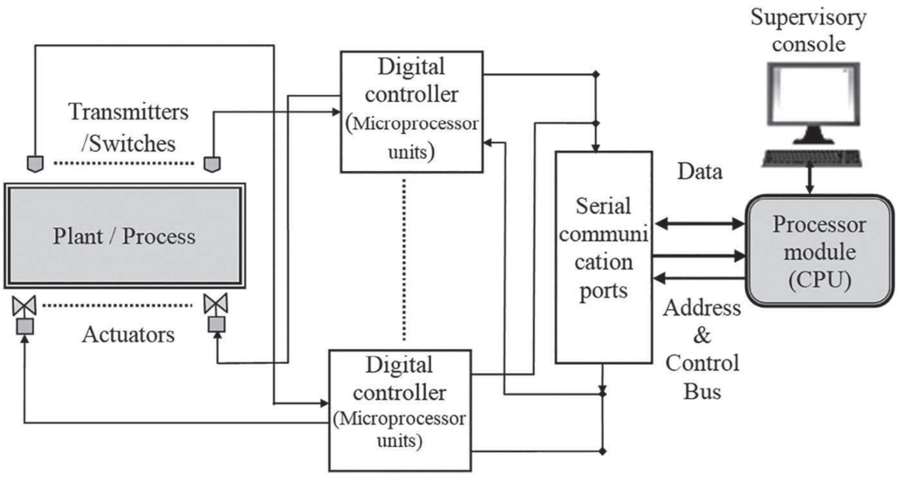


FIGURE 3.16 Computer supervisory control of a process/plant.

be a serial interface between the supervisory console and the digital controllers to convert the parallel digital data into serial form and vice versa. Such an interface is known as a universal asynchronous receiver/transmitter.

3.4 DISTRIBUTED CONTROL SYSTEM

3.4.1 History and Overview of DCS

DCS is a PC-based monitoring and control architecture with customized hardware and software modules which are geographically and functionally distributed throughout the entire plant/process to ensure its fail-safe functionality and at the same time capable of providing higher level of automation from raw material handling to final product shipment.

Journey of DCS began during 1970–75 owing to rapid industrialization, and process instrumentation and control techniques were gradually shifting from simple closed-loop control to composite loop control to realize higher efficiency in operation, rationalization, and labor saving, and to improve product quality. These shifts required more complicated and diversified control techniques, coupled with sequence control techniques with safety automated batch processes, plant auxiliary equipment start-up and various interlocks, different levels of process alarms, huge amount of data storing and retrieving, etc. Before the development PC-based architecture of DCS, there is a long history of its evolution as shown in Figure 3.17.

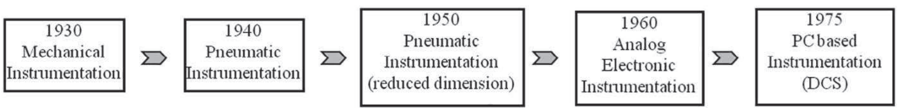
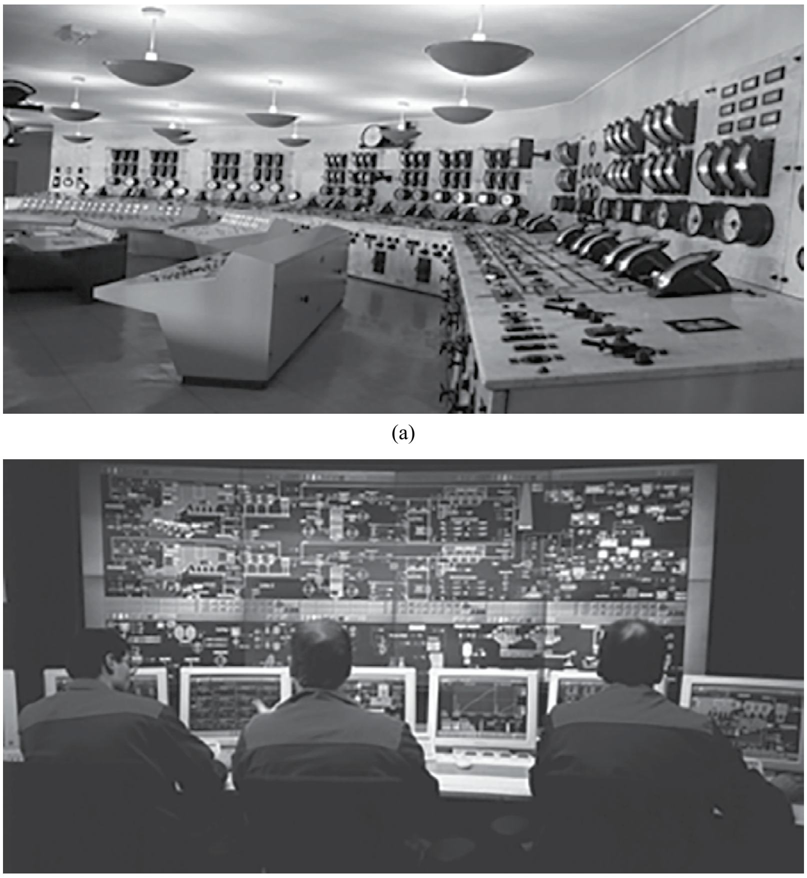


FIGURE 3.17 Evolution of DCS.



(a)

(b)

FIGURE 3.18 (a) Look of the control room in pre-DCS era. (b) Look of the control room in post-DCS era.

For a process/plant, major equipment of DCS are installed in the control room. The appearance and size of the control room has changed a lot as shown in Figure 3.18 due to the transformation of technology related to the process instrumentation from its early pneumatic form to the present PC-based architecture.

With the advent of IBM desktop PC in 1981, and almost at the same time, to fulfill the requirement of automation for process plant, DCS stood out with the adequate support of high-quality hardware modules and inexpensive software packages. DCS is a computerized control system for a process or plant usually with a large number of I/O devices present in control loops, in which autonomous controllers are geographically and functionally distributed throughout the system, but there is a central operator supervisory station for continuous monitoring and control. With time DCS has become more powerful with a lot of additional features

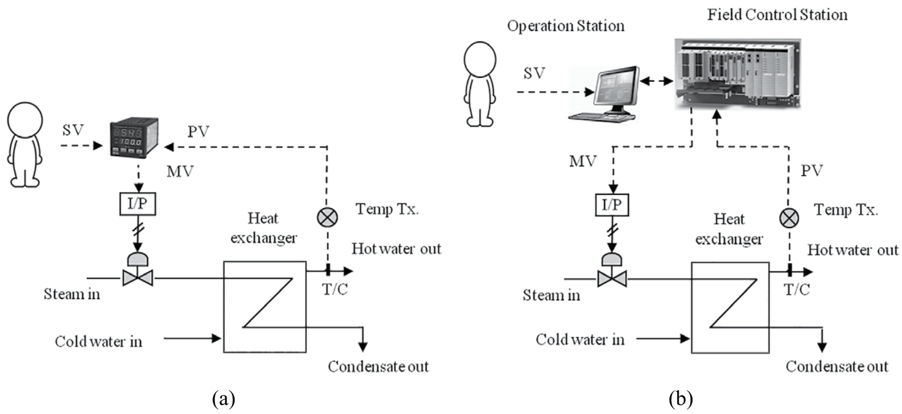


FIGURE 3.19 (a) Closed-loop control with stand-alone controller. (b) Closed-loop control with DCS-based architecture.

related to the entire plant automation network, i.e., from field instruments to the managerial decision-making process.

There is a basic difference between a stand-alone control loop (e.g., a temperature control loop) using an analog/digital controller and a DCS-based control loop as shown in Figure 3.19. In case of stand-alone control loop, operator sets the desired temperature (set point) and hence the controller adjusts the variable to manipulate the valve opening for steam flow adjustment so that the temperature of the process may attain the desired value. Here, the controller (PID) displays the measured PV, supplied SV and calculated 'Manipulated Value' (MV).

In a process plant, a large number of process parameters are to be measured, monitored and controlled. Thus it makes economical sense to provide an individual controller for each loop and to monitor all the parameters at a time. Hence, with DCS-based control a large number of PVs can be fed to an input card and the corresponding MVs can be obtained from output card for actuators located in the field.

DCS are dedicated for systems used in manufacturing processes that are continuous or batch oriented. Processes where a DCS might be used include chemical plants, petrochemical (oil) and refineries, pulp and paper mills, thermal power plants, nuclear power plants, water treatment plants, sewage treatment plants, food processing, agrochemical and fertilizers, metal and mines, automobile manufacturing, metallurgical process, pharmaceutical manufacturing, sugar refining plants, etc.

3.4.2 Centralized versus Distributed Control

DCS is basically a PC-based measurement and control platform widely used in process automation. So, there is a choice between centralized versus distributed architecture of the processor-based control system. Figure 3.20 shows the block

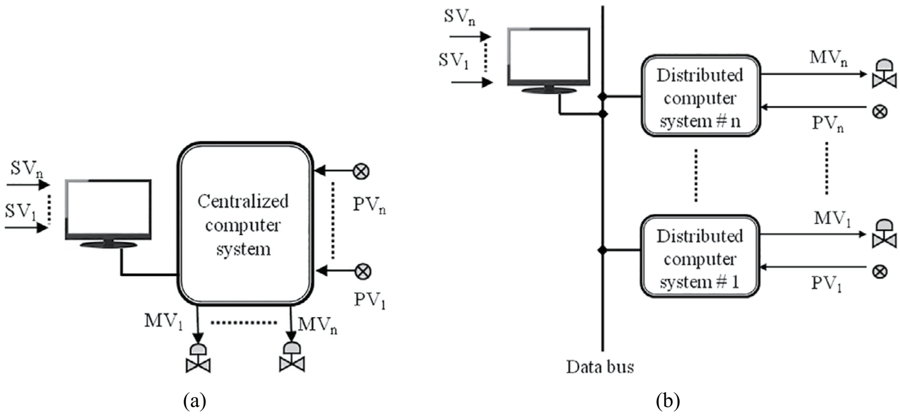


FIGURE 3.20 (a) Schematic diagram of process automation using centralized computer system. (b) Schematic diagram of process automation using distributed computer system.

schematic of the centralized and distributed computer system-based plant automation architectures.

In case of centralized architecture, a single computer-based system performs all the required signal acquisition, processing, monitoring, and control jobs; so, if it fails, the entire plant will be affected and would result in total shutdown of the plant. To avoid this, signal acquisition, processing, monitoring, and control jobs are executed in a distributed manner, i.e., by employing more than one computer-based system over a wide area (connected through bus) but with centralized monitoring. Since the operations are distributed among the different computer-based systems, if one control loop fails, it is the one which would be affected and others will remain in operating mode. To increase the reliability of individual computer-based system, redundancy is provided at different levels, though it will increase the cost. If a loop fails, it would be taken over by the redundant one.

