect RTUs and host systems as well as field devices and RTUs.

I/O Interfaces:

Interface boards come in analog and digital flavors, and are typically designed for input only, output only, or both. These main types of interface boards are often abbreviated as "DI" (digital input), "AO" (analog output), and so forth. These categories are further subdivided based on the range of inputs, the amount of protection against voltage surges, and the amount of intelligence on the interface board. Sometimes an RTU or Programmable logic controller (PLC) has integral interfaces used to allow the deployment of only a RTU (without a bus and interface modules) to monitor or control just a few devices.

The interface boards are in turn connected to physical objects using wires. A typical application found in most SCADA implementations is to connect high current capacity relays to a digital output (or "DO") board to switch power on and off to devices in the field. The DO board switches voltage to the coil in the relay, which closes the high current contacts, which completes the power circuit to the device. Analog inputs are usually 24 V with a current range between 4 and 20 mill amperes (4-20 mA); the RTU or host system then translates this into the appropriate units such as gallons of water left or temperature before presenting the data to the user via the HMI or MMI.

Software and Logic Control:

Modern RTUs are usually capable of executing simple programs autonomously without involving the host computers of the DCS or SCADA system to simplify deployment, and to provide redundancy for safety reasons. A RTU in a modern water management system will typically have code to modify its behavior when physical override switches on the RTU are toggled during maintenance by maintenance personnel. This is done for safety reasons; a miscommunication between the system operators and the maintenance personnel could cause system operators to mistakenly enable power to a water pump when it is being replaced, for example.

Applications:

- Oil and Gas remote instrumentation monitoring, (offshore platforms, onshore oil wells, pump & compressor stations etc).
- Hydro-graphic monitoring and control, (water supply, reservoirs, sewerage systems).
- Environmental monitoring systems (pollution, air quality, emissions monitoring).
- Mine site monitoring applications.
- Protection supervision and data logging of Power transmission network

B. MASTER STATION

The term "Master Station" refers to the servers and software responsible for communicating with the field equipment (RTUs, PLCs, etc), and then to the HMI software running on workstations in the control room, or elsewhere. In smaller SCADA systems, the master station may be composed of a single PC. In larger SCADA systems, the master station may include multiple servers, distributed software applications, and disaster recovery sites. To increase the integrity of the system the multiple servers will often be configured in a dual-redundant or hot-standby formation providing continuous control and monitoring in the event of a server failure.

The SCADA system usually presents the information to the operating personnel graphically, in the form of a mimic diagram. This means that the operator can see a schematic representation of the plant being controlled. For example, a picture of a pump connected to a pipe can show the operator that the pump is running and how much fluid it is pumping through the pipe at the moment. The operator can then switch the pump off. The HMI software will show the flow rate of the fluid in the pipe decrease in real time. Mimic diagrams may consist of line graphics and schematic symbols to represent process elements, or may consist of digital photographs of the process equipment overlain with animated symbols.

Operational philosophy

Instead of relying on operator intervention, or master station automation, RTUs may now be required to operate on their own to control tunnel fires or perform other safety-related tasks. The master station software is required to do more analysis of data before presenting it to operators including historical analysis and analysis associated with particular industry requirements. Safety requirements are now being applied to the system as a whole and even master station software must meet stringent safety standards for some markets. Hardware for SCADA systems is generally ruggedized to withstand temperature, vibration, and voltage extremes, but in these installations reliability is enhanced by having redundant hardware and communications channels. A failing part can be quickly identified and its functionality automatically taken over by backup hardware. A failed part can often be replaced without interrupting the process. The reliability of such systems can be calculated statistically and is stated as the mean time to failure, which is a variant of mean time between failures. The calculated mean time to failure of such high reliability systems can be on the order of centuries.

C. COMMUNICATION INFRASTRUCTURE AND METHODS

SCADA systems have traditionally used combinations of radio and direct serial or modem connections to meet communication requirements, although Ethernet and IP over SONET is also frequently used at large sites such as railways and power stations. The remote management or monitoring function of a SCADA system is often referred to as telemetry. This has also come under threat with some customers wanting SCADA data to travel over their pre-established corporate networks or to share the network with other applications. The legacy of the early low-bandwidth protocols remains, though. SCADA protocols are designed to be very compact and many are designed to send information to the master station only when the master station polls the RTU. Typical legacy SCADA protocols include Modbus, RP-570 and Conitel. These communication protocols are all SCADA-vendor specific. Standard protocols are IEC 60870-5-101 or 104, IEC 61850, Profibus and DNP3. These communication protocols are standardized and recognized by all major SCADA vendors. Many of these protocols now contain extensions to operate over TCP/IP, although it is good security engineering practice to avoid connecting SCADA systems to the Internet so the attack surface is reduced.

RTUs and other automatic controller devices were being developed before the advent of industry wide standards for interoperability. The result is that developers and their management created a multitude of control protocols. Among the larger vendors, there was also the incentive to create their own protocol to "lock in" their customer base. A list of automation protocols is being compiled here.

Recently, OLE for Process Control (OPC) has become a widely accepted solution for intercommunicating different hardware and software, allowing communication even between devices originally not intended to be part of an industrial network. Other protocols such as Modbus TCP/IP have become widely accepted and are now the standard for many hardware manufacturers.

5.10 TRENDS IN SCADA

There is a trend for PLC and HMI/SCADA software to be more "mix-and-match". In the mid 1990s, the typical DAQ I/O manufacturer supplied equipment that communicated using proprietary protocols over a suitable-distance carrier like RS-485. End users who invested in a particular vendor's hardware solution often found themselves restricted to a limited choice of equipment when requirements changed (e.g. system expansions or performance improvement). To mitigate such problems, open communication protocols such as IEC870-5-101/104 and DNP 3.0 (serial and over IP) became increasingly popular among SCADA equipment manufacturers and solution providers alike. Open architecture SCADA systems enabled users to mix-and-match products from different vendors to develop solutions that were better than those that could be achieved when restricted to a single vendor's product offering.

Towards the late 1990s, the shift towards open communications continued with individual I/O manufacturers as well, who adopted open message structures such as Modicon MODBUS over RS-485. By 2000, most I/O makers offered completely open interfacing such as Modicon MODBUS over TCP/IP.

SCADA systems are coming in line with standard networking technologies. Ethernet and TCP/IP based protocols are replacing the older proprietary standards. Although certain characteristics of frame-based network communication technology (determinism, synchronization, protocol selection, environment suitability) have restricted the adoption of Ethernet in a few specialized applications, the vast majority of markets have accepted Ethernet networks for HMI/SCADA.

"Next generation" protocols such as OPC-UA, Wonderware's Archestra, and Rockwell Automation's FactoryTalk, take advantage of XML, web services, and other modern web technologies, making them more easily IT supportable. SCADA systems are becoming increasingly ubiquitous. Thin clients, web portals, and web based products are gaining popularity with most major vendors. The increased convenience of end users viewing their processes remotely introduces security considerations.

5.11 SECURITY ISSUES

The move from proprietary technologies to more standardized and open solutions together with the increased number of connections between SCADA systems and office networks and the Internet has made them more vulnerable to attacks. Consequently, the security of SCADA-based systems has come into question as they are increasingly seen as extremely vulnerable to cyber warfare / cyber terrorism attacks. In particular, security researchers are concerned about:

- The lack of concern about security and authentication in the design, deployment and operation of existing SCADA networks
- The mistaken belief that SCADA systems have the benefit of security through obscurity through the use of specialized protocols and proprietary interfaces
- The mistaken belief that SCADA networks are secure because they are purportedly physically secured
- The mistaken belief that SCADA networks are secure because they are supposedly disconnected from the Internet

Due to the mission-critical nature of a large number of SCADA systems, such attacks could, in a worst case scenario, cause massive financial losses through loss of data or actual physical destruction, misuse or theft, even loss of life, either directly or indirectly. Whether such concerns will cause a move away from the use of existing SCADA systems for mission-critical applications towards more secure architectures and configurations remains to be seen, given that at least some influential people in corporate and governmental circles believe that the benefits and lower initial costs of SCADA based systems still outweigh potential costs and risks. Recently, multiple security vendors, such as Byres Security, Inc., Industrial Defender Inc., Check Point and In nominate, have begun to address these risks by developing lines of specialized industrial firewall and VPN solutions for TCP/IP-based SCADA networks.

Also, the ISA Security Compliance Institute (ISCI) is emerging to formalize SCADA security testing starting as soon as 2009. ISCI is conceptually similar to private testing and certification that has been performed by vendors since 2007, such as the Achilles certification program from Wurldtech Security Technologies, Inc. and MUSIC certification from Music Security, Inc. Eventually, standards being defined by ISA SP99 WG4 will supersede these initial industry consortia efforts, but probably not before 2011.

CHAPTER 6

STUDY OF TRANSDUCER/SENSOR

6.1 SENSOR

A sensor is a device that converts a physical property such as temperature, pressure, relative humidity, flow, etc. into an electrically or mechanically measurable signal. Sensors with transmitters are the field devices placed in the field that actually sense the parameter and send the analog signal to the control hardware. The analog signals used are ohm (RTD), mV (thermocouple), 4-20 mA, +/- 10V etc.

Widely used sensors are:

RTD	Output in ohms (temperature)
Thermocouples	Output in mV (temperature)
Pressure transmitters	4-20 mA, 0-10 V
Flow transmitters	4-20 mA, 0-10 V
Level transmitters	4-20 mA, 0-10 V
Density meter	4-20 mA, 0-10 V

TABLE4.1: Widely used Sensors

6.2 PRESSURE MEASUREMENT

Pressure transducer converts pressure into an analog electrical signal, which is achieved by the physical deformation of stress gages, which are bonded into the diaphragm of the pressure transducer and wired into a Wheatstone bridge configuration. Pressure applied to the pressure transducer produces a deflection of the diaphragm, which introduces strain to the gages. The strain will produce an electrical resistance change proportional to the pressure. Pressure transducers are generally available with three types of electrical output.

- Milli volt
- Volt and
- 4-20 mA

A. Milli volt Output Pressure Transducers:

Are normally the most economical and the output is normally around 30 mV. The actual output is directly proportional to the input power or excitation. If the excitation fluctuates, the output changes. Because the output signal is so low, the transducer should not be located in an electrically noisy environment. The distances between the transducer and the readout instrument should also be kept relatively short.

B. Voltage Output Pressure Transducers:

Include integral signal conditioning which provide a much higher output than a millivolt transducer. The output is normally 0-5 V dc or 0-10 V dc. Because they have a higher level output these transducers are not as susceptible to electrical noise as millivolt transducers and can therefore be used in much more industrial environments.

C. 4-20 mA Output Pressure Transducers:

Since a 4-20 mA signal is least affected by electrical noise and resistance & is best used for long distances. It is not uncommon to use these transducers in applications where the lead wire must be 1000 feet or more.

D. Heavy Duty Industrial Pressure Transducers:

Feature a much more rugged enclosure than other transducers. They are designed to accommodate heavy industrial environments. 4-20 mA outputs provide much greater immunity to electrical noise in industrial environments.

6.3 TEMPERATURE MEASUREMENT

A. Resistance temperature detector (RTD):

- Resistance of any metal changes with its temperature change.
- They are Positive Temperature Co-efficient Devices i.e. Their effective resistance increases with the increase in temperature.

PT 100 –At a Degrees Celsius, its Resistance is 100 ohms

Description: They are used for detection in a temperature range between -200 to +400 Deg C. RTDs are sensors used to measure temperature by correlating the resistance of the RTD element with temperature. Most RTD elements consist of a length of fine-coiled wire wrapped around a ceramic or glass core. The element is usually quite fragile, so it is often placed inside a sheathed probe to protect it. The RTD is one of the most accurate temperature sensors. Not only does it provide good accuracy, it also provides excellent stability and repeatability.

RTDs are also relatively immune to electrical noise and therefore well suited, for temperature measurement in industrial environments, especially around motors, generators and other high voltage equipment.

Advantages: RTDs are stable, accurate, and more linear than thermocouples.

Disadvantages: expensive, power source required, low absolute resistance, self heating.

B. Resistance temperature detector (RTD) Probe:

It is the most rugged form of RTD. A probe consists of an RTD element mounted inside a metal tube, also known as a sheath. The sheath protects the element from the environment.

C. Thermocouples:

Thermocouples are sensors for measuring temperature. They consist of two dissimilar metals joined together at one end. When this junction of the two metals is heated or cooled a voltage is produced that can be correlated back to temperature. They are positive temperature co-efficient devices. Their effective resistance increases with the increase in temperature.

