

Fundamentals of Distributed Control Systems / Digital Automation Systems

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Distributed Control Systems / Digital Automation Systems

In broad terms, instrumentation can be divided into two groups—primary and secondary. Primary instrumentation consists of the sensors and final control elements that are located near the process being controlled. This is an area in which quiet improvements occur continuously. Secondary instrumentation is essentially what one sees in a control room: the equipment used to indicate, alarm, record, and control.

Indicating, alarming, and recording support the principal function, which is controlling. In a continuous process environment, control in its simplest terms means keeping the process variable equal to the set point. In a batch process environment, control means keeping the process variable equal to the set point as well as ensuring that all physical events are synchronize with the sequence of events of the process recipe. Advanced control means determining correct set points or an ideal process recipe. If the control system design ensures that the right set points are being effectively maintained, then consistent and efficient process performance is the result.

Tremendous technological advances in hardware and software have enabled process automation system suppliers to move far beyond systems based on 4–20 mA signals and proprietary communications. Microprocessors now can be embedded virtually anywhere, delivering information not previously available in the eras of the PLC or the distributed control system (DCS). Today's digital automation systems (DAS) are unprecedented in speed, scope and scale.

Introduction

The technological advances in instrumentation that have improved the performance of conventional control applications include the following:

- (1) Pneumatic telemetry permitted the birth of centralized control rooms.
- (2) Electronic analog controls improved accuracy and allowed control panels to be arranged more compactly.

- (3) Digital technology (minicomputers) introduced sophisticated and advanced controls, which made it possible to do logical alarming and indication through CRTs.
- (4) Distributed control systems (DCS) initially lowered installation costs because DCS enabled control modules to be interconnected and grouped, lowered maintenance costs, improved system reliability, and made it easier to configure the process concept and expand the system.
- (5) Today's digital automation systems are built using:
 - accepted industry standards
 - totally interoperable architecture
 - the communications architecture and bandwidth to support the vast intelligence found within digital devices
 - comprehensive batch solutions
 - embedded advanced control
 - OPC, XML, and web services to integrate the process with the global enterprise
 - software to facilitate the migration from existing DCS/PLC systems to DASS.

Figure 8-1 shows other key developments and illustrates the general progression of industrial control from its mechanical regulator beginnings to state-of-the-art distributed control systems and digital automation systems.

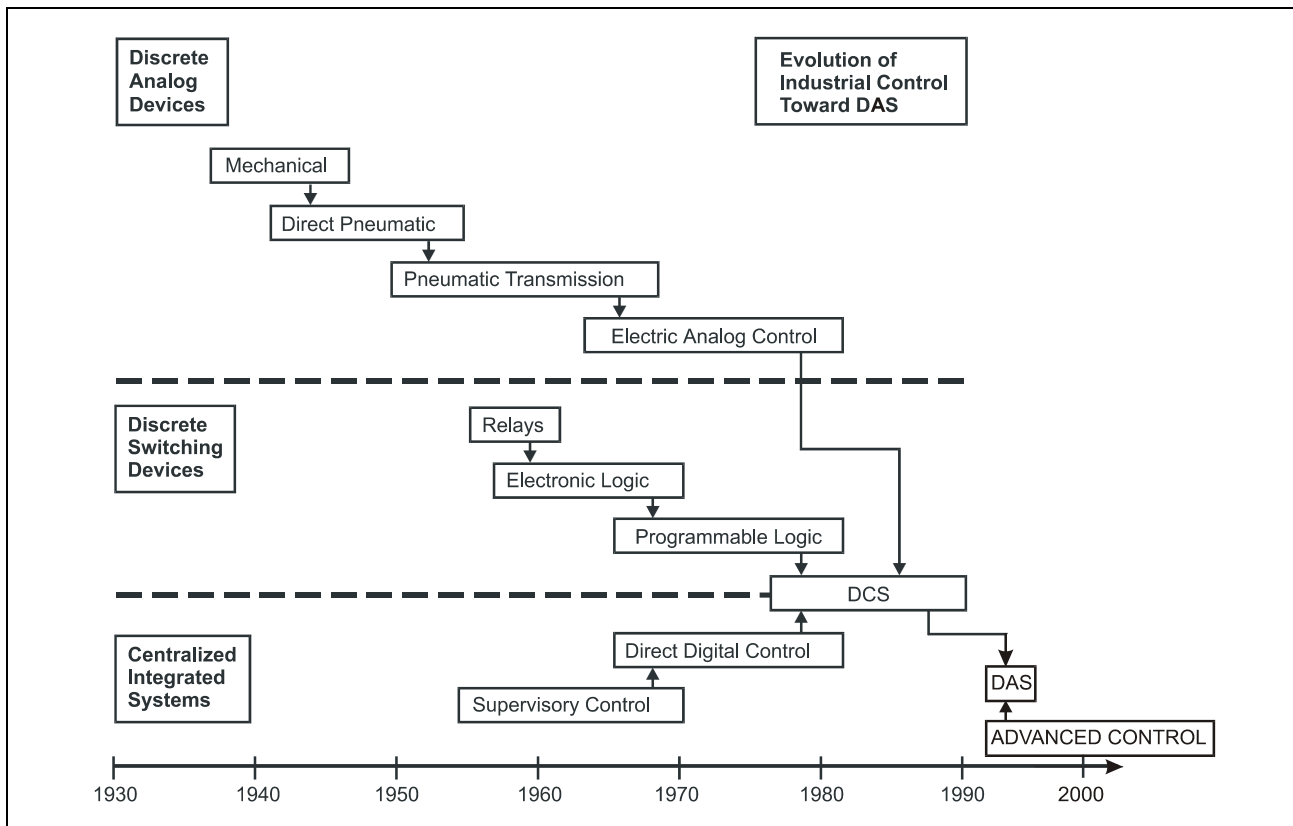


Figure 8-1. Industrial Control from Mechanical Regulator to DAS [Ref. 1]

Overview

Because of its complete dependence on computer technology, the DCS or DAS is clearly software intensive. Consequently, practitioners cannot neglect the software aspect. Nevertheless, we will not discuss advanced computer-related topics such as artificial intelligence, management information systems, optimization, simulation, and modeling in any great detail in this chapter. The implementation of advanced computer capabilities varies widely not only in terms of the way such capabilities are used but where and why they are used. Which specific choices are selected depend on the philosophy and operating needs of the individual plant.

Most DCSs or DASs provide similar capabilities in a comparatively cost-effective way for a given project. However, they may vary greatly in terms of cost of ownership. Simple things such as the ease with which the system can be started up (and restarted after a shutdown) may have profound effects on the overall cost of a DCS or DAS project. Adding a seemingly small number of extra modules or even a software upgrade can double project costs and delay startup. A DCS or DAS purchase requires careful evaluation and planning for the future.

Other factors, such as site preparation costs, ease of expansion, product obsolescence, the upgradability of hardware and software, backward and forward systems' compatibility, maintenance, training, and integratibility with other computers, are important issues when evaluating any DCS or DAS.

DCSs and DASs can also vary widely in terms of reliability and availability. Some suppliers offer proven, off-the-shelf products; some products are still in the developmental stage. Software that is continually promised but never delivered has come to be known as "vaporware." "Vendor support requirements" is a term for how much an owner can do alone before returning it to the vendor to do. Any of these factors could make the difference between an easily implemented, cost-effective computer system and a financial "black hole." Often, apparently low-cost systems turn into overbudget problems because the right questions were not asked in the beginning.

Thus, this chapter presents DCS and DAS basics in a broader scope, from hardware and software to startup, expansion, maintenance, upgrades, and purchasing strategies. We do this in acknowledgement of the fact that a DCS or DAS is a long-term, living investment rather than simply a one-time computer purchase. We conclude this chapter by focusing on solutions for migrating from legacy systems to a digital automation system.

DCS Defined

As implied by its name, a distributed control system is one whose functions are distributed rather than centralized. A DCS consists of a number of microprocessor-based modules that work together to control and monitor a plant's operations. The modules are distributed geographically. This reduces field-wiring and installation costs. It also reduces risk by distributing the control function throughout a number of small modules rather than concentrating it in one large module.

A DCS is a computer network. It differs from an office or personal computer network in that a DCS does real-time computer processing rather than the transactional processing performed by business computers. The difference between real-time and business computers is the way they execute their programs.

Business computers typically do a single program operation at a time. The program will start with some fixed data, perform a complex set of calculations, and provide a set of results. Once the program has done its job, it stops until it is instructed to run again with new data. An example would be the monthly processing of invoices by a utility company.

The real-time computer also executes its program by using fixed data, performing calculations, and providing a set of results. The difference, however, is

that it runs the same program repeatedly with updated data, sometimes several times a second.

A simple example of a real-time operation is the computerized cruise control on a car. For example, assume the speed set point is 100 kph (62 mph). The real-time computer continuously scans the car's actual speed. If the actual speed is lower, say 90 kph (56 mph), the computer will increase the speed by calculating how much more fuel to inject into the engine and then executing that increase. Similarly, if the measured speed were higher, say 110 kph (68 mph), the computer would decrease the fuel intake.

It makes tiny incremental adjustments several times a second by scanning the actual speed, comparing it to the set speed, and recalculating the fuel requirements. A DCS does exactly the same repetitive scanning and recalculating for hundreds or even thousands of devices throughout a plant.

Basic DCS Functions

The DCS, like the programmable logic controller, is connected to primary control elements such as temperature and pressure transmitters, flowmeters, gas analyzers, pH and conductivity sensors, weigh scales, contact switches, valves and motors, and so on. From these field devices it receives electrical signals, for example, 4–20 mA, 1–5 V DC, 24 V AC, and 120 V AC. The DCS converts these signals (digitizes them). Once converted, they can be used by the computer to:

- (1) control loops,
- (2) execute special programmed logic,
- (3) monitor inputs,
- (4) alarm the plant operations,
- (5) trend, log, and report data, and
- (6) perform many other functions.

Field signals are divided into two basic categories—analogue and discrete. Analogue signals are continuously variable; they act like the dining room dimmer, which can gradually change the lighting intensity in the room. Discrete signals can have only two values or positions and are thus called two-position, on-off, or snap-acting. They are often associated with contact devices, such as the light switch in a home. There is no “in between” with discrete devices—they are either open or closed, true or false, on or off.

Analog loop control often involves simply maintaining a process variable (such as temperature or pressure) equal to a set point. It is like the cruise control maintaining its set speed. Of course, many different types of control loops (feed-forward, lead-lag, cascade, etc.) are being executed in a DCS, but simple, set point-maintaining loops often account for the bulk of them.

Discrete control very often consists of simple logic statements coupled with field sensors to provide logic interlocks or process sequences. For example, consider a tank that is filled with a liquid and then heated. To protect the product and/or equipment one could use a logic interlock that says:

- (1) IF the level is below a minimum point,
- (2) THEN the heater coil cannot be turned on (or must shut off).

The process might also call for the liquid to be stirred with an agitator. The previous logic interlock could be coupled with sequencing logic that says:

- (1) First, fill tank.
- (2) Second, turn on heater.
- (3) Third, start agitator.
- (4) Fourth, empty tank.

In the sequence, the second step cannot take place until the first is completed. Likewise, the third step cannot start until the second step is completed and so on. By adding the IF-THEN logic interlock, if the level should ever drop below the minimum level, the heater would still trip off.

The Role of the Computer in DCS

Because a DCS is computer-based and all its information is in digital form, it can easily combine analog control loops with discrete logic (interlocks and sequences). The previous example in which sequencing and logic were used to control the heating and stirring of a liquid in a tank could also incorporate an analog loop to maintain a constant temperature in the liquid. As illustrated in Figure 8-2, all functions would execute simultaneously.

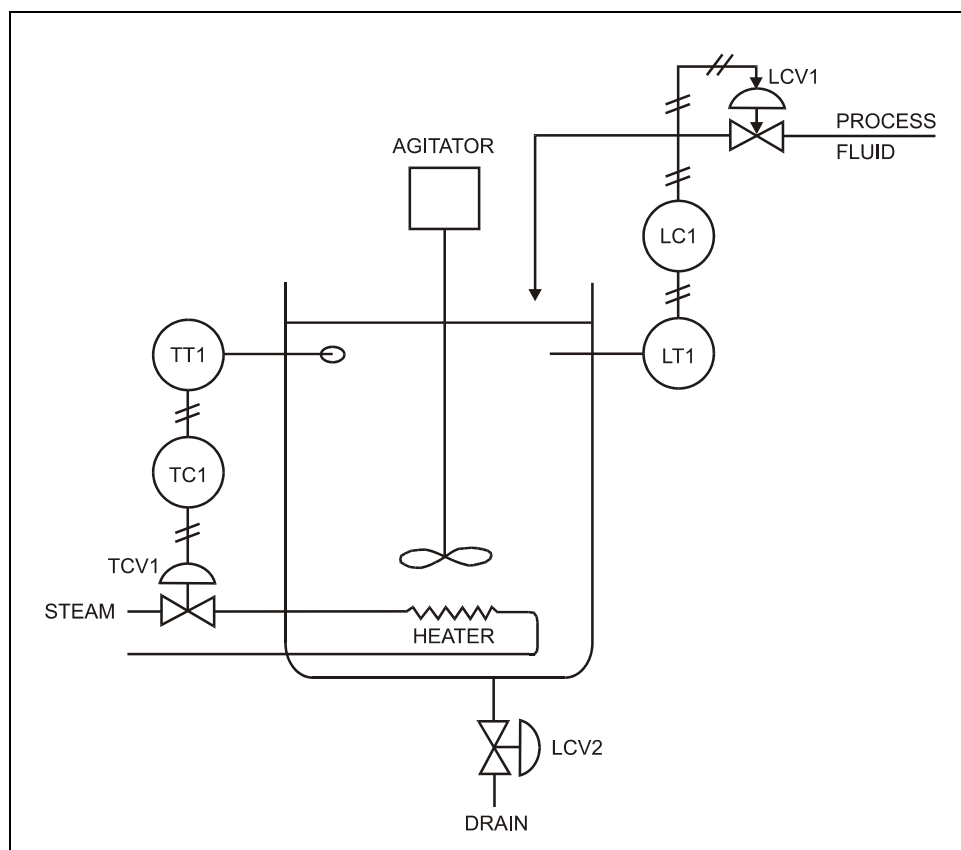


Figure 8-2. Control of Stirred Liquid in a Tank

A DCS can involve as few as a hundred inputs, outputs, control loops, and logic interlocks or tens of thousands of them. It can scan all the primary elements or sensors, characterize the input signals and alarm them, recalculate loop parameters and execute logic, and then send the results to motors and valves throughout the plant. It constantly reevaluates the status of the plant and makes thousands of

incremental decisions in fractions of a second. It is capable of all this and more for two main reasons:

- (1) A DCS is made up of many independent control modules that can operate simultaneously and independently.
- (2) It has the ability to carry out rapid communications between these and other modules by means of a communications link called a real-time data highway.

Multiple, high-speed, incremental control adjustments permit close and coordinated plant control that results in more consistent production. This close control provides a plant with the means to fine-tune the process (for example, to accommodate variations in feedstock). It also provides the means to maintain a more consistent product within process areas, thereby minimizing the amount of compensating done downstream. A more consistent product means fewer rejects and a more efficient operation.

Close control is only the first step toward efficient production. Many plants find that their process units need to make adjustments not only for varying feedstock characteristics but also for changing end product requirements and varying operating techniques. To keep track of and coordinate all these fluctuating circumstances, a DCS incorporates extensive capacity for communications, data storage, and data retrieval. This, then, is another key DCS function, because it enables plant personnel to make the right decisions by supplying information that is both accurate and timely.

Most DCSs are capable of rapidly displaying process information and storing it to be retrieved, reviewed, and analyzed at a later date. Typically, this information would be used by all the departments in the plant, from process engineering and maintenance to production and plant management. A good DCS provides the appropriate personnel with quick and easy access to the appropriate information.

Being computer-based, the DCS also offers intelligent alarm management. It can force the operator to focus on the most important alarm, thus allowing him or her to respond more appropriately to the situation. Some alarm functions include the ability to:

- (1) filter out nuisance alarms,
- (2) recalculate alarm limits,
- (3) re-alarm lingering alarms, and
- (4) prioritize alarms.

DCS and Expert Systems

To reduce costs and improve performance, DCS manufacturers are incorporating many enhancements introduced by the computer industry:

- (1) Higher-resolution CRTs
- (2) Third-party HMIs integrated into the standard DCS architecture
- (3) Migration of proprietary operating systems, applications, and networks to the more open standards available on the market today
- (4) Better networking between the control areas of complex processes
- (5) Gigabyte memory chips

- (6) Enhanced algorithms to continuously tune loops and assure that every loop performs optimally
- (7) Many more state-of-the-art technologies applied to solve classic instrumentation problems

The most important DCS enhancement, however, is a product of the great strides made by the computer industry in artificial intelligence (AI), particularly expert systems. Expert systems have already shown tremendous potential not only as a diagnostic tool but as a development aid for the control engineer.

Expert systems are attractive because they clone the knowledge of a small number of experts and then make it usable by a large number of nonexperts. This is particularly applicable in the control industry. Control systems are usually operated in the automatic mode because efficient operation in the manual mode is dependent on the skills of a particular operator. Some operators are more effective than others.

Expert systems that capture the expertise of the most skilled operators can allow less-skilled operators to perform their tasks with considerably increased proficiency. Such a technique can be used to optimize startups, optimize grade changes in a process, improve overall plant performance and execute emergency shutdowns.

DCS Architecture

Overall Structure

The structure of a DCS is often referred to as its architecture. In terms of functional modules, the DCSs marketed by the various vendors have a lot in common. This section therefore examines these functional modules from the point of view of a generic system that is representative of all manufacturers. Figure 8-3 illustrates the architecture of a such a generic system in terms of functional modules. The key word is *functional*. The modules do not necessarily represent physical components; some manufacturers may combine two or more functions in one physical component.

In addition to the process instruments (such as temperature transmitters, flowmeters, pH sensors, valves, and so forth), which are common to any process control approach, there are six generic functional modules:

- (1) Input/output or I/O modules scan and digitize the input/output data the process instruments. Some may perform elementary simple logic.
- (2) The local I/O bus links I/O modules to controller modules.
- (3) Controller modules read and update field data as well as performing the control calculations and logic to make process changes.
- (4) User interfaces include operator interfaces and engineering workstations.
- (5) The data highway is a plantwide communications network.
- (6) Communication modules provide a link between the data highway and other modules, typically controller modules and user interfaces.

