DCS Fundamentals

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1. Introduction

The process control of large industrial plants has evolved through many stages. Initially, control would be from panels local to the process plant. However, this required a large manpower resource to attend to these dispersed panels, and there was no overall view of the process. The next logical development was the transmission of all plant measurements to a permanently-manned central control room. Effectively this was the centralization of all the localized panels, with the advantages of lower manning levels and easier overview of the process. Often the controllers were behind the control room panels, and all automatic and manual control outputs were transmitted back to plant. However, whilst providing a central control focus, this arrangement was inflexible as each control loop had its own controller hardware, and continual operator movement within the control room was required to view different parts of the process.

With the coming of electronic processors and graphic displays it became possible to replace these discrete controllers with computer-based algorithms, hosted on a network of input/output racks with their own control processors. These could be distributed around plant, and communicate with the graphic display in the control room or rooms. The distributed control system was born.

The introduction of DCSs allowed easy interconnection and re-configuration of plant controls such as cascaded loops and interlocks, and easy interfacing with other production computer systems. It enabled sophisticated alarm handling, introduced automatic event logging, removed the need for physical records such as chart recorders, allowed the control racks to be networked and thereby located locally to plant to reduce cabling runs, and provided high level overviews of plant status and production levels.

The aim of this manual is to introduce, in simple terms, what is meant by DCS in instrument control systems.

2. What is DCS?

2.1. Control System

A **Control System** is a device, or set of devices, that manages, commands, directs or regulates the behavior of other devices or systems using control loops.

Figure 1: Typical Control System in Industry

2.2. Distributed Control System (DCS)

Distributed Control System (DCS) is a specially designed control system used to control complex, large, and geographically distributed applications in industrial processes, that means that the control of a plant is split into small units which are distributed around the plant.

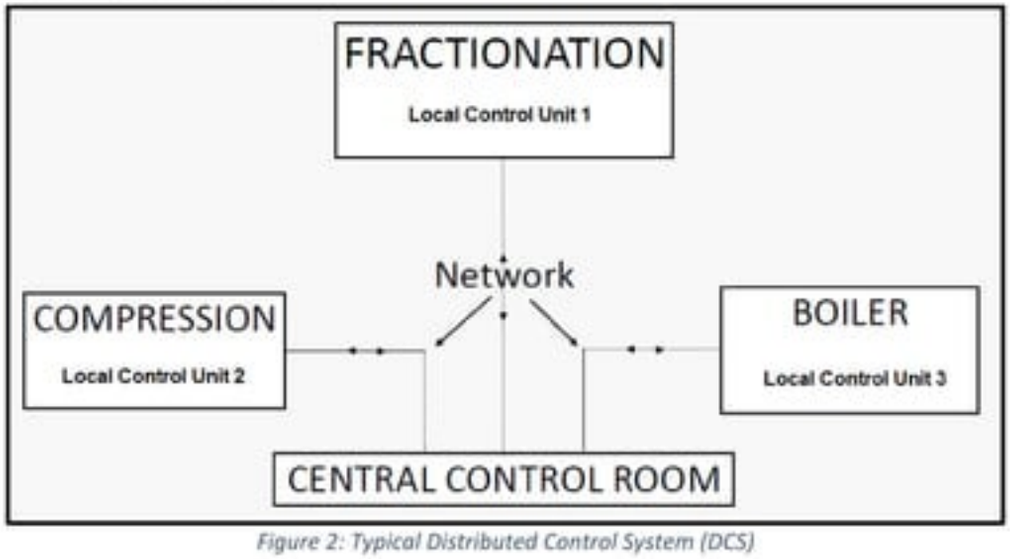


Figure 2: Typical Distributed Control System (DCS)

Figure 2 shows a simple DCS system. The plant consists of three separate (Distributed) local control units: fractionation, compression and boiler. The loops for each unit are controlled by a local control unit. The information required by the operator is sent by a single cable (Data highway) to the central control room. Here, the information is shown on a workstation. The operator can adjust the set points, control the valves and start or stop the motors etc..., from the workstation using the same data highway.

There are various manufacturers of DCS's, ADNOC Gas processing company use a variety of these systems (Centum VP (Yokogawa), Experion PKS (Honeywell), Delta-v (Emerson)), in this manual Yokogawa system is taken as example.

3. DCS Architecture

In DCS, controllers are distributed throughout the entire plant area. These distributed controllers are connected together and to operating PCs through high-speed communication networks and connected to field instruments through instrument cables as shown below in the figure 3.

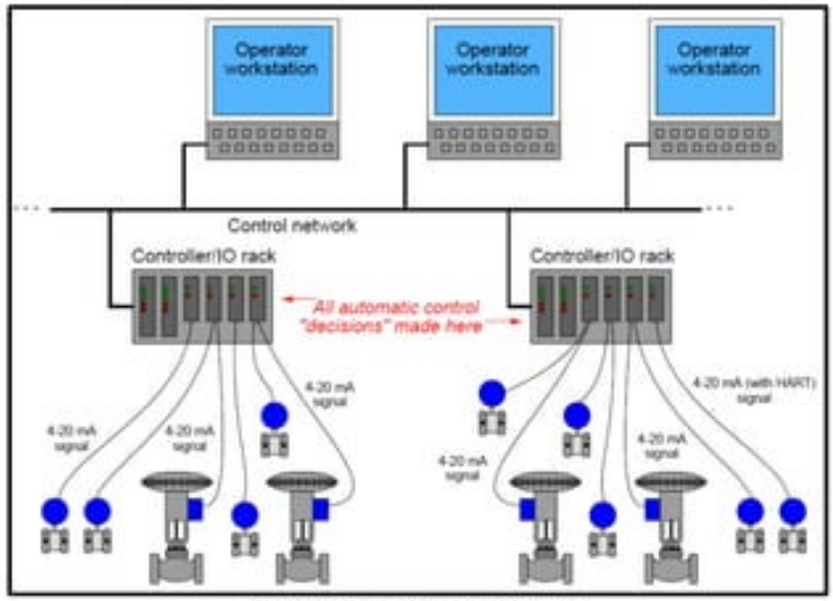


Figure 3: Typical DCS Architecture

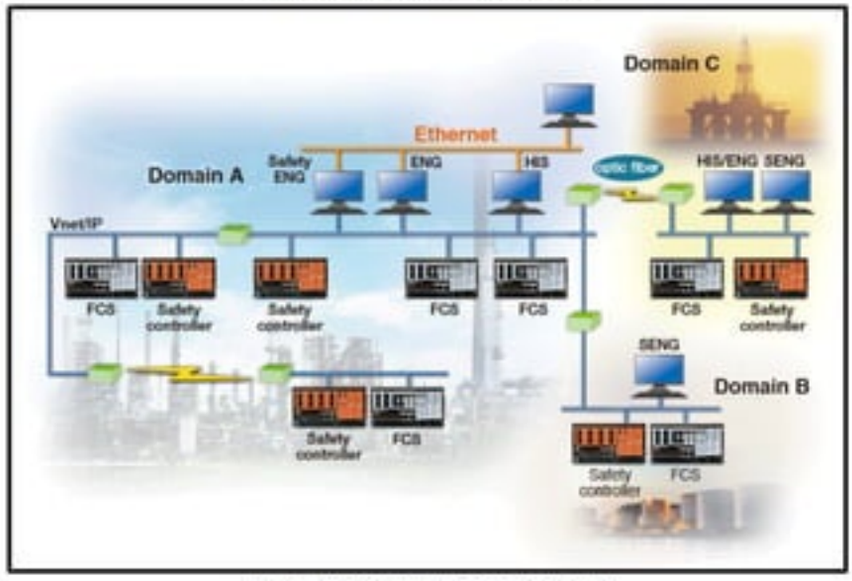


Figure 4: Yokogawa DCS Architecture

FCS: Field Control Station.
HIS: Human Interface Station.
ENG: Engineering Work Station.
Vnet/IP: Yokogawa Control Network

4. Basic Elements of Distributed Control System

4.1. Distributed Controller (Local Control Unit)

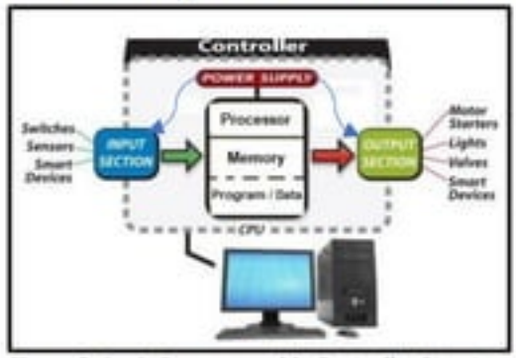


Figure 5: Basic Programmable Controller Structure

The programmable controller (**PC**) contain basically power supply, CPU and I/O modules placed into a rack encloser.

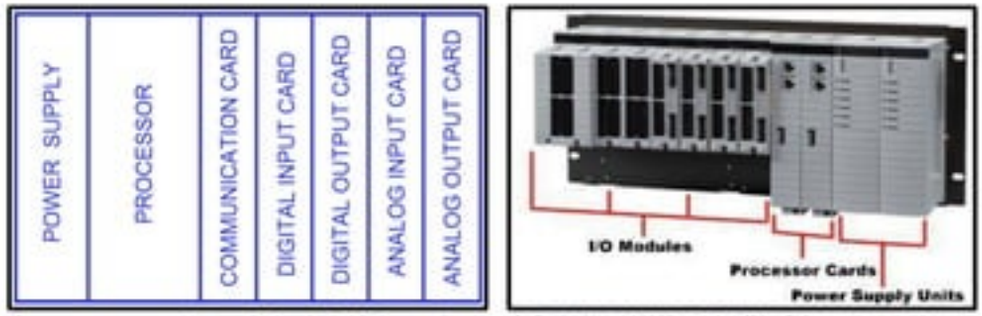


Figure 6: Basic DCS Controller Rack & YOKOGAWA RACK (Node)

4.1.1. Power Supply Module

The power supply module plays a major role in the total system operation. In fact, it can be considered the "first-line manager" of system reliability and integrity. Its responsibility is not only to provide necessary DC voltage levels required to the system components (processor, memory, and input/output modules), but also to monitor and regulate the supplied voltages and warn the CPU if something is wrong. The power supply, then, has the function of supplying well-regulated power and protection for other system components.

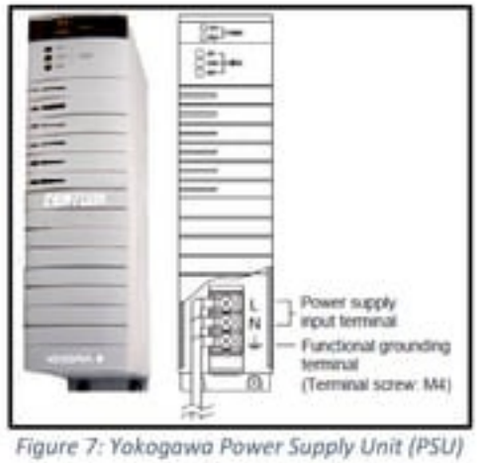


Figure 7: Yokogawa Power Supply Unit (PSU)

The power supply module takes the incoming voltage (usually 120 or 240 VAC) from an uninterruptible power Supply (UPS) and change it as required (usually 5 to 32 VDC).