Beaded wire thermocouples consist of two pieces of thermocouple wire joined together with a welded bead. Beaded wire thermocouples are a good choice for the measurement of gas and air temperature. Since they can be made very small, they also provide very fast response time.

Types/Temperature range

- TYPE J (Iron-Constantine) up to 800 deg. C
- TYPE K (Chrome-Alumeel) up to 1150 deg. C
- TYPE S (Platinum-Platinum alloy) up to 1800 deg. C

A thermocouple probe consists of thermocouple wire housed inside a metallic tube. The wall of the tube is referred to as the sheath of the probe. Common sheath materials include stainless steel and Inconel. Inconel supports higher temperature ranges than stainless steel; however, stainless steel is often preferred because of its broad chemical compatibility. For very high temperatures, other exotic sheath materials are also available.

6.4 FLOW MEASUREMENT

A. **Magnetic Flow meter:**

Operating principle based on Faraday's Law of Magnetic Induction. The liquid acts as a conductor as it flows through the pipe. This induces a voltage, which is proportional to the average flow velocity – the faster the flow rate, the higher the voltage. This voltage is picked up by sensing electrodes mounted in the meter tube and sent to the transmitter which takes the voltage and calculates the flow rate based on the cross sectional area of the meter tube. Principle states that "a voltage will be induced in a conductor moving through a magnetic field."

$E=k*B*D*V$ where,

E=Induced voltage,

B=Strength of magnetic field,

D=Conductor width,

V=Velocity of the conductor

K= Proportional Constant

B. Propeller Flow meters:

It has a blade, which rotates as the flow passes. The rotations are interpreted as flow by a totalizer usually mounted on the meter. Propeller meters do not require a power source to operate. When equipped, the propeller meter can send an output signal (requiring an external power supply) to a remote location. The propeller meter is a low cost/ low maintenance meter.

C. Rota-meter:

It consists of a metal float and a conical glass tube, constructed such that the diameter increases with height. When there is no fluid passing through the Rota-meter the float rests at the bottom of the tube. As fluid enters the tube, the higher density of the float will cause the float to remain on the bottom. As flow increases in the tube, the pressure drop increases. When the pressure drop is sufficient, the float will rise to indicate the amount of flow. The higher the flow rate the greater the pressure drop. The higher the pressure drop the farther up the tube the float rises. This type of flow meter is usually used to measure low flow rates.

D. Ultrasonic Flow meter:

In Ultrasonic Flow meter pulses are beamed from transducers mounted on opposite sides of the pipe. These pulses are fired alternatively upstream and downstream. Pulses fired downstream travel faster as they are carried by the flow. Pulses fired upstream travel slower as it fights the flow. The difference in time for a pulse to travel upstream and downstream is measured. The greater the difference in time between upstream and downstream pulses, the faster the flow. The flow rate is calculated based on the cross sectional area of the meter tube.

Applications of Ultrasonic flow meters:

Ideal for relatively clean liquids in closed pipes such as raw water, influent, filter effluent, backwash water, raw sewage, treated effluent, plant water, acids, bases, light hydrocarbons, acid mine drainage. Not used with higher percentages of solids as these can cause loss of echo (meter failure).

Since the time-of-flight meter uses ultrasonic, there is no liquid conductivity requirement as with a magnetic flow meter. Like magnetic flow meters, they are unaffected by changes in temperature, density, conductivity or viscosity and provide obstruction less flow.

E. Doppler Flow meter:

Doppler ultrasonic flow meters operate on the Doppler shift principle whereby the transmitted frequency is altered linearly by being reflected from particles and bubbles in the fluid. The net result is a frequency shift between transmitter and receiver frequencies that can be directly related to the flow velocity. Doppler meters require a minimum amount of solid particles or air in the line to achieve measurements. Doppler meters are sensitive to changes in density and temperature. These problems make Doppler flow meters unsuitable for highly accurate measurements in some applications.

6.5 BASIC ELECTRICAL DEVICES

There are seven basic electrical devices commonly used in the control of fluid power systems: manually actuated push-button switches, limit switches, pressure switches, solenoids, relays, timers and temperature switches. These devices are briefly described as follows:

A. Push-button switches:

By the use of a simple push-button switch, an operator can cause sophisticated equipment to begin performing complex operations. These push-button switches are used mainly for starting and stopping the operation of machinery as well as providing for manual override when an emergency arises.

B. Limit switches:

Limit switches open and close circuits when they are actuated either at the end of the retraction or extension strokes of hydraulic cylinder that incorporates its own limit switches (one at each end of the cylinder). Either switch can be wired normally open or normally closed. The limit switch on the cap end of the cylinder actuated by an internal cam when the rod is fully retracted. The cam contacts limit switch about 3/16 in. from the end of the stroke. At the end of the cylinder stroke the cam has moved the plunger and stem of the limit switch about 1/16 in. for complete actuation. The limit switch on the head end of the cylinder is similarly actuated. Since these limit switches are built into the cylinder end plates, they are not susceptible to accidental movement, which can cause them malfunction.

C. Solenoids:

Solenoids are electromagnets that provide a push or pull force to operate fluid power valves remotely. When a solenoid (an electric coil wrapped around an armature) is energized, the magnetic force created cause the armature to shift the spool of the valve containing the solenoid.

D. Relays:

Relays are switches whose contacts open or close when their corresponding coils are energized. These relays are commonly used for the energizing and de-energizing of solenoids because they operate at a high current level. In this way a manually actuated switch can be operated at low voltage levels to protect the operator. This low-voltage circuit can be used to energize relay coils that control high-voltage contacts used to open and close circuits containing the solenoids. The use of relays also provides interlock capability, which prevents the accidental energizing of two solenoids at the opposite ends of a valve spool. This safety feature can, therefore, prevent the burnout of one or both of these solenoids.

E. Pressure switches:

Pressure switches open or close their contacts based on system pressure. They generally have a high-pressure setting and a low-pressure setting. For example, it may be necessary to start or stop a pump to maintain a given pressure. The low-pressure setting would start the pump, and the high pressure setting would stop it. Figure 14-2 shows a pressure switch that can be wired either normally open (NO) or normally closed (NC), as marked on the screw terminals. Observe the front scale that is used for visual check of the pressure setting, which is made by the self-locking, adjusting screw located behind the scale.

F. Timers:

Time delay devices are used to control the time duration of working cycle. In this way, a dwell can be provided where needed. For example, a dwell can be applied to a drilling machine operation, which allows the drill to pause for a predetermined time at the end of the stroke to clean out the hole. Most timers can be adjusted to give a specified dwell to accommodate changes in feed rates and other system variables.

G. Temperature switches:

Temperature switch is an instrument that automatically senses a change in temperature and opens or closes an electrical switch when a predetermined temperature is reached. This switch can be wired either normally open or normally closed. Note that at its upper end there is an adjustment screw to change the actuation point. The capillary tube (which comes in standard lengths of 6 or 12 ft) and bulb permit remote temperature sensing. Thus, the actual temperature switch can be located at a substantial distance from the oil whose temperature is to be sensed. Temperature switches can be used to protect a fluid power system from serious damage when a component such as a pump or strainer or cooler begins to malfunction. The resulting excessive build-up in oil temperature is sensed by the temperature switch, which shuts off the entire system. This permits troubleshooting of the system to repair or replace the faulty component.

6.6 PRESSURE SWITCH SENSING ELEMENT

A pressure switch is an instrument that automatically senses a change in pressure and opens or closes an electrical switching element when a predetermined pressure is reached. A pressure sensing element is the portion of pressure switch tat moves due to change in pressure. Four types of sensing element that produce four different models are:

A. Diaphragm:

This model can operate from vacuum pressure up to 150 psi. It has a weld sealed diaphragm direct acting on a snap action switch.

B. Bourdon tube:

This model can operate with pressure varying from 50 to 18000 psi. It has a weld sealed bourdon tube acting on a snap action switch.

C. Sealed piston

This model can operate with pressure varying from 15 to 12000 psi. It has an o-ring sealed piston direct acting on a snap action switch.

D. Diameter-sealed piston

This model can operate with 0.5 to 1600 psi. It has a dia-sealed piston direct acting on a snap action switch. This design combines diaphragm accuracy with piston long life and high proof pressure tolerance.

CHAPTER 7

BASIC EQUATIONS AND METHODOLOGY

7.1 FLOW CHARACTERISTICS VALVES:

All control valves have an inherent flow characteristic that defines the relationship between 'valve opening' and flow rate under constant pressure conditions. Valves of any size or inherent flow characteristic which are subjected to the same volumetric flowrate and differential pressure will have exactly the same orifice pass area. However, different valve characteristics will give different 'valve openings' for the same pass area. Comparing linear and equal percentage valves, a linear valve might have a 25% valve opening for a certain pressure drop and flowrate, whilst an equal percentage valve might have a 65% valve opening for exactly the same conditions. The orifice pass areas will be the same.

The term 'valve lift' is used to define valve opening, whether the valve is a globe valve (up and down movement of the plug relative to the seat) or a rotary valve (lateral movement of the plug relative to the seat). Rotary valves (for example, ball and butterfly) each have a basic characteristic curve, but altering the details of the ball or butterfly plug may modify this. The inherent flow characteristics of typical globe valves and rotary valves are compared in Fig.7.1 Globe valves may be fitted with plugs of differing shapes, each of which has its own inherent flow/opening characteristic. The three main types available are usually designated:

1. Fast opening.
2. Linear.
3. Equal percentage.

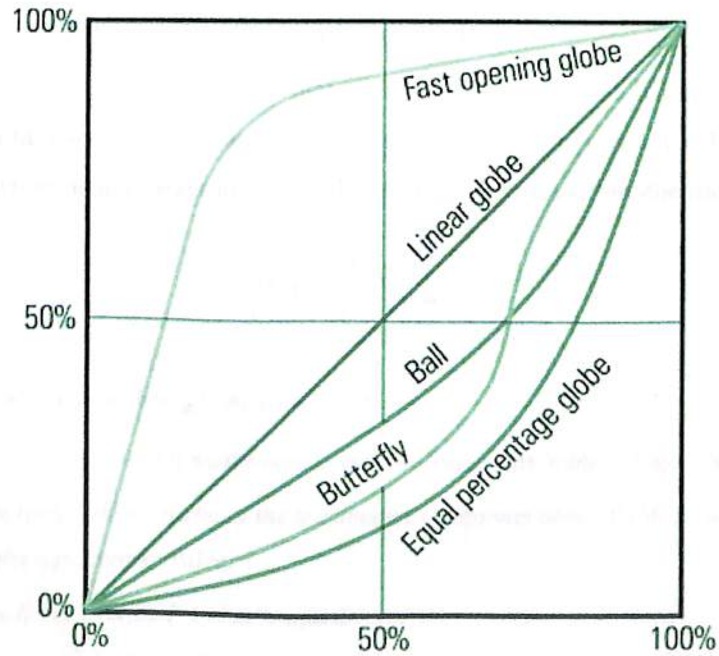


Fig.7.1 : Inherent flow characteristics of typical globe valves and rotary valves

A. Fast opening characteristic

The fast opening characteristic valve plug will give a large change in flowrate for a small valve lift from the closed position. For example, a valve lift of 50% may result in an orifice pass area and flowrate up to 90% of its maximum potential. A valve using this type of plug is sometimes referred to as having an 'on / off' characteristic. Fast opening valves tend to be electrically or pneumatically actuated and used for 'on / off' control.

B. Linear characteristic

The linear characteristic valve plug is shaped so that the flowrate is directly proportional to the valve lift (H), at a constant differential pressure. A linear valve achieves this by having a linear relationship between the valve lift and the orifice pass area

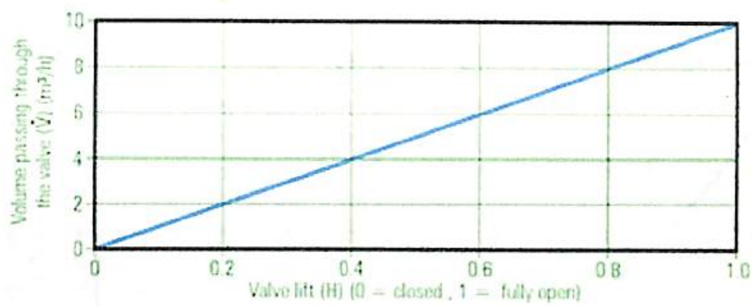


Fig. 7.2 Flow / lift curve for a linear valve

For example, at 40% valve lift, a 40% orifice size allows 40% of the full flow to pass.