3.4.3 Configuration and Specification of DCS

Configuration and specification of a DCS depends on the requirement of a specific plant/process. Depending on the size of the same, total number of tags (identification of an instrument or equipment), nature of tag, variety of signals, sampling speed, storage of plant/process data, and presentation of data, there is a wide choice for selecting the configuration and specification of DCS. As DCS is a large system with modular architecture, the user needs to specify each and every item of it as per requirement. To prepare the configuration and specification requirements, one must have a detailed understanding of the entire plant/process with requisite plant layout (architectural drawing), control room design (civil layout diagram), process flow diagram, Process and Instrumentation Diagram (P&ID), wiring layout (electrical drawing), instrument mounting (mechanical drawing), emergency shutdown

(ESD), safety aspects, etc. For a typical plant, vendor specifications for DCS may be described as follows:

- Design, engineering (including logic and control schemes as per drawings and incorporating the same in DCS), supply, installation, and commissioning of equipment
- Operator consoles, remote consoles, engineering workstation, printers as per detailed specifications
- Control schemes in DCS, coordination with ESD vendor for seamless integration of DCS and ESD systems, and various subsystems as specified
- Field instruments and associated hardware
- Uninterrupted Power Supply (UPS) as per specifications along with future spares
- Cables, cable trays, and structural material for cable laying as per specifications
- Designing of ground routes for cabling
- Junction Boxes (JBs) with terminal strips, cable glands, and wire marking as per detailed specifications
- Fittings and associated hardware for connecting transmitter impulse pipes as per P&ID drawing
- Isolator panel cabinet complete with isolators, pre-wired and marked terminal strips, redundant power supply, cooling fans, etc. as per drawing
- Electrical interface cabinets along with associated hardware/modules/relays, etc. to be placed in substation
- Cabinet to house subsystems, interfacing as elaborated in drawing
- Auxiliary console complete with annunciator, push buttons, LED lamps, reset switches
- Furniture for work stations/PCs including chairs for operators in control room and engineering room
- Commissioning of DCS system including field instruments in association with ESD vendor for seamless integration of both the systems
- All outgoing cables for trip interlock purpose from the ESD system going to various solenoid valves, actuators, indicator lamps, drives, etc.
- Detailed documentation
- Spare parts for all major items
- Training for operation and maintenance staff
- Comprehensive Annual Maintenance Contract (AMC) for at least five years after expiry of the warranty period with minimum number of visits (including emergency and periodic visits) of the service engineer per year

Other than these typical specifications, control and operation philosophy of the plant/process as given below need to be specified:

- All process and utility units and related facilities for the entire plant shall be monitored and controlled from the operator console of DCS located in the control room. All monitors need to be specified with size and other necessary features.

- DCS operator interface shall be the primary integrated window for operation of the control and safeguarding systems and shall provide access to process control, sequence control status, equipment status, alarm overview, trip status overview, override status, real-time trending, historical data trending, generation of dynamic graphics as per process requirement, machine monitoring, etc.
- All control and interlocks shall be monitored, controlled, and engineered through workstations.
- Information will be presented in the form of 'live' graphic displays and simulated instrument faceplates.
- The system shall be configured to permit the operator to determine the cause of an alarm with a minimum number of keystrokes at the console, without having to memorize tag numbers, so that a rapid reaction to an abnormal situation can be achieved.

Along with these specifications, other requirements related to power supply, equipment locations, system integrations, field interface, alarm management, environmental specifications, installation, commissioning, testing, acceptance, future expandability, etc. need to be specified.

3.4.4 DCS-Based Process Loop Designing

A DCS-based temperature control loop is shown in Figure 3.21.

In a DCS-based control loop, process information (from field area) is fed to the I/O cards of DCS (which is placed in control room) through field terminators and

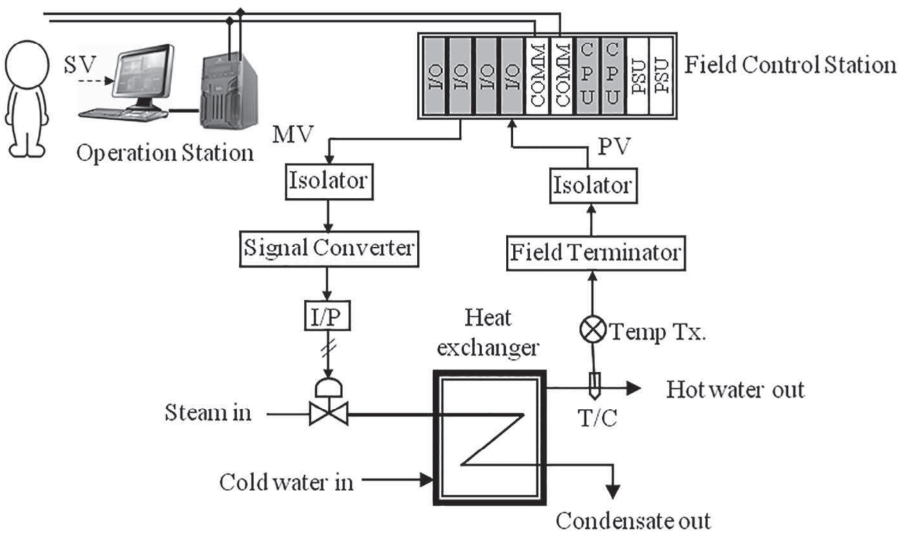


FIGURE 3.21 DCS-based temperature control loop.

isolators. Field terminator terminates the field wiring and converts the 4-20 mA current signals into 1-5 V and all such signals are fed to the input cards using prefabricated cables through isolators. Isolators provide physical isolation between field and control room signals. CPU card generates the corrective action based on the SV provided by the operator and the preassigned control algorithm. Control action in analog form is produced by the output cards, and in most cases, a voltage signal (1-5 V) is produced. This signal is again passed through the isolator module and signal converter unit. The signal converter module converts 1-5 V into 4-20 mA signal, which flows to the I/P converter to change the plug position of a pneumatically actuated control valve. However, there are cases where DCS is used only for field signal monitoring and acquisition purpose.

3.4.5 Reliability of DCS-Based Automation Network

In case of a DCS-based process plant automation network, DCS plays the role of the brain and nervous system. Hence, to ensure healthiness of the entire plant operation, each and every unit of the DCS must be reliable, i.e., they must work without any malfunctioning irrespective of the operating conditions. But, in practice ensuring such reliability is not an easy task for the DCS vendors. Usually, redundancy concept is used to enhance reliability of DCS components. In case of any manufacturing plant, every minute of operation matters a lot. So, a DCS must perform reliably 24×7 for years at a stretch; otherwise it may cause unexpected downtime leading to loss of revenue, lost profit, or even a safety related incident.

With quality hardware and software along with multilevel redundancy and proper maintenance, DCS vendors ensure the availability of such systems to the extent of 99.99999%, i.e., downtime is less than one minute in ten years. Redundancy means that all the critical items of DCS are provided in duplicate, triplicate, and even quadruplet form. If a device starts malfunctioning, self-diagnostic software immediately identifies the faulty one and isolates it from the rest of the system. The existing working load of the malfunctioning unit is automatically transferred to the redundant unit. This changeover takes place smoothly and no hindrance is encountered from the process level. Usually, most critical items like processor module, power supply module, communication module, and cable are always considered to be at least dual redundant. However, depending on the importance of a particular unit, redundancy level may go up.

3.4.6 DCS Vendors and Package Cost Estimation

In modern automation scenario for existing as well as upcoming process plants around the globe, there is a huge competition among the various DCS vendors. Among these companies, market leaders are:

- **ABB:** ABB is a global leader in power and automation technologies and its DCS is one of the most popular choices for industries with brands such as Ability™ System 800xA and ABB Ability™ Symphony Plus.

- **Emerson Electric:** Emerson Electric is a diversified global manufacturing company that brings technology and engineering together to provide innovative solutions to customers in industrial automation. Its DeltaV™ DCS for process industries improves operations by harnessing today's predictive technologies in an easy, intuitive, and interoperable way.
- **Honeywell International:** Honeywell deals with technologies to address some of the world's toughest challenges. It redefined industrial automation with Experion® Process Knowledge System, enterprise wide DCS designed to unify people with process, business requirements, and asset management.
- **Siemens:** For all industrial sectors, Siemens is the world's single source leader of automation technology products. Its SIMATIC PCS 7 DCS combines a unique scalable architecture with powerful engineering tools and a wide variety of additional functions such as alarm management, process safety, and asset management.
- **Yokogawa Electric:** Yokogawa Electric Corporation is a Japanese electrical engineering and software company. Its most proven DCS brands are CENTUM CS and CENTUM VP, which provide simple, fast, highest field proven system, and low-risk upgrades with more than 40 years of backwards compatibility.
- **General Electric:** General Electric is building the world by providing capital, expertise, and infrastructure for a global economy. Its SmartControl DCS is the nervous system of hydropower plants and it enables plant operators to monitor, control, and protect equipment while obtaining all the productivity possible from plant assets.
- **Mitsubishi Heavy Industries:** Mitsubishi has a long range of products from aerospace to plant automation. Mitsubishi Electric's DCS brands PMSX®pro and PMSX®micro have been developed to meet the challenges related to monitoring, operation, and control of power plants.
- **Rockwell Automation:** Rockwell Automation is the world's largest company dedicated to industrial automation and information. Its PlantPAx system is a modern DCS which offers plant-wide control with optimization, secure architectures, and strong support of the system.
- **Schneider Electric:** Schneider Electric is a leading designer and manufacturer of automation and control solutions. Its EcoStruxure Foxboro DCS (an evolution of Foxboro Evo) is a fault-tolerant and highly available system which consolidates critical information and elevates staff capabilities to ensure flawless and continuous plant operation.
- **Toshiba International:** Toshiba is a total solution provider for power automation. Its NV-series and V-series DCS systems provide one of the best solutions for small to large scale process plants.

Estimating the DCS cost for a plant process is not a very simple task as it depends on various factors:

- Total number of tags involved
- Software specifications

- Data acquisition and analysis tools
- Physical size of the process/plant
- Type and choice of field instruments
- Choice of cables and their routing
- Power supply and UPS arrangement
- Number of operator stations, engineering stations, remote consoles, etc.
- Choice of JB, panels, and cabinets
- Commissioning duration
- Spare and duration of AMC
- Documentation and training of plant personnel, etc.

All these parameters are involved in deciding the cost estimation of the entire DCS package. Thus, it varies widely from case to case basis and hence can't be specified in a particular way. Usually during tendering, all the necessary information and requirements must be clearly mentioned to avoid any future confusion. However, in practice it is always found that this huge task always requires a number of modifications and negotiations depending on the actual situations. The price per tag varies usually in the range \$200–\$500.

3.5 HARDWARE UNITS OF DCS

3.5.1 Operator Station – Human-Machine Interface

Operator station is basically a PC monitor through which an operator can access the entire plant information in a systematic manner as numerical data as well as graphical format. It is popularly known as HMI. A properly designed HMI empowers operators to monitor and control processes in a more efficient manner thereby ensuring improved plant safety, increased plant uptime, proper equipment utilization, improved product quality, judicious task prioritization, early prevention and response to abnormal conditions, etc. A properly designed operator interface can also help to reduce operator disappointment and fatigue. Depending on the requirement, operator station can be single monitor as well as multi-monitor type. In case of multi-monitor-based configuration, two or more monitors are stacked together to provide more information regarding the process to the operator. Figure 3.22 shows a multi-monitor-based operator station.

In order to address the need for an explicit, industry standard approach, the ISA formed a committee to address the philosophy, design, implementation, operation, and maintenance of HMIs for DCSs, including processes exercised throughout the HMI life cycle. The resulting standard was published in July 2015 as ISA-101.01. The standard contains nine clauses, with the first three addressing scope, references to other standards, and general definitions of terms and acronyms used in the standard. The remaining clauses describe the best practices, mandatory requirements, and recommendations for implementing an HMI and supporting its life cycle. Display styles refer to how information is presented on a display or part of a display. The functional requirements of a display as determined by the HMI design process should determine the display

FIGURE 3.22 Multi-monitor-based operator station. (Courtesy: Yokogawa Technical Manual.)

style to be used. Display style may also be influenced by physical or technological factors such as:

- How the user interacts with the display (touch screen, keyboard, or mouse)
- Position of the display
- Physical size of the screen
- Quantity of information that can effectively be handled by the user

ISA 101.01 recommends a display hierarchy to provide a structural view of a process as noted in Figure 3.23.