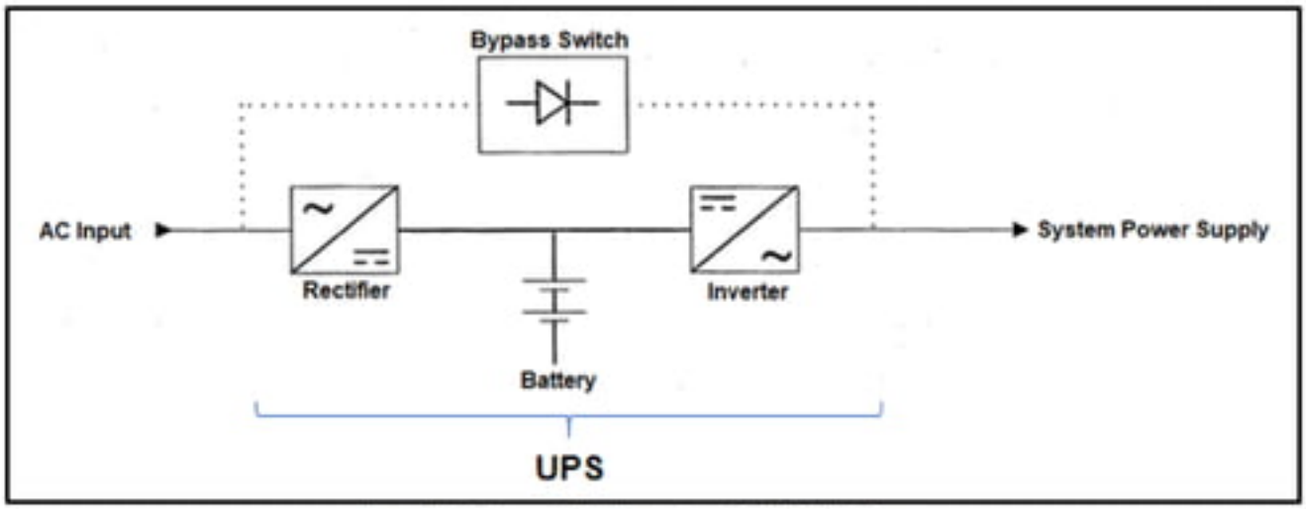


Figure 8: Uninterruptible Power Supply (UPS) Bloc Diagram

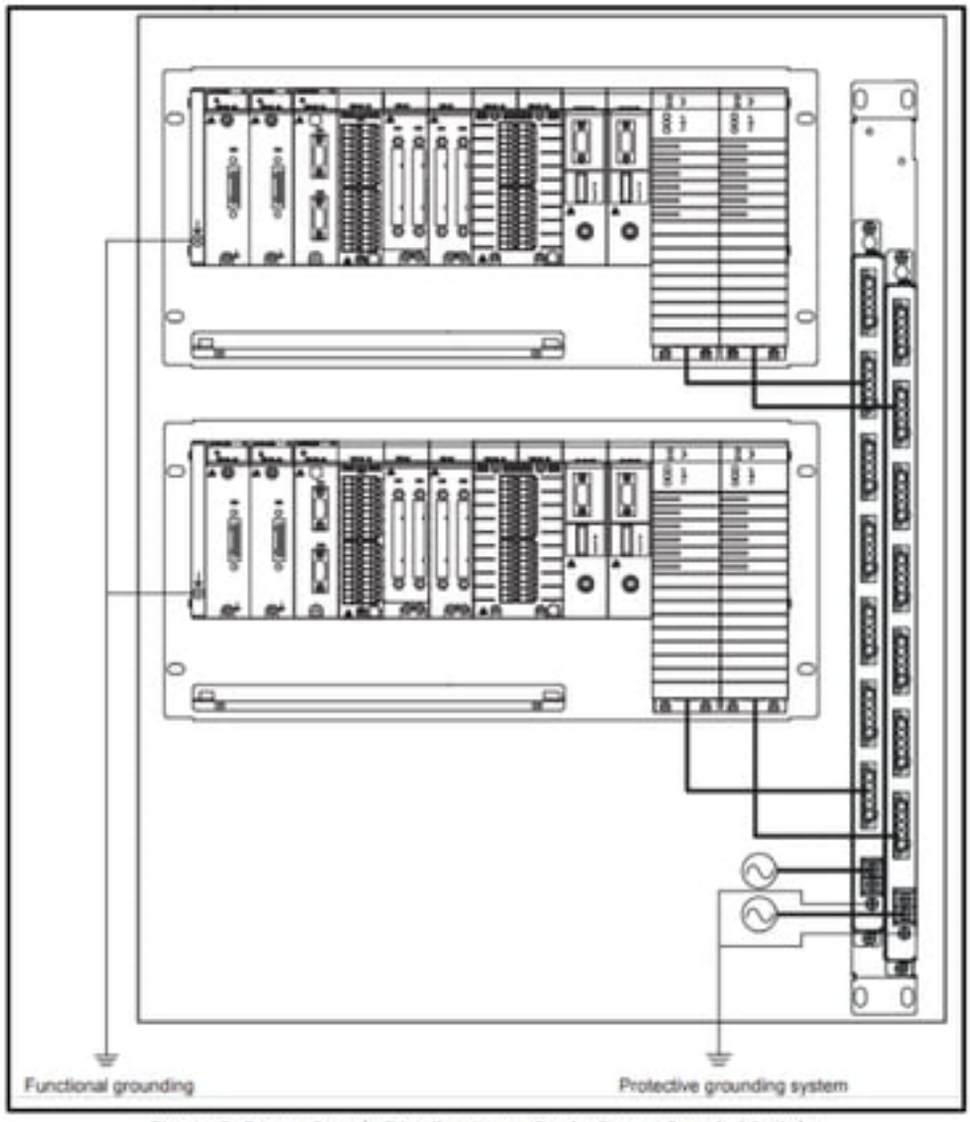


Figure 9: Power Supply Distribution to Racks Power Supply Modules

4.1.2.Central Processing Unit (CPU)

The Central Processing Unit, or CPU, is the most important element of a PLC. The CPU forms what can be considered to be the "brain" of the system. The two components of the CPU are:

- ✓ The processor
- ✓ The memory

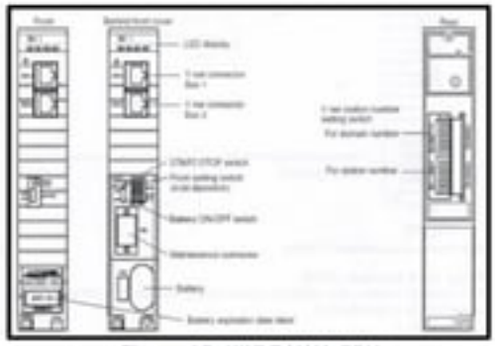


Figure 10: YKOGAWA CPU

4.1.2.1. Processor

Very small **microprocessor (Or Micro)**, integrated circuit with tremendous computing and control capability, provide the intelligence of today's programmable controllers. It performs mathematical operations, data handling, and diagnostic routines that were not possible with relays.

The principal function of the processor is to command and govern the activities of the entire system. It performs this function by interpreting and executing a collection of system programs known as the executive.

The executive, a group of supervisory programs, is permanently stored in the processor and is considered a part of the controller itself. By executing the executive, the processor can perform all of its control, processing, communication, and other housekeeping functions.

The CPU of a PC may contain more than one processor to execute the system's duties and/or communications, because extra processors increase the speed of these operations. This approach of using several microprocessors to divide control and communication tasks is known as **multiprocessing**.

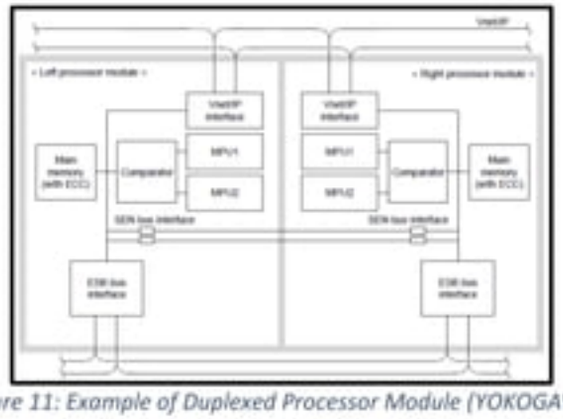


Figure 11: Example of Duplexed Processor Module (YOKOGAWA)

The microprocessors used in PCs are categorized according to their word size, or the number of bits that they use simultaneously to perform operations. Standard word lengths are 8, 16, and 32 bits. This word length affects the speed at which the processor performs most operations. For example, a 32 bits microprocessor can manipulate data faster than 16 bits micro, since it manipulates twice as much data in one operation.

The processor is responsible for detecting communication failures, as well as other failures, that may occur during system operation. It must alert the operator or system in case of a malfunction. To do this, the processor performs **diagnostics**, or error checks, during its operation and sends status information to indicators that are normally located on the front of the CPU or on the front of each module.

Typical diagnostics include memory OK, processor OK, battery OK, and power supply OK. Some controllers possess a set of fault relay contacts that can be used in an alarm circuit to signal a failure. The processor controls the fault relay and activates it when one or more specific fault conditions occur. The relay contacts that are usually provided with a controller operate in a watchdog timer fashion; that is, the processor sends a pulse at the end of each scan indicating a correct system operation. If a failure occurs, the processor does not send a pulse, the timer times out, and the fault relay activates. In some controllers, CPU diagnostics are available to the user during the execution of the control program. These diagnostics use internal outputs that are controlled by the processor but can be used by the user program (loss of scan, backup battery low, ...).

4.1.2.2. Memory

The **memory** is the area in the CPU where all of the sequences of instructions, or programs and all data are stored.

Two different programmable controllers rarely have identical memory maps, but all programmable controllers have similar storage requirements. In general, all PCs must have memory allocated for four basic memory areas, which are as follows:

- ✓ **Executive Area:** The executive is a permanently stored collection of programs that are considered part of the system itself.
- ✓ **Scratch Pad Area:** This is a temporary storage area used by the CPU to store a relatively small amount of data for interim calculations and control. The CPU stores data that is needed quickly in this memory area to avoid the longer access time involved with retrieving data from the main memory.
- ✓ **Data Table Area:** This area stores all data associated with the control program, such as timer and counter preset values and other stored constants and variables used by the control program or CPU. The data table also retains the status information of both the system inputs (once they have been read) and the system outputs (once they have been set by the control program).
- ✓ **User Program Area:** This area provides storage for programmed instructions entered by the user.

The executive and scratch pad areas are hidden from the user and can be considered a single area of memory that, for our purpose, is called **system memory**.

On the other hand, the data table and user program areas are accessible and are required by the user for control applications. They are called **application memory**.

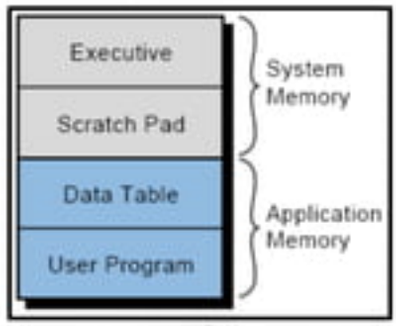


Figure 12:A Simplified Memory Map

4.1.2.3. Processor Scan Cycle

The scan cycle is the process of a programmable controller reading its inputs, executing the configured logic, update its outputs and run some system diagnostics and other communications as applicable at its manufacturer design.

Figure 13: Programmable Controller Total Scan Cycle Representation

The amount of time it takes for the PC to make a scan cycle is called **scan time** of the controller. A typical Scan time for an DCS controller will vary from a few hundreds of a millisecond to 1 seconds.

4.1.3.Input / Output Modules

Every programmable controller must have some means of receiving and interpreting signals from field instruments such as switches, and transmitters, and also be able to effect control over field control elements such as solenoids, control valves, and motors. This is generally known as Input/Output, or I/O, modules that are built into a modular ("rack") divided on slot as shown below in the figure 14.

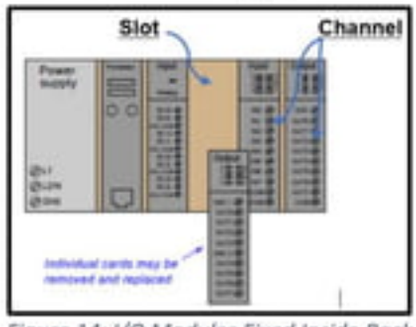


Figure 14: I/O Modules Fixed Inside Rack

An **I/O module** is a plug-in–type assembly and replaceable for the fact that individual cards may be easily replaced in the event of failure without having to replace the entire controller. Specific I/O modules may be chosen for custom applications, biasing toward discrete cards for applications using many on/off inputs and outputs, or biasing toward analog cards for applications using many 4-20 mA and similar signals.
As the programmable controllers have the ability to connect to processor-less racks (Extension racks) filled with additional I/O modules, thus providing a way to increase the number of I/O channels beyond the capacity of the base (Master) unit.

Figure 15: Link Between Master Rack and Extension Racks

Input/output modules for programmable controllers comes in three basic varieties:

- ✓ Discrete (Digital)
- ✓ Analog
- ✓ Communication

4.1.3.1. Discrete I/O

A "discrete" data point is one with only two states on and off. Process switches, pushbutton switches, limit switches, and proximity switches are all examples of discrete sensing devices. In order for a programmable controller to be aware of a discrete sensor's state, it must receive a signal from the sensor through a discrete input channel. Inside each discrete input module is (typically) a set of light-emitting diodes (LEDs) which will be energized when the corresponding sensing device turns on. Light from each LED shines on a photo-sensitive device such as a phototransistor inside the module, which in turn activates a bit (a single element of digital data) inside the PC's memory. This opto-coupled arrangement makes each input channel of a PC rather rugged, capable of isolating the sensitive computer circuitry of the PC from transient voltage "spikes" and other electrical phenomena capable of causing damage:

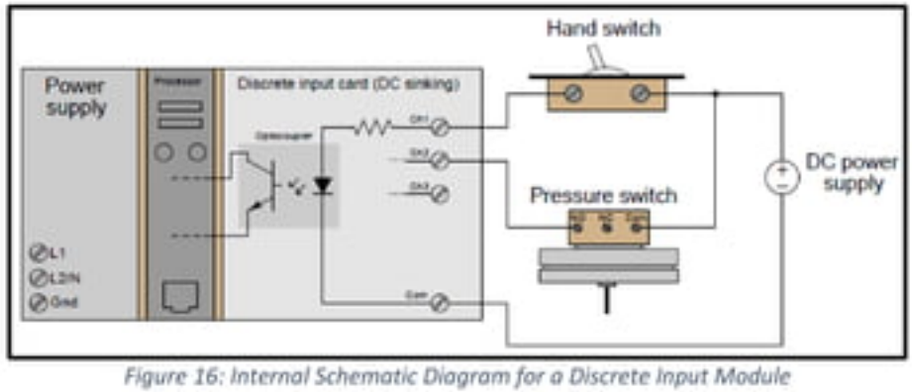


Figure 16: Internal Schematic Diagram for a Discrete Input Module

Energizing an input channel lights the LED inside the optocoupler, turning on the phototransistor, sending a "high" signal to the PC's microprocessor, setting (1) that bit in the input register.
The internal schematic diagram for a discrete input module ("card") shown in figure 16 reveals the componentry typical for a single input channel on that card. Each input channel has its own optocoupler, writing to its own unique memory register bit inside the PC's memory. Discrete input cards for PCs typically have 16, 32, Or 64 channels.