Each DCS vendor has a proprietary approach, and it is possible, for example, for the functions of control and I/O to be combined in the same physical compo-

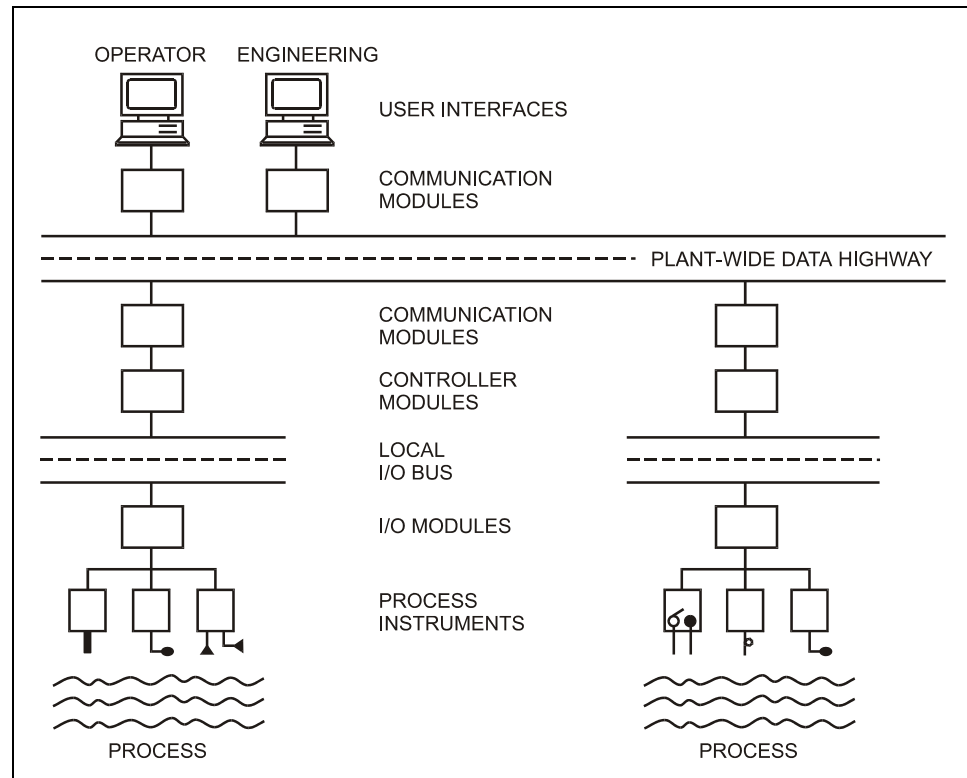


Figure 8-3. Architecture of a Generic DCS

nent. Nevertheless, it is still possible, even preferable, for a DCS to be described by means of the generic functional modules.

Input/Output Modules

Input/output modules provide the main interface between the DCS and the process being controlled. They convert the information provided by the process instruments into digital form. They also provide signal filtering and contact debouncing. In some instances, they can also do alarming, signal characterizing, and low-level logic. Four basic types of signals connect to I/O modules:

- (1) Analog inputs, also called analog ins or AIs
- (2) Analog outputs, also called analog outs or AOs
- (3) Digital inputs, also called digital ins or DIs
- (4) Digital outputs, also called digital outs or DOs

Analog inputs are gradually varying (as opposed to two-position) signals that are typically connected to sources such as 4–20 mA and 1–5 V DC transmitters, thermocouples, and resistance temperature detectors (RTDs). Analog outputs are gradually varying signals, usually 4–20 mA, that are typically connected to devices, such as valves, dampers, and variable-speed motors.

Digital inputs are typically connected to two-position devices such as limit switches, relays, and pulse contacts. Digital outputs are contact openings and closings that operate controlled devices (such as valves, dampers, and motors) in a two-position manner.

I/O modules are typically designed for varying levels of input/output loading, for example:

- (1) A single board connected to a single field device providing single-point integrity
- (2) A single board connected to a single input device and a single output device that provides single-loop integrity
- (3) A single board connected to multiple (4, 8, 12, 16, 32) inputs
- (4) A single board connected to multiple (4, 8, 16) outputs
- (5) A single board connected to multiple inputs and multiple outputs (for example, eight in and four out)

I/O modules may have separate, individual circuits, or they may share components such as analog-to-digital and digital-to-analog converters and multiplexers. Typical features to look for in I/O modules are:

- (1) Isolated or nonisolated grounding on a per-point or per-board basis
- (2) Level of fusing protection on a per-point, per-circuit, or per-board basis
- (3) Accuracy and linearity of the sampling frequency
- (4) Protection from electromotive force (emf) and transients
- (5) Immunity to radio frequency (rf) interference
- (6) Fail-safe positioning
- (7) Overload and surge protection
- (8) Impedance matching with field devices
- (9) Loop feedback sensing
- (10) Manual override of loop control
- (11) Mean time between failure (MTBF) and mean time to repair (MTTR) (field values, not theoretical)
- (12) Criticality—that is, if the board fails, an indication of what else will be affected

With these criteria in mind, one should be able to evaluate the level of reliability I/O modules provide when one compares various vendors' systems. This will indicate when and where to apply redundancy at this level.

Local I/O Bus

The local I/O bus provides a bridge between the I/O and controller modules and, by definition, is restricted in terms of geographical area and data loading. It typically operates at a slower speed than the plantwide data highway, although communication rates can range from 9,600 to 250,000 to 1 million bits per second.

I/O buses can connect any number of I/O and controller modules. The way in which I/O buses provide communications can also vary, from polling or scanning of the I/O by the controller modules to serial communications between I/O and controller modules. I/O buses can also be arranged for serial or parallel communications or a combination of both.

While I/O buses are seldom a bottleneck or a limitation, they become a critical component if they fail. The loss of a single I/O bus can affect the control of many end devices.

Systems from different vendors have different redundancy needs based on criticality and reliability.

When evaluating a system design, one is well advised to consider redundant I/O modules as a key requirement.

Controller Modules

Controller modules are the true brains of a DCS. Their primary function is to use continuously updated information from I/O modules and then perform the complex logic and analog loop calculations needed to produce the controller output signals that keep process variables at the desired values. It is at the controller modules that many DCS functions, such as the following, are performed:

- (1) I/O signal characterization
- (2) Signal filtering
- (3) Alarming I/O modules
- (4) Ranging and engineering units
- (5) Control logic
- (6) Control interlocks
- (7) Sequencing
- (8) Batch control
- (9) Passing on trending information
- (10) Passing on report information

Controller modules are microcomputers and, as such, have similar limitations. Although the numbers associated with the various types of controller modules can have a mesmerizing effect, not all of these numbers are important in one's evaluation of controller module performance. The key ones are:

- (1) available memory for configuration,
- (2) available idle time (based on a given scan rate),
- (3) I/O loading or criticality,
- (4) number of available software addresses for input/output blocks, and
- (5) number of available software addresses for control blocks.

When sizing and selecting a DCS, it is vitally important to ensure that there is enough processing power not only to serve the active I/O and control functions but also to provide some spare capacity for future I/O expansion, additional logic, and extra things such as totalizers. This is an important consideration because adding this processing power after the fact doubly penalizes the owner. First, there is the added cost of the extra modules and other associated equipment, such as communication modules, power supplies, and cabinets. This added cost is often determined on a noncompetitive basis and is, therefore, higher than it would have been if purchased as part of the initial contract.

The second penalty is inferior performance as a result of the extra loading put on the original and the new controller modules, the communication modules, and the data highway. This extra loading is the result of controller modules doing link communications instead of simple control. Link communications are those that pass high volumes of information between control processors. Such communications consume large amounts of memory and scan time in the associated controller and communication modules. This loads the data highway. A simple way to avoid this potentially reduced performance is to specify suitable values of I/O loading, memory usage, and idle time for controller modules. For example, for a given scan cycle (1/4, 1/2, or 1 s on average), one can specify the amount of spare mem-

ory and idle time to be available in the controller module after the I/O and control functions are executed. Spare memory and idle time should normally range from 20 percent to 60 percent, depending on the application. Limiting the number of I/O and control functions that a controller module executes is a good idea for three reasons:

- (1) It ensures the availability of the microprocessor power needed to carry out the specified functions and thereby simplifies configuration engineering.
- (2) It allows for easier, more flexible future expansions and reduces the risk of link communications.
- (3) It reduces the criticality of any given controller module by limiting the number of I/Os and loops controlled, thus limiting the damage caused by failure of the module.

Communication Modules

Communication modules are also microcomputers, but they differ from controller modules in function. Rather than execute control strategies, communication modules manage the flow of information between the data highway and controller modules, user interfaces, and gateways to host computers and PLCs. There is always a physical limit to the amount of data that communication modules can handle. This limit means that communication modules can at times be the source of a bottleneck, particularly when they are interfacing with numerous third-party applications or coping with the increased demand for data from PLCs.

If problems do occur, operators should check the communications rate and memory capacity. Performance improves if one either decreases the number of communication modules or decreases the number of devices served by single modules. Again, there should always be room for expansion. Communication modules are critical to the proper operation of a DCS; without them, the operator may be blind to the process.

Specifying redundant communication modules is almost always a good idea.

Real-Time Data Highway

Real-time data highways come in many variations. Topologies can be linear, loop, or star, and they may or may not include “traffic controllers.” Since a data highway is a microprocessor-based module, it should be viewed as considerably more than one or two cables strung out across the plant.



If controller modules are the brains of a DCS, then the data highway is its backbone. It is an active component through which pass the system's messages and file transfers, all in real time. Countless times each second, it updates the consoles, gateways, and other modules connected throughout the system. It is probably one of the most critical DCS modules because it is common to all other plantwide components. If the data highway should fail, operators are cut off from the process, link communications are lost, and process control is affected. The data highway is the one DCS component that should almost always be made redundant. In this case, redundant does not mean one highway is active and one is a hot standby. It means that both highways are active, which permits a bumpless transfer between highways without the need for human intervention. If traffic directors are part of a data highway, they should also be made redundant.

The following are the principal issues to be addressed when evaluating a DCS data highway:

- (1) Synchronized versus nonsynchronized
- (2) Deterministic versus nondeterministic

- (3) Token-passing versus report-by-exception
- (4) Variation in protocol types (most are proprietary)
- (5) Peer-to-peer versus collision-detection-based communications
- (6) Speed of data transmission
- (7) Maximum transmission distance

The evaluation of the security and reliability of a data highway is not straightforward because many factors are involved. Most importantly, speed isn't everything. Other key factors are module highway access, message buffering and prioritizing, and efficiency. For example, highways that are based on collision detection and report-by-exception can lose 70 to 80 percent of their rated capacity when message loading increases as a result of alarm burst and process upset conditions. Unfortunately, it is under such conditions that it is most important for the data highway to perform efficiently. Generally, one should evaluate a data highway design based on a worst-case scenario. One should consider:

- (1) the number of tags (I/Os and control loops) that are connected to the highway,
- (2) how much trending and reporting information is being transferred,
- (3) the volume of link communications, and
- (4) the number of alarm points.

Once the required data highway capacity is known, the size, number, and configuration of highways (and traffic directors) can then be specified.

Repeaters or gateways are an integral part of real-time data highways. When one data highway is fully loaded and more capacity is still needed, additional highways can be used. Two common approaches are used to permit communications between highways. The first is to link the highways together via a higher-level or so-called super highway. Each real-time data highway is joined to the super highway by means of gateway modules, which are usually redundant. This means that connecting two redundant real-time data highways together would require four gateway modules. The second approach is a straightforward highway-to-highway connection via highway interface modules. In this approach, there is no super highway acting as a go-between.

Whichever approach a plant uses, if one ends up with a requirement for multiple highways, extra costs should be expected. If the requirement happens to be “unplanned,” the extra cost could be substantial, considering the gateways, other interface hardware, software, engineering, and possibly re-engineering involved — all added “after the fact.” Sizing a real-time data highway means looking as far as possible into the future and planning for maximum loading.

Host Computer Interfaces and PLC Gateways

A requirement in many DCS applications is the ability to transfer information to and from other types of computers. This can be required for a variety of reasons, such as:

- (1) integrating the application with management information systems (MIS) computers,
- (2) integrating the application with optimizing or modeling computers,

- (3) integrating the application with production and maintenance computers or computer networks already in place (or to come), and
- (4) integrating the application with other process control computers (such as PLCs).

Whatever the situation, the distinctly different computer systems must be able to communicate with one another. That is, the real-time computer system may have to talk to NT, Windows-based, or Unix-based computers or use some of the more recent established protocols of OPC and ODBC. There is no universal agreement on operating systems (although the trend appears to be toward Windows-based platforms). However, all DCS vendors have taken the approach of using a “translator box” or “host gateway.” Typically, this gateway is a passive device in that it does not initiate communications but merely translates and transports information. Typically, it does this using a method similar in concept to that used in a post office box, as illustrated in Figure 8-4.

This method is often explained in terms of a data transfer table and is generally an efficient means of communication. It is faster and accommodates more data than an approach that uses a direct question and answer on a point-to-point basis. Gateways can also accommodate file transfers of large quantities of data, such as trend or report files, although not all gateways have these abilities.

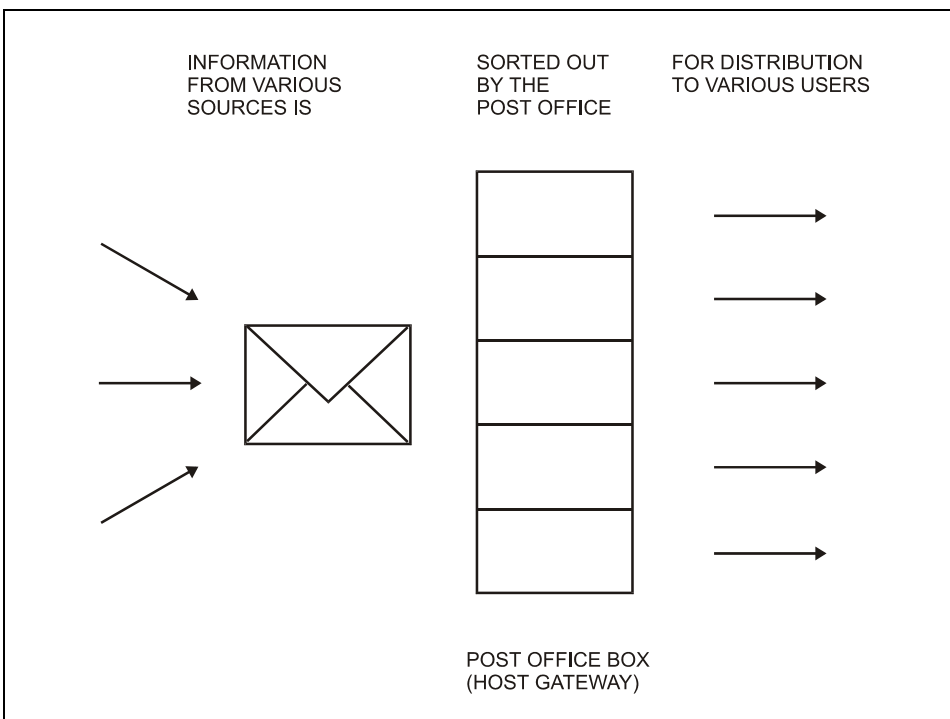


Figure 8-4. “Post Office Box” Operation of a Host Gateway

Since a host gateway module is normally a passive device that simply translates, it needs to be told what information to translate and when to read and write to the various system registers. In short, it requires a driver device with driver software to take charge of the communications. This setup is often a master-slave relationship between the DCS and the host computer.

In communications with a PLC, it is usually the DCS that is the master handling the driver software. The reverse is normally true when a DCS communicates with a host computer. It is essential to know if a vendor includes the driver soft-

ware with the interface or gateway. Proven, off-the-shelf driver software is highly preferred to software that must be custom developed. In the latter case, a user must be prepared to pay a high premium and, in addition, suffer the frustration of on-the-job debugging. Custom software development is very expensive in both the short and long terms.

While a host gateway module is passive in terms of communications, it is an active computer device. Plant personnel must therefore be aware of memory and scan-time limitations with respect to:

- (1) size of database,
- (2) speed of communications,
- (3) rate of database refresh, and
- (4) types of data accessible (for example, trend files, report files, types of live data, and so on).

DAS Defined

The timeline shown in Figure 8-5 places us at the epilogue of the technological revolution's big bang. Not since the Industrial Revolution has there been a more intense change in the way human beings conduct themselves and their businesses. Today, it is possible to buy a completely digital automation system. Of course, to anyone born in the past three decades this may seem ordinary. However, to any process engineer, operator, or technician over the age of forty this is nirvana! In this section, we will describe a digital automation system (DAS) that was built using the immense processing power and memory available only since the mid-1990s.

The main differences between a digital automation system and a traditional DCS or a traditional DCS with digital added are physical size, ease of use, scalability, and interoperability. The key factor that enabled these changes to occur is that intelligence moved to the edge of the network. End devices such as transmitters, valves, motors, and analyzers are now "smart" and have taken over control that previously was in the central host computer or distributed control computers. A smart device is defined as any microprocessor-based device. Being closer to the process, the device can spot problems, like plugged sensor lines, more readily than can the remote automation system. Users can attain a level of predictive maintenance that was not possible before the advent of microprocessors and of bi-directional digital communications using open, interoperable standards like Foundation fieldbus.

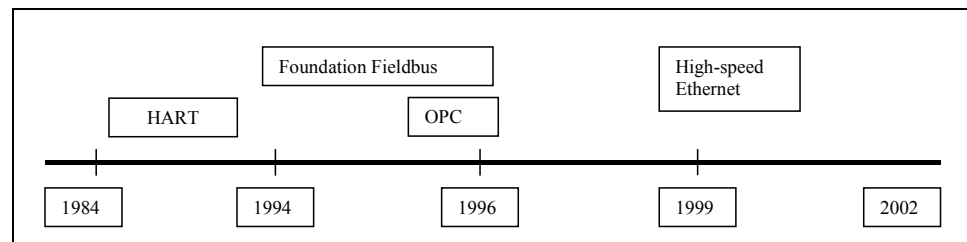


Figure 8-5. Technological Timeline

Today's digital automation system is highly complex. On the hardware side it comprises multiple PCs, client and server platforms, controllers, Ethernet-based networks, multiple digital buses, and smart devices, and on the nonhardware side,

highly sophisticated software programs and standards-based communication protocols. Using the latest commercially available technology, a digital automation system is intensely powerful yet easy to use. Unlike a control system that has added digital subsystems, a purely digital automation system is built with all-digital communications that can easily handle the volume of process, diagnostics, calibration, and asset information contained in smart field devices. The global nature of process automation makes it imperative that the system conform to many international standards set by the following organizations:

- International Electrotechnical Commission (IEC)
- ISA – The Instrumentation, Systems, and Automation Society
- International Organization for Standardization (ISO), and
- Safety and environmental organizations such as OSHA and ATEX

It must be interoperable, which means that various suppliers' devices can be used within the system and multiple third-party software systems can interact seamlessly with it. The system must encompass traditional process control. It must also errorlessly pass a multitude of additional information peer-to-peer, across the Internet, and through wireless devices. Finally, it must be able to easily interact with existing systems so as to accurately transition the data from the old system to the new.

A well-designed digital automation system enables forward-looking process companies to increase plant performance, lower associated costs, and become leaders in their highly competitive industries. By using and integrating the wealth of information the system generates, a digital automation system improves the processes that are used to make the desired product, optimizes plant operations, manages plant assets, and uses predictive maintenance instead of reactive methods to maintain the plant. Simultaneously, the business side of the plant uses some of the process data to optimize organizing, planning, and scheduling both internally and among global business partners.

System Architecture, Functionality, and Standards

Commercial, off-the-shelf digital technologies are the building blocks of a digital automation system. Enterprise-class PCs, workstations, controllers, and devices that are connected to digital buses are networked together using high-speed Ethernet-based communications, both wired and wireless. Figure 8-6 shows the architecture of a digital automation system that supports a multi-tier bus network.