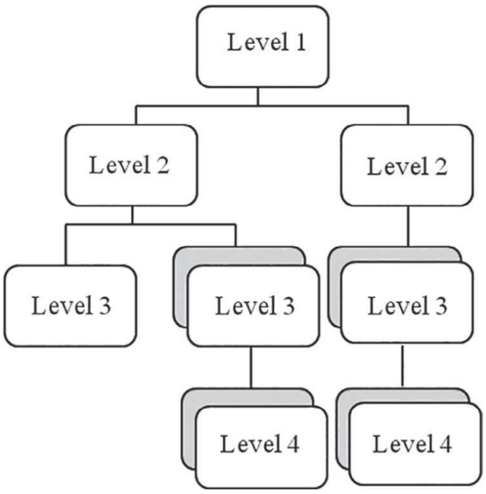


FIGURE 3.23 Recommended display level for operator station as per ISA 101.01.

Using a display hierarchy, the designer can present an overview of a large portion of a process without losing the ability to drill down into other displays for greater levels of detail and control functionality. Because of human cognitive limits, a maximum of four levels of displays are recommended, with Level 1 having the largest scope and Level 4 having the most focused scope. The recommended content for each display level is as follows:

- **Level 1:** These displays show an overview or summary of key parameters, alarms, process conditions, and abnormal situations in an operator's entire span of control by being located all on one display.
- **Level 2:** These displays are high-level process displays with more detail than Level 1 displays. Level 2 displays act as operator's primary interacting displays during normal conditions, so the scope of display can be more limited than Level 1. Level 2 displays should be task based rather than presenting a continuous overview as in Level 1 displays.
- **Level 3:** These are system detail displays that the operator uses to perform nonroutine tasks such as lineup changes, equipment switching, or complex routine tasks. Level 3 displays are also task based and should provide sufficient information for process diagnostics.
- **Level 4:** These displays are diagnostic and are used to provide operating procedures for a piece of equipment or help control and diagnostics. Level 4 displays may best be presented as modal or pop-up displays due to the brevity of information shown and the frequency of use.

It should be noted that display levels are not necessarily aligned with HMI navigation; there may be fewer or more levels in the navigation hierarchy than the defined display levels.

3.5.2 Operator Keyboard and Interacting Tools

To maintain healthy operating condition for plant or process, operators need to interact with the HMI in a seamless manner. Usually, operator keyboard and mouse (track ball) are used to interact but presently touch screen facility is also provided in addition. Figure 3.24a and Figure 3.24b show an operator working on an operator station and an operator keyboard, respectively.

Due to prolonged and continuous use of the keys of operator keyboard, there is a high probability of failure in case of ordinary PC keyboards and hence to avoid such malfunctioning special type of construction is recommended for the operator keyboard. Usually, they are made of flat keys of drip and dust proof construction and are rugged in nature. Their layout is functional, intuitive, and easy to operate. In addition to operator keyboard, engineering keyboard is used for system generation and builder function. These engineering keyboards are normal PC keyboards of good quality. They are not connected to the operator station always but connected only when engineering function is required to be performed.

(a)

(b)

FIGURE 3.24 (a) Operator working on operator station with operator keyboard and mouse. (b) Operator keyboard. (Courtesy: Yokogawa Technical Manual.)

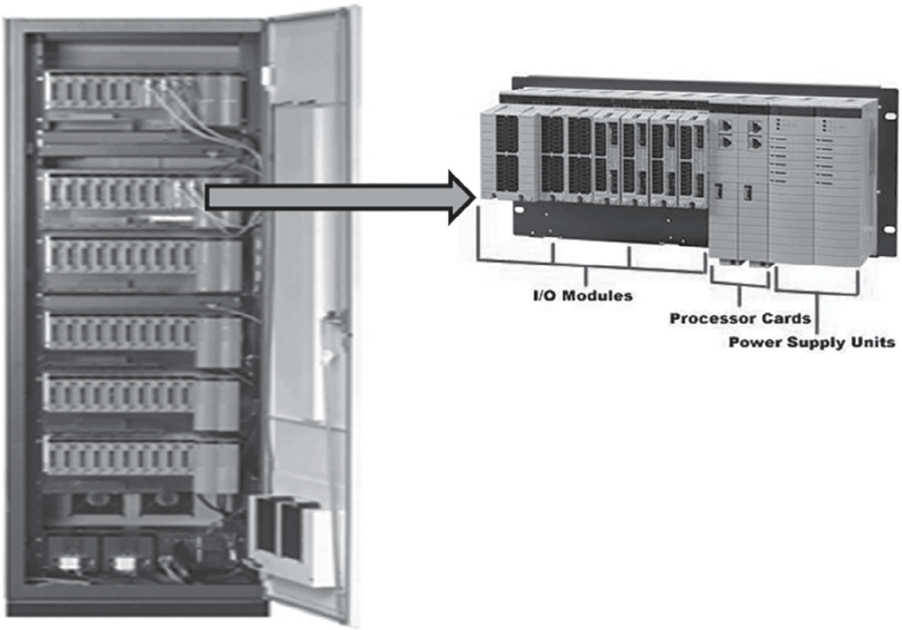
3.5.3 Field Control Station and Node Formation

Field Control Station (FCS) is considered to be the main controlling unit of a DCS. FCS contains all types of I/O cards, processor cards, power supply cards, communication cards, etc. FCS is chosen as duplex in nature for redundancy, i.e., to ensure fail-safe architecture of DCS. FCS is connected to the data communication bus of the DCS and operator station is also connected on the same communication bus. Figure 3.25a and Figure 3.25b show an FCS and a FCS internal configuration respectively.

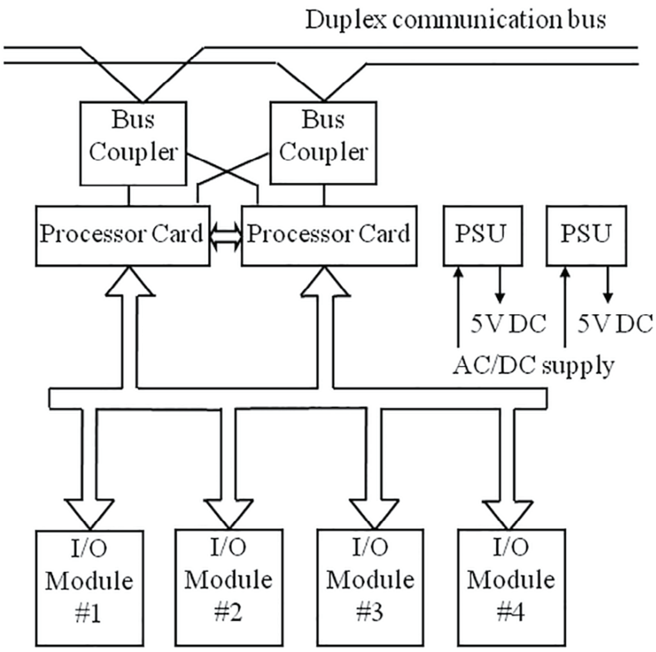
FCSs are connected to each other and to operator station (HMI) and other stations and gateways via communication bus. Data communication over the communication bus enables FCS database to be downloaded and the various settings of an FCS to be set and read from HMI. It also enables a HMI to be notified for alarms by the FCSs. FCSs are equipped with a number of different I/O modules that connect various analog and digital I/O signals as well as general purpose communication lines such as RS-232C to the FCS. The signals acquired by the I/O modules are subjected to input processing, control computation, logic operations, and then output processing before they are finally outputted from the FCS's I/O modules. FCS are designed in such a way that they are easy to install, highly compact, reliable, safe, easy to maintain, less power consuming, and less emission of CO_2, i.e., less harmful to the environment. FCS contains multiple number of Field Control Unit (FCU). In each rack of the (FCU), power supply and processor cards are always duplex to ensure redundancy of DCS from architectural point of view. Each rack of FCU can communicate with other racks through node to node communication bus. Various I/O cards of each rack are connected to the backplane bus.

3.5.4 Configuration of Field Control Station

Configuration of FCS depends on the requirement of the plant in terms of its I/O devices, i.e., the choice of the modules or cards to be installed in the FCS is directly related to the number as well as nature of the field I/O devices. All such cards are called I/O cards for connecting field sensors and actuators. The FCS node



(a)



(b)

FIGURE 3.25 (a) Field Control Station (FCS). (Courtesy: Yokogawa Technical Manual.) (b) Field Control Station (FCS) internal configuration.

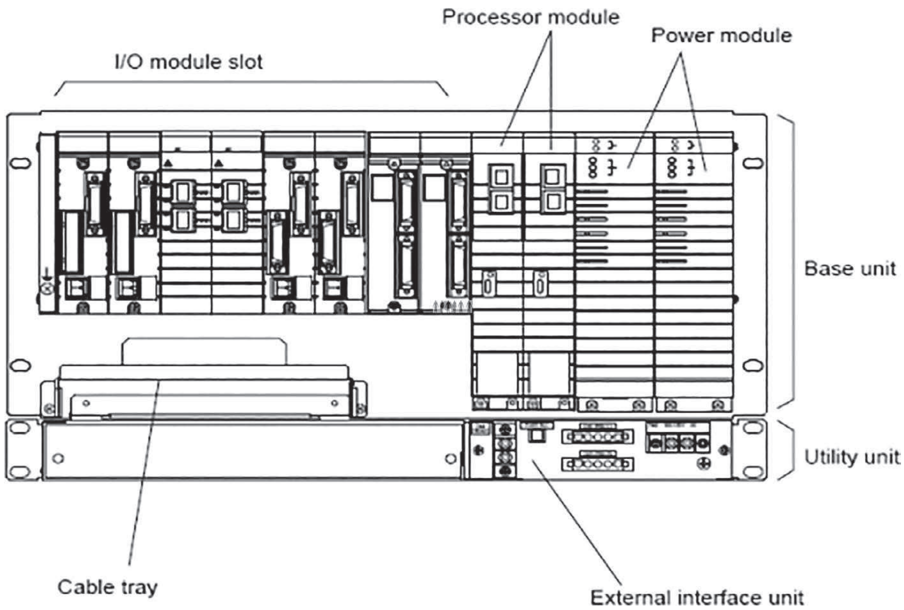


FIGURE 3.26 FCS node configuration. (Courtesy: Yokogawa Technical Manual.)

configuration is shown in Figure 3.26, while Figure 3.27 shows an FCS housing containing multiple nodes.

Other than the I/O cards, power supply and processor cards are the important parts of FCS. To provide fail-safe architecture, power supply and processor cards are accorded redundancy. That is, if the active card fails somehow, the standby card instantly takes over functioning. Hence, in case of processor cards, the standby card always updates itself by equalizing information from the active processor card to have the latest information so that in necessity it can start functioning without any delay. I/O cards may also be configured in duplex form for redundancy.

For a plant with large number of I/O devices, considerable number of nodes must be configured in FCS. For such cases, node to node communication is required and is performed by communication cards as the processor cards are installed only in one node. To support multiple number of nodes as shown in Figure 3.27, a common housing containing common power supply bus and cooling fans is provided. Through bus coupler, all the FCSs are connected to the main duplex communication bus in a multi-drop fashion. Depending on the manufacturer and version, specifications are provided in terms of how many FCS can be connected on the communication bus and what will be the standard configuration of a node inside the FCS.