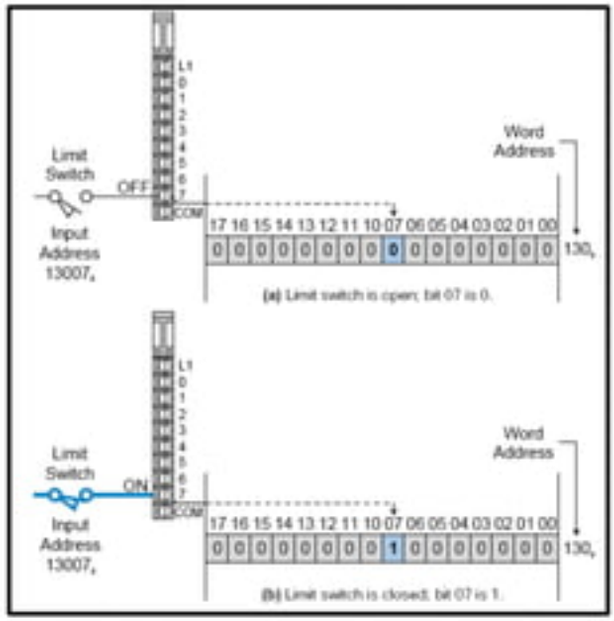


Figure 17: Converting a Discrete Signal to Binary Format

Indicator lamps, solenoid valves, and motor starters (assemblies consisting of contactors and overload protection devices) are all examples of discrete control devices. In a manner similar to discrete inputs, a PC connects to any number of different discrete final control devices through a discrete output channel. Discrete output modules typically use the same form of opto-isolation to allow the PC's circuitry to send electrical power to loads: the internal PC circuitry driving an LED which then activates a photosensitive switching device. Alternatively, small electromechanical relays may be used in lieu of opto-isolating semiconductor switching elements such as transistors (DC) or TRIACs (AC):

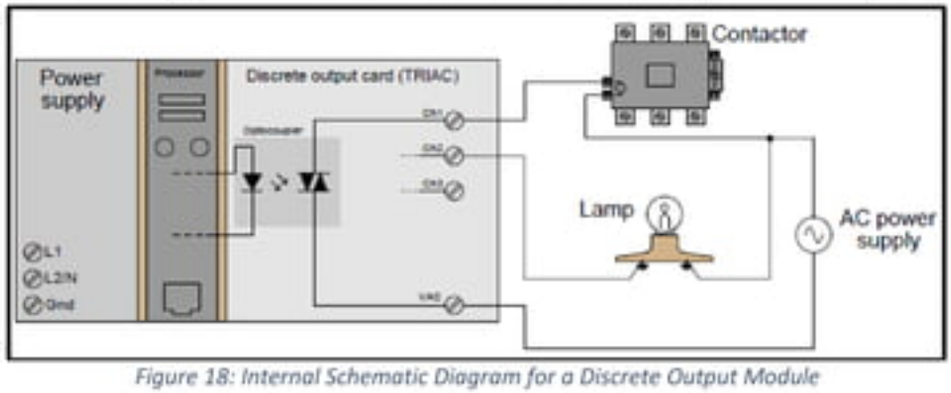


Figure 18: Internal Schematic Diagram for a Discrete Output Module

Setting a bit (1) in the PC's output register sends a "high" signal to the LED inside the optocoupler, turning on the photo-TRIAC, sending AC power to the output channel to energize the load.

As with the schematic diagram for a discrete input module shown previously, the schematic diagram for a discrete output module reveals the componentry typical for a single channel on that card. Each output channel has its own optocoupler, driven by its own unique memory register bit inside the PC's memory. Discrete output cards for PCs also typically have 4, 16, 32 or 64 channels.

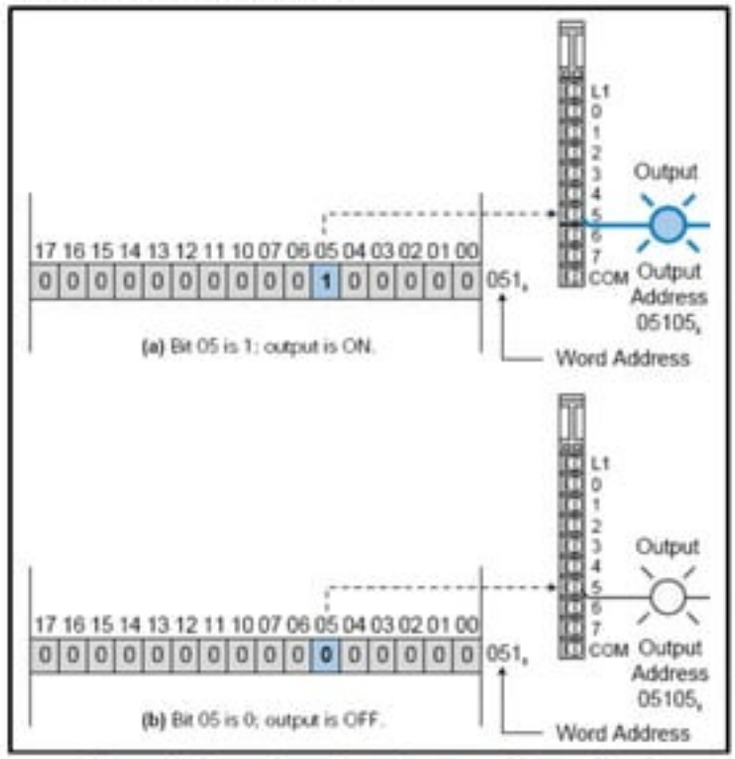


Figure 19: Converting a Binary Format to Discrete Signal

Models	Name
Digital I/O Modules	
ADV151	Digital Input Module (32-Channel, 24 V DC, Isolated)
ADV141	Digital Input Module (16-Channel, 100 V to 120 V AC, Isolated)
ADV142	Digital Input Module (16-Channel, 200 V to 240 V AC, Isolated)
ADV551	Digital Output Module (32-Channel, 24 V DC, Isolated)
ADV157	Digital Input Module (32-Channel, 24 V DC, Pressure Clamp Terminal Support Only, Isolated)
ADV161	Digital Input Module (64-Channel, 24 V DC, Isolated)
ADV557	Digital Output Module (32-Channel, 24 V DC, Pressure Clamp Terminal Support Only, Isolated)
ADV561	Digital Output Module (64-Channel, 24 V DC, Isolated)
ADR541	Relay Output Module (16-Channel, 24 to 110 V DC/100 to 240 V AC, Isolated)
ADV859	Digital I/O Module for Compatible ST2 (16-Channel Input/16-Channel Output, Isolated Channels)
ADV159	Digital Input Module for Compatible ST3 (32-Channel Input, Isolated Channels)
ADV559	Digital Output Module for Compatible ST4 (32-Channel Output, Isolated Channels)
ADV869	Digital I/O Module for Compatible ST5 (32-Channel Input/32-Channel Output, Isolated, Common Minus Side Every 16-Channel)
ADV169	Digital Input Module for Compatible ST6 (64-Channel Input, Isolated, Common Minus Side Every 16-Channel)
ADV569	Digital Output Module for Compatible ST7 (64-Channel Output, Isolated, Common Minus Side Every 16-Channel)
ADV851	Digital I/O Module (16-Channel input, 16-Channel output, 24 V DC)

Figure 20: YOKOGAWA Discrete I/O Modules

4.1.3.2. Analog I/O

In order to interface with an analog sensor or control device, some "translation" is necessary between the analog and digital worlds. Inside every analog input module is an ADC, or Analog-to-Digital Converter, circuit designed to convert an analog electrical signal into a multi-bit binary word. Conversely, every analog output module contains a DAC, or Digital-to-Analog Converter, circuit to convert the PC's digital command words into analog electrical quantities.

Analog I/O is commonly available for many different analog signal types, including:

- ✓ Voltage (0 to 10 volt, 0 to 5 volt)
- ✓ Current (4 to 20 mA)
- ✓ Thermocouple (millivoltage)
- ✓ RTD (Ohm)
- ✓ Strain gauge (Ohm)