Functionally, a digital automation system connects process instruments such as temperature and pressure transmitters, flowmeters, gas analyzers, pH and conductivity sensors, weigh scales, contact switches, valves, and motors to controllers via a common bus that is based on open, interoperable digital communications. Some of the most popular buses today include Foundation fieldbus, AS-i bus, DeviceNet, and Profibus DP. The Fieldbus Foundation's high-speed Ethernet (HSE) is rapidly emerging as well. A digital bus is a high-speed communications pathway between devices and the controller. Additionally, the controller connects to the PCs and workstations via a high-speed Ethernet connection so as to pass large quantities of information every second. Such broadband data flow enables engineers, operators, and technicians to run the process better than ever before and to give business managers a plethora of information to increase enterprise performance. Communications between controllers, operator stations, engineering workstations, and the enterprise use TCP-IP-based communications.

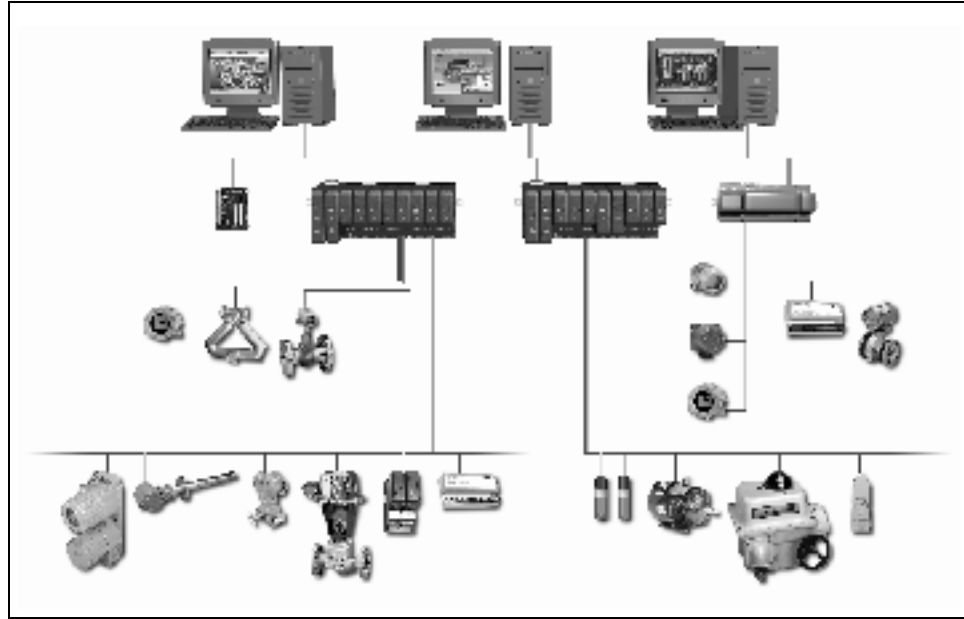


Figure 8-6. Digital Automation System Architecture
(Courtesy of Emerson Process Management)

In the past, automation systems were proprietary, meaning that the system only used one vendor's devices and communications system, and it didn't communicate with third-party systems or did so only through low-band gateways. In the mid-1990s, the influx of new technologies encouraged suppliers and end-users of automation systems to create consortiums to develop standards for automation systems. Consortiums such as Foundation Fieldbus, the OPC Foundation, and the IEC have created and implemented the standards that digital automation systems must adhere to in order to be accepted by process manufacturers worldwide. The customer's operating philosophies and plant constraints now control the process environment instead of the narrow vision of a proprietary system.

Interoperability

Interoperability is an essential design philosophy of a digital automation system. In 1996, the OPC Foundation created a standard data exchange for software communications between process automation components, the control system, and software applications. This universally accepted industry standard enables hardware suppliers to provide OPC servers or clients with their devices. Using embedded OPC communications technology, a digital automation system ensures interoperability between the devices, control system, and software applications. Similarly, XML is the data exchange standard that a digital automation system uses to communicate over enterprise LANs, intranets, and the Internet for transactional data.

The Fieldbus Foundation organization developed a standard to ensure interoperability between digital field devices. These devices, tested and certified by the Foundation, ensure communications between devices as well as with the digital automation system. This is described further in the fieldbus section (see "Fieldbuses") later in this chapter.

Expanded Functionality

The exponential increase in computing power from a conventional DCS to a digital automation system has enabled software engineers to integrate comprehen-

A digital bus is a high-speed communications pathway between devices and the controller.

sive batch solutions and embedded advanced control software, formerly done in powerful host computers, right into the process controllers.

Evolution of Communication Standards

In 1993, the HART Communications Foundation developed a standard protocol for superimposing digital information on a conventional 4-to-20 mA analog signal. This breakthrough in technology expanded communications between devices and the control system. Simultaneously, major device suppliers began selling smart devices at the same price as analog devices. The HART protocol made it possible to precisely measure analog sources and digitally communicate the information to the control system. Additional functionality—such as identifying multiple sensor types, measurement variables, product information, and diagnostic issues—produced a wealth of information from these smart devices. Process manufacturers immediately began reporting increases in reliability, accuracy, and stability using HART devices rather than conventional analog instruments. The rapid acceptance of this new technology was the impetus for the continued development of digital process technology.

Digital Buses and Devices

A digital automation system is connected to the field devices, such as valves, transmitters, analyzers, and motor controllers, by using native interfaces with the digital buses. This enables direct communications between the control system and the devices. The gateways to systems that are not architected to receive the wealth of information in digital field devices are typically limited, slow, and often require that controllers be restarted when devices are added or changed. This causes process shutdowns in many cases. Native implementations of digital buses, on the other hand, mean the digital automation system can receive the full wealth of information and automatically communicate with the digital field devices as they are added and removed without upsetting the process. Communications speed is increased and accuracy is improved, which makes the digital device/bus network more valuable to the control system. A digital automation system should be powerful enough to natively integrate a full spectrum of digital buses, thus enabling the customer to choose the best buses and devices for the plant.

TYPES OF DIGITAL BUSES

Several digital buses are available for process industry use. There are three categories of buses within this market: sensor buses, device buses, and fieldbuses. A sensor bus connects discrete devices such as on-off valves, solenoids, and proximity switches to the digital automation system. A device bus connects more complex devices such as motor, starters and drives to the control system. Finally, the highest-level bus system is fieldbus. A fieldbus connects smart devices in the field to each other and to the digital automation system. Working bidirectionally with the digital automation system, fieldbuses provide regulatory control as well as calibration, configuration, diagnostic, and predictive information. Generally, process manufacturers will use a combination of the three bus types.

SENSOR BUSES

All digital buses reduce wiring costs by connecting to multiple devices on a single pair of wires running back to the system. Additionally, digital sensor buses report status information such as failure or overflow. Previously, this information was not available. An overflowing tank was noticed because there was a puddle on the floor. A digital sensor bus system eliminates this by automatically reporting impending status. This causes a predictive maintenance solution to replace the reactive solution of the past. Beginning with low-level digital sensor buses, such

Implementing digital buses normally replaces conventional point-to-point wiring and thus yields an obvious cost benefit. To ensure that system and network performance are not compromised—no data lost due to poor distribution and loading of drops—the digital bus must be given a sound evaluation in the early stages of engineering design.

as AS-i bus, process plants decrease costs by anticipating device performance. Sensor buses are typically inexpensive and provide little more than on-off information. There is rarely diagnostic information associated with these devices.

DEVICE BUSES

Moving up in digital communication sophistication after sensor buses are device buses. Device buses connect limit switches, motors, starters, valve manifolds, and drives to the control system. Before digital device bus technology, information such as motor speed, motor temperature, and draw were virtually nonexistent or had to be collected via many additional pairs of wires and I/O channels in the automation system. An example of this would be to incorporate running amps in a motor that feeds into a control strategy so as to optimize performance. This information, combined with other improved diagnostics, gives operators and maintenance personnel abundant information by which to improve plant performance at the device level. As with the sensor buses, digital device buses such as DeviceNet and Profibus DP reduce wiring costs and decrease errors associated with manually connecting wires. The best digital device buses connect with multiple vendor devices, which makes them interoperable.

FIELD BUSES

Fieldbus is the highest-level digital communications technology. Fieldbus is based on an open architecture, which means that smart devices from multiple suppliers connect to each other and to the digital automation system. This interoperable, bidirectional communications medium surpasses other bus technologies because it can process variables, configure, control, calibrate, and pass a multitude of historical and predictive maintenance data. Fieldbus, with its high data throughput, relatively simple installation, and advanced capabilities is helping process manufacturing increase plant performance while lowering overall costs.

Fieldbus technology is highly desirable for process manufacturing because it offers reductions in wiring, predictive maintenance alerts, the ability to add devices while the system is running, field-based control, dynamic diagnostics, and asset information. In fact, studies by the Fieldbus Foundation report vast reductions in wiring, terminations, and I/O cards (see Table 8-1). Technology has dramatically improved at the edge of the network. Smart devices connected to a digital automation system significantly improve process performance because they are capable of efficiently processing a wealth of information, including providing advanced control and predicting impending abnormal situations. Process manufacturers are avoiding shutdowns, improving quality by reducing variability, and seeing a return on investment (ROI) because of interoperable, totally digital automation systems.

Table 8-1 Reductions Using Foundation Fieldbus

Task	Percentage decrease
Field wiring	74
Control room space	93
Field device commissioning time	80

Footprint is significantly reduced when Foundation Fieldbus is used. The full cabinet in Figure 8-7a handles 320 inputs and outputs (I/O). The nearly empty field-based system cabinet in Figure 8-7b is shown with 384 I/O.

As with sensor and device buses, there are a number of fieldbus manufacturers. Distinguishing such factors as quality of product, price, availability, and available support help decision makers when choosing a product. However, the

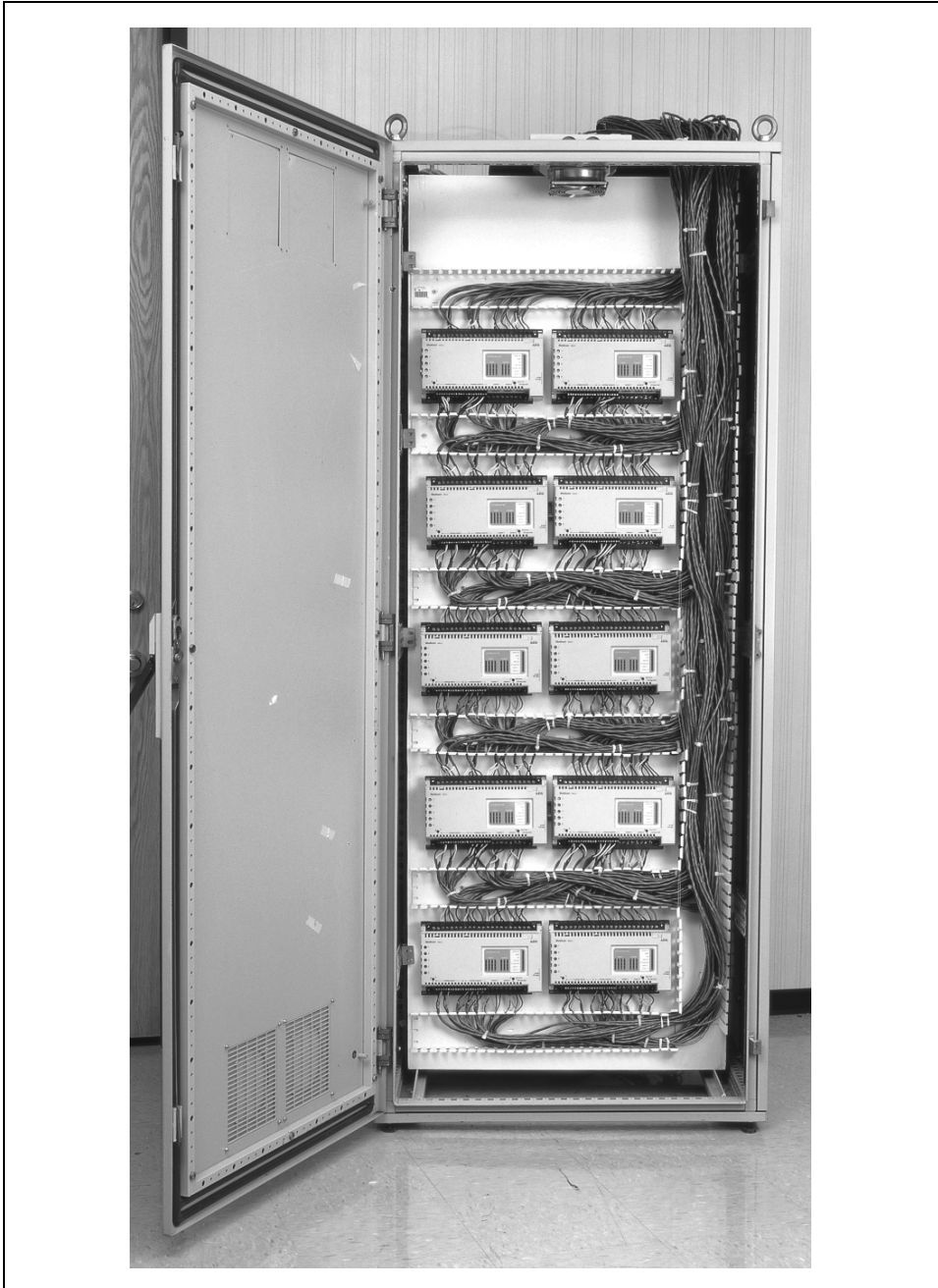


Figure 8-7a. I/O Cabinet Layout Using Conventional Wiring
(Courtesy of Emerson Process Management)

deciding factor for digital bus networks and devices is interoperability. Innovative manufacturers of digital buses and devices are keenly aware of the importance of creating products that meet the needs of the process industry.

Batch

Process manufacturers must adhere to strict regulations and requirements, especially in batch processing environments. Impeccable record keeping is imperative to satisfy government regulations and continuously improve quality. Internationally defined standards such as ANSI/ISA-88.01-1995 – Batch Control Part 1: Models and Terminology, Namur NE33 Batch, IEC 61131-3, ISO 9000,



Figure 8-7b. Cabinet Footprint Using Foundation Fieldbus
(Courtesy of Emerson Process Management)

and the FDA's 21 CFR specify the requirements for good manufacturing practices (GMP) in the design of batch systems. Digital automation systems that follow these standards have an advantage over both legacy systems and loosely developed batch processes in the following ways:

- The five standards just mentioned have defined a physical and functional batch control architecture that creates logical coherence throughout the system.
- A digital automation batch system that conforms to the accepted industry standards ensures an integrated batch control environment.
- A digital automation system batch environment seamlessly integrates the applications of the process with each other and with information systems, beginning with recipe management (configuration) through to batch execution, production planning, and scheduling and ending with batch history and analysis and reporting.

Once again, the giant leap in processing power has made it possible to create a powerful batch-processing environment. Only automation systems built with all-digital communications can achieve this level of integration. A single, global database, not previously possible, enables seamless interaction between recipe management, batch execution, production planning and scheduling, and batch history,

analysis, and reporting. Controller memory capacity, recipe size, and phase logic all have an impact on batch performance. However, the advanced, efficient communications of a digital automation system greatly increase the power of a batch system. The digital automation system ensures the transparent, continuous flow of batch information between the PCs, servers, and controllers, including configuring and processing recipes, allocating equipment, phase-to-phase communications, collecting and reporting history, and communicating with third-party software. The result is diminished process variability and increased plant performance.

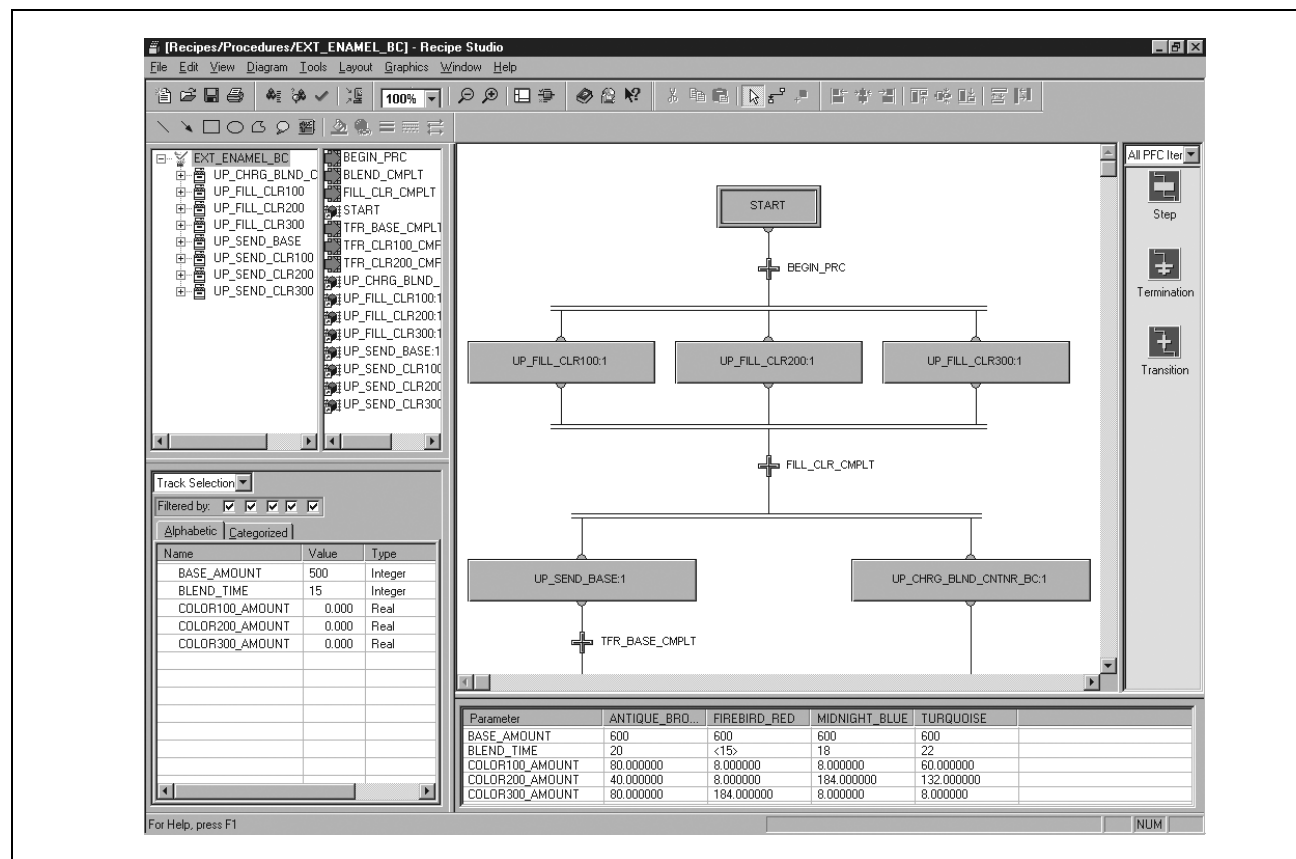


Figure 8-8. Phase Logic Graphical Construction Using IEC 61131-3 Sequential Function Charts

The importance of following the ANSI/ISA-88.01-1995 and IEC 61131.3 batch design standards cannot be overstated. By implementing these batch environment standards, digital automation system manufacturers and users are ensured of a common protocol in recipe management, batch execution, and historical collection.

Advanced Control

Today's technology makes it possible for intensive computing applications such as advanced control to be embedded in the digital control system. The vast amount of processing power and speed now available are enabling advanced applications to become integral parts of the digital automation system. These applications include automatic variability inspection, tuning, fuzzy logic control, model predictive control, simulation, and plant optimization. Advanced applications bring precision control to the process. This precise control increases plant ef-

efficiency by reducing process variability, thereby increasing product quality. In the following paragraphs, we will discuss three advanced control applications found within a digital control system.