C. Equal percentage characteristic (or logarithmic characteristic)

These valves have a valve plug shaped so that each increment in valve lift increases the flowrate by a certain percentage of the previous flow. The relationship between valve lift and orifice size (and therefore flowrate) is not linear but logarithmic, and is expressed mathematically in Equation

$$\dot{V} = \frac{e^x}{\tau} \dot{V}_{max}$$

Where:

$\dot{V}$	=	*Volumetric flow through the valve at lift H.*
x	=	*(ln τ) H Note: 'ln' is a mathematical function known as 'natural logarithm'.*
τ	=	*Valve range ability (ratio of the maximum to minimum controllable flowrate, typically 50 for a globe type control valve)*
H	=	*Valve lift (0 = closed, 1 = fully open)*
$\dot{V}_{max}$	=	*Maximum volumetric flow through the valve*

Valve Lift (H)	Flowrate ($\dot{V}$ m³/h)	Increase in flow from previous increment (%)
0.0	0.20 *	-
0.1	0.30	48%
0.2	0.44	48%
0.3	0.65	48%
0.4	0.96	48%
0.5	1.41	48%
0.6	2.09	48%
0.7	3.09	48%
0.8	4.57	48%
0.9	6.76	48%
1.0	10.00	48%

* Flowrate according to theoretical characteristic due to rangeability. In practice the valve will be fully shut at zero lift.

Table 7.1: Change in flowrate with valve lift for an equal percentage characteristic with constant differential pressure

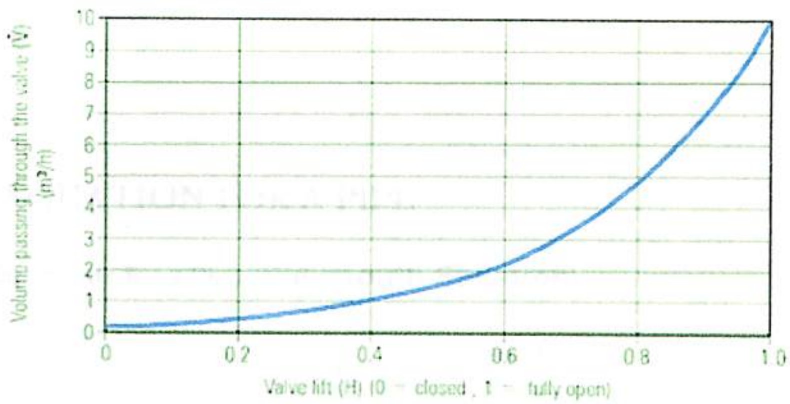


Fig. 7.3: Flowrate and valve lift for an equal percentage characteristic

A few other inherent valve characteristics are sometimes used, such as parabolic, modified linear or hyperbolic, but the most common types in manufacture are fast opening, linear, and equal percentage.

7.2 PRESSURE FLOW RELATIONSHIP OF VALVE

$$C_v = \frac{Q}{962}\sqrt{\frac{SG \times T}{(P_U^2 - P_D^2)}}$$

Where:

Q = *flow (cfh)*
SG = *gas-specific gravity*
C_v = *valve flow coefficient*
T = *temperature (°R)*
P_u, P_d = *Upstream/Downstream pressure (psia)*

7.3 SIZING OF RELIEF VALVE FOR COMPRESSOR STATION

$$A = \frac{Q\sqrt{GT}}{863KF\sqrt{(p_1-p_2)p_2}}$$

Where:

A= discharge area of valve (square inch)

F= correction factor

G= specific gravity

T= inlet vapor temperature (°R)

K= valve discharge coefficient

Q= volumetric flow through valve (scfm)

p_1= *Inlet pressure (psia)*

p_2 =*outlet pressure (psia)*

7.4 FLOW EQUATION FOR A PIPE

Flow Equations for a Pipe (Weymouth Equation)

$$Q = 18.06\frac{T_o}{P_o}\sqrt{\frac{(p_1^2 - p_2^2)D^{16/3}}{GTLz_a}}$$

Where

Q= volumetric discharge of gas in ft^3 / hr under standard condition.

D=diameter of pipe, in inch.

T_o= temperature under standard condition (To=60°F=520°R);

p_o= pressure of the standard atmosphere (p=14.7psig)

p_1 = upstream pressure

p_2 = downstream pressure

T= temperature of the gas in the pipe.

G = gas gravity.

L= length of pipe in mile.

Z_a =average value of compressibility factor.

7.5 CHARACTERISTICS EQUATIONS OF TRANSDUCER AND SENSORS

A. CHARACTERISTIC EQUATION OF PIEZOELECTRIC TRANSDUCER:

The charge generated can be calculate by the crystal can be expressed as

$$q = K_q x_i$$

$$K_q = \frac{g\varepsilon_0\varepsilon_r AE}{t}$$

Where

K_q = *charge sensitivity* ≜ C/cm

x_i ≜ *deflection, cm*

g = *constant (15mV/m Pa for the barium titanate crystal)*

$\varepsilon_0\varepsilon_r$ = *dielectric constant*

A = *area of cross –section of the crystal*

E = *Young s modulus of elasticity*

T = *thickness of the crystal*

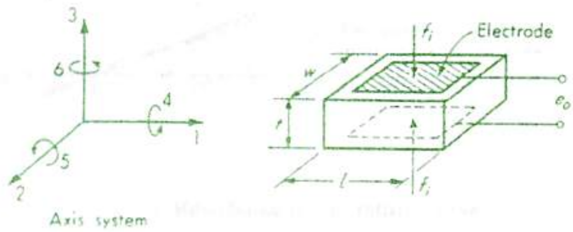


Fig.7.4 Piezoelectric Transducer.

B. CHARACTERISTIC EQUATION OF CAPACITANCE PICKUP TRANSDUCER

A translational or rotational motion may be used in many ways to change the capacitance of a variable capacitor. The capacitance is given by:

$$C = \frac{.00885A}{x}$$

Where:

C = ≜ *capacitance, pF*

A = ≜ *plate area, mm2*

X = ≜ *plate separation, mm*

When the motion is relatively large, the plate separation is usually kept fixed (typically about 1 mm). and the area A is change by moving on plate parallel to the other. For smaller motion, the area is kept fixed and the separation x is varied.

C. CHARACTERISTIC EQUATION OF RESISTANCE TEMPERATURE DETECTOR

$$R = R_0(1 + a_1 T + a_2 T^2 + \cdots + a_n T^n)$$

Where

R= Resistance at temperature T^0 C
R_o=Resistance at temperature 0^0 C
T= Temperature in ^{0}C
a_1, a_2 ...... a_n are constant (values changes depending on material)

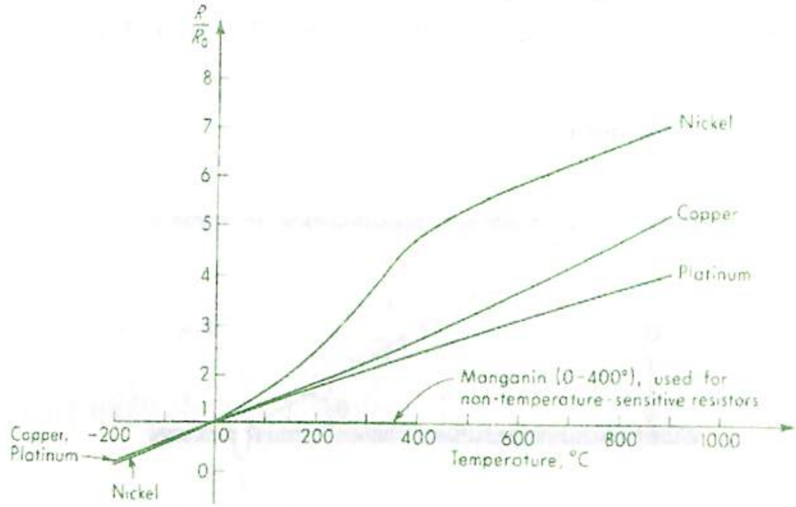


Fig 7.5: Resistance temperature curve

D. CHARACTERISTIC EQUATION OF MAGNETIC FLOW METER

The magnetic flow meter has a bore normally of the same diameter as the inner diameter of the pipe. The meter is connected to a straight section of the pipeline by flanges. A conducting fluid such as water is forced to flow through the flowmeter either by gravity or by a pump. The electromagnet of the flowmeter generates a strong magnetic field having a flux density *B* across the flow. From Faraday's law of electromagnetic induction, the conducting fluid cutting across the magnetic field generates a voltage *Eo* across the bore in a direction perpendicular to the magnetic field. By placing two electrodes on opposite sides of the circumference of the meter bore, this voltage *Eo* can be measured with a high-impedance voltmeter. Application of Faraday's law yields

$$Q = C_3 E_o / B$$

Where

V= mean velocity across the pipe.

Q= discharge.

B= Flux density across the flow

E_o=Voltage across the bore in a direction perpendicular to the magnetic field

C_3 = Constant, value can be found from calibration

E. CHARACTERISTIC EQUATION OF ACOUSTIC FLOWMETER

Most acoustic flowmeters use high-frequency sound (of frequencies higher than 20 kHz) to measure discharge, and hence they are also called ultrasonic flowmeters. There are two general types of such flowmeters: the transit-time type and the Doppler type. The transit-time flowmeter uses two probes, one upstream and the other downstream, mounted diagonally across the pipe as shown in Figure

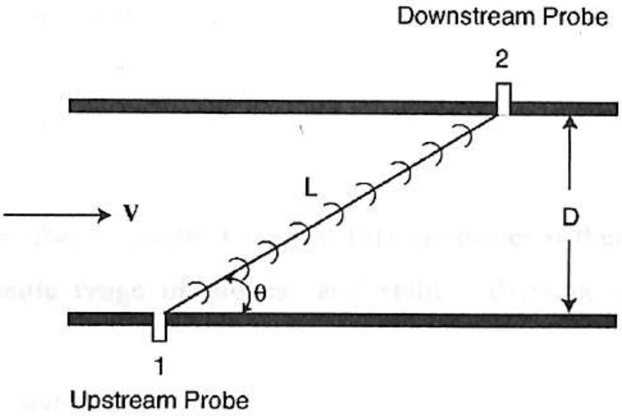


Fig.7.6: Transit-time acoustic flowmeter principle.

V is the mean flow velocity in the pipe can be given by:

$$V = \frac{C^2 \Delta t \tan\theta}{2D}$$

Where

V = mean velocity across the pipe.

D =diameter of pipe

C = Celerity of sound

Δt = t_{12}- t_{12}

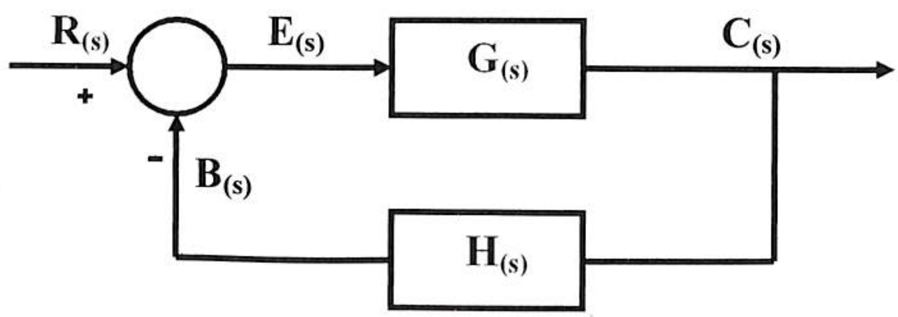
t_{12} =travel time of the wave from the upstream probe to the downstream probe

t_{21} = travel time of the wave from the downstream probe to the upstream probe

Θ = is the angle between the pipe wall and the line connecting the two probes,

7.6 DESIGN ASPECT OF CONTROL SYSTEM

1. Study of process and its mathematical modeling. Mathematical modeling of process under control is to be determined either by theoretical equation or by empirical relation or through practical experience. And hence determine the static & dynamic parameter of the system.
2. Select suitable Transducers/ Sensors to sense input/ output parameters of the system based on
   - Static & dynamic parameter (range) of the system
   - Compatibility of the transducer & sensor
   - Cost related to controlling
   - Suitability of the transducer & sensor
   - Reliability of the transducer & sensor
3. Estimation of feedback system. Using of PID controller if there is any mismatch in the static /dynamic range of process and static / dynamic range of transducers/ sensors.
4. Calculate steady state error e_{ss}



$E_{(s)} = R_{(s)} - B_{(s)}$ ....(i)

$C_{(s)} = G_{(s)} * E_{(s)}$ ....(ii)

$B_{(s)} = H_{(s)} * C_{(s)}$ ....(iii)

By solving the above equation we get

$E_{(s)} = R_{(s)} / [1 + G_{(s)} * H_{(s)}]$ ....(iv)

Hence we can write error signal $E_{(s)}$ is nothing but the ratio of input reference signal $R_{(s)}$ to the characteristics equation $[1 + G_{(s)} * H_{(s)}]$

The steady state error e_{ss} may now be found out by use the final value theorem as follows

$$e_{ss} = \mathbf{Lt}_{s \to 0} \quad \mathbf{E_{(s)} * S}$$

$$= \mathbf{Lt}_{s \to 0} \quad \mathbf{S * R_{(s)} /[1 + G_{(s)} * H_{(s)}]}$$

From the above equation we are able to find out the stability of the system by root locus plot. Also identify the condition of system on application of various standards test signals. Like Unit Step Input, Unit Ramp (Velocity) Input, Unit Parabolic (Acceleration) Input, Impulse Input, whether this can accommodate or not.