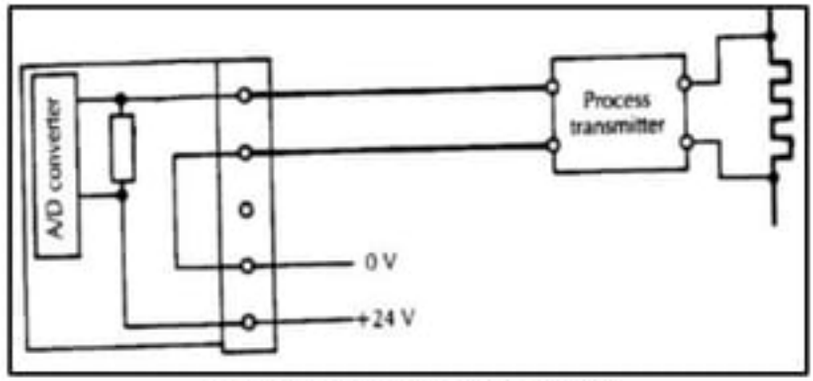


Figure 21: Current Loop Input Connection

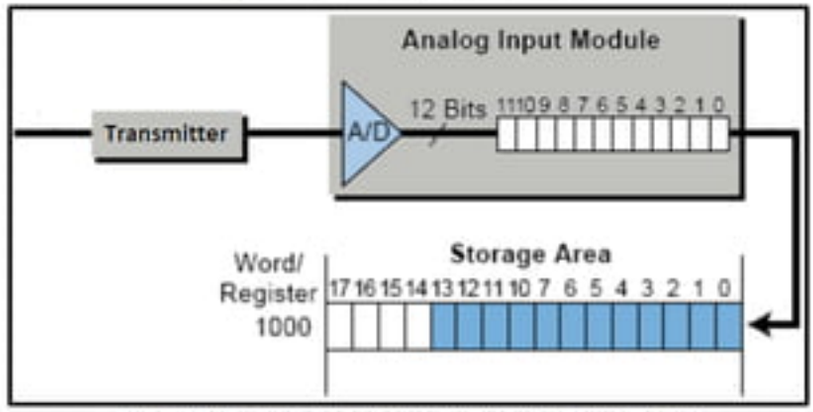


Figure 22: Converting an Analogue Signal to Binary Format

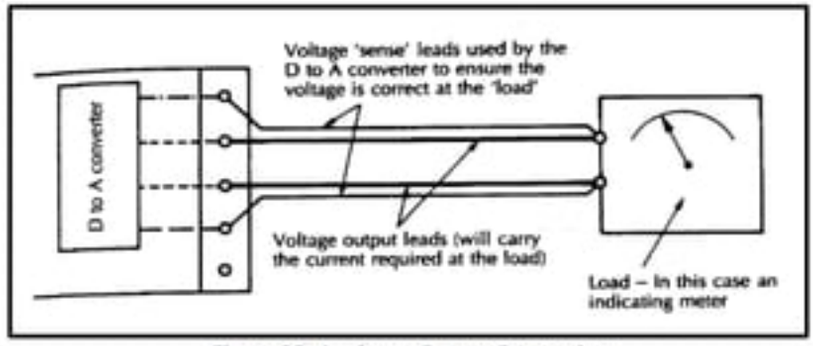


Figure 23: Analogue Output Connection

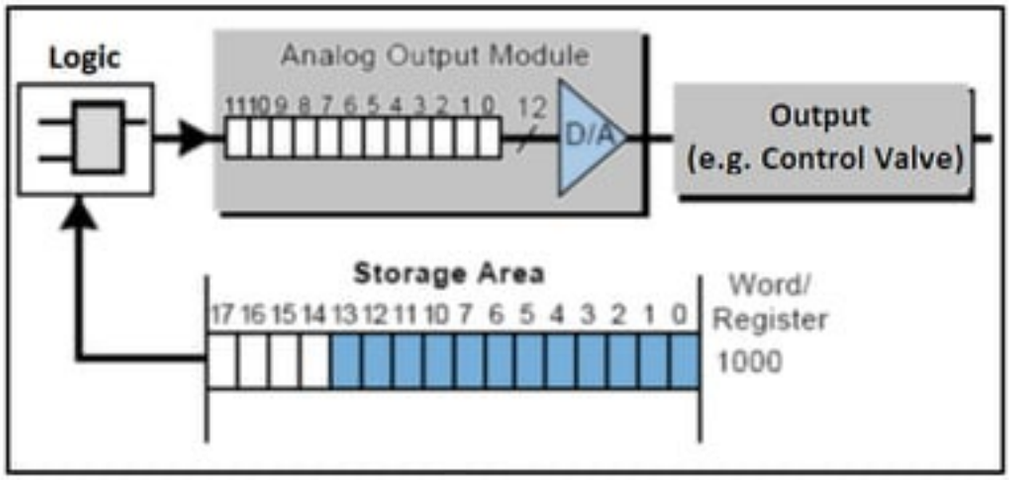


Figure 24: Converting a Binary Value into an Analogue Signal

Models	Name
Analog I/O Modules	
AAI141	Analog Input Module (4 to 20 mA, 16-Channel, Non-Isolated)
AAV141	Analog Input Module (1 to 5 V, 16-Channel, Non-Isolated)
AAV142	Analog Input Module (-10 V to +10 V, 16-Channel, Non-Isolated)
AAI841	Analog I/O Module (4 to 20 mA Input, 4 to 20 mA Output, 8-Channel Input/8-Channel Output, Non-Isolated)
AAB841	Analog I/O Module (1 to 5 V Input, 4 to 20 mA Output, 8-Channel Input/8-Channel Output, Non-Isolated)
AAV542	Analog Output Module (-10 V to +10 V, 16-Channel, Non-Isolated)
AAI143	Analog Input Module (4 to 20 mA, 16-Channel, Isolated)
AAV144	Analog Input Module (-10 V to +10 V, 16-Channel, Isolated)
AAV544	Analog Output Module (-10 V to +10 V, 16-Channel, Isolated)
AAI543	Analog Output Module (4 to 20 mA, 16-Channel, Isolated)
AAT141	TC/mV Input Module (16-Channel, Isolated)
AAR181	RTD Input Module (12-Channel, Isolated)
AAI135	Analog Input Module (4 to 20 mA, 8-Channel, Isolated Channels)
AAI835	Analog I/O Module (4 to 20 mA, 4-Channel Input/4-Channel Output, Isolated Channels)
AAT145	TC/mV Input Module (16-Channel, Isolated Channels)
AAR145	RTD/POT Input Module (16-Channel, Isolated Channels)
AAP135	Pulse Input Module (8-Channel, Pulse Count, 0 to 10 kHz, Isolated Channels)
AAP149	Pulse Input Module for Compatible PM1 (16-Channel, Pulse Count, 0 to 6 kHz, Non-Isolated)
AAP849	Pulse Input Module/Analog Output Module (8-Channel Input/8-Channel Output, Non-Isolated)
Analog I/O Modules with HART Communication Function	
AAI141-H	Analog Input Module (4 to 20 mA, 16-Channel, Non-Isolated)
AAI841-H	Analog I/O Module (4 to 20 mA Input, 4 to 20 mA Output, 8-Channel Input/8-Channel Output, Non-Isolated)
AAI143-H	Analog Input Module (4 to 20 mA, 16-Channel, Isolated)
AAI543-H	Analog Output Module (4 to 20 mA, 16-Channel, Isolated)
AAI135-H	Analog Input Module (4 to 20 mA, 8-Channel, Isolated Channels)
AAI835-H	Analog I/O Module (4 to 20 mA, 4-Channel Input/4-Channel Output, Isolated Channels)

Figure 25: YOKOGAWA Analogue I/O Modules

4.1.3.3. Communications Modules (MODBUS)

Many different digital communication standards exist for PCs to communicate with, from PC to PC and between PCs and field devices. One of the earliest digital protocols developed for PC communication was Modbus, originally for the Modicon brand of PC. Modbus was adopted by other PC and industrial device manufacturers as a de facto standard, and remains perhaps the most universal digital protocol available for industrial digital devices today.
Another digital communication standard developed by a particular manufacturer and later adopted as a de facto standard is Profibus, originally developed by Siemens.

In this manual we will talk only about MODBUS communication as it is the mostly used.

Modbus was started as a method to allow a master device to control multiple slave devices. Each device with a device number is connected to the master device.

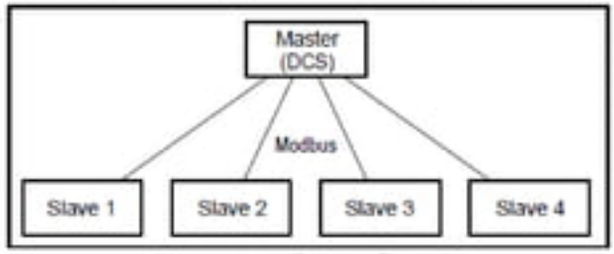


Figure 26: Modbus Configuration

The master can send a query (i.e. poll) or command to a slave on a regular basis or when required. In either case, the master starts signal transmission and the slave responds.

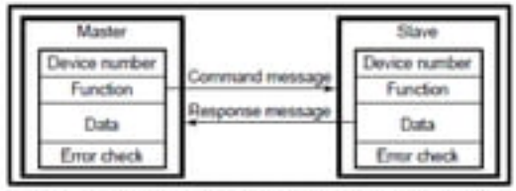


Figure 27: Master-Slave Command and Response Cycle

A message transmitted between devices contains the device number, function, data, and error check code. The function is encoded and depends on the message characteristics and data type.
The error check code checks the validity of the entire message.

4.1.3.3.1. Communication Transmission Modes

There are three modes for signal transmission between the master and slave; RTU (Remote Terminal Unit) mode, ASCII mode and Modbus/TCP.

Kind	Mode	Support Type
Serial communication	ASCII	Slave
	RTU	Slave
Ethernet	Modbus/TCP	Server

Figure 28: MODBUS Communication Transmission Modes

Item	ASCII mode	RTU mode
Number of data bits	7 bits (ASCII)	8 bits (binary)
Message starting character	Colon ":"	None
Message ending character	Carriage return/line feed "<cr><lf>"	None
Message length	2N+1	N
Time interval of data	1 second or shorter	24 bit-time or shorter
Error detection	LRC (logical redundancy check)	CRC-16 (cyclic redundancy check)

Figure 29: MODBUS ASCII & RTU Modes Properties

Item	TCP Mode
Protocol	Modbus/TCP
No. of Session	4 (Max.)
Port No.	502

Figure 30: MODBUS TCP Mode Properties

4.1.3.3.2. Message Configuration

A message consists of four fields: device number, function, data and error check. It is always sent in this sequence.

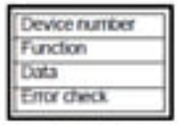


Figure 31: MODBUS Communication Message Elements

✓ ***In ASCII mode***, a colon ":" is the starting character and carriage return/line feed "<cr><lf>" is the ending message string. The portion between the starting character and ending string is the message body. The communication message is entirely ASCII codes, i.e. the message excluding the starting character and ending string consists of "0" to "9" and "A" to "F" representing hexadecimal numbers.

✓ ***In RTU mode***, the message consists of binary codes and can be transmitted faster than in ASCII mode. Signal intervals of more than 24 bit-time in the transmission line, identify the start of a new message.

✓ ***In TCP mode***, the foregoing message is displayed at a unique header (6 bite) of Modbus/TCP (Device No. is ignored).

Device number: User pre-assigned for each slave and ranges from 1 to the limit of the controller. The master performs signal transmission to each slave simultaneously. Each slave checks the device number in the message to determine whether the received message is directed to the slave itself and if so, returns a response message.

Functions: The master specifies the function to be executed by the slave. Most of controllers supports the following functions in the Modbus protocol.

Function No.	Function	Description
01	Coil status read	Reads the ON/OFF status of a series of coils
02	Input relay status read	Reads the ON/OFF status of a series of input relays
03	Holding register content read	Reads the current value of a series of holding registers
04	Input register content read	Reads the current value of a series of input registers
05	Single coil status change	Forcibly changes the status of a coil
06	Single holding register write	Writes a value to a holding register
08	Loop back test	Sends back the same message as the command message

Figure 32: MODBUS Communication Functions

Data: There are two types of data "**coil/relay**" in bits and "**register**" in 16 bits. The coil uses two values (ON/OFF or 0/1), while the register ranges from 0 to 65535. In the coil/relay, there is coil data that is both readable and writable from the master, and input relay contact data that is read-only. There are read/write data holding registers, read-only input registers, and write-only holding registers for real numeric data.

Data			Address	Max. read	Application
Bit	Coil	Read/write	0XXXX	800	Command
	Input relay	Read only	1XXXX	2000	Status
Regsiter	Holding regster	Read/write	4XXXX	100	Set value
	Input regster	Read only	3XXXX	125	Measured value
xxxx: 0001 to 9999					

Figure 33: MODBUS Communication Data

Error check: All messages are followed by an error check code to detect a Signal transmission error (i.e. bit changes). In ASCII mode, an error check code according to LRC (logical redundancy check) is used. In RTU mode, an error check code according to CRC-16 (cyclic redundancy check) is used.

4.1.3.3.3. Slave Response

Normal response: For the single coil status change, single holding register write, and loop back function, the same message as the command message is sent back. As a response message, the read function returns the retrieved data appended to the device number and function code. If an address to which data is not allocated is read, an error is not generated but zero (0) is responded as the read data.

Error response: If the command message is faulty, the slave does not execute the command but sends back an error response.
The master can check whether the command is accepted successfully by checking the function in the response message. If an error is identified, the details can be checked from the error code.
In addition, access to the data consisting of several registers will return an error unless the correct start address of data has been given. Therefore, the correct data boundary must be specified.

Device number
Error function (command function + 128)
Error code
Error check

Figure 34: Slave Error Response in MODBUS Communication

Error code	Description
01	Function code error (non-existent function)
02	Address error of coil, input relay, or register (out of range)
03	Number error of coils, input relays, or registers (out of range)
04	An unrecoverable error occurred on the slave while the command message was being executed.
11	Set data error (out of range)

Figure 35: Error Codes in MODBUS Communication

No response: In the following cases, the slave ignores the command message and does not send back a response (no response).

- ✓ When a transmission error (overrun, framing error, parity error or CRC error) is detected in the command message
- ✓ When the device number in the command message does not match the slave number assigned to the slave.

Note: The master should set a timer to watch the response from the slave, and re-send the same command or the message to the slave when the slave does not respond within the time set by the timer.

4.1.3.3.4. Serial Communication Specifications

Transmission mode : ASCII mode/RTU mode

Communication standard : RS-232, RS-422, RS-485

Transmission : - Half duplex for RS-232 & RS-422 (2-wires system)
- Full duplex (RS-422, RS-485, 4-wires system)

Start-stop synchronization : - (ASCII) 1 start bit, 7 data bits, 1 parity bit, 1 stop bit
- (RTU) 1 start bit, 8 data bits, 1 parity bit, 1 stop bit

Communication speed : 1200/2400/4800/9600/19200/38400 bps (Selectable)

Parity check : Odd /even /none (Selectable)

Maximum length : As per manufacturer design (1Km for YOKOGAWA)

Note:

- ✓ Any mismatch between the master and slave will result in no communication.
- ✓ Once the connection of Modbus/TCP is established, be sure to keep it connected. Frequent connection/disconnection may cause an error in communication operation.

4.1.3.3.5. Serial Communication Wiring

Terminal name	Name
TX+	Send data (positive phase signal)
TX-	Send data (negative phase signal)
RX+	Receive data (positive phase signal)
RX-	Receive data (negative phase signal)
SG	Signal ground

Figure 36: YOKOGAWA Communication Module Terminals Names

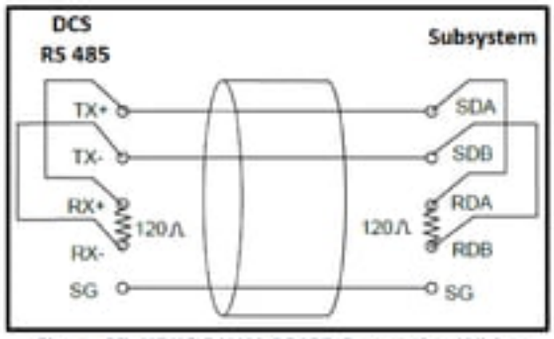


Figure 37: YOKOGAWA RS485 Connection Wiring

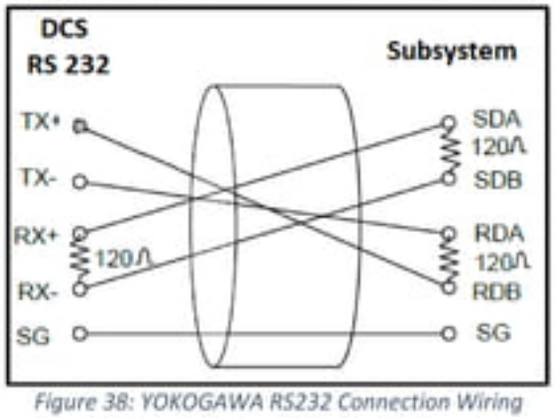


Figure 38: YOKOGAWA RS232 Connection Wiring

4.2. Engineering Working Station

Engineering work station is a computer loaded with engineering software, it is mainly used to perform system generation, configuration and maintenance management.

Some functions of the YOKOGAWA engineering software are illustrated below:

Project Creation: A project is the unit of managing system configuration database containing the configuration information for all stations in the system.