AUTOMATIC VARIABILITY INSPECTION

Process variability and under-performing loops are two major contributors to poor plant performance. In the past, only severely under-performing loops would send a process alarm to the operator. To correct the abnormal condition, engineers would perform calculations manually. Now, digital automation systems automatically and continuously monitor all process variability and control-loop performance. The application automatically calculates total standard deviation and capability standard deviation. The total standard deviation provides a continuous measurement of process variability. Abnormal loop conditions such as improper mode, limited control, uncertain process variability, or excess variability are graphically displayed on workstations. The additional functionality of this advanced control provides quantitative measurements of the amount of variability that could be reduced with optimum control loop performance. Also, this inspection application reports the frequency with which control loops operate in the correct mode. As Figure 8-9 shows, this wealth of information is presented in an easy-to-follow format. Taking advantage of this detailed information, plants can implement additional advanced control applications so as to expertly tune and calibrate control loops.

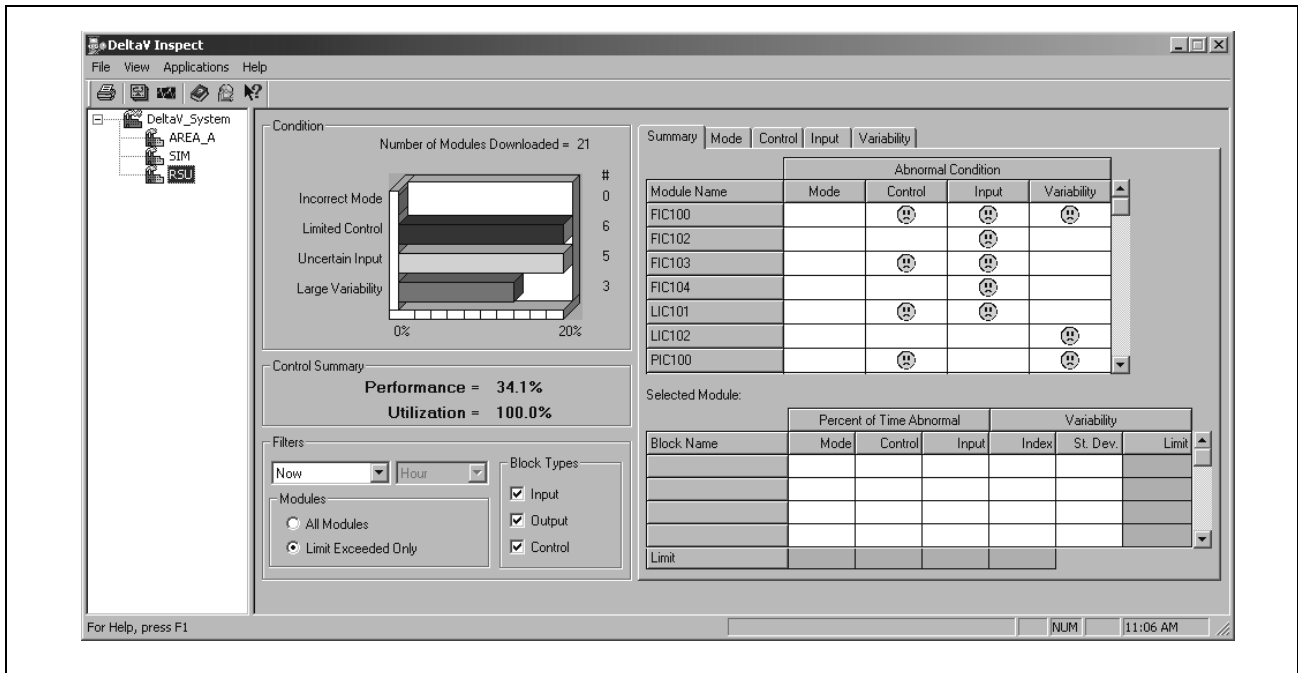


Figure 8-9. System and Process Diagnostics
(Courtesy of Emerson Process Management)

TUNING

Until the advent of digital automation systems, it took an expert to tune a control loop for optimum performance. Now, measuring process dynamics and calculating tuning constants are simply a part of the dynamic digital automation system. Process manufacturers that do not employ a digital automation system with advanced control have many improperly tuned loops. And these poorly tuned

loops mean lower quality, lost production and reduced profits, along with potentially costly environmental and safety issues.

The interoperability of a digital automation system is a crucial factor in achieving optimally tuned loops. Malfunctioning transmitters or sticky valves prohibit proper tuning under any circumstances. In a digital automation system, smart devices communicate diagnostic and health information, which ensures that tuning is only performed on fully functioning components. Once underperforming loops have been detected, the advanced tuning application automatically calculates gain, rate, and reset parameters to expertly tune all loops. Advanced tune applications also can provide simulation and analysis information that enables users to predict control loop performance before the new tuning is used.

FUZZY CONTROL LOGIC

Traditional proportional, integral, derivative (PID) control has been the standard method for loop control in process manufacturing. However, digital automation systems have improved this method with automating fuzzy logic. Before digital automation systems existed, expert knowledge of fuzzy mathematics was a prerequisite for using fuzzy logic control. Now, high-speed digital automation systems running fuzzy algorithms are improving PID loop performance by 30 to 40 percent. Fuzzy advanced control responds faster than PID control to set-point changes and load disturbances without overshoot. For example, in temperature and composition loops where overshoot can ruin the product, fuzzy logic's response curve provides better control. Also, fuzzy advanced control stabilizes loops that have noisy process signals better than does PID control. Before digital automation, PID control was the workhorse of process manufacturers because fuzzy was too difficult. Digital automation systems have taken the complexity out of fuzzy so that process manufacturers can get superior performance out of their control loops.

OPC is a standard interface that makes it possible to develop interoperable applications for servers and clients, makes possible multi-client/server architecture, allows local and remote server access, and manages real-time information.

Communications

Since Windows 3.0, multiple applications have been running simultaneously and exchanging data with each other. The tools that enable diverse software applications and platforms to communicate with each have become more robust, flexible, and faster as technology has advanced. Following are some of the more commonly used communication applications.

OPC and DCOM

For process manufacturing, OLE (object linking and embedding) for process control (OPC) client/server technology, the industry standard, enables software components to directly communicate over a network. Digital automation systems use this technology to integrate multiple applications into common databases for viewing, archiving, and managing data.

There are multiple OPC specifications within the OPC standard, which creates a truly open, interoperable architecture. These multiple standards support real-time data communications for process data, alarm and event data, historical data, and batch data. This standard protocol has eliminated the need for custom device drivers, which were the norm for legacy systems. Hardware vendors now provide a standard OPC server or client with their devices. The OPC specification is a natural part of the digital automation system. Interoperability is ensured, and process manufacturers now have the freedom to choose the best devices for the process. OPC creates a common interface for all applications and platforms. It reduces costs associated with implementing and maintaining applications and eliminates the need for custom-made device drivers.

Windows applications that enable the user to access automation objects from other applications are called OPC Clients. OPC is based on the Microsoft OLE/COM technology. OLE automation provides data access via a local area network (LAN), remote sites, or the Internet. COM enables objects to be defined using methods and properties.

Local: The server and the client are on the same PC.
Remote (DCOM): The server and client are on different PCs.

The Distributed Component Object Model (DCOM) is a protocol that enables software components to communicate directly over a network in a reliable, secure, and efficient way. DCOM has the potential to completely hide the fact that software applications are running on different computers. Customers and vendors alike thus realize significant integration cost savings.

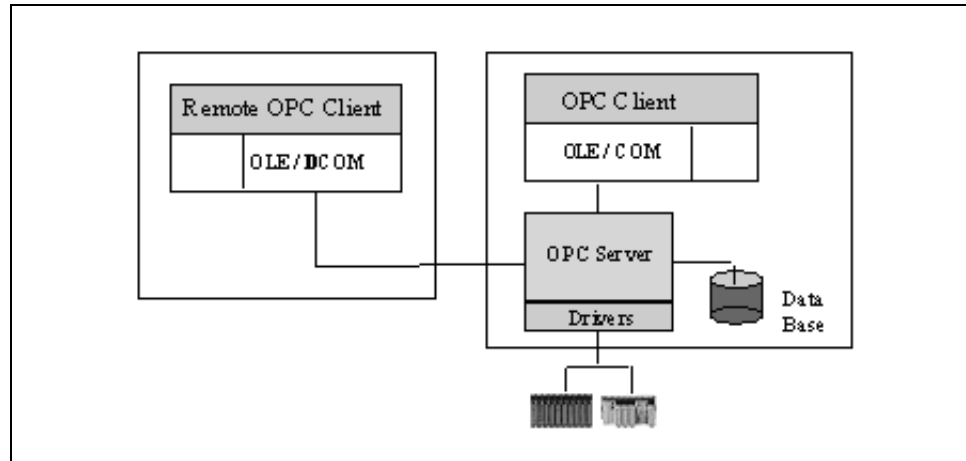


Figure 8-10. OPC/DCOM Local/Remote Architecture

XML

XML (for “eXtensible Mark-up Language”) is a data definition standard that is currently being used in all industries to exchange business data across intranets and the Internet. Current global business trends such as enterprise resource planning (ERP), customer relationship management (CRM), and online learning are promoting the use of XML. Digital automation systems use XML to integrate themselves with these latest business applications. For example, a digital automation system can integrate a production control system with the maintenance system so the equipment proactively generates work orders. Then, it delivers inventory information to suppliers for the purpose of inventory management and plant scheduling. Working with the ERP system, production schedules and quotas are automatically delivered to the production control system.

Another example of XML’s diverse functionality is communicating device alerts to the appropriate personnel. A digital automation system can send device alerts along with instructions on how to fix the problem to a pager, cell phone, PDA, or workstation. This embedded functionality of digital automation systems goes far beyond the capabilities of DCS or PLC systems simply because these systems were written before XML existed.

Power Distribution System

Power distribution is the part of a DCS and DAS that is most often overlooked, and, like the real-time data highway, the power distribution system is a system component that is linked to all other components in the system. It is the DCS and DAS component that takes raw electrical power, converts it, conditions it, and regulates it for all the other computer modules in the system.

The typical power distribution system can be split into two parts—bulk power and power regulation. With bulk power, the key issue is to ensure that variations in the main AC source do not exceed the capabilities of bulk power supplies. Battery backup, usually mentioned in the same breath as bulk power supplies, may take various forms: an uninterruptible power supply (UPS), separate battery

packs, or integral battery packs. Whichever approach is used, the batteries should be able to take over instantaneously if power fails or dips. Loss of power to the microprocessor modules could erase some sections of memory and also require the system to be rebooted. Battery backup is sized to keep the system energized long enough to meet essential needs. Typical backup times may range from two or three minutes to two hours.

Power regulation is also vital to the operation of a DCS. Nevertheless, redundant power regulation is recommended for most system modules and most applications.

User Interfaces

In many industries, the user interface has undergone quite a revolution over the past fifty years. Given the complexity of today's processes, engineering personnel as well as for process operators need user interfaces. In the days of smaller and simpler industrial plants, manual control was the first form of operator interface. An operator would walk a tour, check tank levels and pressure gages, and adjust valves. As industrial operations grew in size and sophistication, tours became longer, and more operators were required. Adjustments became less straightforward as processes became more interrelated. Manually collected data became less helpful in providing a true picture of what was going on.

With the advent of relay logic panels and pneumatic transmission the concept of a centralized control or monitoring room emerged. For the first time, information was brought to the operator. However, the centralized information was incomplete, and what was there tended to be unreliable. Consequently, operators still made their tours, reading strip-chart recorders and local panel indicators.

Electronic analog controllers and PLCs soon made possible more precise, cost-effective, and reliable control. It also made for a more centralized control room. Fewer operators were required for ever larger and more complicated plants. However, since much of the old pneumatic control equipment and relay panels still existed, manual intervention was still necessary, and operators continued to do their tours. If an operator went out for an hour or two and a process upset occurred just after he or she left, it could be some time before it was corrected. Off-spec products and rejects usually the result.

In the late 1960s and early 1970s the first digital computers emerged and were quickly followed by the first CRT-based display stations. For the first time, virtually any instrumented information about the process was available at the touch of a button.

Since then, CRT-based consoles have increased in power, speed, and reliability. They permit almost instantaneous access to measured variables throughout even the largest production plant. Single control centers that operate entire paper mills, steel mills, and refineries are increasingly replacing the multiple operator rooms distributed throughout a site. Today, plants use common operator interface stations with multiple displays on a single CRT, reducing the number and types of consoles required.

The operator or human-machine interface (HMI) is the “razzle-dazzle” module in a DCS. It is the one device that strongly influences people's perceptions of the entire DCS. An impressive operator interface translates into an impressive DCS. The question is, “Is this just a pretty face or is the beauty more than skin deep?” The answer to this question depends on the extent to which the following features are present:

- (1) access to and size of the database,
- (2) integrity of information,

The power distribution system is not a high-cost DCS component, but it is important and should not be skimmed on. It is highly recommended that plants planning for their future power needs and use partial loading of 50 percent to 75 percent of the rated capacity. Redundancy in bulk power and power regulation is a wise investment.

- (3) speed (static and dynamic) at which the screen (or image) builds, and
- (4) reliability and redundancy.

Operator interfaces come in many different configurations, with very different capabilities and methods of operation. Some operator interfaces are still “tag limited,” that is, they are restricted to the size of database they can access. DCS vendors offer PC-based interfaces in consoles that range in capacity from five hundred to ten thousand tags. These interfaces usually have a live RAM-resident database that duplicates the database that resides in the I/O and controller modules.



This RAM database is continually updated from the field, and screen-display information is continually refreshed from it. One should be cautioned here that the operator sees information from the interface database and not directly from the field measurement. If the system operates on a report-by-exception basis and communication is lost, the operator could be unaware that the process is doing something completely different.

So-called display-based consoles do not use a RAM-resident database. These interfaces store various display pages, whose dynamic points will be refreshed directly from field measurements when the pages are loaded onto the screen.

The time it takes to refresh a screen image (screen build) is an important factor to evaluate when considering an operator interface. A screen display is usually divided into areas of static and dynamic data. Static data is associated with objects (such as boxes, tanks, pipes, and valves) that do not change (except for color, flashing, or reverse video) with the process. They are a fixed part of the display.

Dynamic data consists of live field data such as process-variable values, loop set points, controller outputs, and contact status. It is information that is constantly updated, or refreshed, on the CRT.

Screen builds can be as fast as 1/4 second and as slow as 2 to 15 seconds. This speed can be affected by things such as:

- (1) size of display page (amount of static information),
- (2) number of dynamic points on display pages,
- (3) location of resident display pages (hard or floppy disk), and
- (4) use of display pages from another highway module.

Typically, RAM-resident display pages that have few dynamic points will build very quickly. Screen build times could be much longer if an interface has to display many dynamic points that are scattered throughout a plant and have to travel over a busy data highway.

Some operator interfaces have a multitasking ability—that is, they can carry out several functions at the same time. Thus, while an operator is using the interface, activities such as trending, reporting, and alarm and event logging are going on in the background. An operator interface can sometimes be configured to act as an engineering workstation as well. These extra tasks should not affect the fundamental purpose of the interface, which is to give the operator an efficient window on the process being controlled. This should not be a problem if the added functions are treated as enhancements to the interface.

Multitasking operator interfaces cost more than the single-tasking units, but they can be more cost-effective than buying a number of separate single-tasking units.

Another important factor to consider when evaluating an operator interface is how many the job needs, including the associated hardware. The following are typical choices:

- (1) Number of CRTs
 - one per operator
 - three CRTs for two operators
 - two or more per operator
- (2) Number of sets of electronics
 - one per CRT
 - one per two or more CRTs
- (3) Number of hard disks
 - per interface
 - per electronics

In evaluating a plant's needs, it is a good idea to imagine what happens to the operator if any one component fails. For example, if there are four CRTs, two sets of electronics, and two hard disks, one would ordinarily expect to be secure. However, if the electronics are each handling separate databases and one fails, part of the plant may be running blind simply because it cannot access the other's database. Running blind may not necessarily be fatal, but it is generally considered unsafe. Such a situation can be readily prevented with today's interfaces, which allow appropriate levels of flexibility and redundancy to be built in.

Interfaces tend to be expensive modules in a DCS. Adding them in an unplanned way often leads to a budgetary problem because added equipment and engineering is required.

Operator Interface Hardware

The operator interface hardware consists of CRT displays, keyboards and other access devices, and hardcopy devices. It also includes power supplies, disk drive units, and card files.

The CRT video display unit is the main interface component. It is the vehicle by which system users operate, control, and manage the entire control process. CRT displays replace the conventional analog control panel, and they provide the user with an easy view of the process through a hierarchical series of displays. The layout of the various components depends on the manufacturer as well as the user's preferences. In principle, however, the interface should be designed to increase the operational capabilities of the people who use it. In other words, it should follow good ergonomic design principles (see Chapter 10).

CRT DISPLAY MONITORS

CRT monitors operate through a dedicated video module that has its own processor, which may support alphanumeric keyboards, mice or trackballs, and an alarm horn. The sizes of color monitors vary from nineteen inches to twenty-one inches and larger. Monitors may be mounted into a workstation or on a desktop, and newer models can be flat-screen. The video information monitors display may include text, charts, and graphics.

Monitors may include a touchscreen display as an optional feature. With this option, the user selects display objects by touching a menu on the screen. This is accomplished by means of infrared LEDs and phototransistor detectors that are mounted opposite one another on the front surface, forming an invisible lattice of infrared light beams. Each time the beams are intercepted, either by a finger touching an object on the screen or by a pointing device, a signal is sent to the processor that indicates the position of the selection.

ALPHANUMERIC KEYBOARD

The alphanumeric keyboard is a regular computer terminal keyboard, with the standard QWERTY key arrangement and ASCII-formatted output. It may have additional keys to help the engineer configure the data base, build displays, and set up system application packages such as historical trending.

OPERATOR KEYBOARD

The operator keyboard is a specialized device that is designed to make the operator's interaction with the process faster and easier. It can be a full-stroke keyboard or a spill-proof membrane style with tactile feedback. Various dedicated keys allow an operator to select important functions with a single keystroke. The actual layout of the keyboard varies with the DCS supplier.

Some keyboards contain an annunciator section with light-emitting diodes (LED) and a Mylar key switch. Each LED can be configured by the user as ON, OFF, or FLASHING, according to process conditions. The numeric section contains numeric and data-entry keys and cursor control.

TRACKBALL AND MOUSE

The trackball is a cursor control device. It allows users to control the cursor position by manually rotating a mechanical ball whose position is converted into data signals that are equivalent to those generated by the normal cursor control keys. The trackball also has a push button to acknowledge alarms and messages and to select an action, as one would do with the "Enter" key on a regular keyboard.

The mouse is another table-top cursor control device. When the user moves the mouse across a surface, an internal mechanical ball in contact with the surface rotates, generating cursor control signals similar to those of the trackball. Acknowledge and Enter push buttons are also provided.

HARDCOPY DEVICES

Hardcopy devices include printers. The printer is used for alarm and event logging, graphics, and reports. Printer output may be in color or in black and white. With a color printer, a user can print blocks, characters, and graphics with different colors. Alarm conditions can print with a different color to distinguish them from normal operator actions.



Figure 8-11. Operator Interface Hardware

Operational Philosophy

The role of the operator can be described in terms of the four plant conditions given in Table 8-2.