3.5.5 Analog and Digital Input-Output Cards

I/O cards installed in FCS are of different types, mainly classified as analog and digital. Field transmitters and sensors are analog devices whose outputs are usually 4–20 mA current or 1–5 V voltage signals and are fed to the analog input

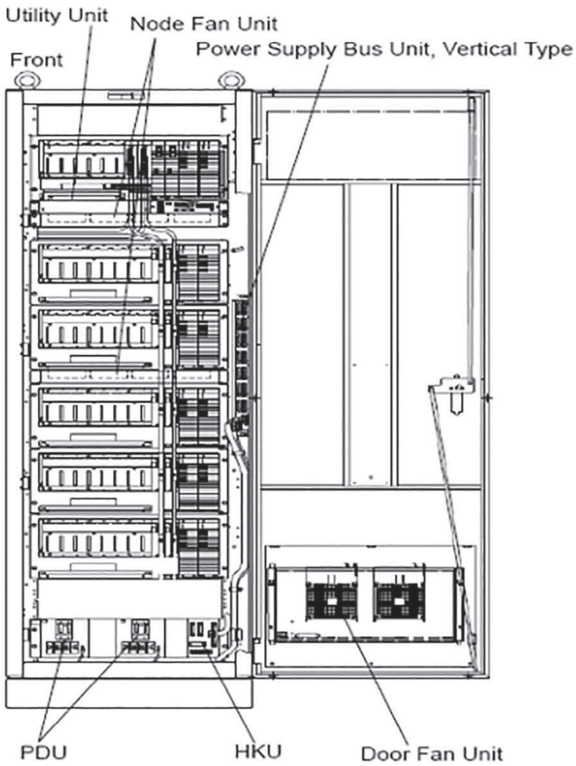


FIGURE 3.27 FCS housing containing multiple nodes. (Courtesy: Yokogawa Technical Manual.)

cards of the FCS. Alternatively, switches (pressure switch, level switch, temperature switch, etc.) are the logical input devices whose output is usually 24 V DC voltage signal and are fed to the digital input cards of the FCS. In some cases, digital signals are also called status signals and the corresponding input cards are called status input cards.

Analog output cards usually provide control action in terms of 4–20 mA current or 1–5 V voltage signals. For actuating pneumatic control valves, 4–20 mA current signal is converted into pneumatic signal (0.2–1 Kg/cm^2) with the help of I/P converters. Digital output cards provide logical output (usually 24 V DC voltage signal) for actuation of the solenoid valves, relay coils, etc. In addition to conventional analog and digital cards, other cards or modules are available for pulse signals, different type of thermocouples, RTDs, etc. For HART, Fieldbus, and Profibus-enabled field instruments, special type of cards/modules are also available. Number of channels are available on both the analog and digital cards and hence users can choose according to their requirements from a wide range of family. Analog and digital cards are available in the available family of cards where both input and output channels are available. All these cards are mounted on a backplane bus as shown in Figure 3.26.

3.5.6 Processor Modules

Processor modules or processor cards are always chosen in redundant manner to ensure fail-safe architecture of the DCS. Each processor module has two microprocessor units which perform the same control computations, and the results are compared by a comparator for each calculation. When the results from both the microprocessor units are same, the module is assumed to be in healthy operating condition and the obtained results are transmitted to main memory devices and bus interface modules. If the results from both the microprocessor units don't match, then abnormality is detected and the active processor module is replaced by the standby processor module. Seamless transfer will take place as the standby processor card always update itself through equalizing function from the active processor card. Usually, for an FCS, only the upper node contains the processor cards and hence rest of the nodes of FCS communicate to the upper node to access the processor card.

3.5.7 Power Supply Module

Power supply module of FCS is the most important part as it provides the necessary power connection to all the I/O modules. Hence, to ensure fail-safe architecture of FCS, power supply modules are always chosen to be duplex. The power supply card is designed to supply power to the common nests, such as the CPU cards, communication cards, and I/O module nests. Usually, the standard output voltage is +5 V DC with noise and ripple free. The +5 V DC outputs from the two power supply cards are always active for redundancy purposes. The input voltage monitoring signal (AC ready) and output voltage monitoring signal (DC ready), together with guaranteed retention time of the +5 V DC output, enable control to continue over a temporary power failure. The output voltage retention time, immediately after a power failure, is clearly defined in the specifications since it is closely related to the software saving process in the CPU card. To ensure continuous supply of power to the power supply module, in addition to the power line connectivity, online UPS as well as diesel generator set arrangement are also provided.

3.6 COMMUNICATIONS IN DCS ARCHITECTURE

3.6.1 Field Cabling and Junction Box

In designing a process automation network, the role of field cabling and JB, along with their physical locations, is very crucial. Information from field instruments are communicated to the control panels of DCS by field cabling through JBs. Control signals are also fed back to the field (actuators) through JB and field cabling. Figure 3.28 schematically shows field and control room cabling.

Thousands of field transmitters are installed in a process plant. So, it is practically a tough task to lay straight individual cables from each field transmitter to control room to display the value of the PV on the operator station. Hence, particular number of field devices/transmitters are wired and terminated in a field JB. Cables used for

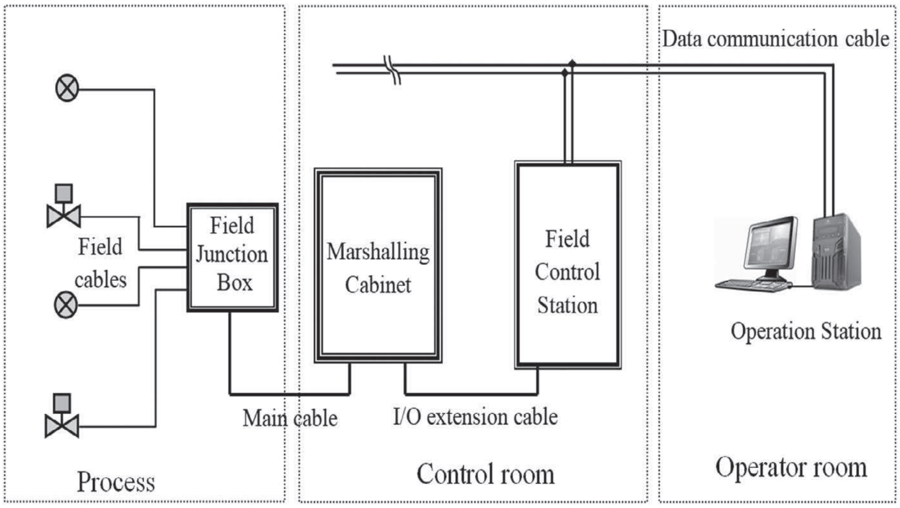


FIGURE 3.28 Schematic diagram of field and control room cabling.

connecting the field device to JB are called field cables. Usually, one pair of cables are provided for each field device. Here, as shown in Figure 3.28, for carrying four signals to/from control room four pairs of cables are needed and also some space is set aside for any future cable requirement. This main cable connects the field JB on the one hand and FCS on the other, located in the control room.

For a plant of moderate size, more than hundreds of JBs are installed in the field area, i.e., more than hundred pairs of main cables are installed, which are coming from field to control room. So, practically it is truly difficult to directly connect these main cables to analog/digital I/O cards of FCS. To avoid these problems, additional marshalling cabinets are used for terminating these large numbers of main cables. The main purpose of marshalling cabinet is to provide main cables termination and then redistribute the wiring of field devices to respective cards or modules of FCS of DCS, etc. FCSs are connected to the operator station through duplex data communication bus. Processor cards present in the FCS perform all the necessary signal processing based on predefined program (using SV and process value) and the resultant control signal is again fed back to the field devices (actuators) in the reverse path. All necessary information is displayed by the operator station.

3.6.2 Multiplexing and Signal Cable

In case of field cabling over a wide area of a process plant installation, cost becomes prohibitive as each and every field device needs to be connected by a pair of cables. To minimize the cabling cost, use of MUX in JB is quite common. Multiplexing technique is most convenient for cases where similar type of signals are required to be sent over a distance and the rate of change of the signals is moderate. Both analog and digital MUXs are quite common in case of field cabling. As an example, for

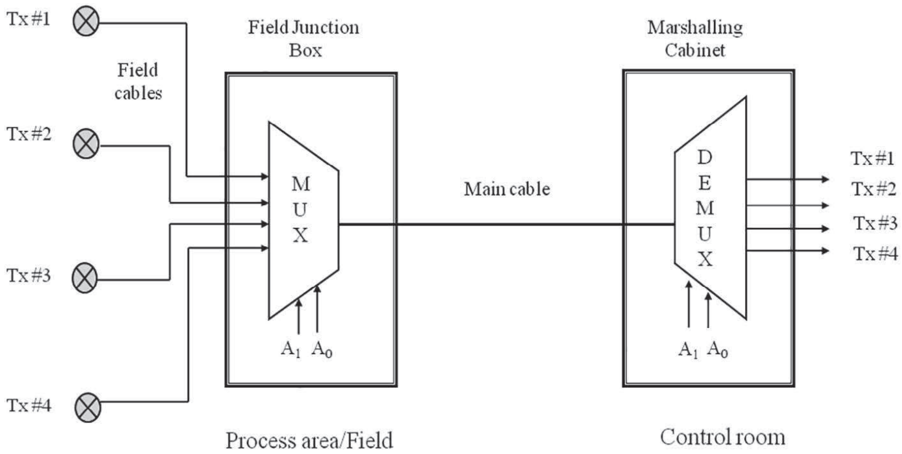


FIGURE 3.29 Schematic diagram of signal cabling with MUX and DEMUX.

slowly varying signals like temperature (i.e., multipoint temperature monitoring in case of distillation column, furnace, etc.), MUXs are widely used. Figure 3.29 shows signal cabling with the help of MUX and DEMUX.

The multiplexed signal is carried by the signal cable from JB located in the field to the control room. In the marshalling cabinet, it is demultiplexed. Usually, input channels are selected sequentially but it is not mandatory. There are cases where a particular channel may be repeatedly scanned by proper choice of address lines.

3.6.3 Safety Barrier

An intrinsic safety barrier provides protection to a field device mounted in a hazardous location in the field from unwanted large power. Basic components of intrinsic safety barriers are fuse, Zener diode, and resistor as shown in the Figure 3.30.

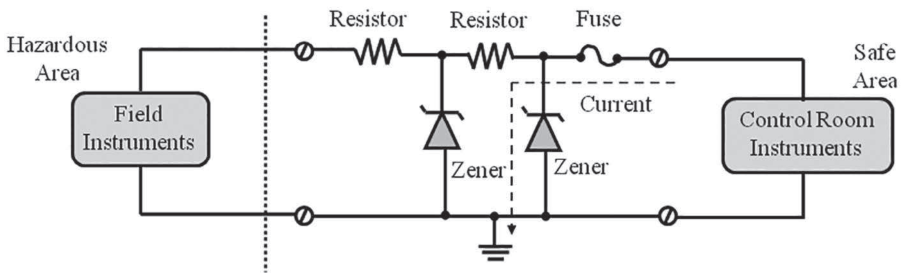


FIGURE 3.30 Intrinsic safety barriers.