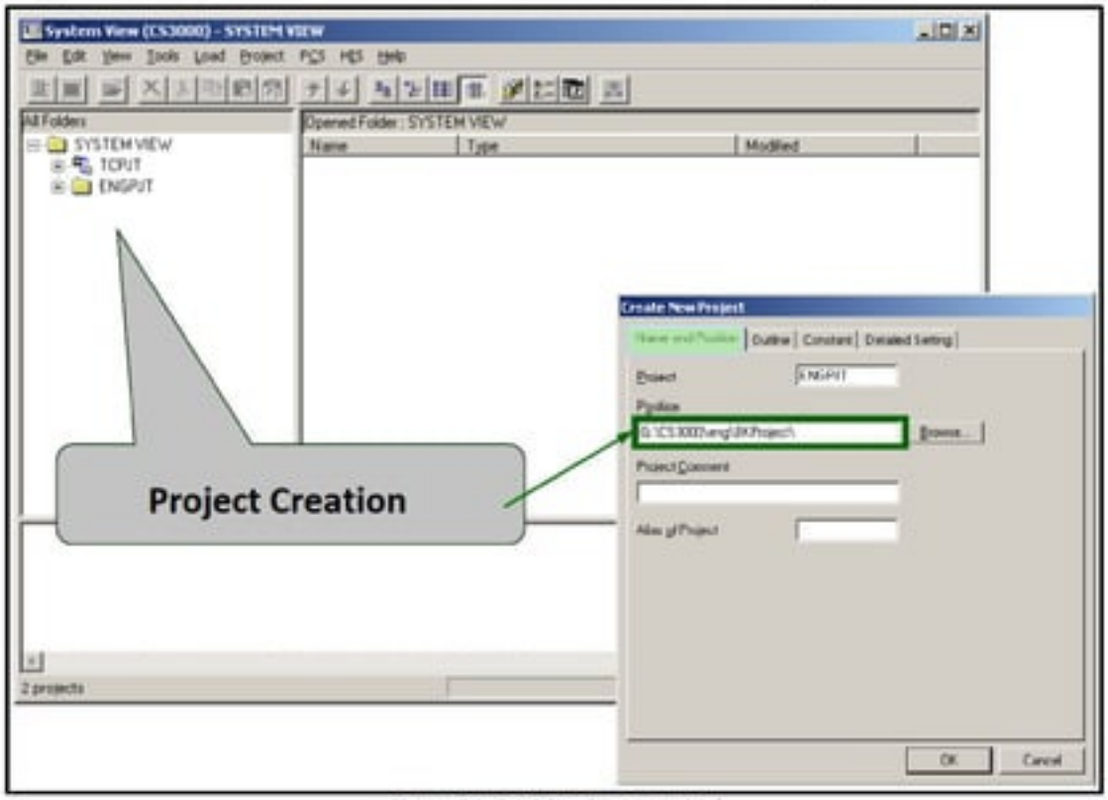


Figure 39: EWS (Project Creation)

Users Registration: Specify user names, Users groups and security privilege levels.

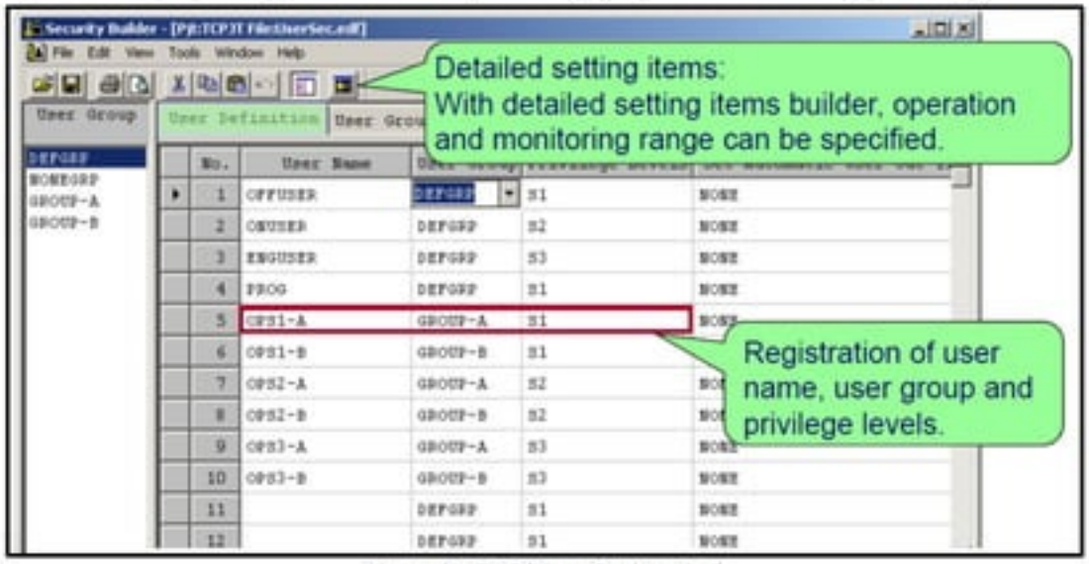


Figure 40: EWS (Users Registration)

Control Station Creation: Create the programmable controller by selecting the type and defining all required properties.

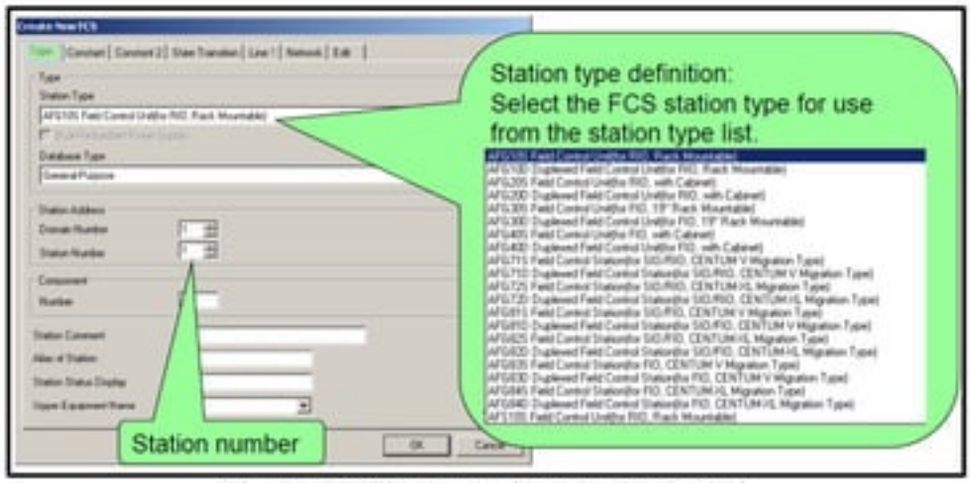


Figure 41: EWS (Programmable Controller Creation)

Operation & Monitoring Station Creation: Creation of new human interface station with all required properties (type, number, network and so on).

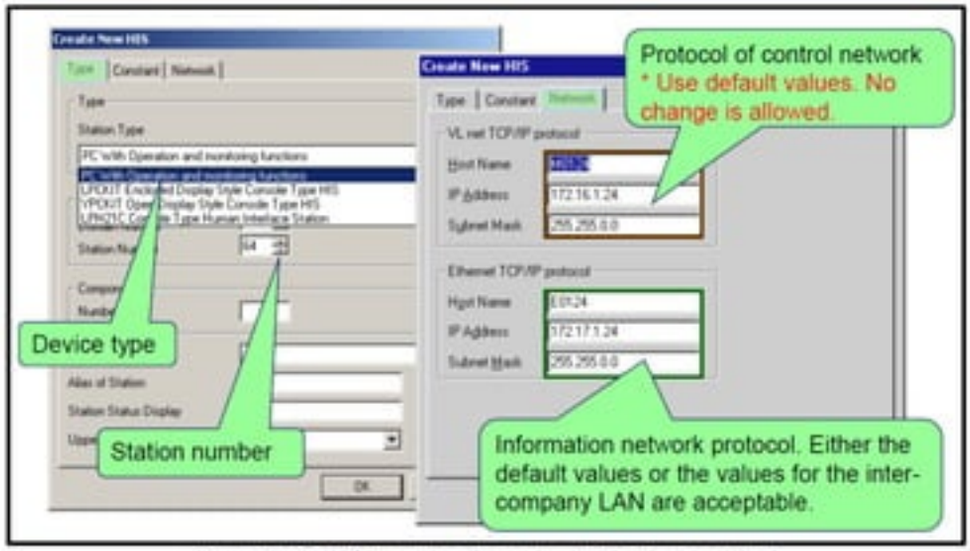


Figure 42: EWS (Operation & Monitoring Station Creation)

I/O Modules Creation: Create I/O Module folder in the control station folder may be used to create or add the required inputs and outputs.

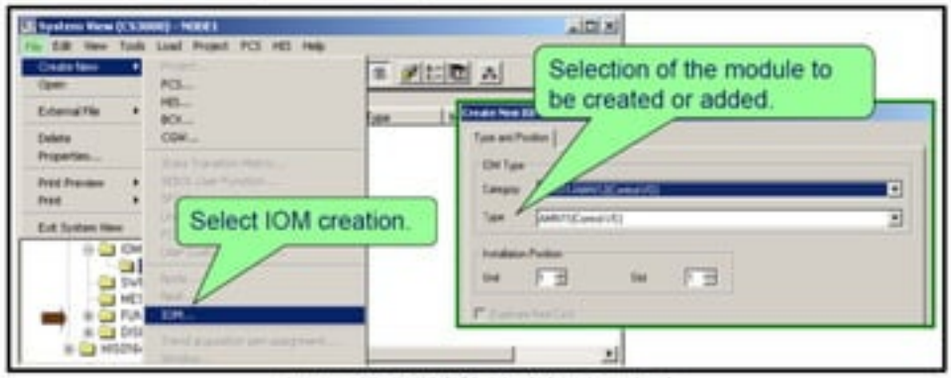


Figure 43: EWS (I/O Modules Creation)

Graphic Windows Creation: Create windows to be used for graphic pages design and animation.

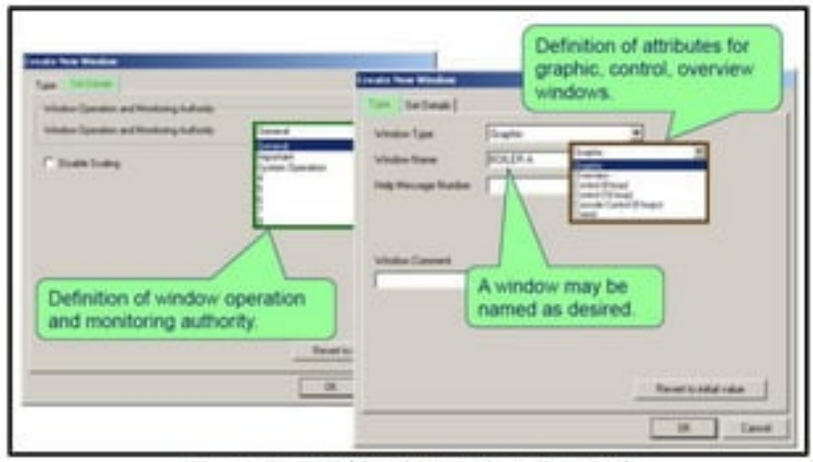


Figure 44: EWS (Graphic Windows Creation)

Program Configuration: Create program as per the logic diagram and the control narrative.

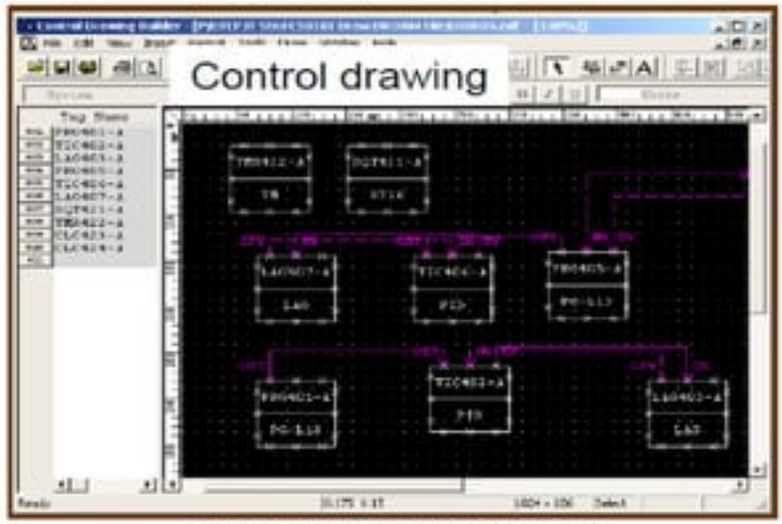


Figure 45: EWS (Program Configuration)

System Download: Download system data base to the control stations.

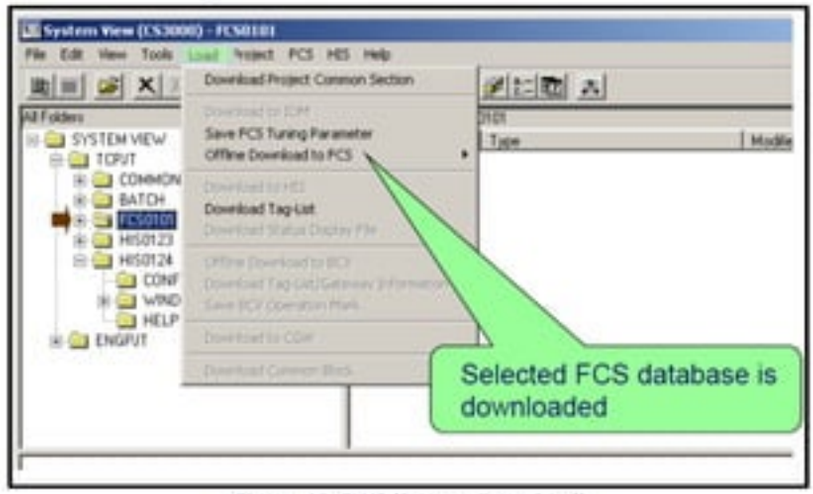


Figure 46: EWS (System Download)

4.3. Human Interface Station

The Human Interface Station (HIS) or Human Machine Interface (HMI) is mainly used for operation and monitoring, it displays process variables, control parameters, and alarms necessary for users to quickly grasp the operating status of the plant. It also incorporates open interfaces so that supervisory computers can access trend data, messages, and process data.