Level 1 - Steady-state operation. In a steady-state plant condition, the operator's role is normally limited to maintaining an overview of the whole or part of the process plant and to monitoring the trend records of key variables or variables that are in an acknowledged alarm condition.

Table 8-2. Plant Conditions and Role of Operator

Level	Plant Condition Description	Operator Mode Description
1	Steady-state operation	Overall process surveillance
2	Minor plant/unit upset	Unit and section monitoring
3	Planned startup/shutdown or feed changes	Interactive
4	Major plant upset or emergency	Priority loop Interaction

Level 2 - Minor plant/unit upset. When a condition of minor upsets occurs on a particular section of the plant or when the operator anticipates an upset as a result of changing conditions in a related process area, the operator needs to take a closer look at the plant area in question. In this mode of operation, it is essential that the operator have easy access to a summary of the loops involved as well as to the related trends. Usually, two CRT consoles are required to maintain sound process control. While the operator looks at the individual loops, a standby overview display should be on all the time.

Level 3 - Planned startup/shutdown. In this operational mode, the operator's information needs are similar to those in the previous unit-monitoring mode. However, in this mode the operator is now interacting with the process because he or she needs to change and manipulate the control loops.

Level 4 - Emergency/major upset. In a major upset condition the operator's interaction with the system is the most intense. It is essential that he or she be able to access the required information and manipulate the available parameters of the priority loops with speed and simplicity. The operator should format special page displays giving status and multitrend reports in advance so they can be used under upset conditions, while recognizing full well that there can always be an unpredictable major upset. In this situation, the judgment of the operator, in conjunction with the process's parallel safety interlock and shutdown systems, should override any predefined procedures.

Interface Displays

The specific configuration of each operator console and the number of consoles required will depend on the type of plant involved. Regardless of the configuration, however, when the system is powered up, the first screen displayed is usually the main menu, which can be retrieved at any time during operation. Interface displays are described in terms of:

- (1) display hierarchy,
- (2) plant overview displays,
- (3) trend displays,
- (4) alarm displays, and
- (5) graphic displays.

The display hierarchy is a sequence of different displays that take the operator from the general to the specific, for example, from a plant overview display to a group display that shows one group, unit, or individual loop. Figure 8-12 illustrates a typical display hierarchy.

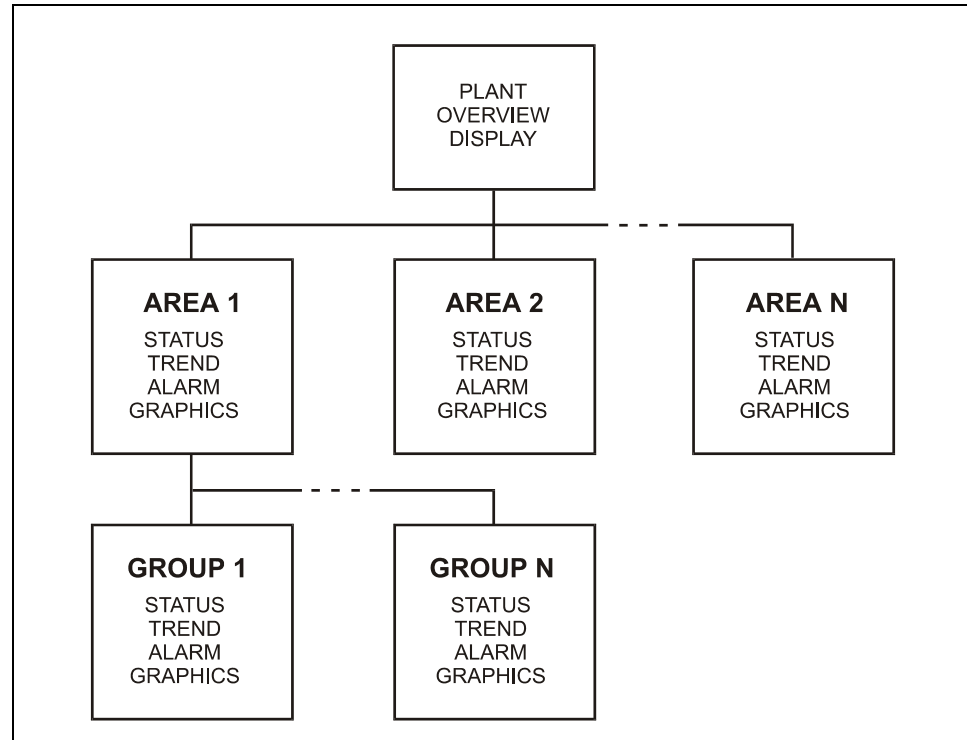


Figure 8-12. Typical Display Hierarchy

The plant overview display includes the name of the process area, bar graphs of normalized deviation, color alarm blocks, a list of alarms, and the date and time. The actual display configuration would depend on the manufacturer's specifications. From the overview display, the operator can take no direct action. Direct action can only be taken when a more specific display, such as a loop in alarm, is selected. Other overview displays are obtained by using a page-forward and page-back process.

Group displays may contain individual control loops showing tag name, a bar graph of measured variable, the output value, the set point, the process value in engineering units, the set-point source (remote, local, or tracking), the output mode (auto, manual, tracking), and also alarm information. A page-forward and page-back technique can be used to select other groups.

Trend displays indicate the rate of change of the key variables in a process and are important indicators of plant status. This information can help the operator identify or anticipate process upset conditions. The user can select a real-time or historical mode (from one second to one month, typically) and scale in both percentage and engineering units for all variables as well as for the time base. Trends are often recorded on a hardcopy printer. Table 8-3 lists the principal features to look for in trend displays.

Trending and reporting are methods for archiving information, and they require that there be a method for backing up hard disk files. It is important for the operator to understand how this backup is accomplished and how the data can be retrieved (and reviewed) later on.

Table 8-3. Principal Features of Trend Displays

(1)	Sample frequencies available (one per sec, one per five sec, one per minute).
(2)	Number of variables that can be trended.
(3)	Duration of trending periods available (one hour, one shift, one day, one week, one month, one year).
(4)	Amount of RAM and amount of hard disk space available for trend files.
(5)	How sampling and duration are related and how they affect each other.

Alarm displays provide a list of alarms along with their tags, types, descriptions, priorities, and acknowledgment status. Alarms are listed chronologically according to the time of detection of the alarm. The size of an alarm list is defined by the user and usually contains approximately two hundred alarms. As the number of alarms exceeds this figure, the oldest alarms drop off. Dedicated keys on the keyboard or functions configured on the screens permit the operator to quickly identify active alarm conditions, to scroll up and down the alarm listings, and to acknowledge alarms.

The graphic display is a schematic of the process being controlled. The display is dynamic, giving the operator real-time data on the condition of the process. The display is also user-definable and is constructed with a variety of geometric shapes, texts, and process control symbols. Graphic displays indicate loop tag names, measured values, output values, output modes, and engineering units. The operator can control the display's graphic representation directly by means of animated symbols and color changes of parameters such as tank levels and process temperatures.

Engineering Workstations

The engineering workstation is used principally to:

- (1) configure the database and console,
- (2) update and decompile the database, and
- (3) implement application software.

Engineering workstations are usually physically separated from the location of the operator interface. This permits engineers to work independently before, during, and after the DCS is installed.

Engineering workstations are often put together with the same hardware as the operator interface, that is, from CRTs, electronics, keyboards, hard disks, and/or tape drives. The key difference between the workstation and the operator interface is the software. Thus, an engineering workstation could be used as an operator interface if it had the proper operator interface software.

The engineering workstation is typically used off line. However, with the right software it can be used on line as a diagnostic tool. In general, however, the engineering and operator functions are separated, even by placing the workstations in different physical locations. This is to minimize any potential interference by the engineering workstation in the day-to-day running of the plant.

Basic DCS/DAS Software Modules and Functionality

Programming Concepts

All computer systems need software (programming) to be able to execute their assigned tasks. The DCS or DAS, which is highly computer-based, must be

programmed with process information, control algorithms, and the operator interface instructions that are necessary for proper operation.

Some control functions can be preprogrammed by the system supplier, while other functions must be configured by the user's control system engineer. Computer-based control systems come with standard fill-in-the-blank software for data acquisition, process control, alarming, and operator displays. Software can be classified as “executive,” “system support,” and “application,” even though manufacturers’ descriptions do not always seem to fit neatly into these categories.

Executive Software

As mentioned in Chapter 7, executive software is the operating system of the computer. It is comprised of the programs that supervise the actual operation of the system. Executive software performs functions such as the following:

- (1) scheduling and initiating the execution of system-application programs;
- (2) allocating main memory and loading programs into main memory; and
- (3) supervising I/O operations.

System Support Software

System support software consists of programs that help the user develop application programs. These programs are generally supplied by the vendor. They include:

- (1) computer language processors that translate high-level language programs into machine-language programs;
- (2) editors, to facilitate the creation or modification of user-written programs; and
- (3) debugging aids (to find program errors).

Application Software

Application software consists of programs for tasks that are directly related to the primary functions of a system. Examples are reading analog or digital inputs into memory, computing control outputs based on input and set-point values, and converting this information into engineering units.

Communications Software

The communications system facilitates the exchange of information between process control and information devices. Communications software is proprietary, even though there is a standard, which is based on the International Standards Organization’s (ISO) Open System Interconnection (OSI). This standard enables one communication system to be connected to another using a standard protocol. A protocol is a set of conventions that govern the way devices communicate with each other. As we mentioned earlier in the subsection “Communications” in the section on DAS, OPC creates a common interface for all applications and platforms. This provides a more open and less proprietary communications interface.

The OSI reference model of seven layers of communications networks is an industry standard for linking intelligent devices in a distributed applications environment. As long as a manufacturer complies with this standard, which includes a unique twelve-digit manufacturing code and serial number at the transport level, then a communications link can be established between two or more computers. The seven layers are described in Table 8-4.

Table 8-4. Seven Layers of the OSI Reference Model

Layer 7	Application — Provides the interface for the application to access the OSI environment
Layer 6	Presentation — Provides for data conversion in order to preserve the meaning of the data
Layer 5	Session — Provides user-to-user connections
Layer 4	Transport — Provides end-to-end reliability
Layer 3	Network — Provides routing of data through the network
Layer 2	Data link — Provides link access control and reliability
Layer 1	Physical — Provides an interface to the physical medium

System Configuration

System configuration, which includes the configuration of the database and console, is the main engineering function. Database configuration is used to create, maintain, and document the system database. It involves building, compiling, installing, and downloading the database and then updating it at run time. Console configuration is used to specify the contents and to define the portion of the database that is assigned to each console. It involves the following:

- (1) defining the console environments or scope;
- (2) specifying the loops that are to appear on the operational displays;
- (3) specifying the graphics to be associated with the operational displays;
and
- (4) specifying the users who are allowed access to each console.

The configuration process is organized in a hierarchical manner. Configuration techniques can vary widely from manufacturer to manufacturer. They can range from syntax-laden, line-by-line programming to small interactive logic blocks or large multifunction blocks. A block for one DCS vendor does not mean the same thing as a block for another. In the same way, a display page means different things to different suppliers. Some are prestructured while others are customized graphics.

Depending on the owner's knowledge of the control system, it may be desirable to have the vendor be responsible for configuring the system. The complexity of different configuration techniques can easily lead to extra engineering hours. Long-term costs may be incurred if one considers all the potential troubleshooting, modifications, and expansions that may be necessary. Table 8-5 gives examples of the specific tasks that are entailed in configuration.

An owner should exercise caution if he or she is planning to configure a system entirely on his or her own or through a third party.

Table 8-5. Typical Configuration Tasks

Configure an input block.	Develop faceplates.
Do signal characterization.	Define groups (normally four or eight faceplates).
Define alarming parameters.	Define multitag displays
Set range/scale and engineering units.	Design dynamic graphics.
Define links to control blocks.	Define trend reports.
Configure control blocks with PID or other algorithms.	Define alarm and event logs.
Configure displays.	Define other modules.
Develop alarm banners.	

Finally, note that upgrading the system software will likely involve modifying the configuration. This can be almost as expensive as buying the original system. We discuss this topic in more detail in the section titled “Upgrading a DCS” later in this chapter.

Software as provided by a supplier does not always fit neat categories. Whatever the supplier’s approach to the software, you can safely assume that they will not guarantee the absence of bugs. As a rule, software will have fewer bugs the more it has been field-tested in actual installations. Generally speaking, a single integrated package is better than a number of little packages. Another consideration is the consistency of operation between different software packages. That is, are the same commands and techniques used from one application package to another? As always, the simpler the better.

Installation

Installing a DCS is the process of placing the components, environmental conditioning, power distribution, and wiring in physical locations.

Physical Location

The components of a DCS or DAS may or may not be distributed widely throughout a plant. A plant’s type and its philosophy of operation play key roles in where the same component will be physically located from one project to the next. Table 8-6 presents one possible distribution scheme for DCS or DAS equipment.

The basic intent of control room design is to ensure that equipment performs optimally and that the operator is personally comfortable. Future expansion is also an important consideration when laying out a control room. Figure 8-13 shows a typical layout for a control room and a computer room.

Vendors provide the dimensions and clearances needed to plan equipment layouts or move equipment through doorways and halls.

Table 8-6. Typical Distribution of DCS or DAS Equipment

Control Room	Engineering Room	Computer Room
Operator consoles	Engineering workstations	Cabinets containing: - process I/O cards - controllers - communications modules
Operator keyboards	Printers	
Printers		

Lighting is an important aspect of control room design. Typical lighting recommendations from manufacturers include the following:

- (1) Use indirect or recessed incandescent lighting fixtures with diffusion lenses to prevent glare and to ensure uniform illumination.
- (2) Provide illumination levels of approximately 420 lumens per square meter where CRTs are operated.
- (3) Provide illumination levels of approximately 650 lumens per square meter where CRTs are not operated.
- (4) Where variable lighting intensity is desirable or required, consider task lighting and/or lighting controls, such as dimmers.

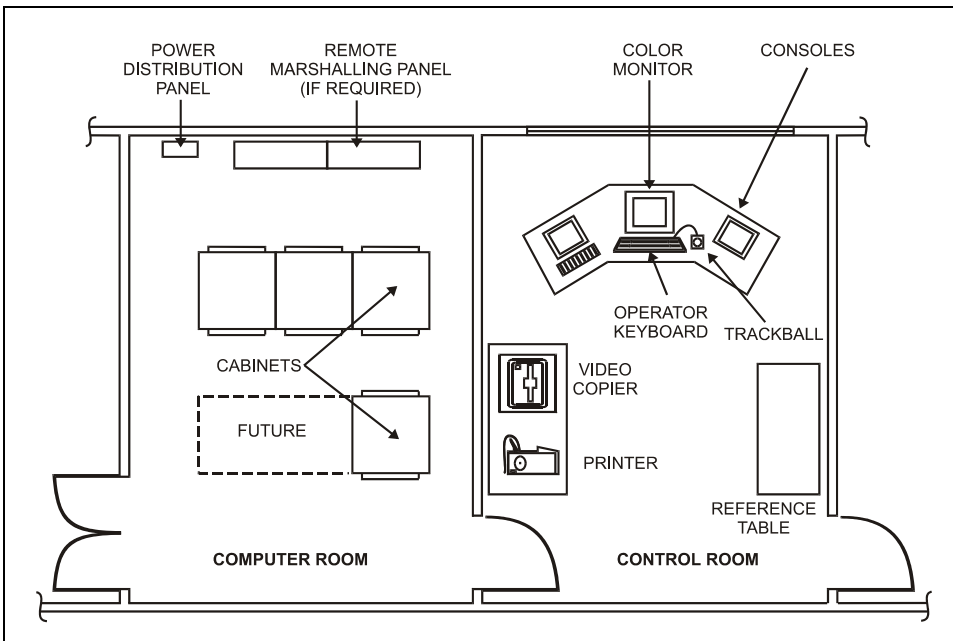


Figure 8-13. Typical Control Room and Computer Room Layout

Emergency lighting is necessary so essential functions are not shut down in case a power failure knocks out the plant's illumination. Emergency lighting can be powered by a battery backup system or by an emergency generator.

Take vibration into account if the control room is next to large machinery such as shakers or presses. To protect sensitive control equipment, install shock absorbers or isolation pads on the offending machinery. The operational and the static vibration limits are specified by the control system equipment manufacturer.

Environmental Conditioning

Environmental controls ensure that equipment operates optimally and that operators are comfortable. When selecting environmental conditioning systems, temperature, humidity, and air filtration must be considered. Temperature in a process environment is generally maintained between 65°F (18°C) and 75°F (24°C). Relative humidity should be around 50 percent. Aside from optimal equipment operation and personal comfort, proper environmental conditioning also helps reduce the buildup of static electricity charges. See Table 8-7.

Table 8-7. Typical Equipment Environmental Characteristics

Characteristics	Controller Subsystem Signal Conditioning Card and Terminations	Data Processor Subsystem (with Disk Drive and Printers)	All Other Subsystems and Interfaces (without Printers or Disk Drives)
Operating temperature	32 - 122°F (0 - 50°C)	50 - 104°F (10 - 40°C)	32 - 104°F (0 - 40°C)
Storage temperature	-40 - 140°F (-20 - 60°C)	-40 - 140°F (-20 - 60°C)	-40 - 140°F (-20 - 60°C)
Relative Humidity	10 - 90%	20 - 80%	10 - 90%
Maximum Wet Bulb Temperature	90% RH at 90°F (32°C)	90% RH at 80°F (26.7°C)	90% RH at 90°F (32°C)

To determine how much air conditioning to provide in the control room, one must consider the internal and external factors that contribute to heat gains and losses in the control room area. Internal factors include equipment, lighting, and people, all of which generate heat. External factors include outside temperature, exposure to sun, and wind. If the control room is located inside a building, generally only internal factors will be taken into consideration.

To reduce the risk that exterior airborne contaminants will damage electrical components or disk and tape drives, the control room should be maintained under a positive pressure of approximately 25 pascals with respect to its exterior.

Different levels of corrosion protection are given in the standard, ANSI/ISA-71.04-1985 - Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants.

Power Source

Two important power source criteria are power quality as well as grounding of the DCS and must be considered in the design and installation of the DCS.

POWER SOURCE QUALITY

Depending on the country in which a DCS is installed, DCS system equipment will operate on 115–230 V AC, 50 to 60 Hz, single phase. Dedicated power supplies mounted in the system cabinetry supply DC power for the actual system components. Manufacturers use the following parameters to characterize the quality of power needed for acceptable operation of their equipment:

- (1) Range of voltage variation from the nominal value
- (2) Range of frequency variation from the nominal value
- (3) Harmonic distortion

The total AC power requirements can be calculated by adding up the individual power consumption values for each device. These values are specified by the manufacturer.

Table 8-8 shows the power consumption and cooling requirements for a typical system.