5. Finally done the PID control operation logically through a hardware software interface (i.e. PLC) for the faster and accurate controlling of the system. Because it is rather impossible to control a Multi Input Multi Output (MIMO) system by adjusting the PID (Integral gain K_i, Proportional gain K_p & Derivative gain K_d value).

CHAPTER 8

RESULT & DISCUSSION

8.1 PROCESS DESCRIPTION

A compressor station has Auto and Manual mode of operation. This is done by Auto/ Manual selector switch. i.e. both can't operate at same time. The prime mover for compressor is electric driven induction motor, which is started by star/ delta connection.

If al the main and auxiliary components of compressor station are in normal condition i.e. no shut down condition occur then the compressor can be run normally (in auto mode) by pressing the Start Push Button in star mode, and after 10 second it will automatically switchover to delta mode. Compressor can be stopped by pressing either stop Push Button or by Manual ESD Push Button.

At the time of critical safety there are three shutdowns mode can occur in compressor station.

1. **Station Shutdown Restartable** mode is triggered by one of the following condition
   - High discharge pressure
   - Low suction pressure
   - High discharge temperature

On detection of one of these conditions, a normal stop is send on to the units (compressor). As seen in **Fig 3.1,** valve return to a normal shutdown position with no change in station main valve position. Units can be restarted remotely after 10 second of clearing of the shutdown condition. The unit valves stay open and the compressor is pressurized for a certain time period.

2. **Station Shutdown Lockout** mode triggered by any of the following conditions:
   - Valve fault
   - Station scrubber high liquid level shutdown
   - Station scrubber high differential pressure shutdown

On detection of any of these conditions, a hard-wired emergency stop is issued to the units and the station suction and discharge valves signaled to close. As soon as the differential pressure across the station block vale is at a low enough value to permit safe opening of the block valve, it is signaled to open (**Fig 3.2**). The condition has to be cleared before the station can be brought back into service.

3. **Emergency Shutdown** mode is triggered by any of the following condition
   - Fire
   - Gas leak
   - Unit seal failure
   - Low control voltage
   - Unit valves fail to close

- Manual ESD via push button

On detection of any of these conditions (Fig 3.3), a station shutdown lockout is issued, causing the unit to stop, the suction and discharge valve to close, and block valve to open. When the station suction and discharge valve are both fully closed the station blow down valve opens, venting all gas within the station to the atmosphere.

8.2 INPUT OUTPUT TABLES FOR PLC PROGRAMMING

Development of logical control system for the above process is needed a PLC programming and then based on PLC programming made a SCADA program. In the proposed work PLC Programming is done in **SIEMENS SIMATIC STEP7** software & SCADA Programming is done in **SIEMENS WINCC** (Windows Control Center) software.

The result of the PLC programming is given here under in tabular form

INPUT SYMBOL TABLE				
S.NO	**SYMBOL**	**ADDRESS**	**DATA TYPE**	**COMMENT**
1	AUTO SW	I 0.0	BOOL	AUTO/MANUAL SELECTOR SWITCH
2	MANUAL	I 0.1	BOOL	AUTO/MANUAL SELECTOR SWITCH
3	START PB	I 0.2	BOOL	START PUSH BUTTON
4	STOP PB	I 0.3	BOOL	STOP PUSH BUTTON
5	HDP	I 0.4	BOOL	HIGH DISCHARGE PRESSURE INDICATOR
6	LSP	I 0.5	BOOL	LOW SUCTION PRESSURE INDICATOR
7	HDT	I 0.6	BOOL	HIGH DISCHARGE TEMPARATURE INDICATOR
8	VF	I 0.7	BOOL	VALVE FAULT INDICATOR
9	SSHLL	I 1.0	BOOL	STATION SCRUBBER HIGH LIQUID LEVEL INDICATOR
10	SSHDP	I 1.1	BOOL	STATION SCRUBBER HIGH DIFFERENTIAL PRESSURE INDICATOR
11	FIRE	I 1.2	BOOL	FIRE INDICATOR
12	GAS LEAK	I 1.3	BOOL	HIGH GAS LEVEL(GAS LEAK) INDICATOR
13	USF	I 1.4	BOOL	UNIT SEAL FAILURE INDICATOR
14	UVF to C	I 1.5	BOOL	UNIT VALVE CLOSING FAILURE INDICATOR
15	LCV	I 1.6	BOOL	LOW CONTROL VOLTAGE INDICATOR
16	M ESD	I 1.7	BOOL	MANUAL ESD PUSH BUTTON

TABLE 8.1: INPUT SYMBOL TABLE

OUTPUT SYMBOL TABLE				
S.NO	**SYMBOL**	**ADDRESS**	**DATA TYPE**	**COMMENT**
1	AUTO	Q0.0	BOOL	AUTO MODE INDICATOR
2	MAIN	Q0.1	BOOL	MOTOR MAIN ON/OFF INDICATOR
3	STAR	Q0.2	BOOL	MOTOR STAR MODE INDICATOR
4	DELTA	Q0.3	BOOL	MOTOR DELTA MODE INDICATOR
5	SSV	Q0.4	BOOL	STATION SUCTION VALVE ON/OFF INDICATOR
6	SDV	Q0.5	BOOL	STATION DISCHARGE ON/OFF INDICATOR
7	SRV	Q0.6	BOOL	STATION RECYCLE VALVE ON/OFF INDICATOR
8	USV	Q0.7	BOOL	UNIT SUCTION VALVE ON/OFF INDICATOR
9	UDV	Q1.0	BOOL	UNIT DISCHARGE ON/OFF INDICATOR
10	SBV	Q1.1	BOOL	STATION BLOCK VALVE ON/OFF INDICATOR
11	URV	Q1.2	BOOL	UNIT RECYCLE VALVE ON/OFF INDICATOR
12	U BD V	Q1.3	BOOL	STATION BLOWDOWN VALVE ON/OFF INDICATOR

TABLE 8.2: OUTPUT SYMBOL TABLE

TIMER/COUNTER SYMBOL TABLE				
S.NO	**SYMBOL**	**ADDRESS**	**DATA TYPE**	**COMMENT**
1	STAR DELTA	T1	TIMER	STAR TO DELTA CHANGE TIMER
2	SSDR OFF DELAY	T2	TIMER	SSDR OFF DELAY TIMER TO DELAY IN START AFTER SSDR

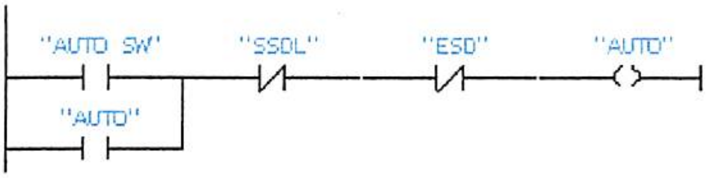
TABLE 8.3: TIMER/COUNTER SYMBOL TABLE

MEMORY BIT SYMBOL TABLE				
S.NO	**SYMBOL**	**ADDRESS**	**DATA TYPE**	**COMMENT**
1	SSDR	M0.0	BOOL	SSDR MODE INDICATOR
2	SSDL	M0.1	BOOL	SSDL MODE INDICATOR
3	ESD	M0.2	BOOL	ESD MODE INDICATOR
4		M0.3	BOOL	
5		M1.0	BOOL	
6		M1.1	BOOL	
7		M1.2	BOOL	
8		M1.3	BOOL	
9		M1.4	BOOL	
10		M1.5	BOOL	
11		M1.6	BOOL	
12		M1.7	BOOL	
13		M2.2	BOOL	
14		M2.3	BOOL	
15		M2.4	BOOL	
16		M2.5	BOOL	
17		MW4	WORD	STAR DELTA TIMER INDICATOR
18		MW6	WORD	SSDR OFFDELAY TIMER INDICATOR

TABLE 8.4: MEMORY BIT SYMBOL TABLE

8.3 LADDER LOGIC DIAGRAM

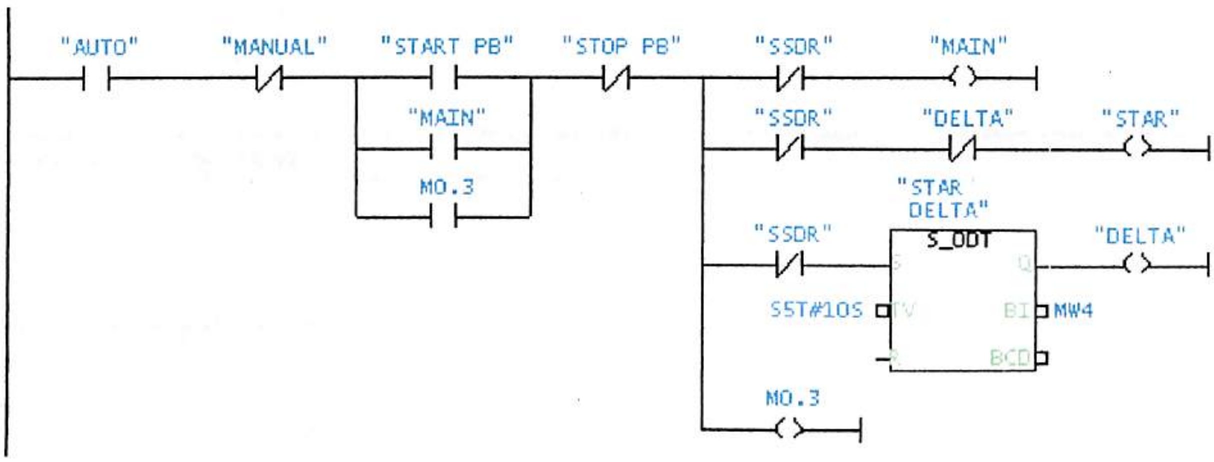
Network: 1 AUTO MANUAL SELECTION



Symbol information

I0.0	"AUTO SW"	AUTO/MANUAL SELECTOR SWITCH
Q0.0	"AUTO"	AUTO MODE INDICATOR
M0.1	"SSDL"	SSDL MODE INDICATOR
M0.2	"ESD"	ESD MODE INDICATOR

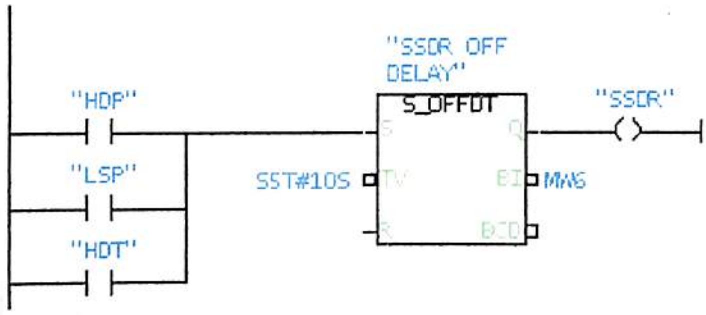
Network: 2 MAIN CONTROL



Symbol information

Q0.0	"AUTO"		AUTO MODE INDICATOR
I0.1	"MANUAL"		AUTO/MANUAL SELECTOR SWITCH
I0.2	"START PB"		START PUSH BUTTON
Q0.1	"MAIN"		MOTOR MAIN ON/OFF INDICATOR
M0.3	M0.3		
I0.3	"STOP PB"		STOP PUSH BUTTON
M0.0	"SSDR"		SSDR MODE INDICATOR
Q0.3	"DELTA"		MOTOR DELTA MODE INDICATOR
Q0.2	"STAR"		MOTOR STAR MODE INDICATOR
T1	"STAR	DELTA"	STAR TO DELTA CHANGE TIMER
MW4	MW4		