Some YOKOGAWA displays are illustrated below:

Overview Window: Graphic window used as menu to access all monitoring windows of overall plant.

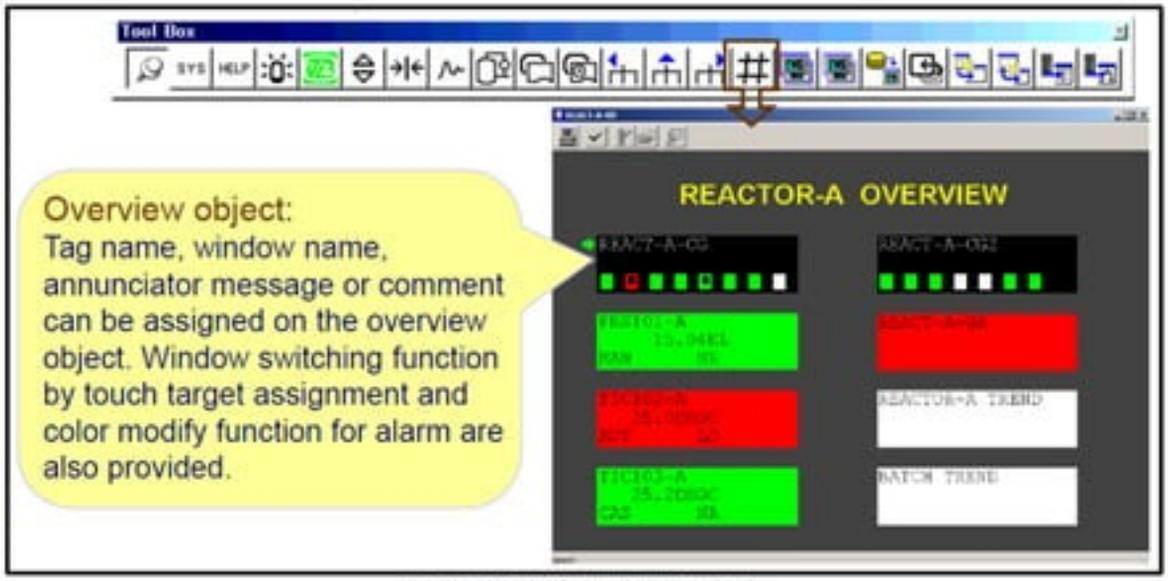


Figure 47: HIS (Overview Window)

Graphic Window: Created by the user and animated in order to recognize visually the state of the process control.

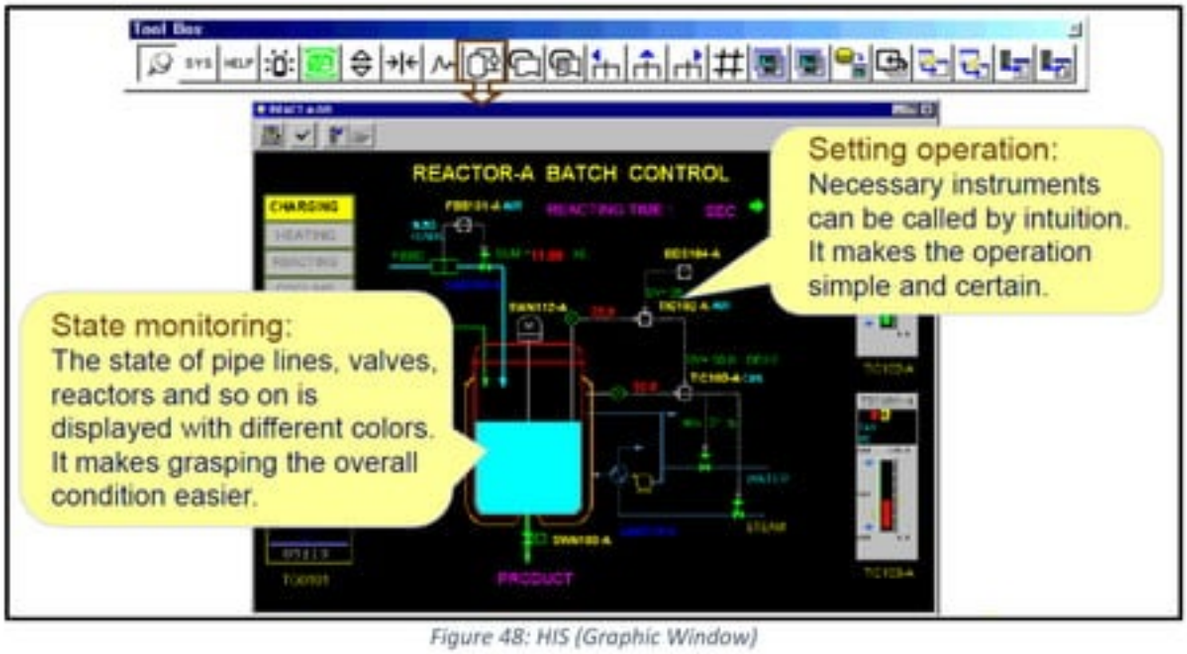


Figure 48: HIS (Graphic Window)

Faceplate Window: Instrument interface.

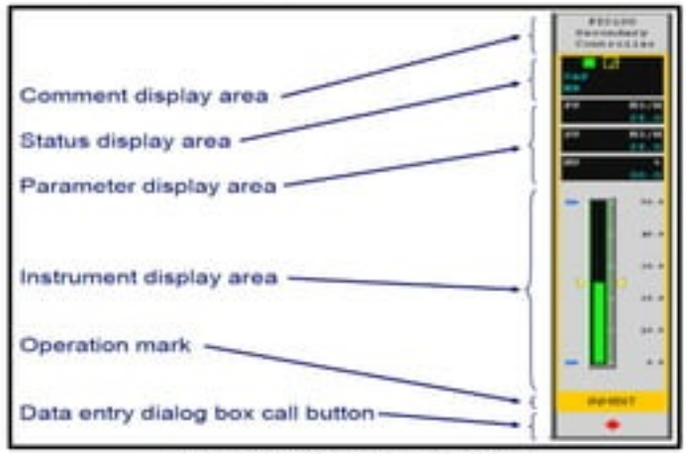


Figure 49: HIS (Faceplate Window)

Tuning Window: Displays the control status of the function block. It is also used for tuning the various control parameters.

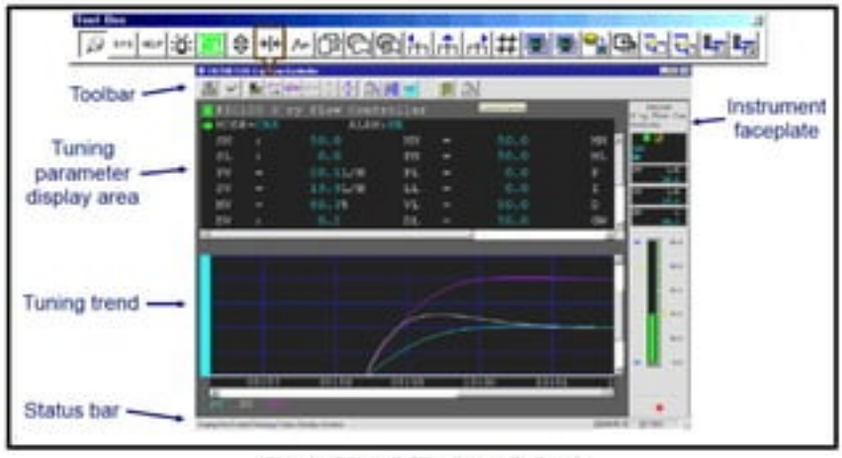


Figure 50: HIS (Tuning Window)

Trend Window: Acquires different types of process data and displays time-series change in a graph.

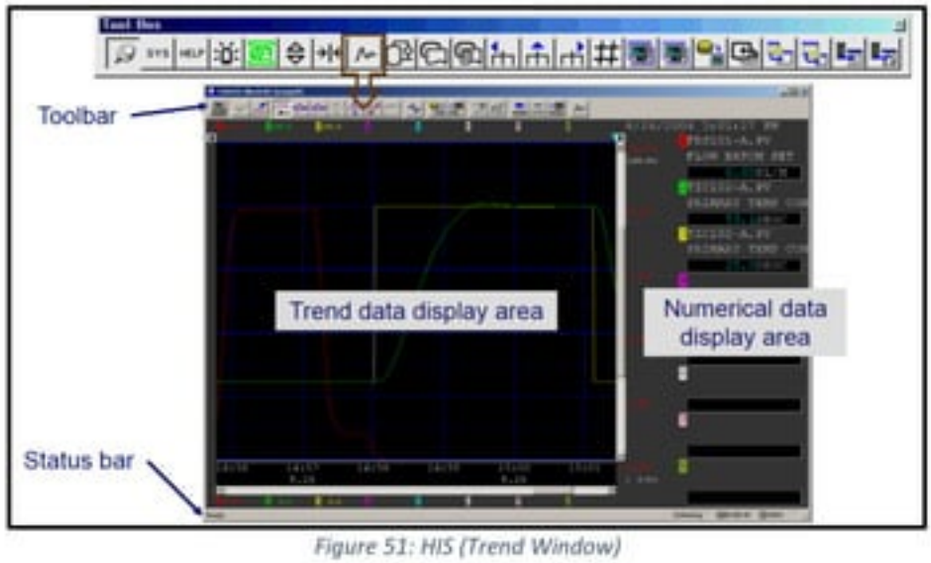


Figure 51: HIS (Trend Window)

Process Alarms Window: Displays process alarms in the order they are generated starting with the most recent alarm.

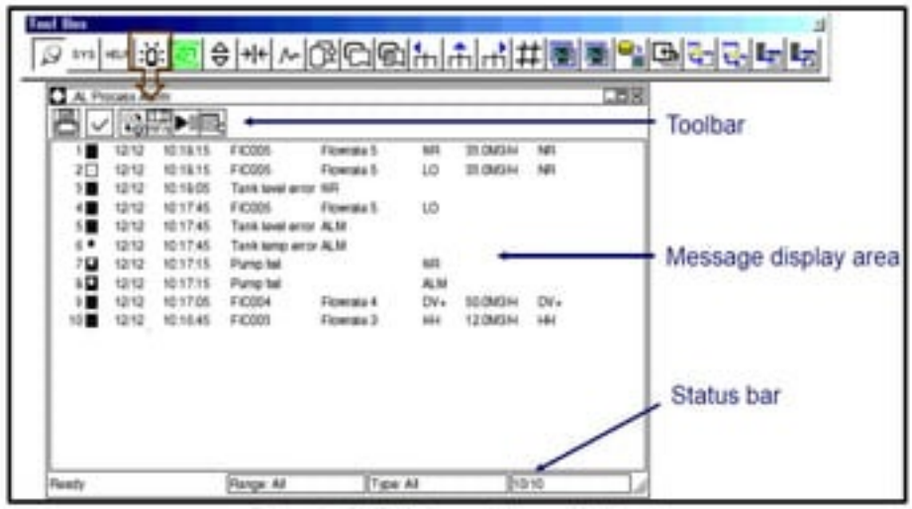


Figure 52: HIS (Process Alarms Window)

System Alarms Window: Displays system alarm messages to notify the user of system hardware (Stations down, card error etc…) in the order with the most recent ones first.

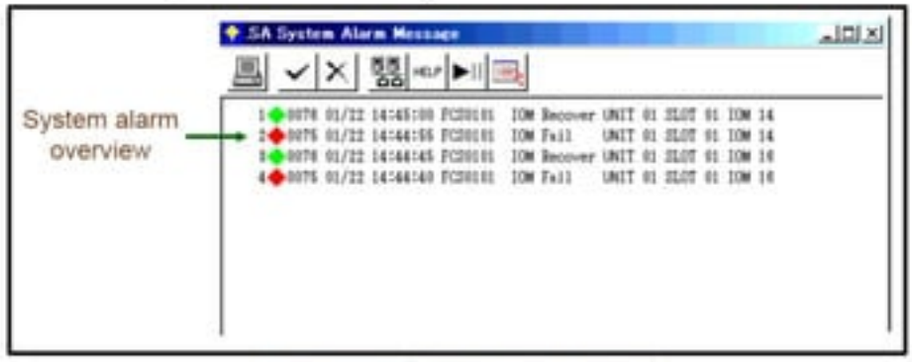


Figure 53: HIS (System Alarms Window)

System Status Window: Displays controllers, cards and network status.