Table 8-8. Typical AC Power Consumption and Cooling Load

Equipment Description	AC Power Draw (V A, Typical)	Cooling Load (Btu/h, Typical)
Console subsystem with 2 color monitors and keyboards	900	3200
Data processor or gateway subsystems	1000	3200
Controller subsystem (3 fully loaded card files)	900	3105
SC controller subsystem (3 fully loaded card files)	1464	4850
Multi-bus I/O system (fully loaded)	1600	4000
19-in. Color monitor without touch screen	80	276
19-in. Color monitor with touch screen	95	300
System maintenance terminal	60	110
Black and white or multi-color printer operating standby	138 55	431 170
Systems terminal printer	120	410
Workstation processor	820	2830
Local control panel	42	150
Remote hardened console	95	300

As an option, some manufacturers offer a backup power arrangement. When the primary AC power fails or drops below approximately 15 percent of the nominal voltage level, internal batteries supply DC power to the system for a predetermined period of time. The AC power is reconnected when the level returns to its nominal value. A simple battery backup does not regulate either frequency or voltage when the system works from primary AC power. Such regulation is possible only if the backup power is provided by an uninterruptible power supply (UPS).

Since the power supply is such a critical element, installation planning may stipulate uninterruptible power supplies (UPS) to ensure that vendor's equipment specifications are met.

GROUNDING SYSTEM

To minimize the effects of electrical noise (steady state or transient) caused by large electrical equipment, large relays, and motor contactors, the primary AC power source must be stable and noise-free and possibly even completely independent. In addition, an adequate grounding system is needed to avoid conditions that lead to equipment operability problems. Such conditions include electrical noise caused by ground currents circulating through the system and by static electricity discharges.

The grounding system should terminate at common grounding electrodes (ground rods). It should also have a resistance to earth of one ohm or less when the system grounding is used in combination with power generation equipment. When it is not, five ohms or less is recommended. Grounding systems require periodic inspection and testing. Figure 8-14 illustrates a typical grounding installation.

The grounding system will also minimize the hazard of electric shock to personnel.

Wiring

Type of cable and termination, as well as location of I/O and cabinets must all be considered in the DCS installation. The following sections outline recommended practices and specifications.

CABLING AND TERMINATIONS

Wiring coming from field equipment may terminate directly at cabinets that contain the I/O cards or at conveniently located remote marshaling panels. The remote marshaling panel is simply an electrical box that contains terminal blocks and is designed to facilitate wiring between field junction boxes and I/O cabinets. Wiring cabinets have cable entry openings at the top and bottom. This makes it easier to design computer rooms when there is a raised floor or elevated cable tray. Figure 8-15 illustrates typical cable routing inside a cabinet, and Figure 8-16 illustrates analog inputs and outputs and field wire termination.

TYPE OF CABLE

Cables recommended for 120 V AC service should have the following characteristics:

- (1) Conductors: seven-strand, class B, 14 AWG
- (2) Ground conductor: single, seven-strand, class B, concentric bare
- (3) Inner jacket: high temperature PVC
- (4) Outer jacket: flame-retardant PVC
- (5) Armor: interlocking aluminum alloy or galvanized steel

Single-pair or triad cables that are recommended for 24 V DC and 4–20 mA service should have the following characteristics:

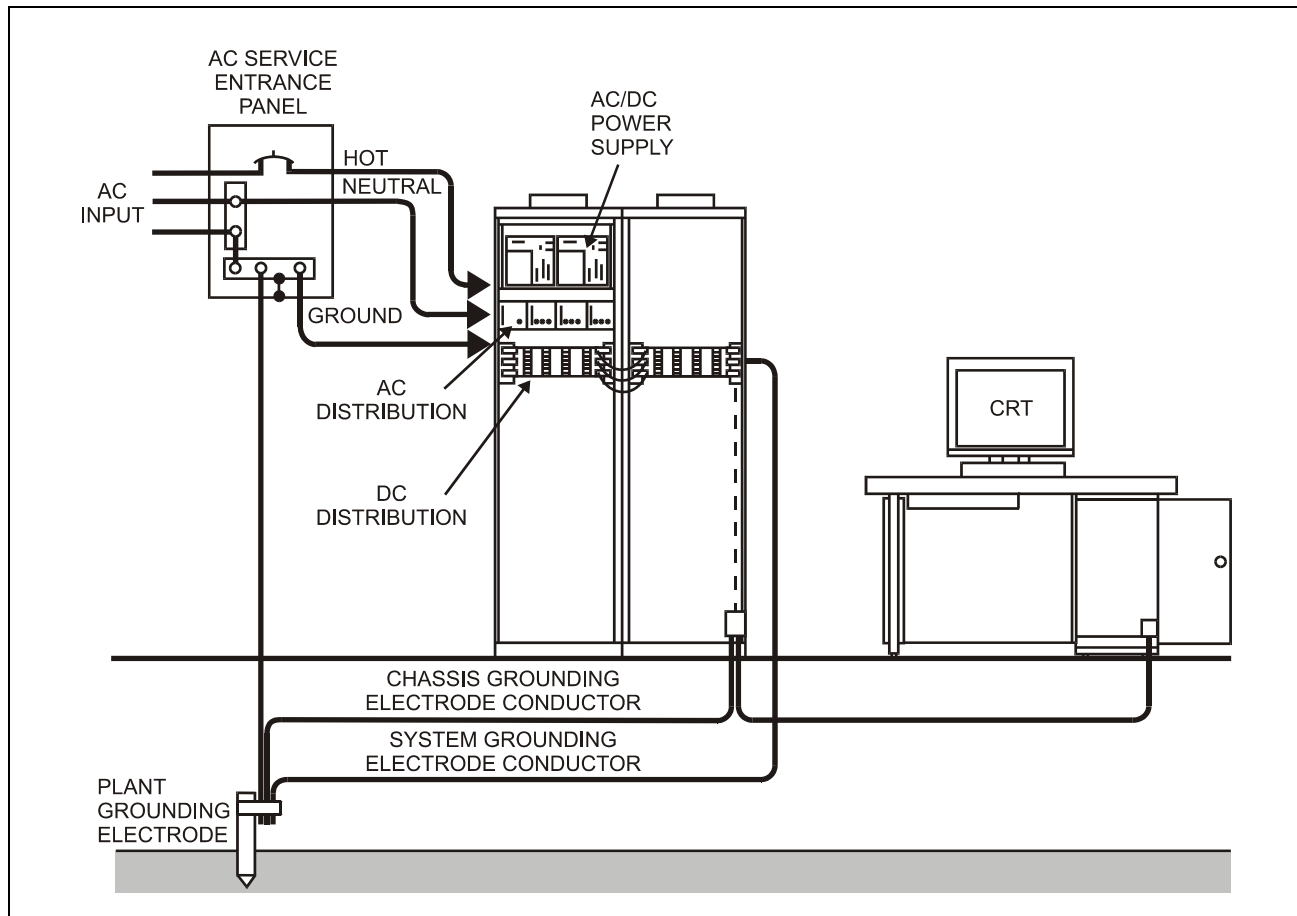


Figure 8-14. Typical Grounding Installation [Ref. 4]
(Courtesy of Emerson Process Management)

- (1) Conductors: seven-strand concentric bare copper, class B, 16 AWG
- (2) Shield: aluminum/Mylar tape shield with tinned copper drain wire
- (3) Lay of twist: two inches nominal
- (4) Jacket: FR PVC

Multiple-pair or multiple-triad cables that are recommended for 24 V DC and 4–20 mA service would have the following characteristics:

- (1) Conductors: seven-strand concentric bare copper, class B, 20 AWG
- (2) Shield: aluminum/Mylar tape shield with tinned copper drain wire, individual and overall shield (4–20 mA analog signals), overall shield (24 V DC and on-off signals)
- (3) Lay of twist: two inches nominal
- (4) Jacket: FR PVC

The choice of armored or nonarmored cable is up to the user, but generally armored cable is the safe choice.

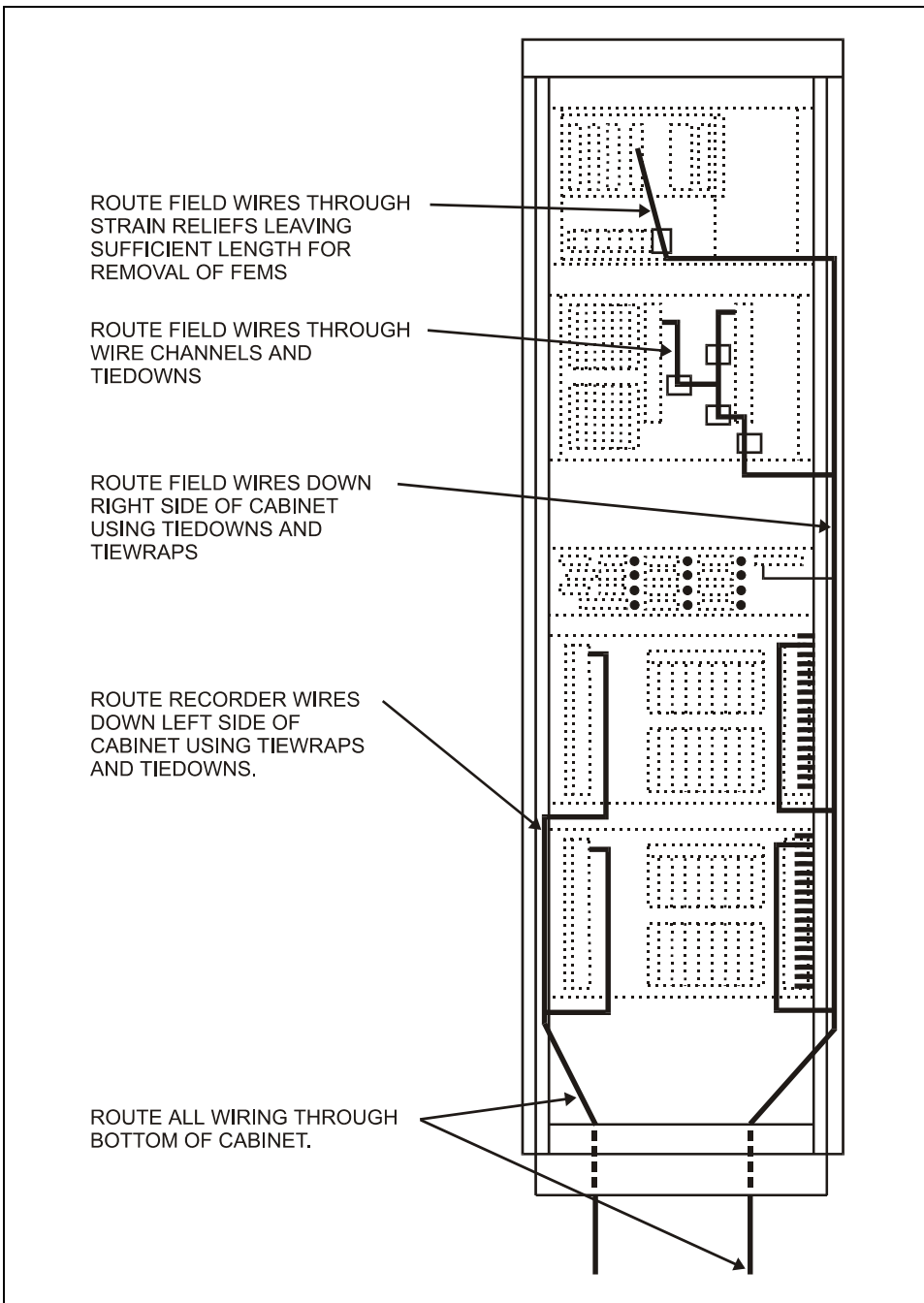


Figure 8-15. Typical Cable Routing in a Wiring Cabinet [Ref. 4]
(Courtesy of Emerson Process Management.)

Intrinsically Safe Barriers

An intrinsically safe barrier has terminals for connecting field and control room wiring, which minimizes the number of panel terminals. Also, the barrier system provides a sharp line of demarcation between the hazardous and safe area. The barrier is a completely passive device that requires no power source and passes a 4–20 mA DC signal at a nominal 24 V DC power rating with virtually no degradation (less than 0.1%).

A barrier contains wire-wound resistors to limit current and redundant Zener diodes to limit the voltage. A fuse is in series with the resistors. The question often

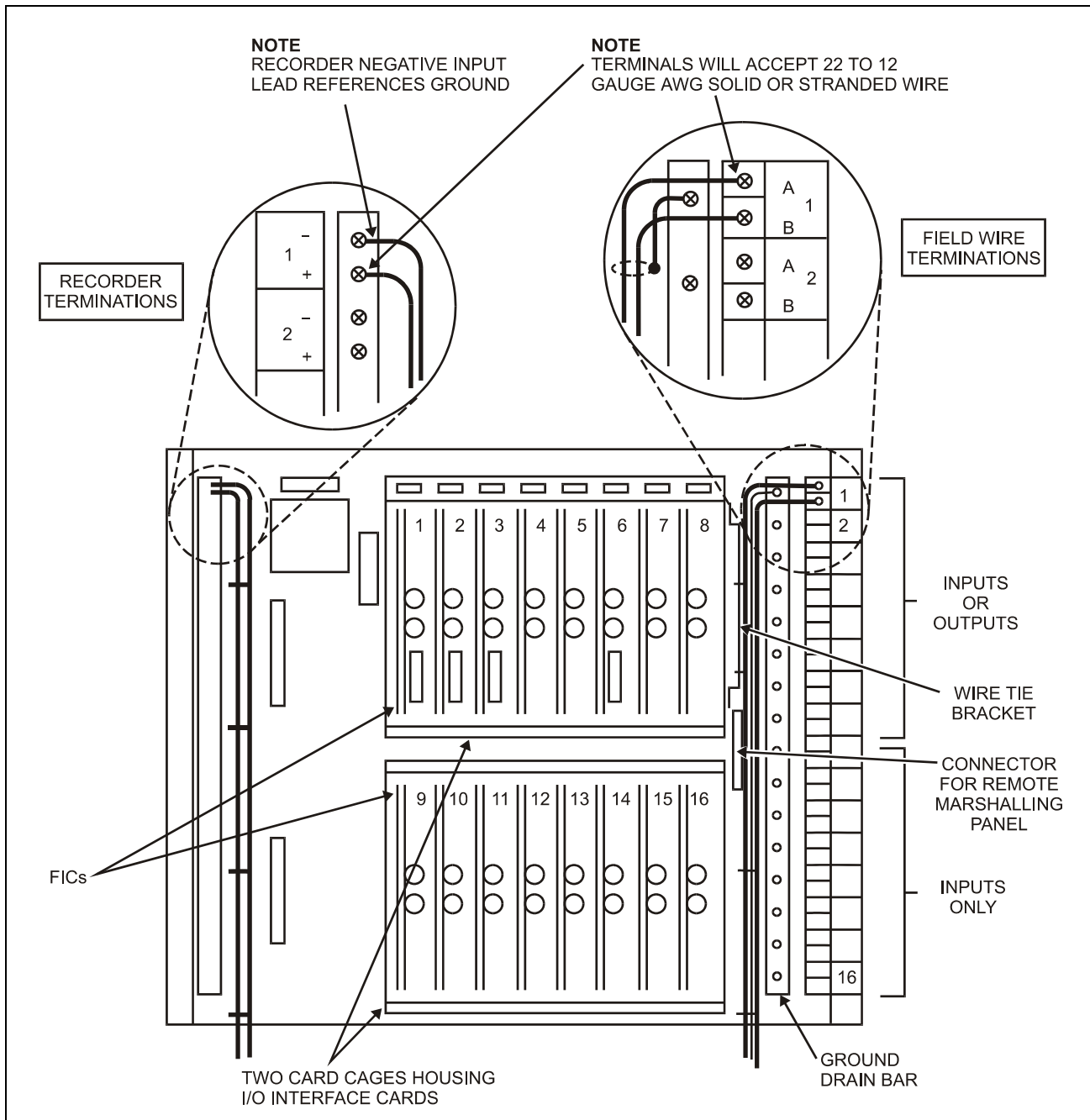


Figure 8-16. Typical Field Termination of AIs and AOs [Ref. 4] (Courtesy of Emerson Process Management.)

arises why a fuse alone would not do the job. If a high voltage were placed on the input terminals with only a fuse and resistors present (without diode), an explosion could occur in the hazardous area before the fuse could blow. A fuse can pass sufficient energy to cause the explosion before it opens. Only microseconds are needed, under the right conditions, for an explosion to take place. Without some method for limiting voltage, a fault voltage that appears on the barrier input terminals, when combined with increased current, could be passed along to the hazardous area.

System Check-Out and Site Power-Up

The system check-out and site power-up activity is almost always the exclusive domain of the DCS or DAS vendor because it is associated with the warranty of the system. An owner should always be sure that these two functions are included in the vendor's price. The owner may not have the expertise to do it and certainly does not want to pay the exorbitant price that some vendors ask after the fact. It is clearly a good idea for the system check-out and power-up to be included in the vendor's original price and quoted under competitive conditions. There should also be a payment retention (ranging from 5 to 20%) that is payable when the system is accepted. This ensures that the system is up and running before the final payment is made. Experienced owners know that "money talks."

Typical System Layouts

Although the approach of this chapter has been to look at distributed control systems in a generic way, each vendor tends to have a unique and sometimes proprietary approach. Figures 8-17, 8-18, and 8-19 show how the overall structure can vary among different manufacturers.

It would be of little value to analyze each structure for its various strengths and weaknesses because each is generally the result of the vendor's proprietary approach. For the purposes of this chapter, it can be simply stated that there are more similarities than there are differences.

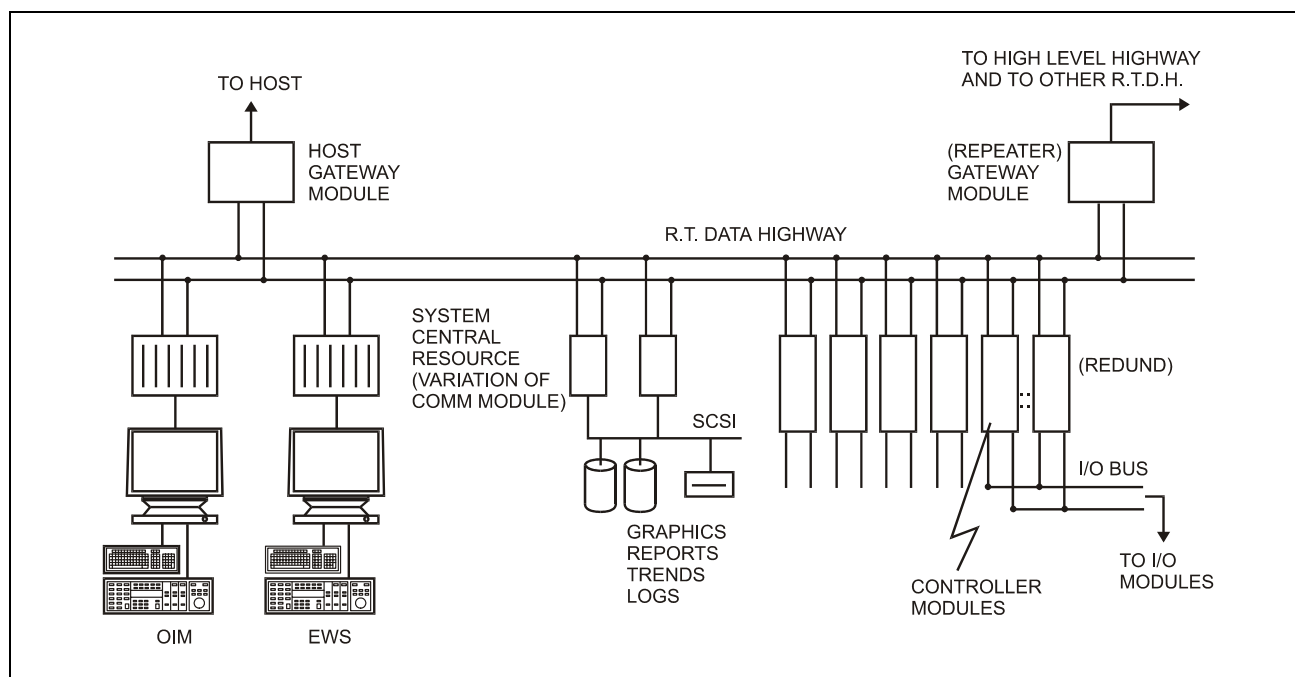


Figure 8-17. DCS Structure Typical of Foxboro

Startup Services

DCS startup services may easily get overlooked when evaluating a vendor's system because the buyer doesn't readily see their importance at the time of purchase. Usually, it is only after installation that the tremendous importance of things like staging, functional testing, and training become apparent.

