Building Management System

Part 4

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Field Controllers and Control Protocol

Introduction

In Part 2 and 3 of this series, we discussed Field Devices (Tier-4) like sensors, relays and valve actuators, which continuously measure and monitor the required variable parameters and continuously communicate them to Field Controllers (Tier-3). Field Controllers are intelligent devices (Direct Digital Controllers – DDC) that control the field devices throughout the facility. Field Controllers report their current values to and receive supervisory commands from Network Engines or Supervisory Controllers (Tier-2). Let us deliberate on Field Controllers and the communication protocols that are followed.

Field Controllers

Before the advent of DDC, buildings used PLC based systems, applied 'zone-wise'. They could handle only a few points and controlled elements. Attempts to expand the scope of PLC and connecting them together to apply them for building-wide systems became very complex and impractical. DDCs could handle this easily. Currently, PLCs are used in Industrial process automation systems.

DDC compares the sensor's signal with a desired set point and regulates an output signal to a controlled device. Digital controllers perform the control function using a microprocessor and control algorithm, which is usually a pre-defined application program to ensure correct operation of individual equipment.

A few examples of DDC are chiller controller, AHU controller, roof top AC controller and VAV box controller.

One may have questions like why do we need application-specific controllers and why the Supervisory Controller cannot take care of these functions. Drawing an analogy, for easy understanding, the 4-tier architecture of BMS that we are discussing could be compared to a full-fledged organization like a manufacturing plant or a corporate office. For smooth functioning, organizations have individual departments like sales, marketing, production and accounts, which have their own departmental processes to handle their unique and specific work. For seamless functioning and to achieve the organizational goals all these departments are integrated (report to) a higher level function like a plant head or general manager. Similarly in BMS, we have application-specific DDC for handling AHU, FCU, VAV, DX units, chillers, etc. All these are integrated over the network and are managed by the Supervisory Controller.

In very small offices, depending on the size of the organization and business needs, there may be no dedicated departments but a simplified organization structure. Similarly, in BMS also, a simplified architecture (which does not use the typical 4-tier architecture) is available with limited features and capabilities for use in small projects. We will discuss it later in the concluding Part 7 of this series.

How a DDC Works

A sample DDC is shown in *Figure 1*. These versatile controllers use BACnet MS/TP, LON or N2 network. Some models have LCD screen and a button touch pad panel for local monitoring of the DDC.

Figure 1: Direct Digital Controller

A DDC is customized for the intended use by applying optimum design logic for that application, which usually encompasses set points, design logic, timers, time schedules, trend logs, alarms, etc. The Field Devices are connected to the DDC in a daisy chain fashion (*Figure 2*), using a twisted pair shielded cable. This connection

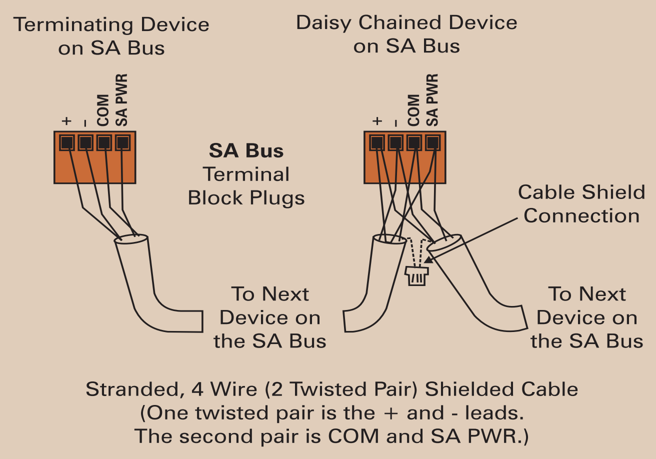

Figure2: SA bus connecting the Field Devices

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between the Field Devices and Field Controllers is called an SA bus (SA: Sensor and Actuators). Two-way communication between the field controllers and field devices occurs over the SA bus. Usually, a DDC supports only one SA bus. The manufacturer of BMS controllers specifies the number of devices that a DDC can support on an SA bus, the length of SA bus wiring, etc. The DDC provides power supply for the 'network-type' sensors and other devices connected on the SA bus.