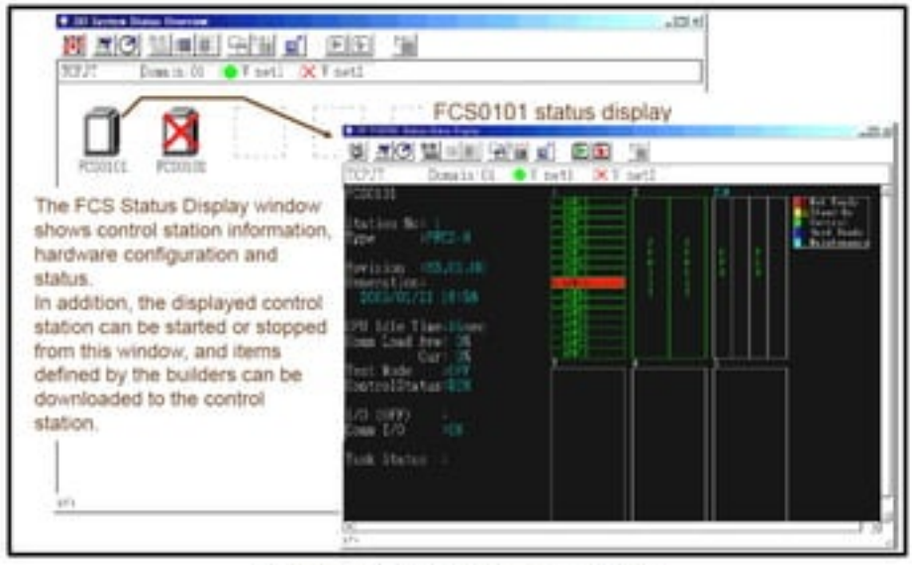


Figure 54: HIS (System Status Window)

4.4. Network

Real-time (High speed) control system bus links that all stations such as Control stations, EWSs, HISs with high security.

4.5. Redundancy

The Mean time between failures (*MTBF*) of any system dependent upon certain critical components may be extended by duplicating those components in parallel fashion, such that the failure of only one does not compromise the system as a whole. This is called **redundancy**.

A common example of component redundancy in instrumentation and control systems is the redundancy offered by DCS, where processors, network cables, and even I/O (input/output) modules may be equipped with "hot standby" duplicates ready to assume functionality in the event the primary component fails.

Redundancy tends to extend the MTBF of a system without necessarily extending its service life. A DCS equipped with redundant microprocessor control modules in its rack, will exhibit a greater MTBF because a random microprocessor fault will be covered by the presence of the spare ("**hot standby**") microprocessor module.

However, given the fact that both microprocessors are continually powered, and therefore tend to "wear" at the same rate, their operating lives will not be additive. In other words, two microprocessors will not function twice as long before wear-out than one microprocessor.

The extension of MTBF resulting from redundancy holds true only if the random failures are truly independent events, that is, not associated by a common cause.

5. Logic Programming

Although it seems each model of PC has its own standard for programming, there does exist an international standard for controller programming that most PC manufacturers at least attempt to conform to. This is the IEC 61131-3 standard.

One should take solace in the fact that despite differences in the details of PC programming from one manufacturer to another and from one model to another, the basic principles are largely the same.

The IEC 61131-3 standard specifies five distinct forms of programming language for industrial controllers:

- ✓ Ladder Diagram (LD)
- ✓ Structured Text (ST)
- ✓ Instruction List (IL)
- ✓ Function Block Diagram (FBD)
- ✓ Sequential Function Chart (SFC)

5.1. Ladder Diagram (LD)

The ladder diagram consists of two vertical lines representing the power rails. Circuits are connected as horizontal lines, i.e., the rungs of the ladder, between these two verticals.

In drawing a ladder diagram, certain conventions are adopted:

1. The vertical lines of the diagram represent the power rails between which circuits are connected.
2. Each rung on the ladder defines one operation in the control process.
3. A ladder diagram is read from left to right and from top to bottom.

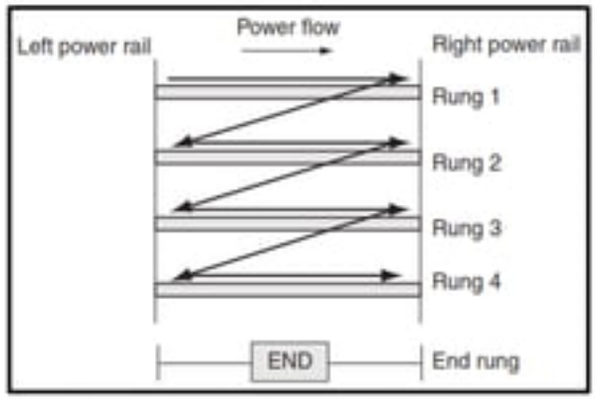


Figure 55: Ladder Diagram Execution Direction

4. Each rung must start with an input or inputs and must end with at least one output.
5. The inputs and outputs are all identified by their addresses, the notation used depending on the manufacturer. This is the address of the input or output in the memory.

5.1.1.LD Symbols:

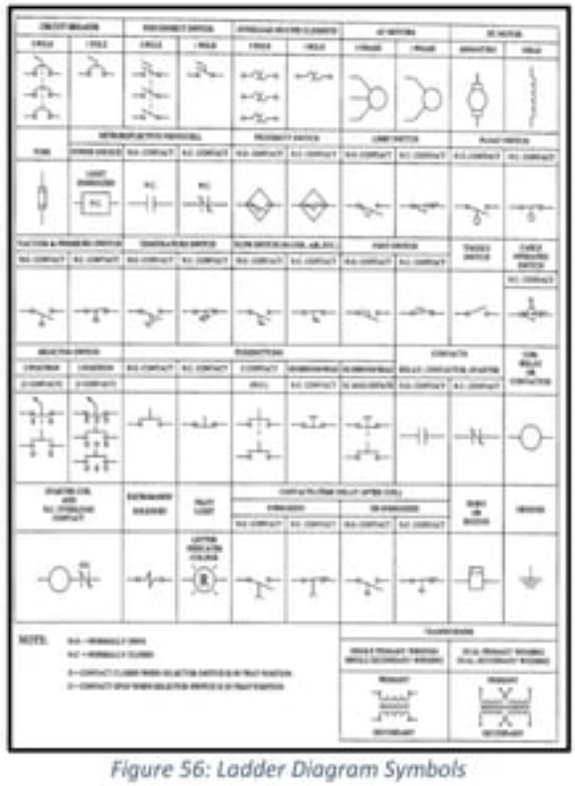


Figure 56: Ladder Diagram Symbols

5.1.2.Example (Level Control)

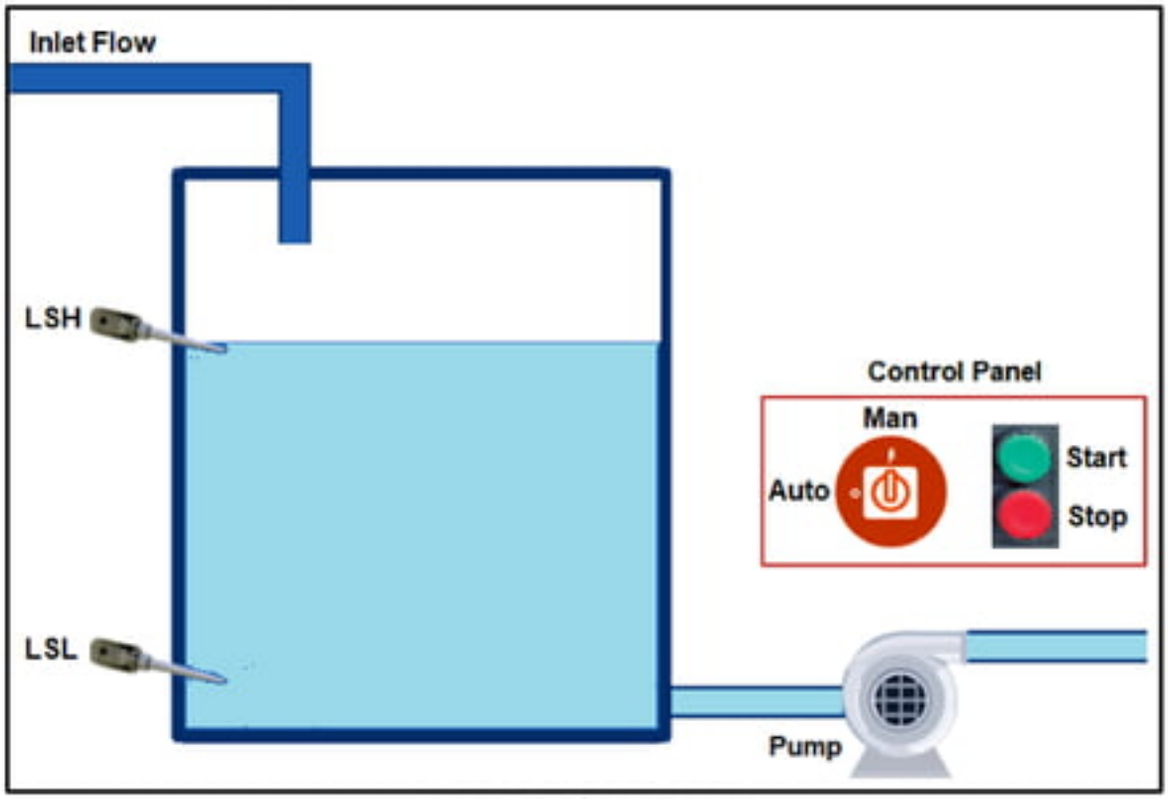


Figure 57: Level Control Design

If **Auto mode** selected, then pump will be logically controlled based on Low-Level switch (LSL) and High-Level switch (LSH):

- Pump stop when the level reaches low-level or stop push button pressed.
- If the level of the liquid reaches high point, the pump will be started so that the liquid can be drained and thus lowering the level.

If **Manual mode** selected then pump will be controlled by operator:

- Pump stop when the level reaches low-level or stop push button pressed.
- Pump will be started when start push button pressed.

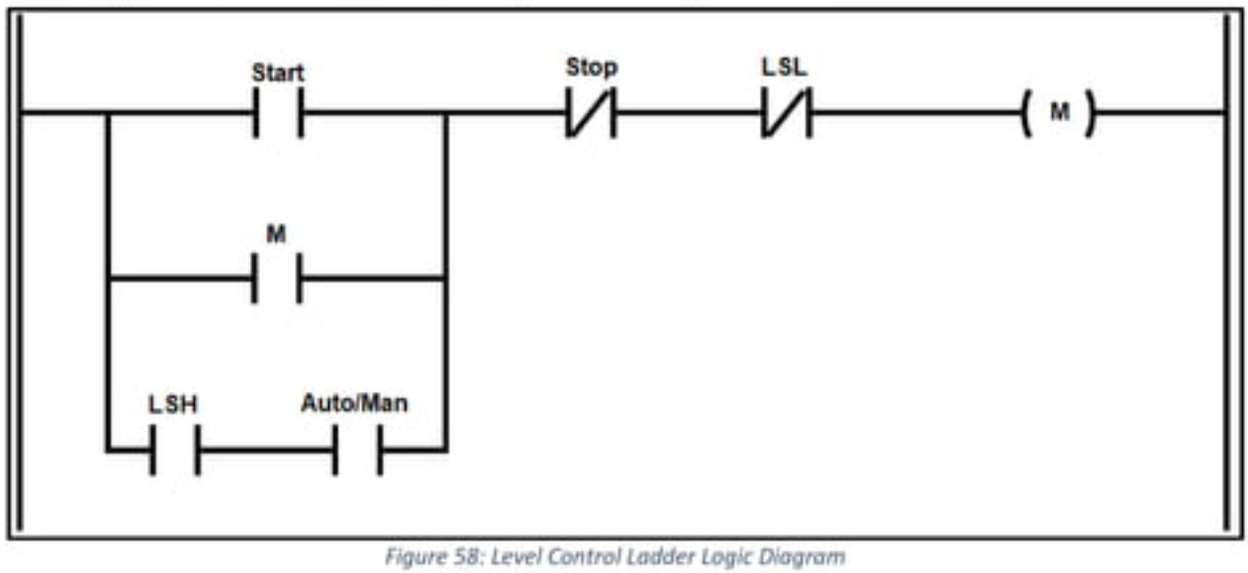


Figure 58: Level Control Ladder Logic Diagram

5.2. Structured Text (ST)

The structured text consists of a series of instructions which, as determined in high level languages, ("*IF..THEN..ELSE*") or in loops (*WHILE..DO*) can be executed.

Example:

```
IF value < 7 THEN
    WHILE value < 8 DO
        value := value + 1;
    END_WHILE;
END_IF;
```

5.2.1. ST Operators & Instructions

Operation	Symbol	Binding strength
Put in parentheses	(expression)	Strongest binding
Function call	Function name (parameter list)	
Exponentiation	EXPT	
Negate Building of complements	- NOT	
Multiply Divide Modulo	* / MOD	
Add Subtract	+ -	
Compare	<,>,<=,>=	
Equal to Not Equal to	= <>	
Boolean AND	AND	
Boolean XOR	XOR	
Boolean OR	OR	Weakest binding

Figure 59: ST programming Language Operators

You can build structured text programs using these statement types:

- ✓ Assignment - Assigning the value of a variable.
- ✓ Function Call - Call a function discarding the return value.
- ✓ RETURN - Return from a Program Unit early.
- ✓ IF - Execute statements if a condition is true (or false).
- ✓ CASE - Execute statements based on a selector value.
- ✓ FOR - Execute statements a defined number of times.
- ✓ WHILE - Execute statements while a condition is true.
- ✓ REPEAT - Execute statements until a condition is true.
- ✓ EXIT - Exit a loop early.