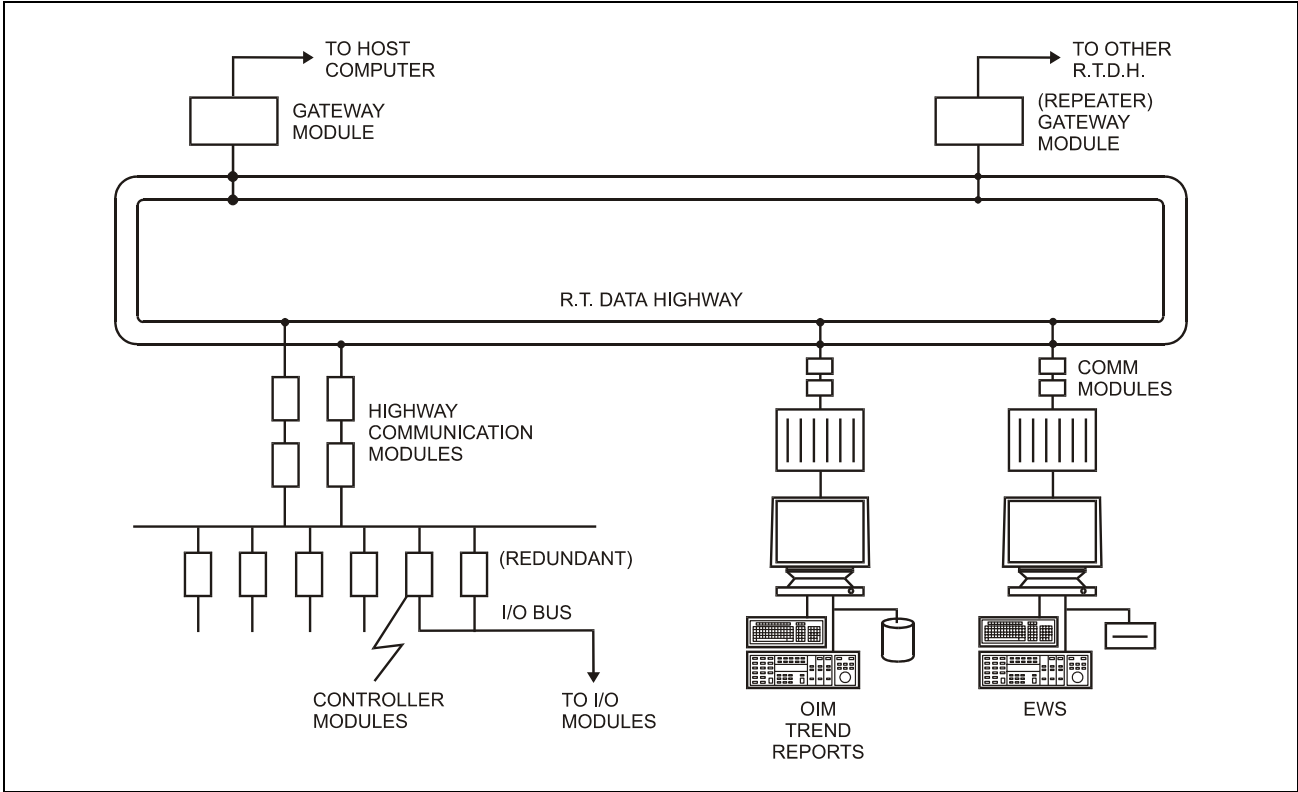


Figure 8-18. DCS Structure Typical of Bailey

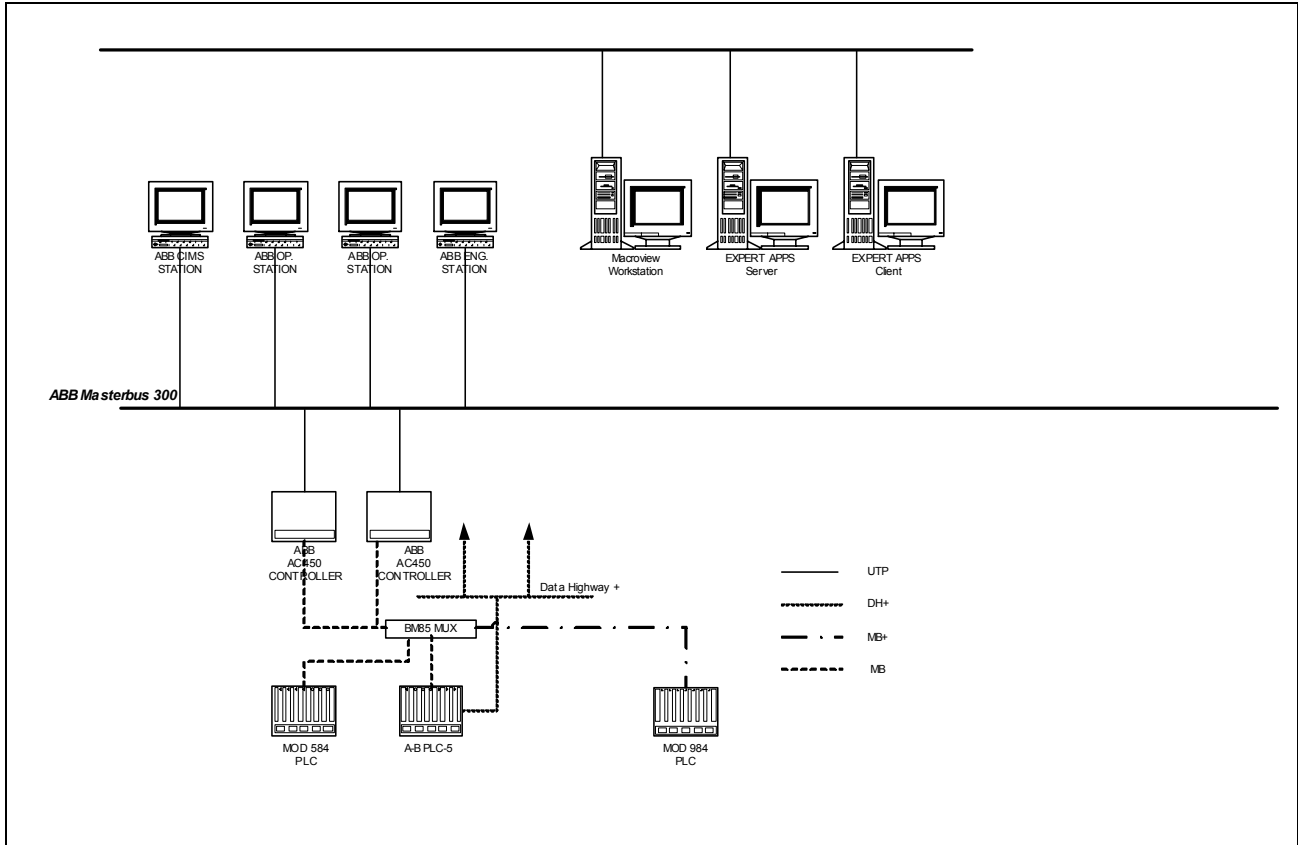


Figure 8-19. DCS Structure Typical of ABB

STAGING

This is a little-known service, especially to first-time buyers. Depending on an owner's experience, it could be seen either as a waste of time or as a valuable tool instrumental to an efficient, on-time startup. Staging may be defined as a type of stress or operational test that is aimed primarily at DCS or DAS hardware. It is an activity in which the entire DCS or DAS is completely assembled and the cable connected so as to duplicate the eventual site installation. After powering up with only the system software programs running, the system is expected to operate without problems for a given period of time (usually forty-eight hours or more). Some DCS/DAS vendors will further stress test the system in an overheated environment by cycling the AC power supply and increasing the surrounding temperature to 50°C or more.

Stress testing is done to eliminate the “infant mortality” associated with computer components. *Infant mortality* is the expression used to describe the tendency of a component that is destined to fail to do so very early in its life. For a component that survives this early period, the rate of component failure will drop to a low level for a long period of time and then increase again as the aging process takes over. As Figure 8-20 shows, the curve that expresses this process takes on the shape of a bathtub.

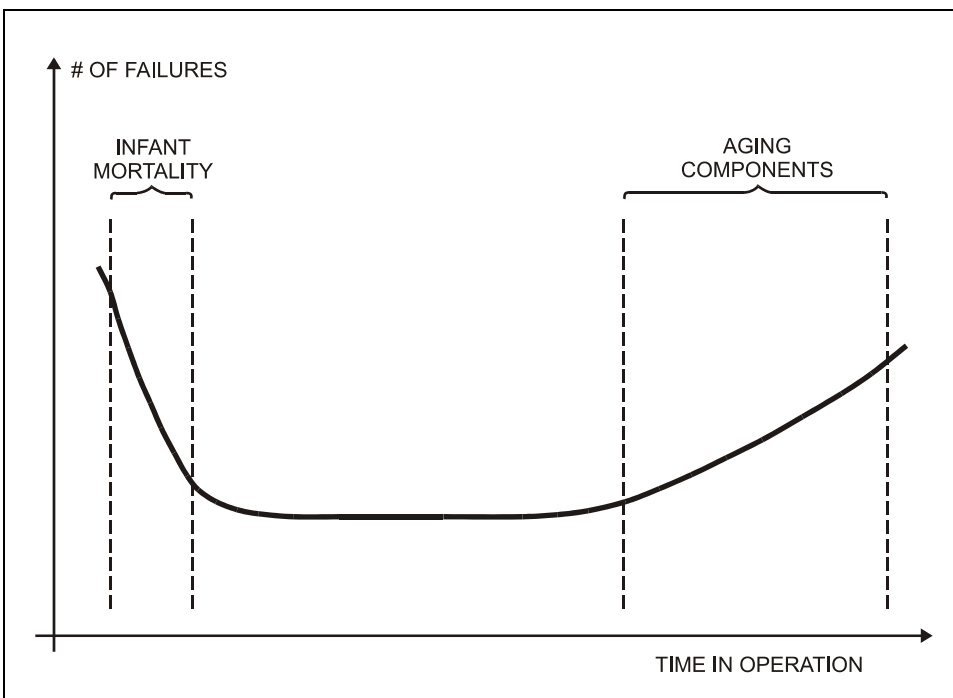


Figure 8-20. Mortality of DCS/DAS Components As a Function of Time

The time required for staging is considered time very well spent, even (especially) when a project is on a tight schedule. Component failures that occur on site during startup can cause frustrating delays that are readily avoided by the staging process. In addition, staging ensures that there are no missing cables, connections, or system components when the DCS arrives at the site.

SYSTEM FUNCTIONAL TEST

The system functional test is similar to staging except that it focuses on the configuration rather than the DCS/DAS hardware. This service involves assembling and powering up the system with the system software programs, and it also

includes the configuration software. The purpose of this test is to eliminate problems in the loops and logic of the particular application. Inputs and outputs are verified and simulated, and logic interlocks and loops are flexed.

Generally speaking, this service is best performed off site, away from the distractions of the plant. The time required for a functional test should be two or three weeks for everything from assembly through testing, re-crating, and reshipping. The advantage of the system functional test is that it allows the vendor's technicians to identify and correct problems under conditions that are as close as possible to ideal. Troubleshooting on the job is difficult at best. Besides the distractions and the pressure to perform once startup has occurred, isolating the source of the problem is often more complicated. In other words, is it the system configuration or is it the field equipment?

TRAINING

Every manager wants his or her staff properly trained in running the control system as well as diagnosing and repairing it. Most project specifications call for some combination of off- and onsite training. Off-site training is usually done in a formal classroom setting by instructors who are often, but not always, full-time professionals. Ideally, the classroom instruction is supplemented by hands-on laboratory work.



Onsite training has the advantage that it is done with the actual equipment that will be operated. On the other hand, the instructor is often an installation technician who, though knowledgeable about the system, can be greatly lacking in teaching ability. In addition, onsite training is frequently a cram session in which too much information is passed on too quickly for the operator to really absorb it effectively.

Because the importance of training is often undervalued, what little is done is often of little use. A proper training program can involve the development of quite an elaborate master plan. A good one takes into account the actual and required skill levels of the people who will have to deal with the DECISion/DAS. It will include all the training programs necessary to take individuals from their actual to future skill levels. This learning is best done over an extended time so it is effective and, therefore, useful. Training courses that are part of the master plan may come from any number of sources, including vendors, local colleges, owners' in-house programs, and so on.

Finally, training should be seen as an ongoing process, in which refresher courses are part of the overall plan. The world of DCS/DAS is closely connected to computers and therefore evolving at breakneck speed.

System Documentation

System documentation consists of the process of collecting written materials and electronic media that describe the DCS/DAS. Ideally, it must be complete enough to tell an owner everything he or she needs to know about the system. At the same time, it must be as easy to use as picking up a phone and calling the vendor. Anyone who has used a personal computer and any assortment of available software knows how difficult it is to end up with "ideal" documentation.

Maintenance

Placing an order for a DCS/DAS signals the start of an owner's concern with a number of factors involved in the satisfactory operation of the system. These include site preparation, mounting hardware, installation time, staging, documentation, commissioning, training, and finally maintenance.

Although the design of today's modern digital circuits promotes minimal maintenance and a high degree of self-monitoring, an owner still needs to know how such circuits work and how they should be maintained.

Flexible Level of Support Programs

Historically, a plant provides the level of maintenance for its DCS/DAS system that will most effectively provide satisfactory operation at a reasonable cost. The strategy for supplying effective maintenance has to be worked out by both the user and the manufacturer. Manufacturers are generally quite willing to work closely with customers to help them become familiar with things.

For smaller systems, many customers are interested in doing as much as possible with their own resources. This is to be encouraged as long as it does not result in an operational hazard or equipment damage. When it comes to complex maintenance activities (those requiring specially trained service personnel) the owner should consider a higher level of maintenance support. Choosing the combination of support services that best fits the needs of the customer will lower product costs and promote higher quality. Since a DCS/DAS can be considered a production tool, its real value depends on how effectively it is used. A well-designed maintenance program adds to this effectiveness.

As shown in Figure 8-21, a reactive maintenance philosophy of replacement and repair shortens a system's life. The more proactive approach of preventive and predictive maintenance extends the life of the system. However, the payoff really occurs when operational services and system upgrades are provided. Then system life is extended almost indefinitely, and the DCS provides greater functional value.

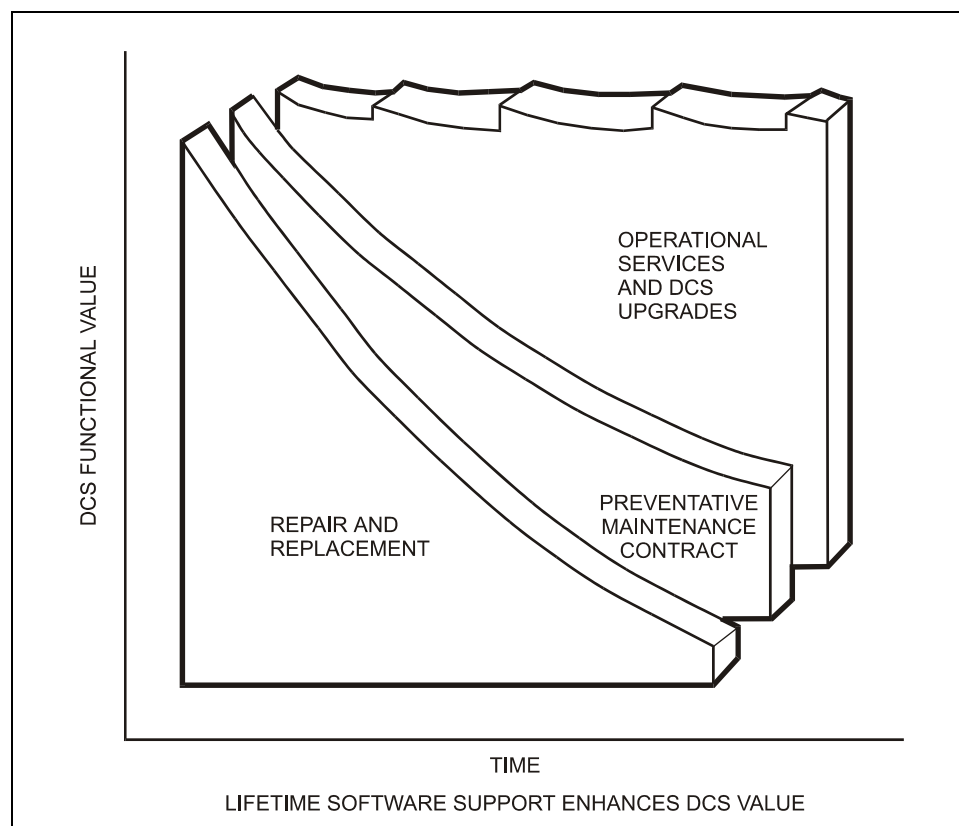


Figure 8-21. DCS/DAS Value As a Function of Maintenance Approach
(Courtesy of Honeywell, Inc.)

Categories of Maintenance

Every organization has its own maintenance philosophy. It is up to management to determine what overall approach to maintenance is needed to achieve acceptable reliability for the DCS or DAS.

Maintenance can be seen as falling into three categories:

- (1) Enhancement maintenance
- (2) Preventive maintenance
- (3) Corrective maintenance

Manufacturers and designers will customize their programs to meet users' requirements in these three areas.

ENHANCEMENT MAINTENANCE

Enhancement maintenance involves using the most recent releases of hardware and software, which have been redesigned for improved maintenance and functionality. Keeping a DCS at current revision levels provides a cost-effective way of operating at peak performance.

The DCS manufacturer can implement software enhancement and support programs in three different ways:

- (1) Through periodic software enhancements issued to the customer
- (2) Through technical engineering assistance made available to the customer at any time
- (3) By the manufacturer managing the client's DCS documentation

PREVENTIVE MAINTENANCE

The intent of preventive maintenance is to keep a system from breaking down by providing regular equipment inspections. Since there is no obvious immediate benefit to this type of maintenance, it can vary widely according to individual preferences (and perhaps to the salesman's skill in selling the idea). It is up to management to provide a structure that will produce a balanced program that uses in-house resources together with the support programs offered by the systems manufacturer.

CORRECTIVE MAINTENANCE

Corrective maintenance consists of performing qualified repairs to a system that has failed and thereby returning the system to its original usable condition. Providing this type of service on such a complex integrated system as a DCS or DAS can be a formidable challenge for both plant maintenance departments and equipment vendors.

Owners must find an efficient way to supplement their in-house capabilities with outside industrial support groups. It is very important that such outside support services be provided by an experienced team and with the same promptness that the user would provide with his or her own resources, had they been available.