Higher voltage or current levels may appear in a field instrument due to poor insulation or any other reason, leading to more thermal energy in the same. This may lead to fire or explosion. To avoid such unsafe situations, Zener diode present in a safety barrier will break down and will force the fault current to ground. Here, Zener diodes limit the voltage and the series resistor limits current in the hazardous area. If current value exceeds the specified limit, fuse in the safety barrier will blow away. For safe passage of fault current to ground during faulty condition, proper grounding of the safety barrier is extremely important. Two Zener diodes are used for redundancy purpose and to ensure fail-safe operation of the safety barrier. Sometimes, galvanic isolation is provided by an isolation barrier. The isolation barrier isolates the field signal from control room signal with the help of transformer or opto-isolator. In some cases, only isolation barriers are used. It also provides strong common mode rejection and prevents the formation of ground loop.

3.6.4 Extension and Compensating Cabling

Thermocouples located in the field of a process plant and signals from Thermocouples are taken to the marshalling cabinet in control room with the help of two types of cables: extension cable and compensating cable (Figure 3.31a and Figure 3.31b). Extension cable is a thermocouple cable which is identified by the letter X (e.g., for K type thermocouple, it is termed as KX). Wires of the extension cable are of the same materials as the thermocouple wires themselves. But it is not cost-effective for a long run of thermocouple. Compensating cables are connected at the end of thermocouples and have the same thermo emf characteristics as that of the thermocouple, but can't withstand the high temperatures that a thermocouple is exposed to. Compensating cable is a more cost-effective solution than extension cable.

Same material as of thermocouple with lesser purity and can measure up to 900°C; used to extend signal from sensor to remote measuring instrument.

Alloy material having almost similar thermoelectric characteristics as of thermocouple and can measure up to 200°C. It is a cheaper option used to extend signal from sensor to remote measuring instrument over a limited temperature range.

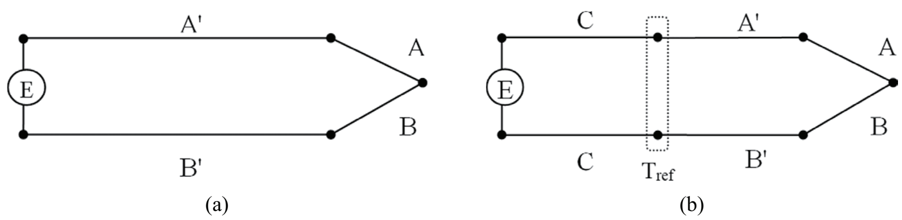
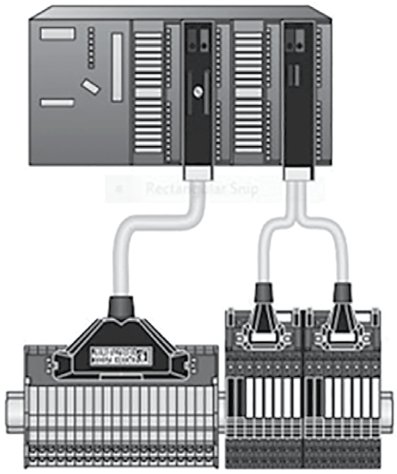
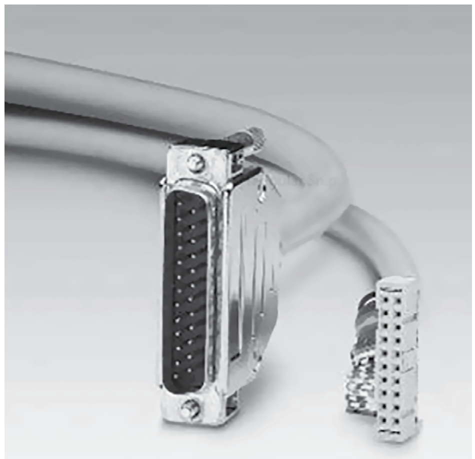


FIGURE 3.31 (a) Extension cable. (b) Compensating cable.



(a)



(b)

FIGURE 3.32 (a) Prefabricated cabling. (b) Prefabricated connector. (Courtesy: Yokogawa Technical Manual).

3.6.5 Fabricated Cabling for Various Input-Output Cards

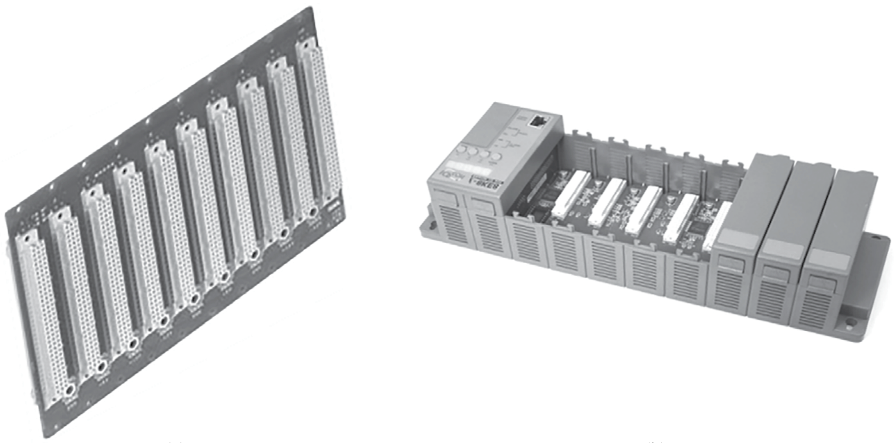
Field signals are to be connected to the appropriate channels of the I/O cards in a judicious way. As huge number of wires are involved, proper care must be taken to avoid issues like possibility of wrong connection, mixing of wires, and difficulty in troubleshooting, etc. To avoid this, prefabricated cables are employed for connecting various I/O cards in FCS to the terminators of marshalling unit. Figure 3.32a and Figure 3.32b show a prefabricated cabling and a connector, respectively.

Prefabricated cables help to ensure fast and fault free wiring, plug and play solution, orderly structure, and considerable time savings. For proper connectivity, different types of front end modules and connectors are provided with the cables for secure connection.

3.6.6 Backplane Bus

It is a special type of bus on which all the I/O modules, along with the power supply and processor modules of a node of FCS, are connected. Such a backplane bus connector and a backplane bus with I/O module are shown in Figure 3.33a and Figure 3.33b.

The backplane bus helps in connecting the following: (a) required power to all the I/O cards, (b) node to node communication modules (c) to and fro data flow between processor cards and I/O cards and (d) data equalization between two processor modules. All the modules are connected to this bus in multi-drop fashion so that they can be connected as well as disconnected without disrupting the operation of the



(a) (b)

FIGURE 3.33 (a) Backplane bus connector. (b) Backplane bus with I/O modules.

system (hot connection/disconnection) and it is a very important feature for easy maintenance of the system.

3.6.7 Data Highway and Repeaters

Figure 3.34 shows a data highway and repeaters in DCS-based architecture.

Data highway is the backbone of the LAN related to plant automation network. It connects FCSs, operator stations, and other devices so that they can communicate and exchange data with one another. Duplex coaxial cable system is the physical means of transmitting this data between nodes. Redundancy is ensured with duplex

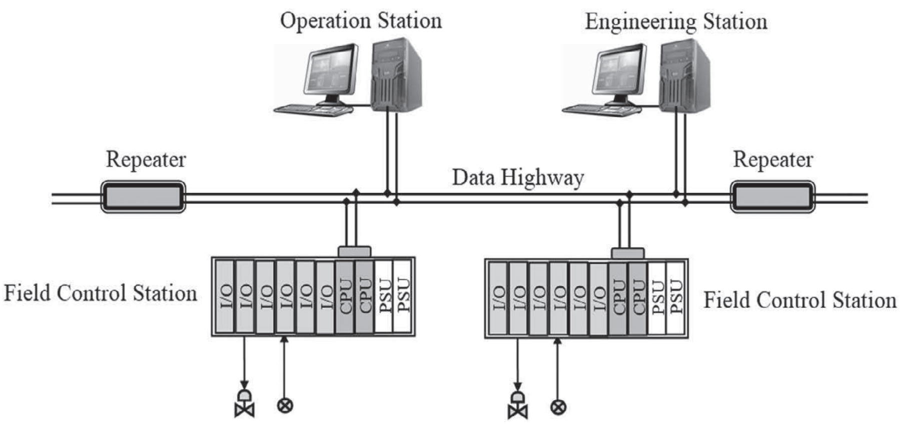


FIGURE 3.34 Data highway and repeaters.

configuration. Data transfer rate varies from 10 Mbps to 1,000 Mbps depending on the requirement and configuration of the network. All the devices are connected on the data highway in a multi-drop fashion. In most of the cases, CSMA/CD communication technique is followed. Real-time communication is the most important feature of this scheme because of its deterministic nature. Usually the data highway is extended up to 10–20 km with the help of repeaters.

Optical bus repeaters convert electrical signals of coaxial cable into optical signals for optical fiber cable. The use of an optical fiber cable allows devices to be free from noise and potential grounding problems. Optical bus repeaters are used for approximately every 4–5 km or shorter transmission distance.

3.6.8 Ethernet for Management Information System

Management Information System (MIS) refers to the processing of information through computers and other intelligent devices to manage and support managerial decisions within an organization. Ethernet is used for file transfer and information communication among operator station, engineering station, and other general purpose Ethernet instruments. Ethernet communication is usually performed via an Ethernet card mounted in a computer or a server. Ethernet is defined as IEEE 802.3 standards, which state the physical and data link layer specifications for Ethernet. Present high-speed IEEE 802.3 standards are:

- 1000 Base-SX (IEEE 802.3z) – 1 Gigabit Ethernet running over multimode fiber-optic cable.
- 1000 Base-LX (IEEE 802.3z) – 1 Gigabit Ethernet running over single-mode fiber.
- 10 GBase-T (802.3.an) – 10 Gbps connections over category 5e, 6, and 7 Unshielded Twisted Pair (UTP) cables.

Ethernet protocol consists of low-level physical and data link layers, usually employed in bus or star topology. Here, data link layer is divided into two sublayers: Logical Link Control (LLC) and MAC. LLC establishes the transmission paths between computers or devices on a network. On a network, the network interface card has a unique hardware address which identifies a computer or peripheral device. The hardware address is used for the MAC sublayer addressing. Ethernet uses the MAC hardware addresses for the source and destination for each packet transmitted.

Ethernet uses CSMA/CD when transmitting packets. It is an algorithm for transmitting and receiving packets over a common network hardware medium that avoids collisions during transmission of packets. The network is checked for other transmissions; when the medium is clear, transmission can begin. If a collision is detected, the packet is retransmitted later.

The MIS in plant automation is shown in Figure 3.35.