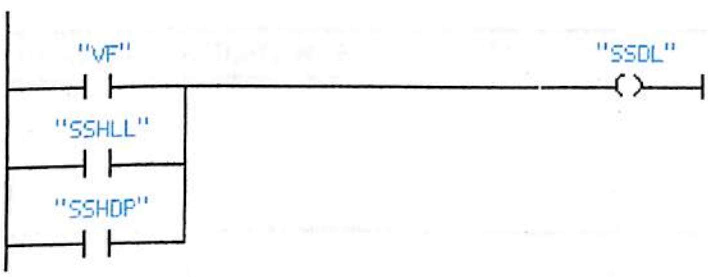
Network: 3 SSDR MODE



Symbol information

I0.4	"HDP"	HIGH DISCHARGE PRESSURE INDICATOR
I0.5	"LSP"	LOW SUCTION PRESSURE INDICATOR INDICATOR
I0.6	"HDT"	HIGH DISCHARGE TEMPARATURE INDICATOR
T2	"SSDR OFF DELAY"	SSDR OFF DELAY TIMER TO DELAY IN START AFTER SSDR
MW6	MW6	
M0.0	"SSDR"	SSDR MODE INDICATOR

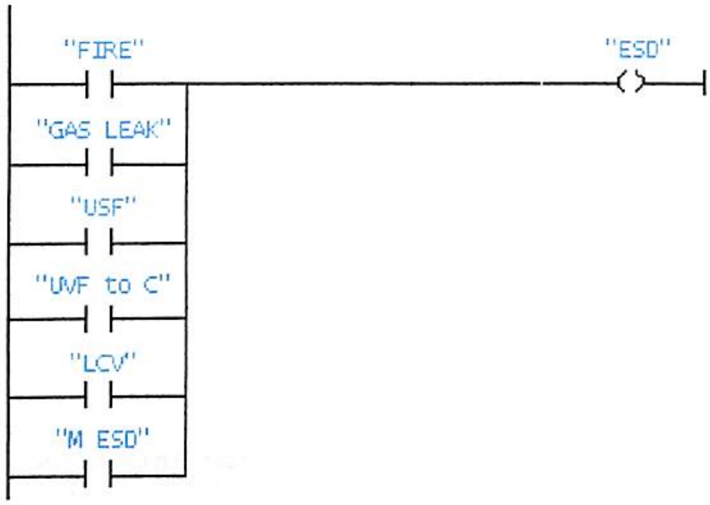
Network: 4 SSDL MODE



Symbol information

I0.7	"VF"	VALVE FAULT INDICATOR
I1.0	"SSHLL"	STATION SCRUBBER HIGH LIQUID LEVEL INDICATOR
I1.1	"SSHDP"	STATION SCRUBBER HIGH DIFFERENTIAL PRESSURE INDICATOR
M0.1	"SSDL"	SSDL MODE INDICATOR

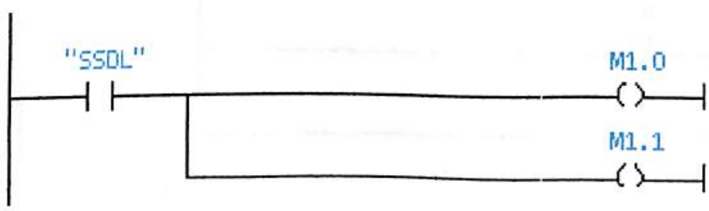
Network: 5 ESD MODE



Symbol information

I1.2	"FIRE"	FIRE INDICATOR
I1.3	"GAS LEAK"	HIGH GAS LEVEL(GAS LEAK) INDICATOR
I1.4	"USF"	UNIT SEAL FAILURE INDICATOR
I1.5	"UVF to C"	UNIT VALVE CLOSING FAILURE INDICATOR
I1.6	"LCV"	LOW CONTROL VOLTAGE INDICATOR
I1.7	"M ESD"	MANUAL ESD PUSH BUTTON
M0.2	"ESD"	ESD MODE INDICATOR

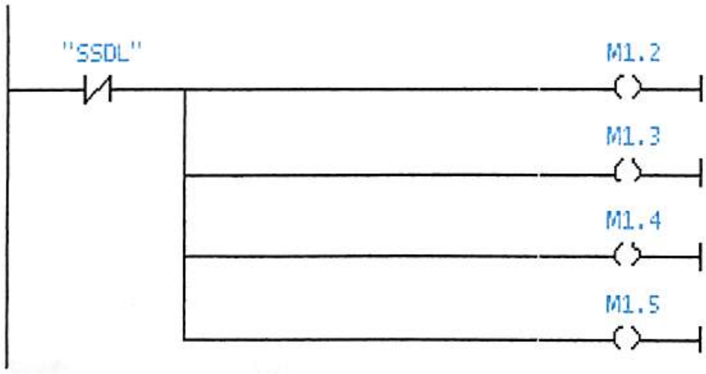
Network: 6 ACTUATION OF VALVE IN SSDL



Symbol information

M0.1	"SSDL"	SSDL MODE INDICATOR
M1.0	M1.0	
M1.1	M1.1	

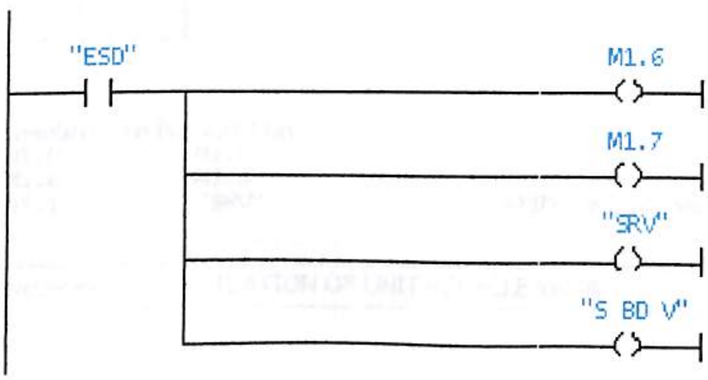
Network: 7 ACTUATION OF VALVE IN SSDL



Symbol information

M0.1	"SSDL"	SSDL MODE INDICATOR
M1.2	M1.2	
M1.3	M1.3	
M1.4	M1.4	
M1.5	M1.5	

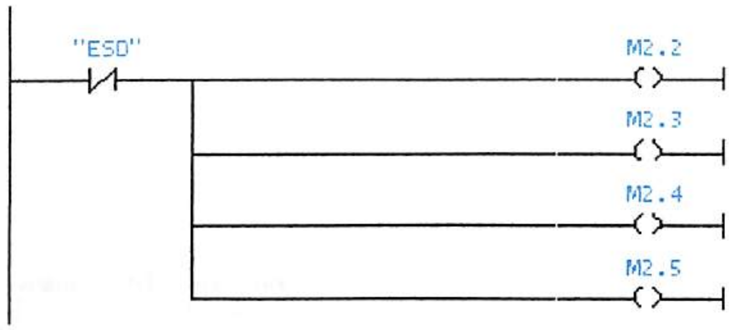
Network: 8 ACTUATION OF VALVE IN ESD



Symbol information

M0.2	"ESD"	ESD MODE INDICATOR
M1.6	M1.6	
M1.7	M1.7	
Q0.6	"SRV"	STATION RECYCLE VALVE ON/OFF INDICATOR
Q1.3	"S BD V"	STATION BLOWDOWN VALVE ON/OFF INDICATOR

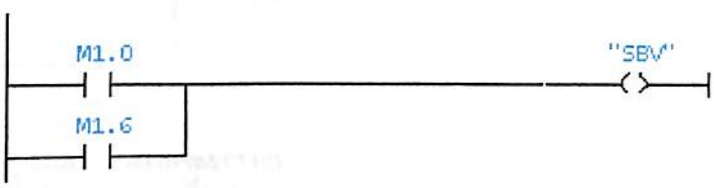
Network: 9 ACTUATION OF VALVE IN ESD



Symbol information

M0.2	"ESD"	ESD MODE INDICATOR
M2.2	M2.2	
M2.3	M2.3	
M2.4	M2.4	
M2.5	M2.5	

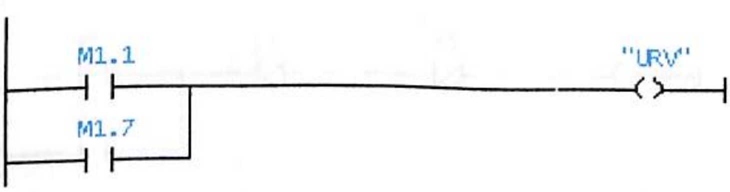
Network: 10 ACTUATION OF STATION BLOCK VALVE



Symbol information

M1.0	M1.0	
M1.6	M1.6	
Q1.1	"SBV"	STATION BLOCK VALVE ON/OFF INDICATOR

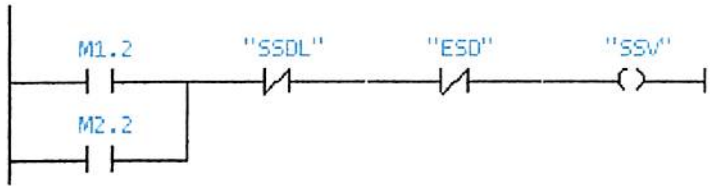
Network: 11 ACTUATION OF UNIT RECYCLE VALVE



Symbol information

M1.1	M1.1	
M1.7	M1.7	
Q1.2	"URV"	UNIT RECYCLE VALVE ON/OFF INDICATOR

Network: 12 ACTUATION OF STATION SUCTION VALVE



Symbol information

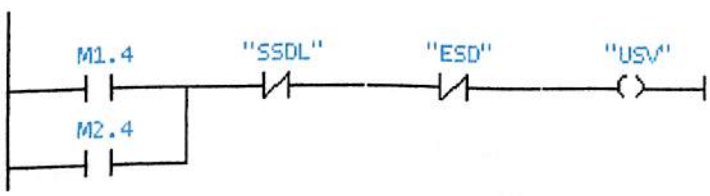
M1.2	M1.2	
M2.2	M2.2	
M0.1	"SSDL"	SSDL MODE INDICATOR
M0.2	"ESD"	ESD MODE INDICATOR
Q0.4	"SSV"	STATION SUCTION VALVE ON/OFF INDICATOR

Network: 13 ACTUATION OF STATION DISCHARGE VALVE

Symbol information

M1.3	M1.3	
M2.3	M2.3	
M0.1	"SSDL"	SSDL MODE INDICATOR
M0.2	"ESD"	ESD MODE INDICATOR
Q0.5	"SDV"	STATION DISCHARGE ON/OFF INDICATOR

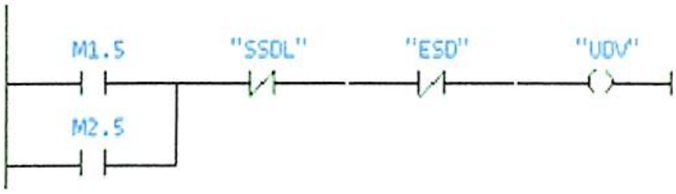
Network: 14 ACTUATION OF UNIT SUCTION VALVE



Symbol information

M1.4	M1.4	
M2.4	M2.4	
M0.1	"SSDL"	SSDL MODE INDICATOR
M0.2	"ESD"	ESD MODE INDICATOR
Q0.7	"USV"	UNIT SUCTION VALVE ON/OFF INDICATOR

Network: 15 ACTUATION OF UNIT DISCHARGE VALVE



Symbol information

M1.5	M1.5	
M2.5	M2.5	
M0.1	"SSDL"	SSDL MODE INDICATOR
M0.2	"ESD"	ESD MODE INDICATOR
Q1.0	"UDV"	UNIT DISCHARGE ON/OFF INDICATOR