Service Contracts

Each organization has its own maintenance philosophy and must, therefore, determine what service program suits its needs best, so the DCS/DAS remains available, capable, and dependable. The service activities needed to support a proper program of maintenance are shown in Figure 8-22.

A variety of services are available from outside firms, including:

Experience indicates that the ratio of the cost of preventive maintenance to the cost of repair and replacement is about 1:2.

- (1) On-call service
- (2) Equipment maintenance
- (3) Equipment or system audits
- (4) Maintenance service retainers
- (5) System utilization services
- (6) Software support services
- (7) Resident field engineers

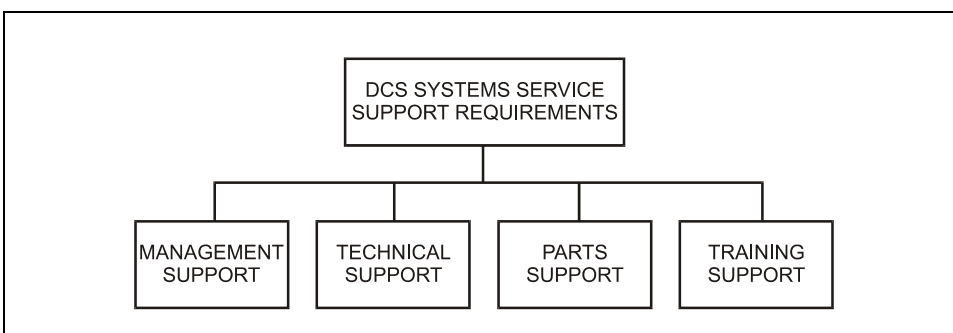


Figure 8-22. Maintenance Support Activities

On-call service is service done by a support group that maintains well-trained service engineers who are capable of troubleshooting nearly any DCS or DAS.

Equipment maintenance is done according to a contract in which routine preventive and corrective maintenance is performed by a qualified engineer located in the general area of the client.

Equipment or system audits are done according to an agreement that includes periodic review of system performance by a qualified engineer who is familiar with the process that the DCS/DAS system is controlling. This sometimes includes added features, such as extended support journals, semiannual performance reviews, technical support with PC computer-based bulletin boards, and so on.

Maintenance service retainers are agreements whereby on-demand service is made available at a level of so many days, at an agreed cost per day, and for a specified term. Emergency demand service is not the same thing. It means delivering adequate service support in time to avert possible downtime. This would be an extra cost to the retainer.

System utilization services are provided according to an agreement whereby a process specialist is scheduled to actually operate the process in order to optimize it for the customer.

Software support services are provided via telephone system and modem, usually by qualified systems and application engineers. This can include periodic system update letters, software updates, and remote diagnostics.

Resident field engineer services involve an agreement in which an engineer resides in the immediate area of the client's plant and reports to work only at that plant.

Note that the organization that supplies service support may be the original equipment manufacturer or a sophisticated repair center established by a third party. Third parties can provide maintenance and repair for laboratory, industrial process control, and electronic test equipment. This support can include warranty and nonwarranty service, as well as installation and startup assistance.

Purchasing Strategies

DCS purchasing strategies will vary depending upon whether the decision taken is to completely replace a system or to expand and upgrade hardware and/or software to newer versions. The following sections outline the different options that can be considered.

Long-Term Buying

A DCS or DAS must be purchased in the context of a long-term management commitment. Planning in advance for such a purchase will ensure that answers are more readily available when problems occur. Some of the factors to be considered in such long-term purchases are:

- (1) System effectiveness
- (2) Technical performance
- (3) Capability
- (4) Availability
- (5) Support effectiveness
- (6) Reliability
- (7) Maintainability
- (8) Safety
- (9) Accessibility
- (10) Software configuration
- (11) Quality
- (12) Software enhancement

System effectiveness is the ability of the system to sustain successfully the overall system demand within a given time when it is operated under specific conditions. It also can be characterized as capability, function availability, and support effectiveness.

Technical performance is similar to technical capability but often additionally means a measure of what total technical support the manufacturer can offer.

Capability is a measure of how well a system performs.

Availability is the probability that a system will operate satisfactorily and effectively when it is needed or used to control a process under specific conditions.

Support effectiveness is the service support that is required to sustain the equipment and keep it operating effectively by furnishing it with whatever enhancement it needs.

The *reliability* of a system is the probability that it will perform as intended without failure for a specific time period under specific design conditions.

The *maintainability* of a system is its inherent capacity to have technical knowledge and management skills applied to it so it can be effectively operated and efficiently maintained.

The *safety* of an overall system is an assessment that both system and human safety levels are attained whenever the system is used.



Safety design is of great importance because it protects the system against failure and breakage and eliminates the hazardous conditions that can cause operating accidents and injury.

Accessibility is the ease with which personnel can access a control system to attend to an assembly or subassembly, as well as that system's capacity to quickly yield answers to specific questions.

Software configuration is what an organization must consider in terms of physical properties and functional characteristics in the makeup of a DCS. The design of the DCS's hardware/software must be intelligently engineered, and the specific system configuration installed at the plant must satisfy that customer's needs.

The quality of equipment and service is especially important for reducing a system's downtime. Quality means that the system should be at least 99 percent fault-free. DCS suppliers must have the capability to provide quality in both products and services.

Software enhancements must be considered so that the system's functionality can be expanded or improved with every new product the manufacturer releases. Software enhancements provide the platform for new system applications by adding new system functions, improving system performance, and introducing new technology innovations.

Expanding and Upgrading

When it comes to the expandability of a DCS, modularity is often the only thing considered. Unfortunately, in most cases, there is no discernible difference from one DCS to another in modularity. All DCSs are modular by nature and, therefore, expandable. The only difference among them is where the "break points" are in terms of add-ons. The term *break point* refers to that number of inputs and/or outputs beyond which additional hardware is needed—sometimes at a dramatically increased cost. It is possible for the addition of a single point to necessitate extra cabinetry, power and communication modules, and data highways.

The unseen difference in system expandability often lies in its backwards compatibility and its upgradability. All DCS designs are changing constantly and at a pace unfathomable to most laymen. Computer chips can become obsolete within months. DCS vendors have to keep up with such changes to stay competitive. In addition, customers are constantly demanding added functionality. As a result, software is continuously being written and integrated into vendors' systems.

Dealing with Obsolescence

The constant evolutionary change of DCS/DSAs has both good and bad aspects. The good news is that costs will drop while the systems become easier to use, more powerful, and less human-labor intensive. This makes for more efficient and competitive plant operations. The bad news is that system components will become obsolete (and therefore costly to support, repair, and replace) and will require a program of continual upgrades to stay current.

Many current DCS owners find that new, more powerful modules or even whole new systems come on the market less than a year after they made the initial purchase. The question for them then becomes whether to buy the "slightly out-of-date" version and make it compatible or update to the "new" technology. It is a complex decision and poses the risk of potentially skyrocketing costs.

Costs can be excessive in either case. Older components can become very costly after their manufacturer discontinues them or they are pronounced obsolete. They then become more difficult to get repaired. Spares and technical support are harder to obtain and are more expensive. Upgrading existing equipment can also be an expensive proposition, depending on the design of the system. This is one area of real differentiation between vendors. Every vendor will swear to "back-

Technological advancements made in the past six years are the leading cause of process control system obsolescence. The availability of replacement parts and services for pre-1990 control systems is limited.

wards compatibility” and, to some extent, will have it. But there are systems with good compatibility and others with very poor compatibility.

It is often a good idea to review the R&D program of the vendors you are considering. This will indicate what the outlook for the firm is for the future and will give you a better perspective on their product. Their R&D program is also a good barometer of the company's stability and commitment to the product. Having one or two years of system upgrades built into the project is a good insurance policy.

Upgrading a DCS

Obsolescence can be avoided by identifying an “upgrade path.” In other words, find out exactly how upgrading will be done. Some of the options are:

- (1) Upgrade the system software only.
- (2) Upgrade both the system and configuration software.
- (3) Upgrade hardware modules that have been modified with system software.
- (4) Use all new hardware and software.

Understanding the relationship between a vendor's hardware and software will make it easier for plant personnel to decide on the “what and when” of upgrades. For example, a plant ought to consider upgrades to a DCS that will not be expanded. Keeping a DCS up to date is a good way to protect one's initial investment.

With an appropriate program of upgrades, a plant can avoid the wholesale replacement of an older system that has become obsolete.

This sort of upgrading means that, after a couple of years, when significant (to the user) functional improvements have been made, the plant has brought the system up to the current technology. This spreads out the costs and implementation time entailed in making DCS changes. If it seems that few functional changes are taking place in a system, chances are the manufacture isn't investing in R&D. If this is the case, it would be wise to hold off on an upgrade and perhaps even look at alternatives systems.

Upgrade paths will vary from vendor to vendor. Some will be more costly and difficult than others. Some require downtime; others do not. As much as possible, find out what is likely to be involved before making a final selection. Talk to other users to get a feel for what they have done. This will often be a good indicator of things to come.

Migration Solutions

Example 1: Hybrid DCS / HMI

An alternative to expanding and upgrading a DCS with the same vendor parts is to consider a hybrid solution, as shown in Figure 8-23. Because of cost constraints and limited production downtime, the plant in this example opted for a hybrid solution that consisted of replacing obsolete operator stations with an off-the-shelf HMI and then integrating these into the existing plant architecture. A graphics converter was used to convert the DCS graphics to the HMI format. Minor modifications to the graphics were required. A standard interface provided by the DCS vendor was added between the HMI and the DCS network.

Most reputable companies will guarantee the availability of a product for around ten years after it has been discontinued. Get it in writing! Read the guarantee and understand it.

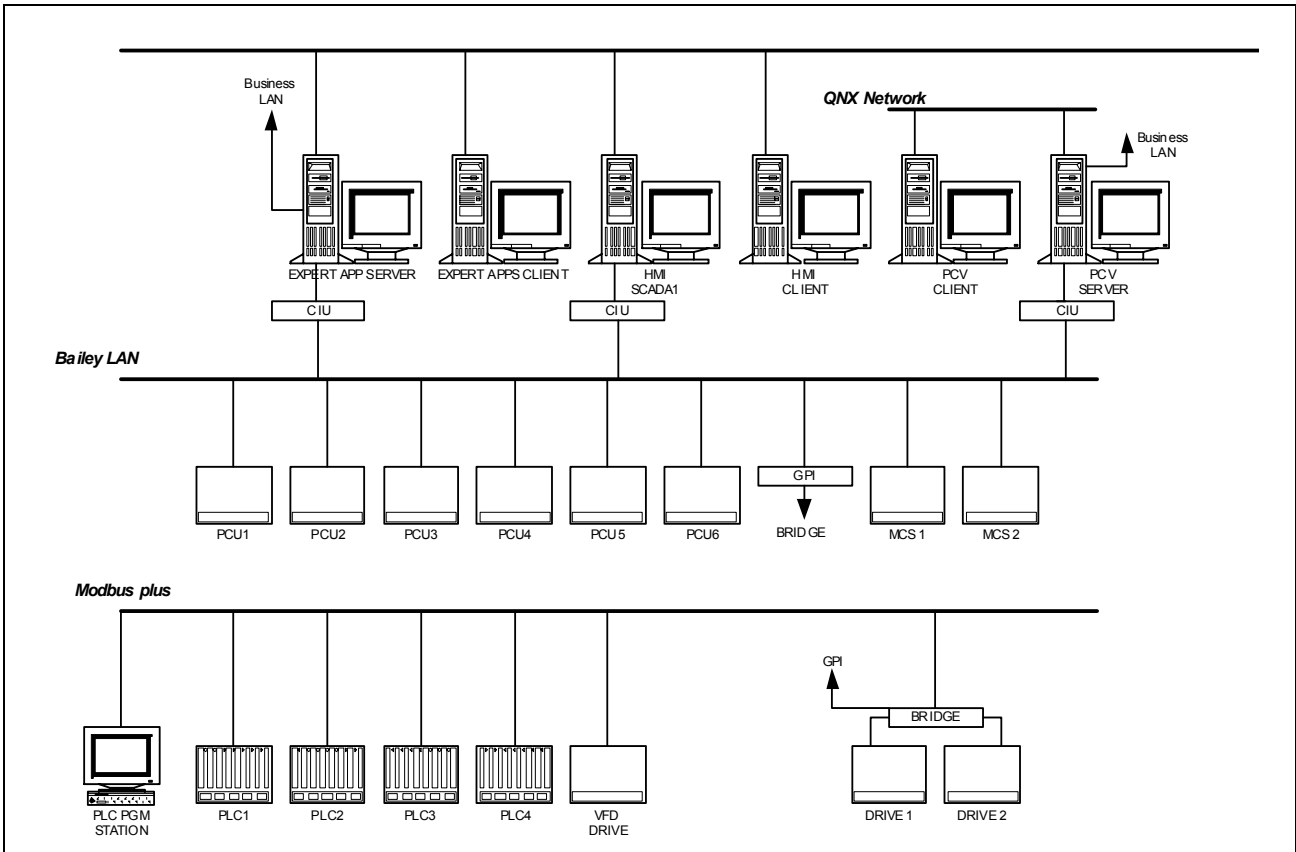


Figure 8-23. Hybrid Solution: DCS / HMI integration

Example 2: Digital Automation Systems

Although at one time state of the art, proprietary DCS systems are challenging to maintain and not as reliable, secure, robust, or scalable as standards-based, high-speed, digital automation systems. However, the interoperable nature of a digital automation system enables it to be connected with DCS and PLC systems to do the following:

- provide scalability
- incorporate new bus technology
- improve process optimization
- lower maintenance costs
- integrate smart diagnostics.

A digital automation system offers multiple migration techniques that enable process manufacturers to choose the best solution for their transition to a digital automation system. The solutions presented here all ensure minimal downtime and a phased approach to the migration process. Over time, the digital automation system will completely replace the proprietary system.

CABLE CONNECTION

The controllers in a digital automation system can connect to the existing termination panel of a DCS by using a trademarked cable and a mass termination block. After simply connecting the cables, personnel use software running in the digital automation system to verify input/output configurations. The software then either connects directly to the controller or uses OPC to set up communications. The digital automation system then uses file-conversion utilities to translate and

replicate DCS graphics and engineering configurations such as batch applications. Also, as time permits, it is easy to build high-resolution graphics in the digital automation system. Once these steps are completed, advanced control applications, such as tuning, may be applied to quickly get the process to optimum capacity. This solution uses existing wiring and engineering configurations, doesn't disturb field connections, eliminates engineering configuration, and produces minimal downtime.

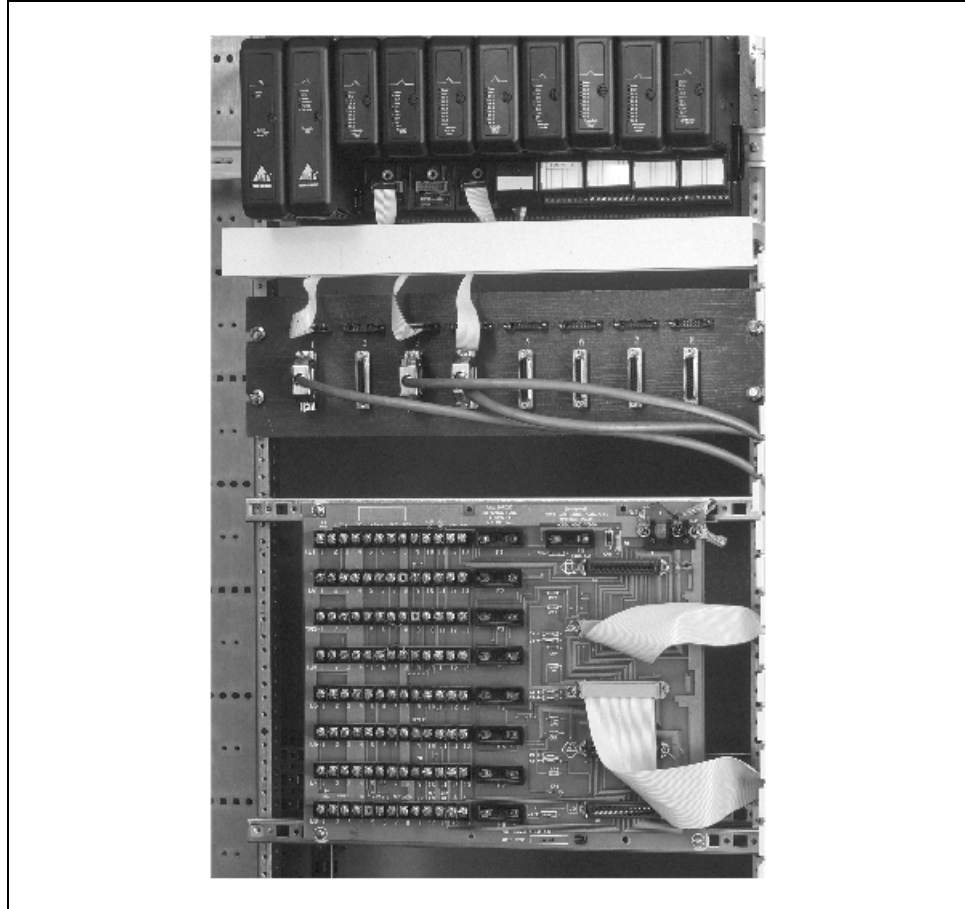


Figure 8-24. DAS Connectivity to Existing DCS
(Courtesy of Emerson Process Management)

Some process manufacturers will use a serial interface and MODBUS protocol to set up communications between the proprietary system and the digital control system. This solution uses a serial I/O card in the digital automation system controller with a serial communications link. This requires the use of custom-written drivers for both ends of the serial link. Some types of proprietary systems will necessitate the use of this migration method.

CONSOLE CONNECTION

An OPC server gets data from the proprietary control system, puts the data into a standard format, and is read by an OPC-compliant client. Normally, a server provides data to clients only. However, a digital automation system makes possible data sharing between OPC servers. This functionality links not only to the control system but to all plant subsystems. This creates plantwide interoperability at the workstation level.

Conclusion

The process control paradigm has changed. Where once it was advantageous to use a proprietary system, doing so now hinders a firm's competitive advantage in the global workplace. The technological revolution has placed great demands on process manufacturers to reduce plantwide costs and process variability while simultaneously increasing plant performance and efficiency. Completely digital automation systems harness the intense memory and processing power that is now available to help process manufacturers achieve their goals of reducing costs and process variability while increasing performance and efficiency.

A digital automation system is built to open, interoperable standards. High-speed communications technology enables terabits of data to pass through intranets and the Internet. Standards-based digital automation systems take advantage of this by passing process information through the DAS as well as across the Internet and seamlessly interacting with a multitude of other applications.

Devices at the edge of the network are smart and capable of passing a wealth of information to a digital automation system. The capacity to process and pass on this information efficiently and effectively distinguishes a digital automation system from legacy systems. Immensely increased functionality such as predictive maintenance, asset management, comprehensive batch solutions, and embedded advanced control are additional distinguishing factors of a digital automation system. By efficiently processing this increased wealth of information, digital automation systems are enabling process manufacturers to get the most out of their capital investments, optimize their processes, work in safer environments, and ultimately produce best-in-class products.

Finally, digital automation systems are keeping up with technology. Their design and functionality make them an enabling technology, not an end in themselves. As technology changes and new standards are set, digital automation systems, unlike legacy systems, are positioned to embrace the new and continue to assist process manufacturers in meeting their multiple goals.

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