In modern process plant automation, MIS plays a very important role at each conceivable level of the network, i.e., from raw material handling to future production planning. Management people can acquire detailed information about the plant/

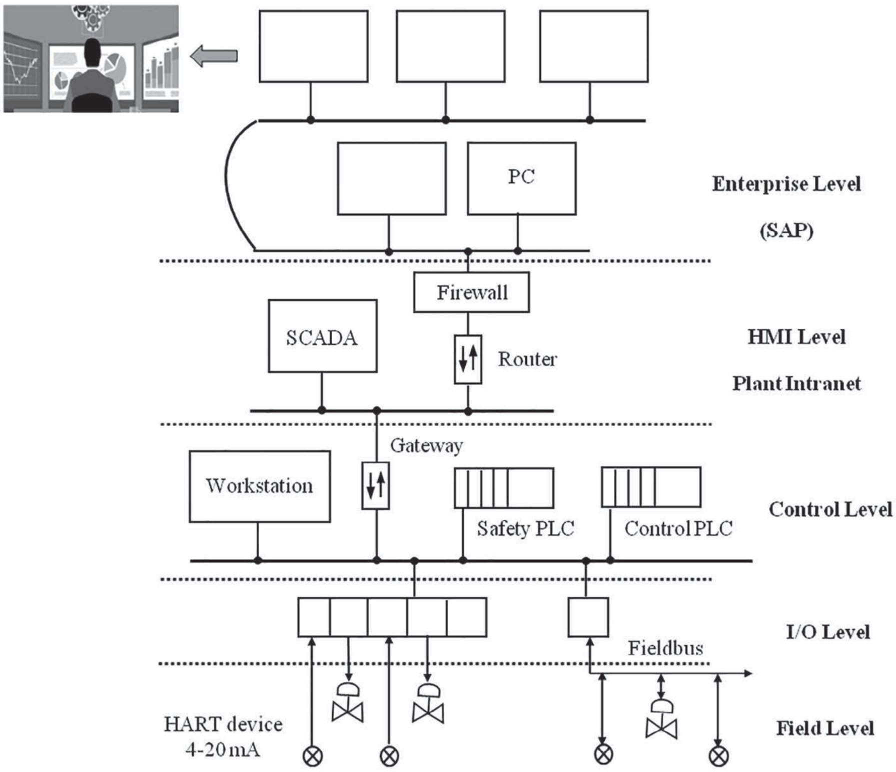


FIGURE 3.35 Management information system in plant automation.

process through MIS in various formats and based on this information, they decide the present as well as future planning for the entire organization with the help of various software tools. Different business analysis tools are utilized for analysis and decision-making purposes.

3.7 SOFTWARE PACKAGES OF DCS

3.7.1 Concept of Display Panels

Display panels of a DCS are nothing but the standard format of HMI which is responsible for operation, monitoring, and display for the entire plant operation along with the DCS components. It is basically a software package (mostly based on Windows operating system) for easy and clear visibility of entire plant operations data and status in a systematic manner. At present, along with the DCS software, other Windows-based application software like report preparation, analysis of process data, production planning, etc. can also be run on the same PC. Conventional PC monitor or multiple number of monitors (stacked monitor) are used for easy access of large amount of information through HMI. Operation and monitoring

4 Supervisory Control and Data Acquisition (SCADA)

4.1 INTRODUCTION

SCADA is an acronym that stands for Supervisory Control and Data Acquisition. It is a type of *Industrial Control System* (ICS); the other two in the clan are Distributed Control System (DCS) and Programmable Logic Controller (PLC). SCADA distinguishes itself from the other two by being a multilocation, large distant sites. A SCADA-based system normally does a *supervisory control* rather than the *closed-loop control* normally encountered in process industries. To keep a tab on the health of machines, machineries and devices, and their subsequent control on a continuous day in, day out basis is a very tedious and monotonous job and may lead to errors due to operational fatigue. Thus, a need arose to have some SCADA for geographically separated sites. The first time a SCADA system was applied was during the thirties of the last century for supervisory control of substation equipment connected to a grid.

It is a system which collects field data from dispersed field locations, transfers it to a central computer facility, and displays the information so gathered on the operator's panel (either graphically or textually). The operator sitting on the control panel (called Human-Machine Interface [HMI]) monitors and controls the entire system in real time as per the program inbuilt into the system. Depending on the sophistication and complexity of the software, control can be fully automatic or else can be initiated by operator commands. A SCADA system is an integration of data acquisition from different field devices at different locations, data transmission, centralized monitoring and display at a central location, and taking appropriate control actions on a real-time basis.

Internet of Things (IoT) and cloud computing, which are of very recent origin, have drastically changed not only SCADA systems but also the whole gamut of monitoring, supervising, security, surveillance, and management of processes across varied industrial and commercial sectors. In a typical non-IoT-based SCADA system, data is stored in PLC memory addresses. But when a SCADA system is integrated with IoT technology, data may come from different sensors, controllers or databases.

A SCADA system is a combination of hardware and software. Typical hardware includes a Master Terminal Unit (MTU, which acts as the control server) and communication equipment (like radio, cable, telephone line, or satellite) at the central location and Remote Terminal Units (RTUs)/PLCs, sensors/actuators, and Intelligent Electronic Devices (IEDs) at remote locations. The communication hardware ensures communication between MTU and RTUs as shown in Figure 4.1.

RTUs and PLCs do the job of feedback control at the sites while supervisory control is done by the host (MTU). Software, inbuilt into the system, monitors and

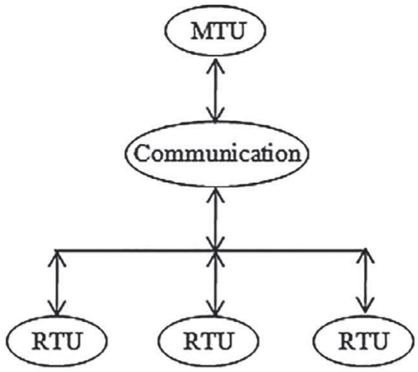


FIGURE 4.1 Communication between MTU and RTUs.

displays the parameter values of different processes, what action to be taken if some parameter goes out of range, etc. An IED can directly be polled and controlled by SCADA master (MTU) and local programming can override the control of SCADA control center. A SCADA system is designed to be fault-tolerant because of adequate redundancy incorporated into the system.

The control center components are connected by Local Area Network (LAN) while field diagnostics, repair, control of actuators, and monitoring sensor data are usually carried out over a separate dial-up or Wide Area Network (WAN) facility. Transporting control information and data from field sites are done over standard and proprietary protocols running over serial communications. The SCADA control center is connected with RTUs/PLCs via WAN. The central station (MTU) has HMI, data logging, and other facilities shown in Figure 4.2.

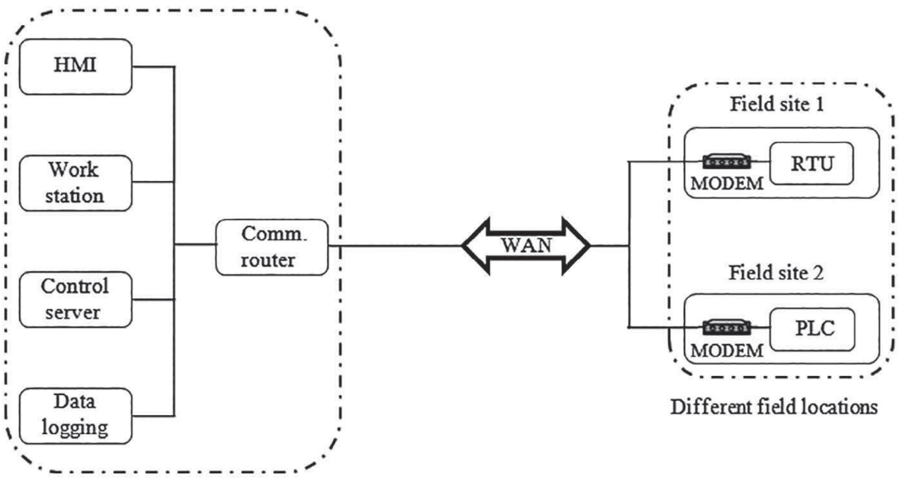


FIGURE 4.2 Schematic of MTU and RTUs/PLCs via WAN.

The communication architectures for data transport between MTU and RTU vary as per the needs, complexity, and a host of other factors.

A SCADA system can be a very simple one like monitoring the environmental conditions of a building to complex systems like power generation, distribution, losses encountered during transmission, and a host of other situations.

SCADA systems are standardized by different standard organizations like IEEE, Electrotechnical Commission, Electric Power Research Institute, American National Standards Institute (ANSI), etc.

4.2 SCADA BASICS

SCADA systems and architectures are continuing to evolve – the latest being the one based on IoT. Figure 4.3 shows a basic SCADA system consisting of different blocks, namely field devices, RTUs, PLCs, Communication infrastructure, SCADA Programming, HMI, supervisory system, MTU, engineering workstations, and data historian.

Field data in either analog or digital form are collected by RTUs or PLCs and sent to the SCADA master (MTU) through a communication interface. The value of the variable is then displayed on the HMI screen along with any trending, if there is such a need, which depends on the programming inherent in the system. This is shown in Figure 4.4. Information/control signals can be sent back to the actuators as per the process needs. This is evident from the bidirectional nature of the communication interface.

4.2.1 Different SCADA System Topologies

Communication architectures between MTU and RTU vary as per the system complexities, number of sites to be brought under the purview of SCADA, etc. Figure 4.5 shows different architectures in which field data from different sites are brought to a central control station. Depending on the suitability, point-to-point, series, series-star, and multi-drop architectures are followed to take care of the individual site requirements. Out of the four different architectures shown, point-to-point functionality is the simplest, but at the same time, it is expensive because each individual channel requires separate connection. Number of channels can be reduced in a series

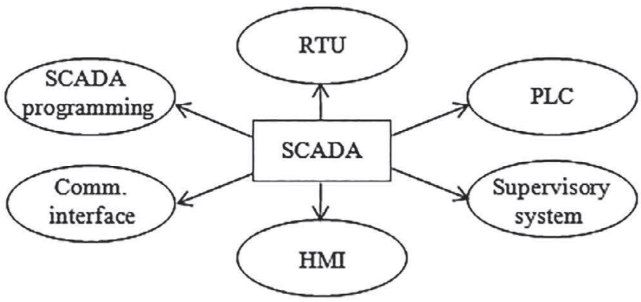


FIGURE 4.3 Components of a SCADA system.

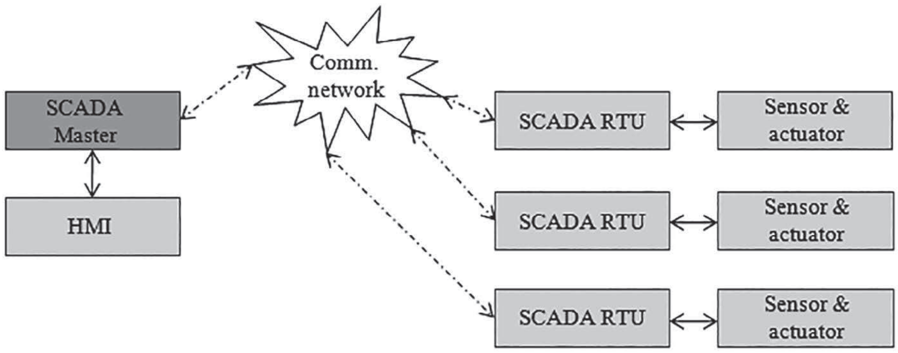


FIGURE 4.4 A basic SCADA system.