5.2.2. Example (Converting LD to ST)

Level Control Figure 57:

```
If (Start=1 OR M=1 OR (LSH=0 AND AM=1)) AND Stop=1 AND LSL =1 Then
M=1;
ELSE M=0;
END_IF;
```

5.3. Instruction List (IL)

An instruction list (IL) consists of a series of instructions. Each instruction begins in a new line and contains an operator and, depending on the type of operation, one or more operands separated by commas. In front of an instruction there can be an identification mark (label) followed by a colon (:).

A comment must be the last element in a line. Empty lines can be inserted between instructions.

Example:

```
LD      TRUE            (*load TRUE in the accumulator*)
ANDN    BOOL1           (*execute AND with the negated value of the BOOL1 variable*)
JMPC    label           (*if the result was TRUE, then jump to the label "label"*)
LDN     BOOL2           (*save the negated value of *)
ST      ERG             (*BOOL2 in ERG*)
label:
LD      BOOL2           (*save the value of *)
ST      ERG             (*BOOL2 in ERG*)
```

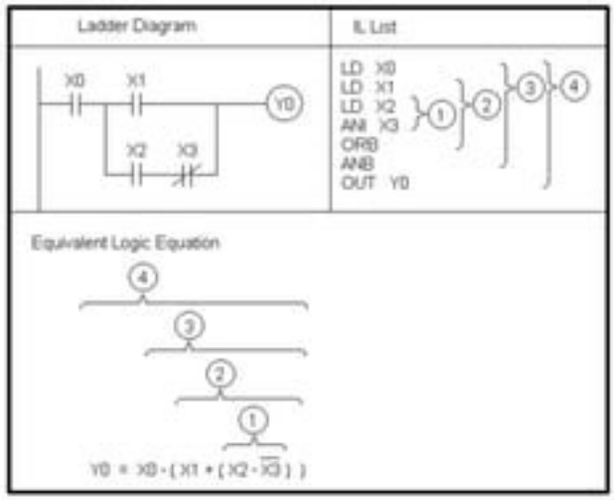
5.3.1. Modifiers and operators in IL

Operator	Modifiers	Meaning
LD	N	Make current result equal to the operand
ST	N	Save current result at the position of the Operand
S		Put the Boolean operand exactly at TRUE if the current result is TRUE
R		Put the Boolean operand exactly at FALSE if the current result is TRUE
AND	N, (	Bitwise AND
OR	N, (	Bitwise OR
XOR	(	Bitwise exklusive OR
ADD	(	Addition
SUB	(	Subtraction
MUL	(	Multiplication
DIV	(	Division
GT	(	>
GE	(	>=
EQ	(	=
NE	(	<>
LE	(	<=
LT	(	<
JMP	CN	Jump to label
CAL	CN	call function block
RET	CN	Return from call of a function block
)		Evaluate deferred operation

Figure 60: Operators in IL with Their Possible Modifiers

- ✓ C with JMP, CAL, RET: The instruction is only then executed if the result of the preceding expression is TRUE.
- ✓ N with JMPC, CALC, RETC: The instruction is only then executed if the result of the preceding expression is FALSE.
- ✓ N otherwise: Negation of the operand (not of the accumulator)

5.3.2. Example (Converting LD to IL)



5.4. Function Block Diagram (FBD)

The **Function Block** Diagram (FBD) is a graphical programming language that can describe the **function** between input variables and output variables.

5.4.1. Example of simple control loop (YOKOGAWA)

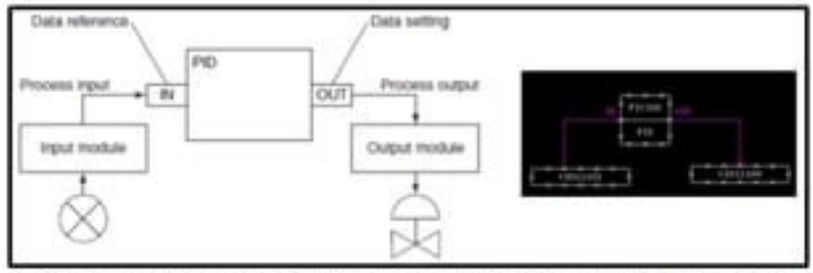


Figure 61: Simple Control Loop Configured by YOKOGAWA PID Functional Block

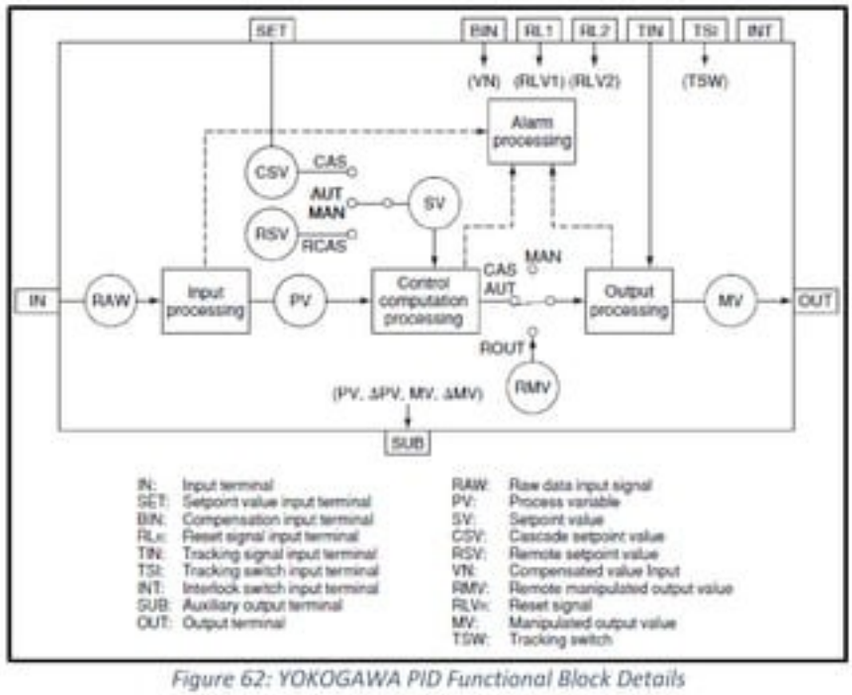


Figure 62: YOKOGAWA PID Functional Block Details

5.5. Sequential Function Chart (SFC)

The sequential function chart a graphically oriented language which makes it possible to describe the chronological order of different actions within a program.

Main components of SFC are:

- ✓ Steps.
- ✓ Actions to be executed at every step.
- ✓ Transitions Conditions.

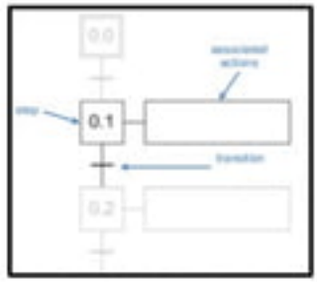


Figure 63: SFC Main Components

5.5.1. Steps

Steps in an SFC diagram can be active or inactive. Actions are only executed for active steps. A step can be active for one of two motives:

- ✓ It is an initial step as specified by the programmer.
- ✓ It was activated during a scan cycle and not deactivated since.

Steps are activated when all steps above it are active and the connecting transition is superable (i.e. its associated condition is true). When a transition is passed, all steps above are deactivated at once and after all steps below are activated at once.

5.5.2. Actions

An action is a series of instructions in IL or in ST, a lot of networks in FBD or in LD, or again in sequential function chart (SFC), it is always connected to a step.

5.5.3. Transition/Transition condition

A transition is the condition that must be "True" to pass from one step to another.

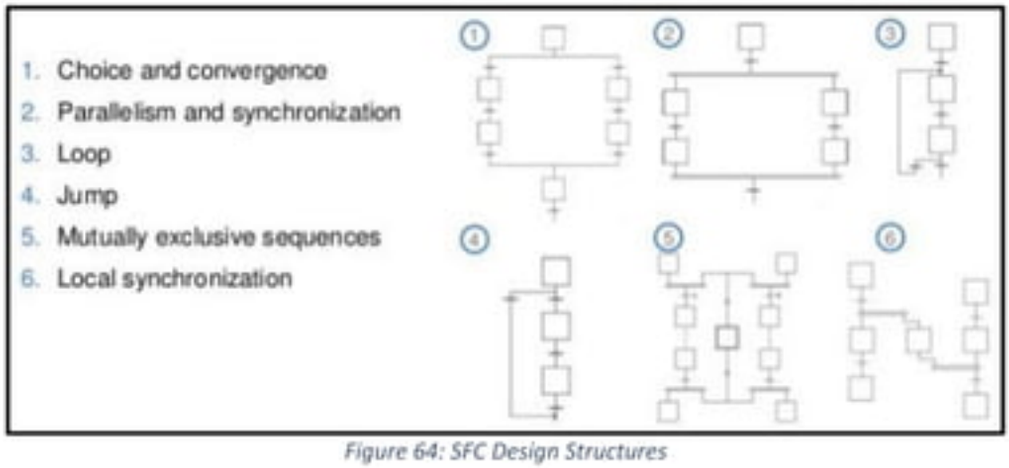


Figure 64: SFC Design Structures

6. System Maintenance and Troubleshooting

6.1. Field Instrument Maintenance

DCS relies on the transmitters reading, if the transmitter zero or span adjustment is not accurately set up, then DCS will accept the received signal as being correct and poor control, or an in-accurate data display will be the result.

6.2. Precautions for Static Electricity

System components are sensitive to damage from static electricity. The damage suffered by a component may not be immediately obvious, as the effects can be cumulative; a component suddenly failing in service for no apparent reason. In order to minimize this risk, the following precautions should be observed wherever practicable:

- ✓ When storing or carrying a maintenance part, put it in an anti-static bag with a label describing precautions for static electricity, when delivered.
- ✓ During maintenance, wear a wrist strap with grounding wire and ground the wire via 1MΩ resistor.
- ✓ When placing a card with a built-in battery (Power Supply Unit) on conductive sheet, set the battery switch to OFF or remove the battery.

6.3. Daily Maintenance

A monitoring station (EWS, HIS) always monitors the status of each element, and upon occurrence of and recovery from a failure of stations or networks announces it to the user with a buzzer sound and display message.
Also, the system engineer is carrying out daily routine inspection and reporting the findings for the following:

- ✓ Controllers status
- ✓ Modules status
- ✓ Monitoring stations status
- ✓ Networks status

6.4. Replacing Power supply module

6.4.1. Procedure for Removing power supply modules

1. Confirm the other power supply module is working properly.
2. Switch off the circuit braker corresponding to the module to be removed.
3. Disconnect the module to be removed from the external power interface unit.
4. Remove the fixing screws of the power supply module.
5. Pull the power supply module forward and remove it from the base unit.

6.4.2. Procedure for Installing power supply modules

1. Install the power supply module on the base unit.
2. Fix the screws of the power supply module.
3. Insert the corresponding connector of the power supply module to the external interface unit and switch on the corresponding circuit braker.

6.5. Replacing Processor module

6.5.1. Procedure for Removing processor modules

1. Confirm that the processor module to be removed is in standby state.
2. Remove the fixing screws of the processor module.
3. Pull the power supply module forward and remove it from the base unit.

6.5.2. Procedure for Installing processor modules

1. Confirm the new processor module sittings are the same as the replaced one.
2. Install the processor module on the base unit.
3. Fix the screws of the processor module.
4. Confirm the processor module is at normal state and completed copying the program.

6.6. Replacing Battery

- ✓ Replace a battery pack when the validity period expires.
- ✓ Wear a wrist strap when handling a battery.
- ✓ Do not throw a battery pack in a fire.
- ✓ Do not disassemble a battery pack.

6.7. Backup

It is required to back up the system periodically and whenever any changes are carried out.

6.8. Power Outage

If the power supply is interrupted to the DCS, the UPS system not maintaining the supply, then the following state will occur:

- ✓ All modules will shut down.
- ✓ All data highway units will shut down.
- ✓ All outputs to control valves will go to 0mA; valves should be designed to go to a fail-safe condition.
- ✓ All digital outputs will go to 0V; valves should be designed to go to a fail-safe condition.

7. Advantages Disadvantages of DCS

7.1. Advantages of DCS

- ✓ The use of centralized control, with the whole plant able to be viewed and operated through one central operator Interface window.
- ✓ Data presentation is in a systematic format enabling easy comparison of various parameters.
- ✓ It is possible to control through dynamic graphic.

- ✓ Operator's action can be logged, thereby eliminating confusion.
- ✓ The alarm system can be regrouped.
- ✓ Complex computations, analysis, etc. can be carried out easily.
- ✓ Management information can be generated at regular intervals.
- ✓ The super-imposed trends help in the analysis of plant parameters.
- ✓ Ease of introducing additional plant, additional controllers, process units or other items that can be attached to the network at any time, within the constraints of communications handling.
- ✓ Ease of commissioning. Small units of process can be commissioned individually by linking them to a network and Operator interface, without the entire plant being available.

7.2. Disadvantages of DCS

- ✓ The cost of installing a DCS may not be justified for small plant operations.
- ✓ All information and data presented in a systematic format is hidden behind the CRT. Hence, it requires a skilled operator.
- ✓ In an emergency, decisions have to be taken single handedly, as few operators are there in the control room.
- ✓ Failure of one controller effects more than one loop. Hence it calls for very high MTBF (Mean Time Between Failures) and high degree of redundancy.