The microprocessor in the DDC works using digital inputs and outputs. To facilitate working with analog devices, analog/digital converters (ADC) are used. Refer *Figure 3*. A block diagram of a microprocessor-based controller is shown in *Figure 4*. Input

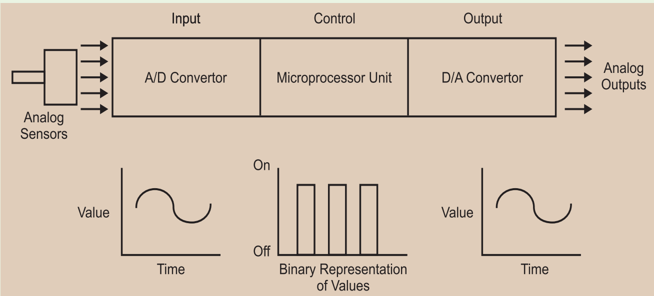

Figure 3: Analog to Digital to Analog conversion in DDC

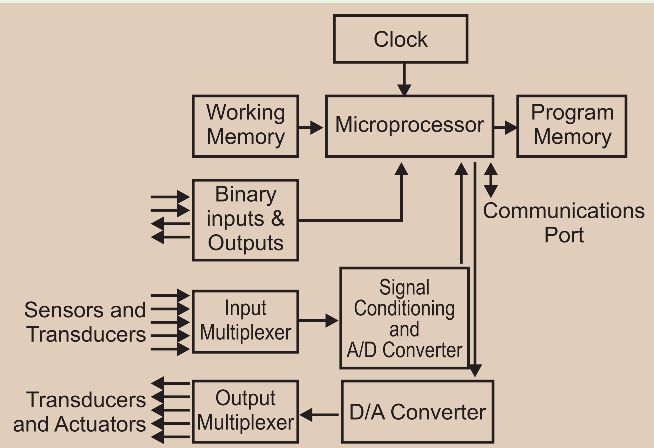

Figure 4: Block diagram of a DDC

analog signals, typically from temperature, pressure or other types of sensors, are scanned sequentially by a multiplexer at regular sampling intervals. The signals are digitized by an Analog-to-Digital Converter (ADC), commonly with a resolution of 16-bit or 32-bit, and read by the microprocessor. The current lot of microprocessors uses 32-bit processor for speed and accuracy. Some controllers work with lower bit resolution.

The controllers are controlling the process variables whose values are measured continuously by sensors. Here, 'continuous' can have different meanings in different environments. In an analog environment, it has its original meaning. In a digital environment, it depends on the sampling rate. From a building control point of view, the measurement is still considered to be continuous when the sampling rate is in terms of milliseconds and sometimes even seconds.

The controller processes the input data, applies the sub-routine programs in-built in the software as per control logic and creates an output action. The digital output is converted to an analog output by a Digital-to-Analog Converter (DAC). Digital input and output circuits from the panel push buttons and the panel displays of the DDC are also connected to the processor. The analog and digital outputs from DDC control the relays, actuators, positioning/throttling devices, etc. to control the system parameters.

The DDC is capable of applying any of the standard control responses – like two-position control, floating control, proportional control, proportional plus integral control or PID, etc. – as required by the application and as built in the microprocessor software by the DDC designer. The type of control responses (PID, floating etc.) were discussed in Part 3 of this series, which may be referred for a refresher. Standard energy management routines may also be pre-programmed and may interact with other control loops where appropriate.

The operator may enter parameters such as set points, proportional or integral gains, minimum on and off times, or high and low limits, etc., but the in-built control algorithms in the DDC make the control decisions.

Firmware and Software

Pre-programmed control routines, known as firmware, are sometimes stored in permanent memory such as programmable read-only memory (PROM) or erasable programmable read-only memory (EPROM), and the application or set points are stored in changeable memory such as electrically erasable programmable read-only memory (EEPROM). The operator can modify parameters such as set points, limits and minimum off times within the control routines, but the primary program logic cannot be changed without replacing the memory chips.

User-programmable controllers allow the algorithms to be changed by the user. The programming language provided with the controller can vary from a derivation of a standard language to custom language developed by the controller's manufacturer, to graphically based programming. Pre-programmed routines for proportional, proportional plus integral, Boolean logic, timers, etc., are typically included in the language.

Types of DDC

Simple controls may have a single control loop that can perform a single control function (e.g., temperature control of a unit ventilator). A single control that is fixed in functionality with flexibility to change set points and small configurations is called an application-specific controller. Many manufacturers include application-specific controls with their HVAC equipment, such as chillers and AHUs.

Some digital controllers (e.g., a programmable room thermostat – *Figure 5*) are designed for dedicated purposes and are adjustable only through manual switches and potentiometers mounted on the controller. Such controllers cannot be net worked with other controllers and are referred as stand-alone controllers. On the other hand, net workable controllers can be grouped and networked together in the form of distributed control. Communication links generally use either a poll/ response or a peer protocol in the case of distributed control. Communication between DDCs and with Supervisory Controllers occurs over FC bus (FC: Field Controller). Refer *Figure 6*.