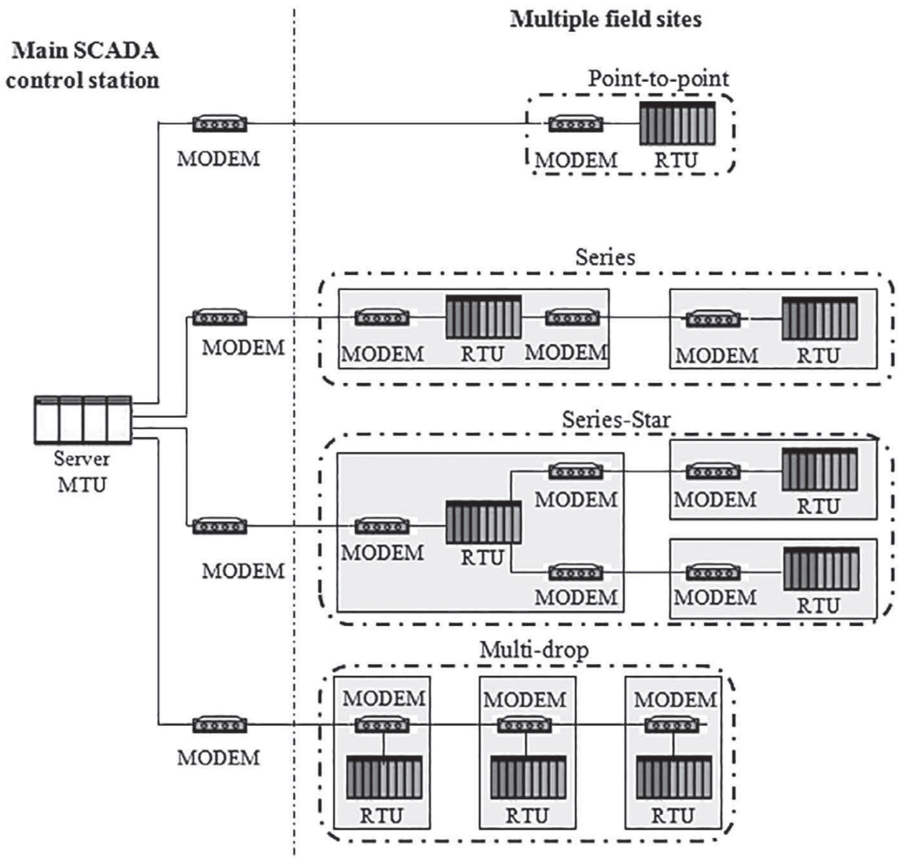


FIGURE 4.5 Different topologies employed in a single SCADA system. (Courtesy: NIST: Guide to Supervisory Control and Data Acquisition (SCADA) and Industrial Control Systems Security, Special Publication 800-82, K. Stouffer, J. Falco, and K. Kent.)

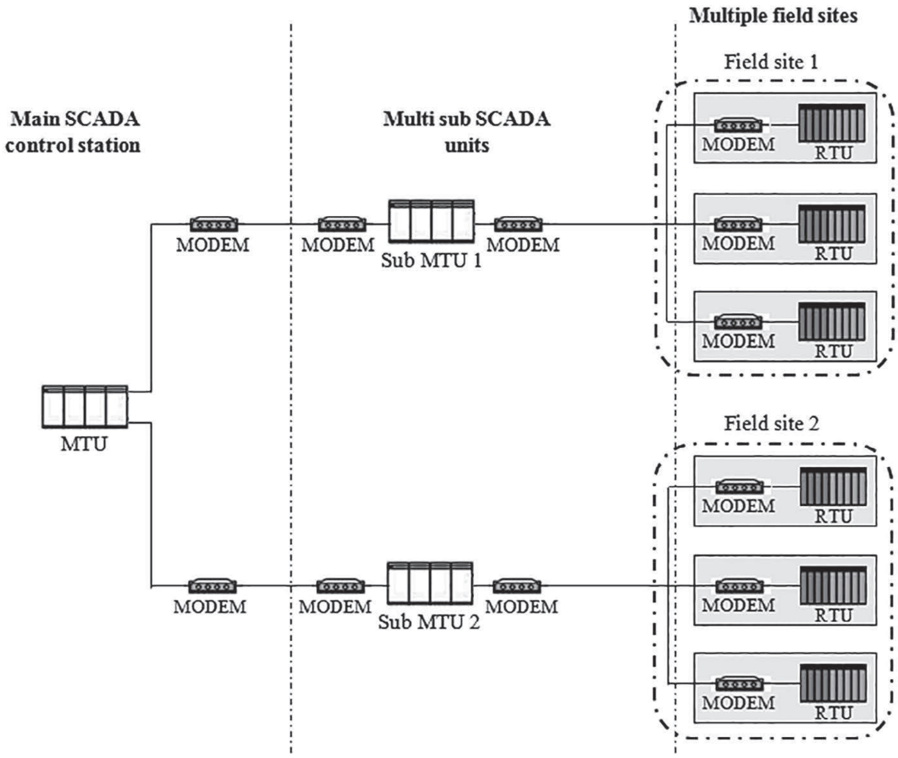


FIGURE 4.6 A large SCADA system employs several sub-MTUs. (Courtesy: NIST: Guide to Supervisory Control and Data Acquisition (SCADA) and Industrial Control Systems Security, Special Publication 800-82, K. Stouffer, J. Falco, and K. Kent.)

connection, but it impacts the efficiency and complexity of SCADA operations. Series-star and multi-drop connections are employed depending on the deployment of sensors, their numbers, etc.

A large scale SCADA system deploys several sub-MTUs, in addition to one main MTU. Such a system has hundreds of RTUs. The whole system is segregated into several subsystems and each one comes under one sub-MTU. This technique obviously reduces the burden on the main MTU. Such a scheme is shown in Figure 4.6.

4.3 EVOLUTION OF SCADA

As the need to monitor and control various processes grew over the years, a solution to the vexed issue was found in the form of SCADA. Engineers often refer to 1960 as the beginning of SCADA systems. Evolution of SCADA is based on two distinct approaches: *technological evolution* and *market evolution*.

As technological advancements continued to evolve with the discovery of transistors, microprocessors, computers and the like, sensing of process variables in the field, processing of field data, sending it to a remote location in a reliable manner, displaying it on a console at the operator's premises, and controlling the process all became a reality.

In the 1950s it was telemetry-based SCADA using telephone wires to send information to a remote location, but the next big step in the evolution of SCADA-based systems was based on the development of solid-state devices. Introduction of microprocessors in 1971 and subsequent availability of mini-computers coupled with increase in processor speed and memory size resulting in real-time data scanning, status monitoring, alarming, and data display as per the operator's choice gave a huge fillip to the widespread use of SCADA in a multitude of applications. SCADA vendors very quickly realized these technological advancements and started manufacturing SCADA systems as per the needs of the specific industries and sold them as turn-key solutions to their various requirements.

This technological evolution, coupled with the need to have intelligent, secure, and safe systems, led the vendors to develop new architectures for SCADA systems. Thus came into being the different generations of SCADA systems based on technological advancements.

4.4 SCADA ARCHITECTURE

As technology is progressing at a frenetic pace in the areas of communication, measurement, and control, SCADA – the technology which is more than 50 years old, is keeping pace with these technological advancements and constantly evolving. There is a constant clamor for technological evolution based on the need to have more intelligent, safe, and secured systems. Thus the architecture of SCADA has passed through several generations starting from monolithic, distributed, networked, and IoT-based SCADA – the last one is based on the idea of cloud computing.

4.4.1 First Generation: Monolithic

This first-generation monolithic SCADA is based on mainframe systems in which the concept of networking was absent. Thus they were stand-alone systems in which the control systems were unable to interconnect with each other. A monolithic SCADA system is shown in Figure 4.7.

Communication protocols used in monolithic SCADA were proprietary in nature and were developed by vendors of RTU equipment. The protocol permitted scanning, control, and data interchange between the master controller and the sensors and actuators of RTUs. The WAN was designed for communication with RTUs in the field only and the WANs of today are much more advanced than they were during that time.

Two identical mainframe systems—one primary and the other a backup, were used to provide redundancy in the first-generation systems. They were connected at the bus level. The backup constantly monitored the primary and in the event of its failure, used to take over the system activities.

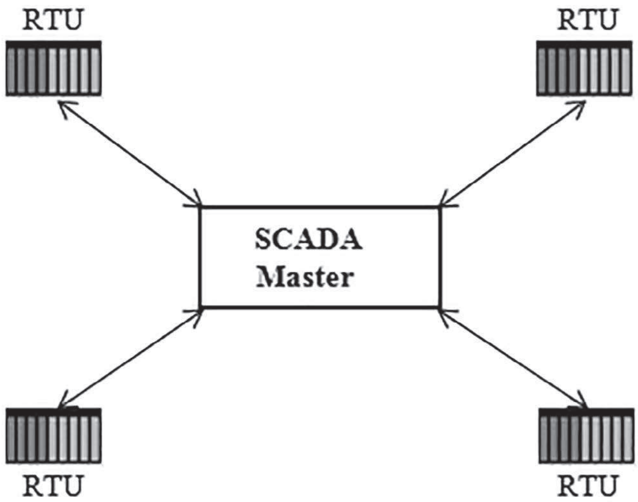


FIGURE 4.7 First-generation SCADA: Monolithic.

4.4.2 Second Generation: Distributed

System miniaturization and improvements in LAN technology led to the development of second-generation, i.e., distributed SCADA. Processing was distributed among multiple systems and multiple stations with each performing a specific function and sharing information with each other in real time. A distributed SCADA system is shown in Figure 4.8. These stations were typically of the minicomputer class and less expensive than their first-generation counterparts.

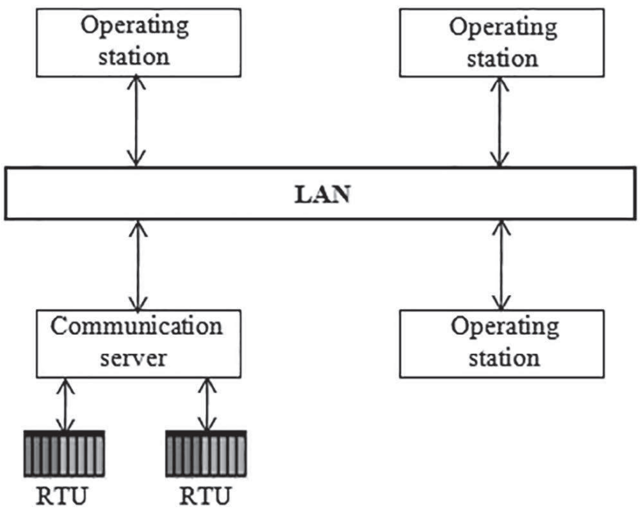


FIGURE 4.8 Second-generation SCADA: Distributed.

Some among the distributed stations served as communications processors communicating with RTUs, some as operator interfaces providing HMI, and still some served as calculation processors or database servers.

The LAN used in the second generation was based on proprietary protocols developed by vendors. This assured increased speed, real-time traffic management, and enhanced system reliability. Although the second generation is distributed in nature, since the LAN used was proprietary, they were unable to communicate with external devices.

Since the system functionalities were distributed among the network connected devices, it not only enhanced the processing power but also improved redundancy and reliability of the overall system. Distributed architecture ensured that all stations on the LAN are kept online all the time.

4.4.3 Third Generation: Networked

The third-generation, i.e., networked SCADA was developed because of the rapid industrialization, huge increase in the number of automatic process control systems, their associated complex nature and the increased need to have an open system which will be vendor independent such that seamless replacement of a device from one manufacturer can be replaced with that of the other. Thus, the third-generation transformed itself from a vendor dependent and proprietary environment to an open system architecture. An example of a networked SCADA system is shown in Figure 4.9.

4.4.4 Fourth Generation: Internet of Things

The fourth-generation SCADA architecture has embraced IoT technology to reduce infrastructure cost, better and easier maintenance, and better integration. This has

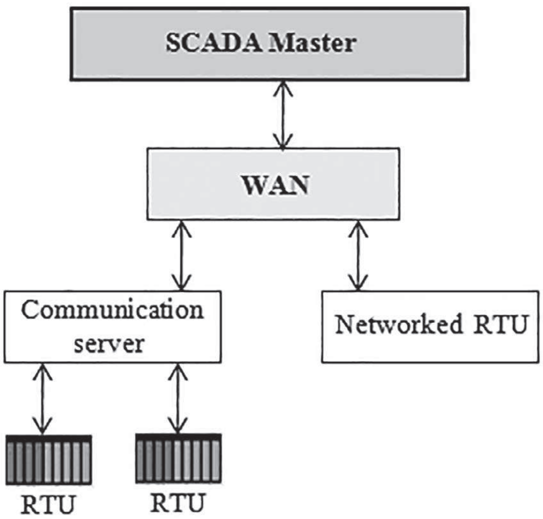


FIGURE 4.9 Third-generation SCADA: Networked.