8.4 SCADA SCREEN

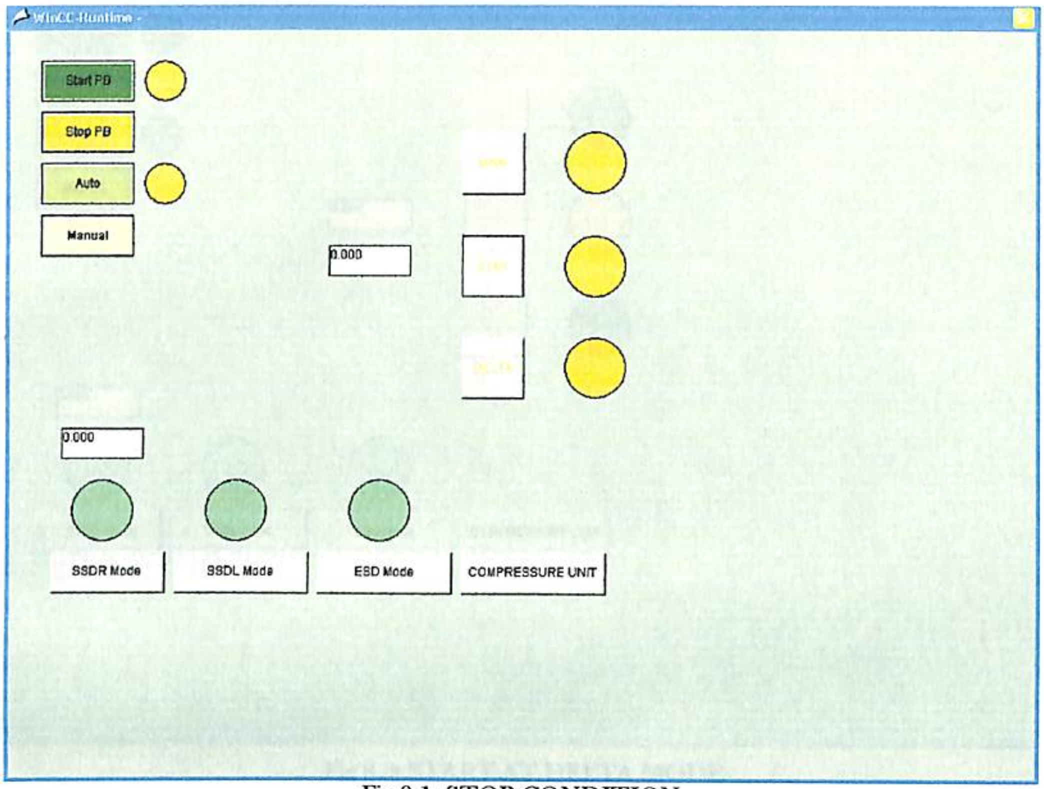


Fig 8.1: STOP CONDITION

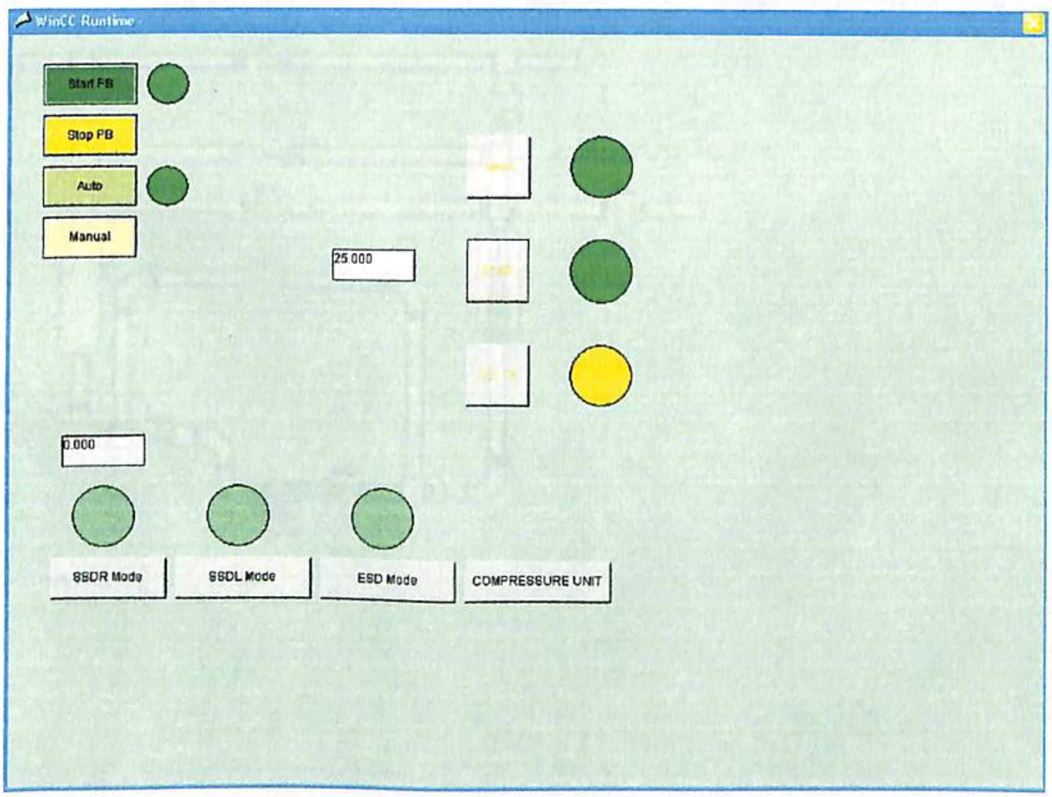


Fig 8.2: START AT STAR MODE

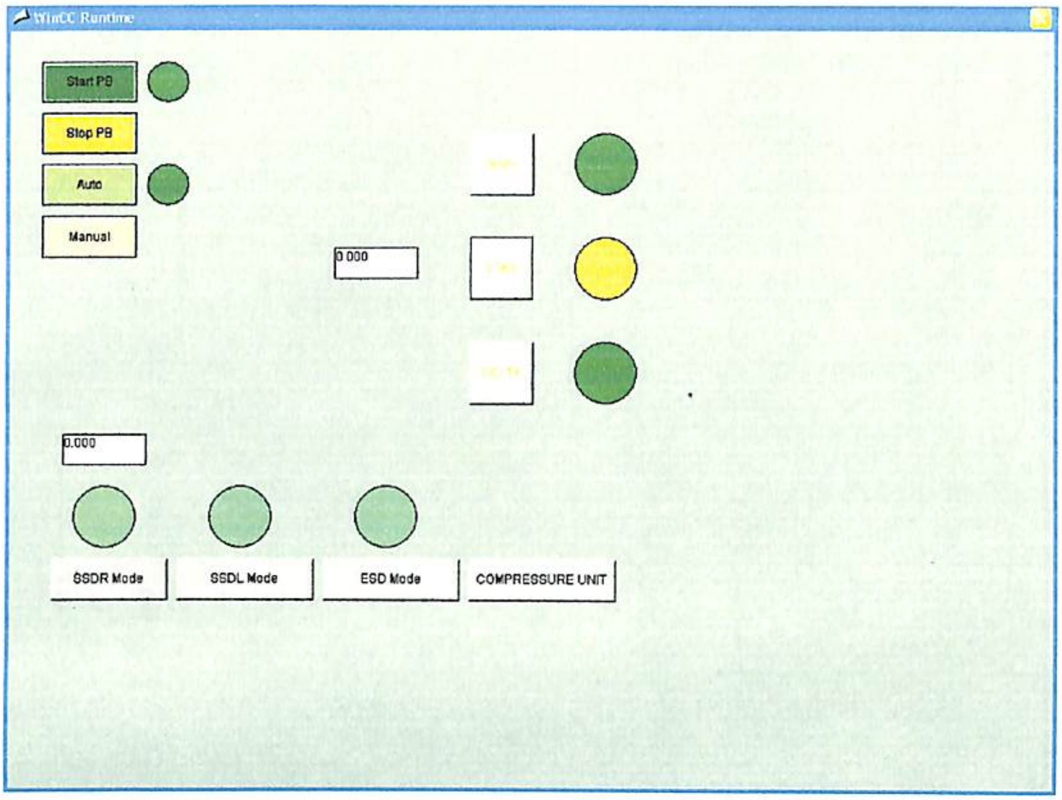


Fig 8.3: START AT DELTA MODE

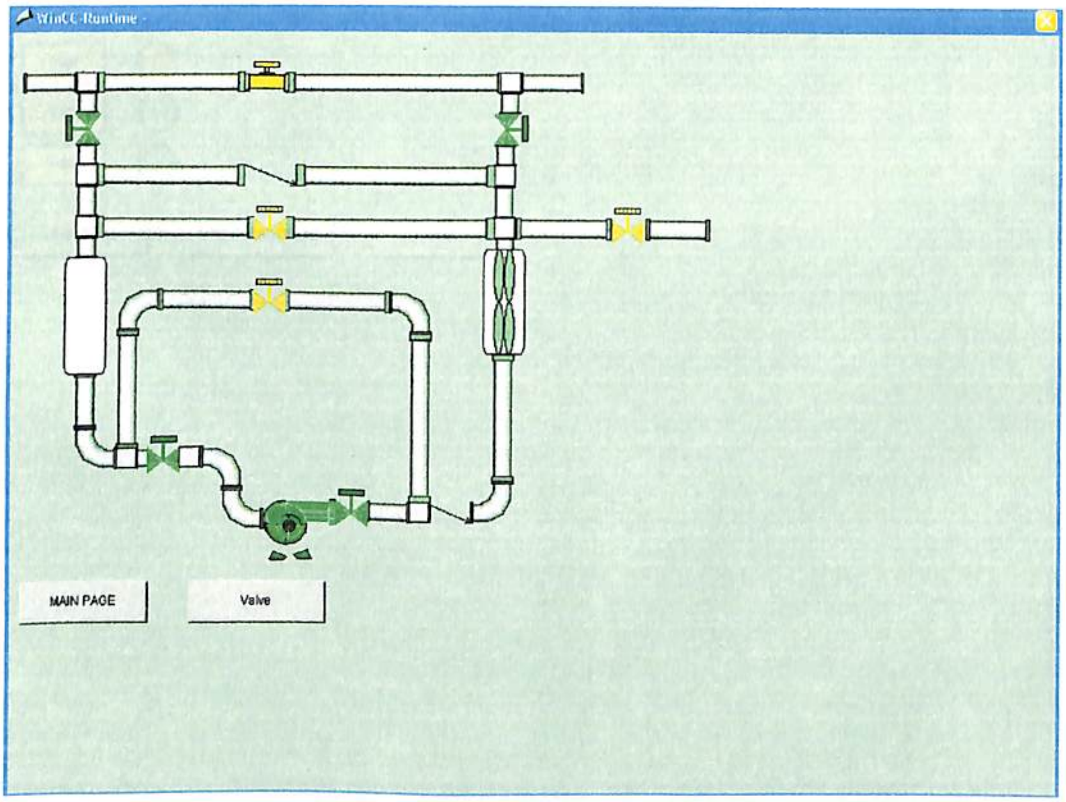


Fig 8.4: STATION AT NORMAL RUNNING

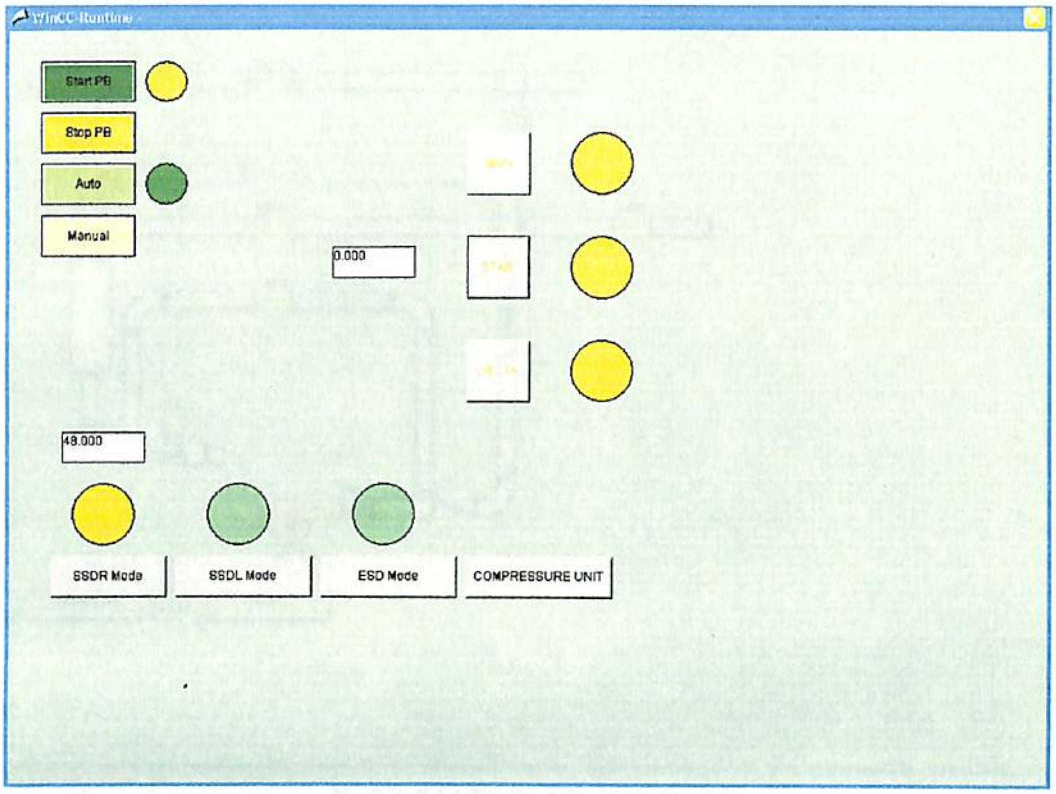


Fig. 8.5: SSDR MODE MAIN PAGE

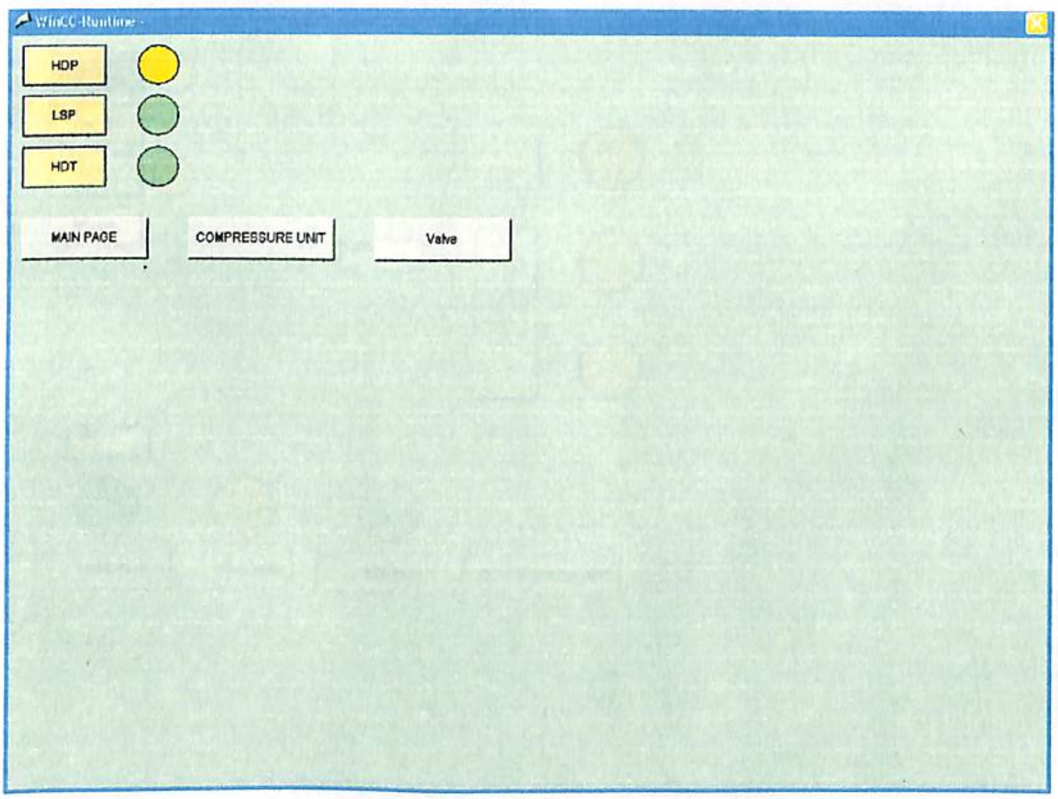


Fig 8.6: SSDR MODE PAGE

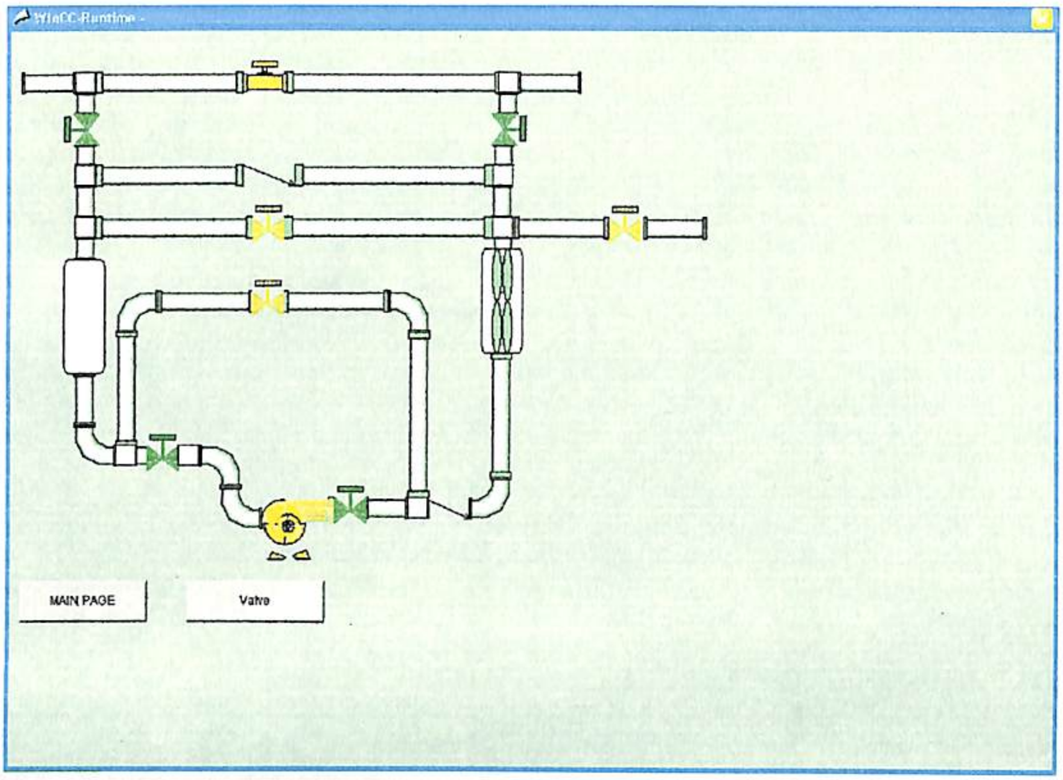


Fig 8.7: STATION AT SSDR MODE

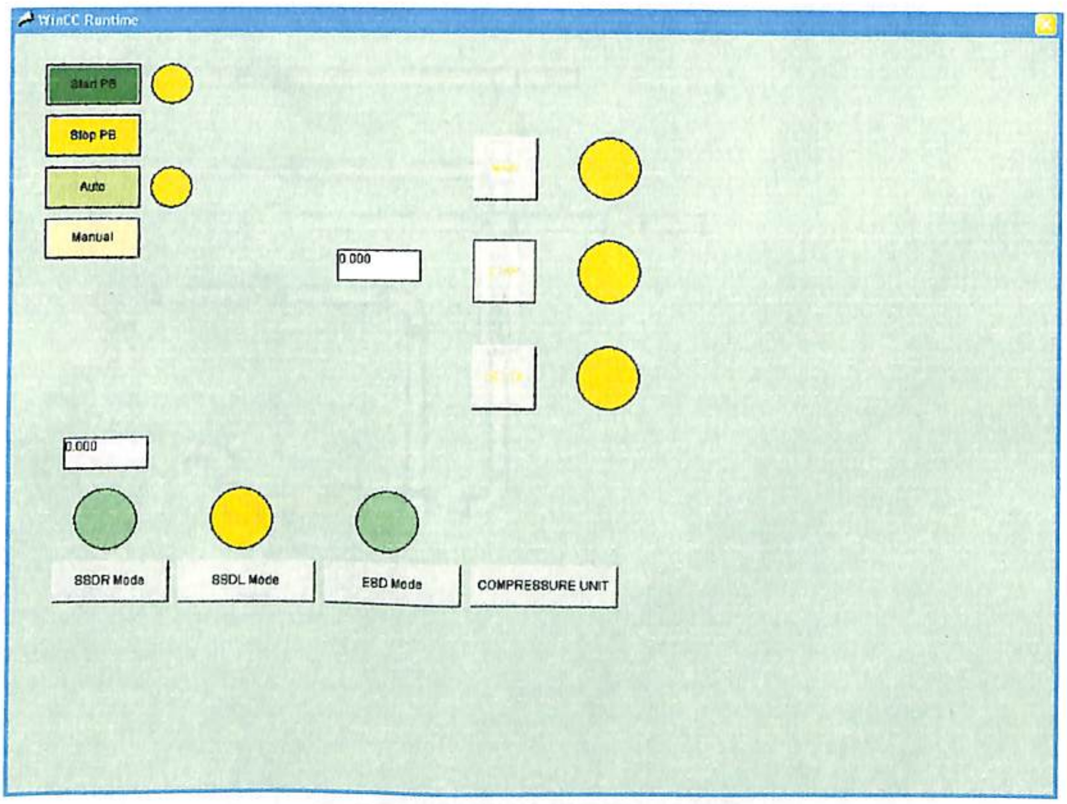


Fig 8.8: SSDL MODE MAIN PAGE

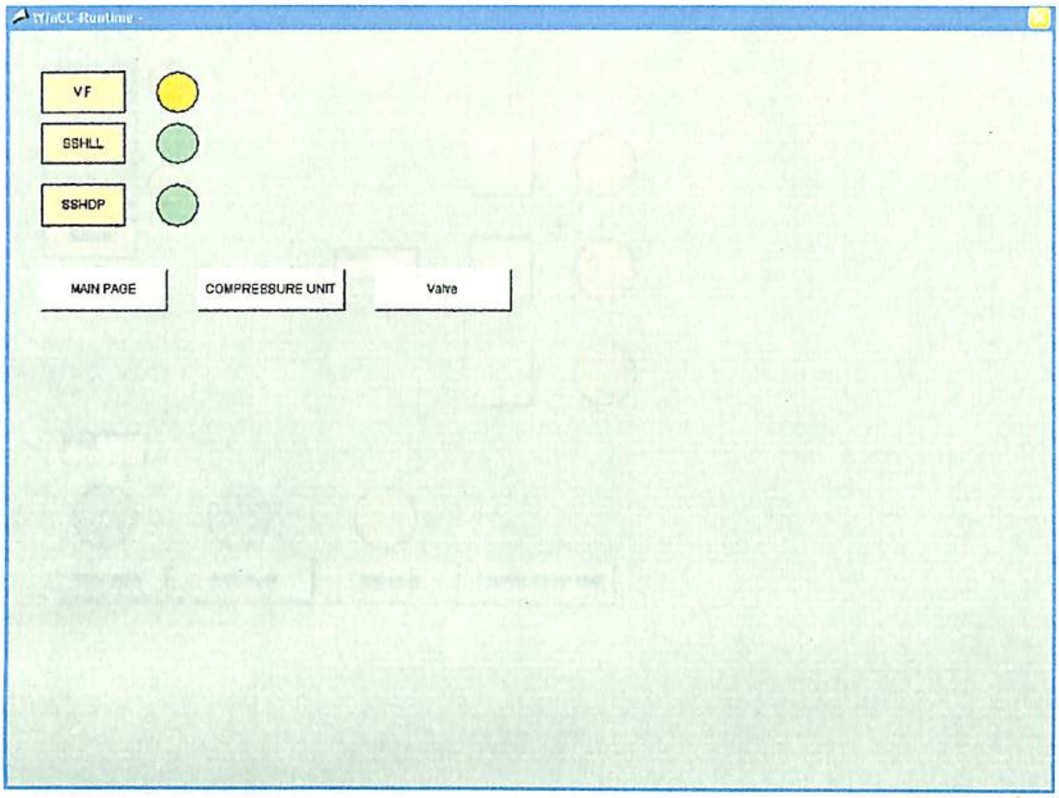


Fig 8.9: SSDL MODE PAGE

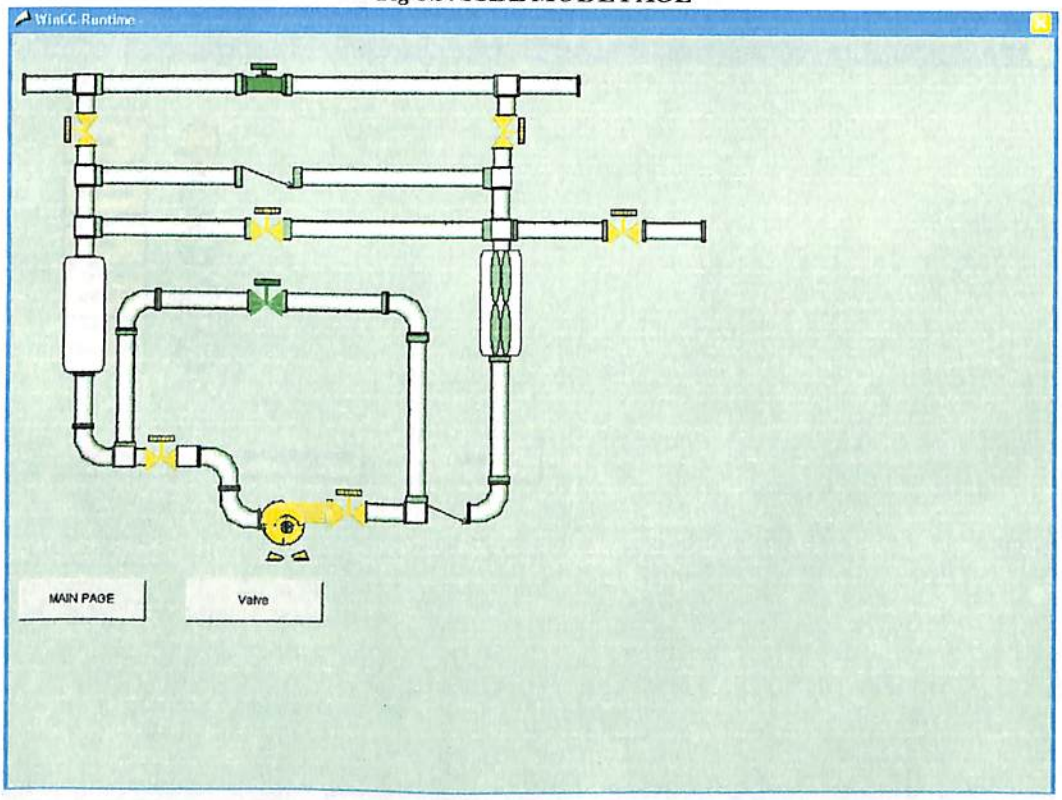


Fig 8.10: STATION AT SSDL MODE

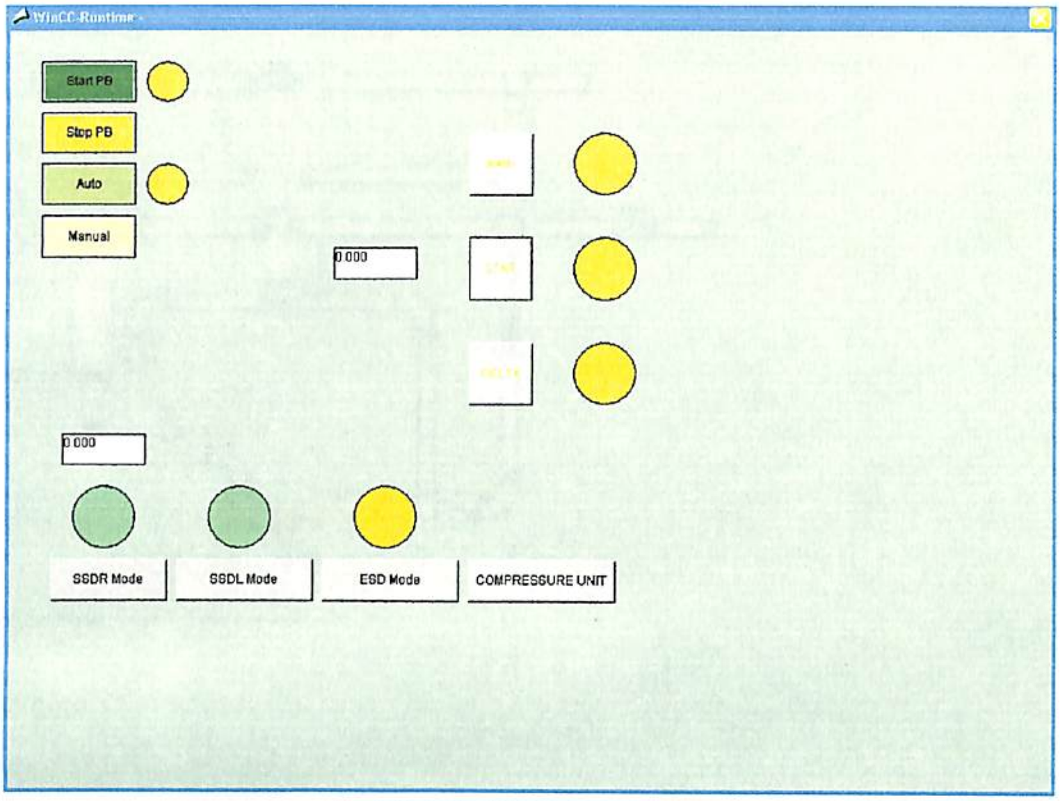


Fig 8.11: ESD MODE MAIN PAGE

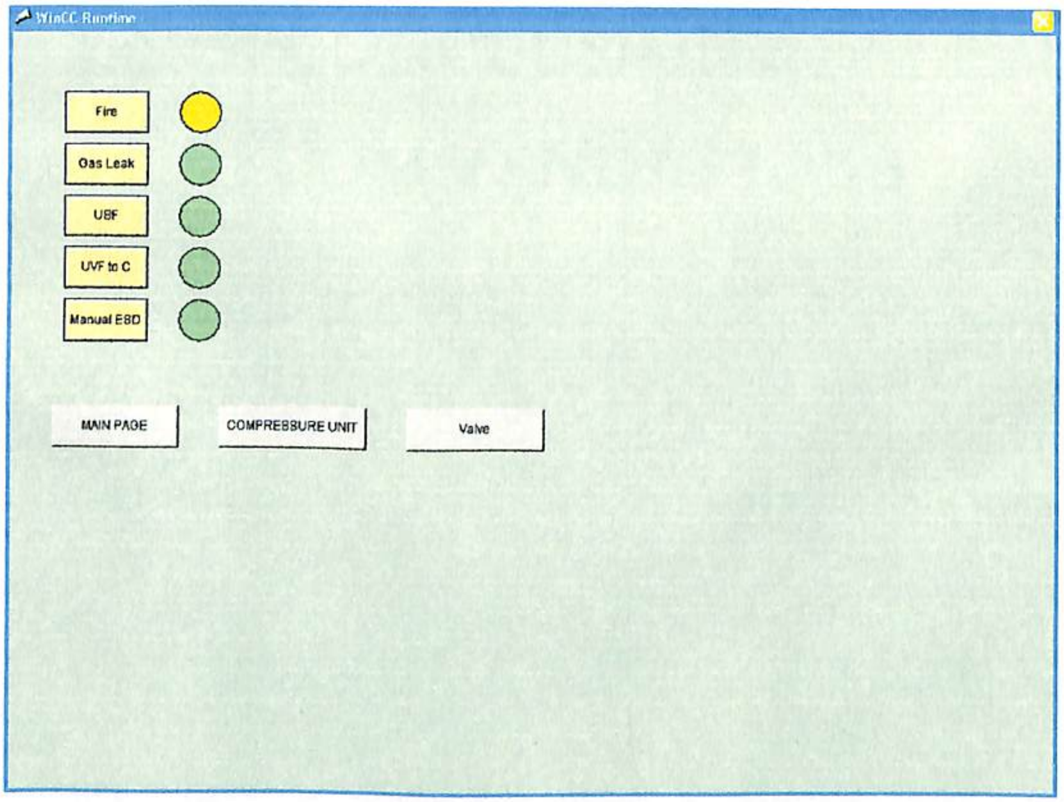


Fig 8.16: ESD MODE PAGE

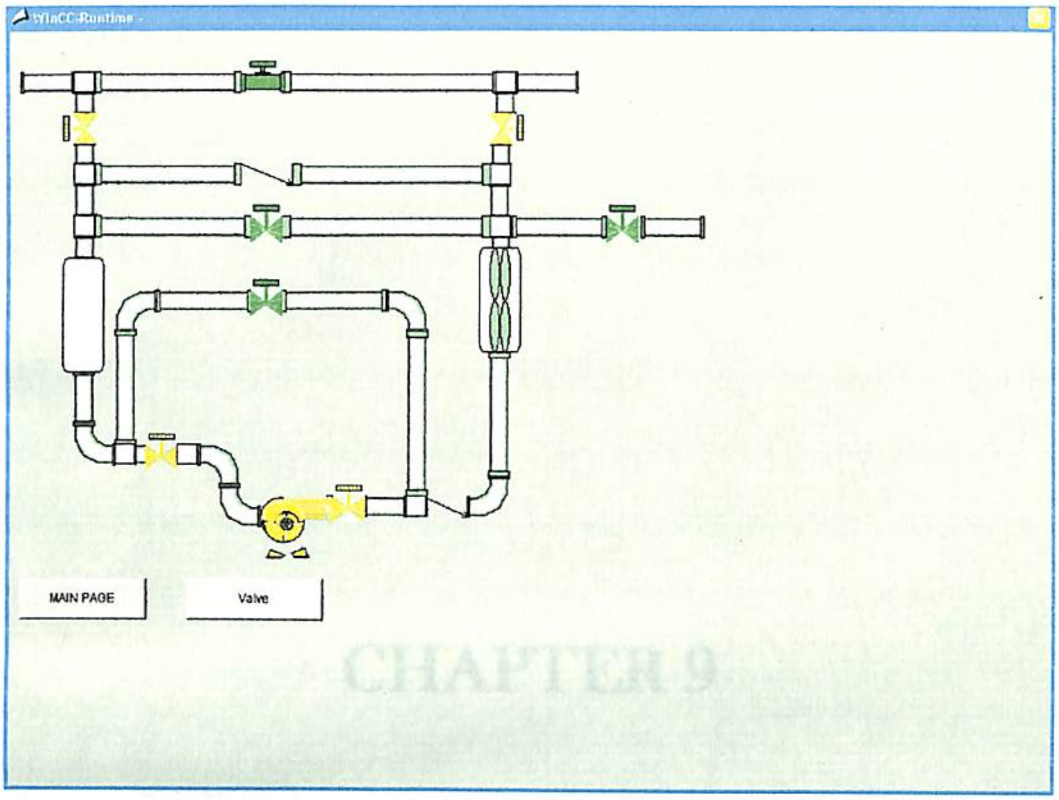


Fig 8.17: STATION AT ESD MODE

CHAPTER 9

CONCLUSION & RECOMMENDATIONS

In the proposed work I have tried to use PLC & SCADA techniques for compressor station critical safety operation using the concept of logical control.