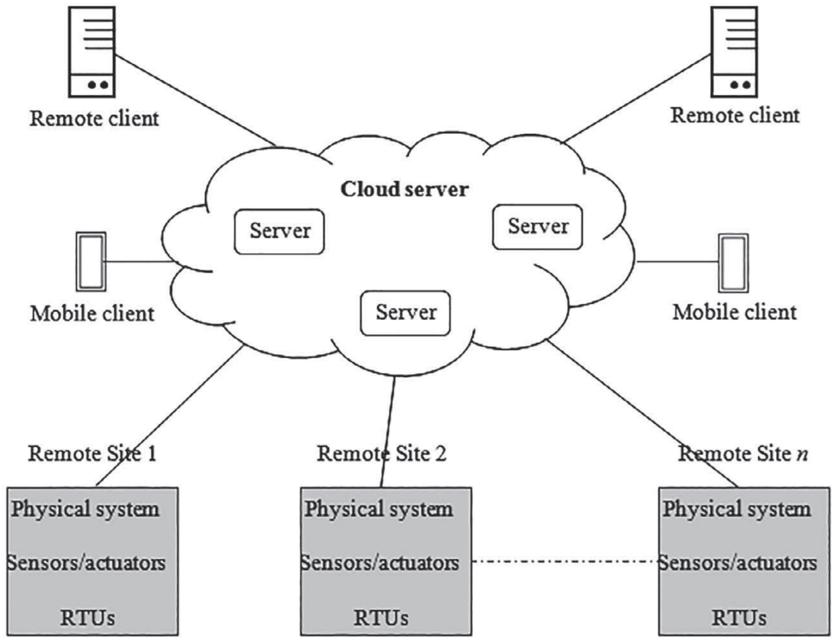


FIGURE 4.10 Fourth-generation SCADA: Internet of Things.

become possible because of the commercial availability of cloud computing. Cloud computing allows remote servers to be networked into the cloud – enabling centralized data storage.

Open network protocols available in IoT provide a well-defined security boundary which is more comprehensible and manageable. It is the common use of open network protocols, e.g., the Transport Layer Security (TLS). These protocols allow easier management of security boundaries and identify and patch potential vulnerabilities. Once a vulnerability is identified and patched, it can very easily be applied to the rest of the network using this protocol. The IoT-based architecture of SCADA is shown in Figure 4.10.

When data comes from different types of sensors, controllers, and databases, it is very likely that one-to-one mapping becomes a problem. It can be overcome by data modeling by taking the help of object-oriented programming. A data modeling is a virtual representation of a device and is constructed using SCADA software. It contains address mapping, web-based info, database entries, media files, etc. Today, communication is evolving toward platform independent, service-oriented architecture. Thus software developers of SCADA are trying to penetrate more and more into data modeling.

4.4.5 Differences Between Different Generations

Table 4.1 shows the differences between the different generations of SCADA systems.

TABLE 4.1
Differences between the Different Generations of SCADA Systems

Serial Number	Generation	Type	Differences
1	First	Monolithic	A small system, low security, independent system
2	Second	Distributed	Multiple systems connected via LAN. Moderate security risk, reduced cost with low latency
3	Third	Networked	Geographically different systems connected via WAN. More security risks involved. Communication via Ethernet, fiber-optic cables, etc.
4	Fourth	SCADA integration with IoT	Encompasses IoT-based systems with cloud computing, geographically dispersed systems. Less cost, ease of maintenance, security provided by protocols like TLS (Transport Layer security), (Secure Socket Layer) SSL

4.5 FUNCTIONS OF SCADA

In a SCADA, enormous amount of data are generated from numerous sensors, actuators, and others situated at geographically separated locations. These data at multiple locations need to be transported at a central location for storing, analysis, display, and subsequent control actions to be taken by the master control unit (MTU). Thus, a SCADA system will have to do different functions in an organized manner, which are listed below: data acquisition/collection, data communication, data presentation, and control.

4.5.1 Data Acquisition

A SCADA system monitors many sensors – both analog and digital, i.e., discrete in nature. Analog sensors continuously track the voltage or current outputs whereas the digital ones may sense the opening or closing of a relay or switch or any other discrete event. Thus a RTU has to deal with various data types – both analog and digital. Also, the number of bits made available from different sensors do vary. Thus acquisition of data is a complex job and they are coded in protocol formats by RTU before being eventually sent to MTU.

4.5.2 Data Communication

Communication between MTU and RTU may be wired or wireless, via LAN or the internet. Wired transmission includes buried cables or modems and is of low bandwidth normally. The wireless transmission may include spread spectrum, microwave, or VHF/UHF radios. For high-speed, low data rate applications, integrated services digital network (ISDN) and digital subscriber lines (DSL) are used. These systems of transmissions were in use in earlier days. Nowadays, SCADA data is put on Ethernet and IP over SONET.

SCADA data is sometimes put in closed LAN/WAN to prevent it from being accessed by open internet. Data is encoded before being sent in closed protocol format. But nowadays, it is sent in open standard protocol format. The sensor's output is encoded by RTU and sent to the SCADA master, i.e., MTU. In turn, MTU sends control commands in protocol formats to RTU, which is then decoded and proper control action is passed on to the sensors and actuators, etc.

There are two ways in which a master station can communicate with a slave station: message-based polling mode and standard polling mode.

Data transfer between master and slave is also possible by 'Polled Report-by-Exception' method.

4.5.2.1 Message-Based Polling Mode

This mode is used when the user needs to be able to limit when and how frequent the master station communicates with each slave station. Communication with slave station is non-time critical in this mode of operation. This mode is not recommended when continuous communication between master and slaves is a necessity.

A master station initiates communication with a particular slave station only when a message (MSG) instruction in ladder logic is triggered to a slave station's address. Thus this method provides complete flexibility to the user, through the ladder logic, over when and how often to communicate with each slave station.

4.5.2.2 Standard Polling Mode

It is used where communication between the master and all the slaves is time critical in nature and the SCADA system is large. It is also used for slave station initiated messages. It is not recommended for situations when the user needs to be able to limit when and how often the master station communicates with each slave station.

In this mode, master station polls each slave station connected to it in a round-robin fashion by sending one or more 4-byte poll packets to each of the slave station addresses. The slaves were initially configured by the user. This polling of the slaves goes on and is independent and asynchronous to any MSG instruction that might be triggered in the master station ladder logic.

If the master station is in the 'run' mode and a 'MSG' instruction is triggered, the said 'MSG' will be transmitted after finishing polling the current slave station in the poll list and before it starts polling the next station in the poll list. If several 'MSG' instructions are triggered simultaneously, a minimum of four message packets may be sent out between two successive slave station polls. These messages will be completed when the address of the slave station comes in the polling list and addressed by the master.

If the 'MSGs' are meant for different slave stations, they will be serviced as their turns come successively one after the other in the polling list.

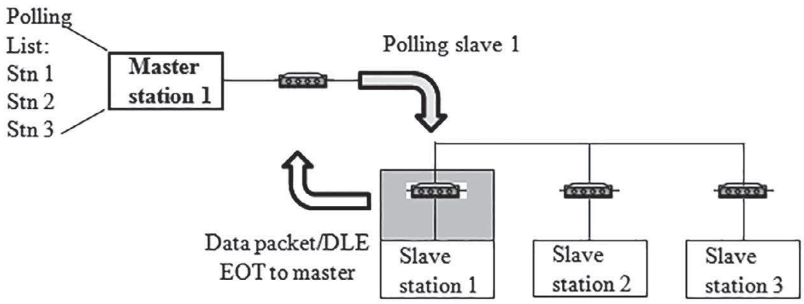


FIGURE 4.11 Polling the slaves by the master and their responses. (Courtesy: Allen Bradley SCADA System, Application Guide by Rockwell Automation.)

In this mode, there can be 'single message per poll scan' or 'multiple messages per poll scan'. In the former, a single message is transmitted from the transmit queue of the polled station. For the latter, the addressed polled station will continue to be polled until and unless the message queue becomes empty.

The active node list residing in the master is updated when a slave station responds/does not respond on being polled. In this, one bit is assigned to each of the slave station addresses (0–254 or 255 slave addresses). In case the slave station does not respond when polled, its active node list bit is cleared (reset) and if the slave station responds on being polled, its active node list bit is set. Apart from the above, the active node list can report a good/bad communication status for all slave stations (connected to it) to an operator interface connected to the master station for monitoring, alarming or logging purposes.

Figure 4.11 shows the standard polling mode of communication in which the master station polls the slaves, but the slave station whose address tallies with the address sent by the master, responds.

A master station polls the slave stations in the order the slave stations appear on the list. The connected slave station responds by sending either a data packet or a packet indicating that the slave has no data to be sent.

4.5.2.3 Polled Report-by-Exception

In this mode of communication, a slave station initiates data transfer to the master. A slave station monitors its inputs to assess any change in the input data. If it occurs, the concerned slave initiates a data transfer to the master, letting it informed that a change in data has taken place in the slave. This technique thus frees the master from repeatedly polling all the slaves in order.

4.5.3 Data Presentation

Information sent by the RTU in protocol data format is received by MTU and is subsequently processed. MTU maintains a comprehensive report of the collected data and in case some process parameter goes out of range, it immediately sends a signal, routed via RTU to the concerned controller for taking corrective action. The monitored data is displayed on an operator console in what is termed a HMI. The master continuously monitors the outputs of all sensors and displays them as per the program inbuilt into it.

4.5.4 Control

A complex modern SCADA system automatically takes care of all the controls needed in closed-loop control systems. If temperature in a furnace shoots beyond the permissible level, the system automatically regulates the heat input into it. Electricity production in a thermal plant is automatically regulated as per the consumer demand. A SCADA system can respond to variations in multiple inputs to a process. In case the automatic system fails, process control can be maintained in the form of HMI on the operator's console.

4.6 ELEMENTS OF SCADA

A SCADA system usually consists of several subsystems. The subsystems may vary from very simple, easy to implement to complex ones like supply and monitoring of water in a locality. The system consists of the following elements: An MTU, an RTU, field devices, HMI, PLCs, SCADA communication, data acquisition server, data historian.

4.6.1 MTU (Master Terminal Unit)

The master station, also called the central host or MTU, collects, stores, and processes data from various RTUs. The MTU provides an operator interface for display of information and subsequent control of remote sites. Time required by the MTU to scan all the RTUs and come back to the first one is called 'scan time' or 'scan interval'. In a complex SCADA system, several submaster stations are used which gather information from the remote sites (RTUs) and they feed back their data to the master (MTU) of the system.

The jobs performed by an MTU can be put as follows:

- It monitors/controls the entire SCADA communication system through communication link which may be LAN/WAN.
- It checks the communication link with a RTU, ascertains its present status, sends a request to the RTU for data/information, and collects the same.
- Displays data/graph visually by using HMI.

4.6.2 RTU (Remote Terminal Unit)

RTU is a microprocessor-based stand-alone data acquisition and control unit which monitors and controls equipment at remote locations far-off from the central unit or MTU. An RTU collects data from field devices, codes them in a form acceptable by the MTU. A typical RTU has analog and digital inputs/outputs. An RTU can be thought of as an advanced Input-Output (I/O) device with communication facilities embedded in it.