Development of a complete logical control system for compressor station critical safety operation more than 500 input output parameters have to be taken care, where as I have taken only 16 input & 12 output parameters, to make the PLC & SCADA program, due to limited time and unavailability of commissioning field data hence the complete process modeling could not completed.

In future this project could be updated in online operation model using adaptive math modeling.

REFERENCES

1. Mo. Mohitpour, Jason Szabo, Thomas Van Hardveld "Pipeline Operation & Maintenance A Practical Approach" ASME PRESS 2005 5th edition
2. Ernest O Doebelin, Dhanesh N Manik "Measure System Application and Design" Tata McGraw-Hill 2007, 5th edition.
3. Dardo Marqués, Manfred Morari "On-line optimization of gas pipeline networks" *Automatica, Volume 24, Issue 4, July 1988, Pages 455-469*
4. Roberto Camoirano, Giuseppe Dellepiane "Variable frequency drives for MSF desalination plant and associated pumping stations" *Volume 182, Issues 1-3, 1 November 2005, Pages 53-65*
5. Charles M. Mitchell, Kevin Williams "Failure experience of programmable logic controllers used in emergency shutdown systems" *Reliability Engineering & System Safety, Volume 39, Issue 3, 1993, Pages 329-331*
6. Mokhatab, Saeid,Santos, Sidney P.,Cleveland "design & control of compressor station" Publication: Pipeline & Gas Journal, Date: Friday, June 1 2007
7. Siemens Automation and Drives, http://www.processingtalk.com/news/sie/sie217.html www.siemens.com/simatic-pcs7,
8. httpwww.hinz.comaboutexperienceexperience-oilandgas.html
9. Lewis, R.W., *IEC61131-3 Programming Standard*, www.SearchEng.co.uk. www.spitzerandboyes.com
10. Paper presentation at the 2nd international pipeline week conference and exhibition, organized by gulf publishing co. and pipeline and gas industry magazine , held in October 1998,in Houston, Texas.
11. Practical SCADA for industry, David Bailey & Edwin Wright, Newness publishers, 2003.
12. Journals , free online patented research papers , U.S patents
13. www.spe.org
14. Pipeline and gas journal / march 2003 / www.pipelineandgasjournal.com
15. E.W. McAllister, P I P E L I N E RULESOFTHUMB H A N D B O O K, Gulf Professional Publishing, 5th edition
16. Henry Liu, Pipeline Engineering, Lewis Publishers, Taylor & Francis e-Library ,2005