Figure 5: Stand-alone FCU DDC

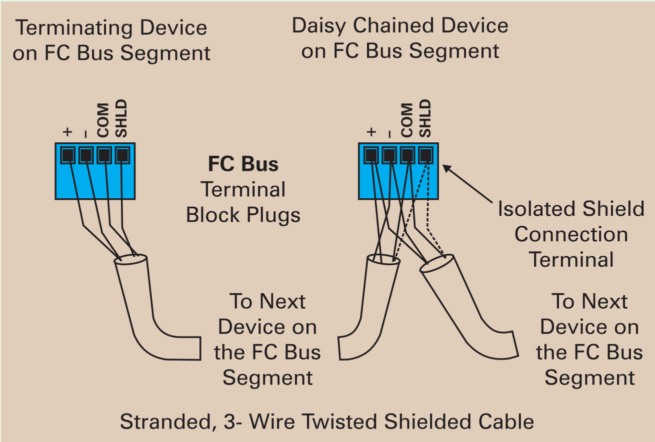

Figure 6: FC bus connecting the field controllers

The sensor and the controller can be combined in a single instrument such as a room thermostat, or they may be two separate devices.

Advantages of DDC

The advantages of DDC include the following:

- Sequences or equipment can be modified by changing software, which reduces the cost and diversity of hardware necessary to achieve control.
- Features such as demand setback, reset, data logging, diagnostics, and time-clock integration can be added to the controller at a small incremental cost.
- Precise, accurate control can be implemented, limited by the resolution of sensor and analog-to-digital (A/D) and digital-to-analog (D/A) conversion processes. PID and other control algorithms can be implemented mathematically and can adjust performance based on multiple sequences or inputs.

Figure 7: Hand-held devices for field use

- Controls can communicate with each other using open or proprietary networking (e.g., Ethernet or Internet) standards.
- Usually, hand-held terminals are used by technicians (*Figure 7*) for troubleshooting, and full-sized, fully functional terminals are used at a fixed location to monitor the entire digital control system. Standard internet browsers can be used to access system information.

Selection of DDC

A DDC is selected based on the number of IO (Input/Output) points required for a system, encompassing all field devices (including other make) that are involved in that application area. The IO points could be analog input or output, digital input or output or analog and digital value points. (Please refer Part 3 of this series). It is advisable to list down the entire IO summary for each of the equipment and then summarize the total IO points. Two examples of IO summary for a constant-speed fan cooling tower and an air cooled chiller are shown in *Table 1* and *2*. Similar details are prepared for other equipment like AHU, pumps, etc.

Table 1: IO summary example for fixed speed fan cooling tower

Chiller Plant Equipment	Point	Point Type
Cooling tower with constant speed fans	On/Off control	BO
	On/Off status	BI
	Trip status	BI
	Auto/Manual control	BI
	High speed control	BO
	Low speed control	BO
	Condensing water isolation valve On/Off control	BO
	Condensing water isolation valve On/Off status	BI

A typical DDC selection chart, based on the IO points it can handle, is shown in *Table 3*. In the table, Universal (UI or UO) could be either analog or digital, CO is a configurable output and RO is the relay output.

The DDC is suitably chosen for the required IO points. To enhance the IO point capability of a controller, IOM (Input Output Module) can be used. Refer *Figure 8*. IOM does not have any programming logic embedded in it. The IOMs could be used in two ways: either on the SA bus to increase the point count of controllers, or in the FC bus as a multiplexor and for peer to peer connectivity. *Table 4* shows a sample IOM selection chart for enhancing the point count of a controller, when used on the SA bus. *Table 5* shows an example of selection of controller and IOM for the required number of IO points.

Figure 8: IOM (Input Output Module)

Communication Protocol

We humans communicate to each other by speaking the same language, say English or Hindi, and we use a medium to

Table 2: IO summary example for air cooled chiller

Standard BMS Point List for Chiller System				Associated Sensing/Controlling Equipment	
Chiller Plant Equipment	No.	Point	Point Type	Associated BMS Equipment	Description
Air cooled chiller	3	On/Off control	BO		
		On/Off status	BI		
		Trip status	BI		
		Auto/Manual status	BI		
		Chilled water flow status	BI	FS80-C	Water flow switch
		Chiled water isolation valve On/Off control	BO	VF600 c/w VA300	On/Off valve actuator c/w brass well
		Chiled water isolation valve On/Off status	BI		
		Chilled water supply temperature	AI	TE631AP-1 c/w WZ1000-5	Temperature sensor c/w brass well
		Chilled water return temperature	AI	TE631AP-1 c/w WZ1000-5	Temperature sensor c/w brass well

communicate, say over a phone. When we do not know the same language, we use an interpreter. The communication protocols in BMS have similar analogy.

Table 3: DDC selection based on IO points (indicative example.)

Number of points available for different DDC							
Point Type DDC	UI	BI	BO	CO	AO	UO	RO
MS-NCE25xx-0	10	8	7	4	4		
MS-FEC 161-0	2	1	3	4			
MS-FEC 2611-0	6	2	3	4	2		

Table 4: IOM selection chart – to increase no of IO points (Indicative example)

Point Type DDC	UI	BI	BO	CO	AO	UO	RO
MS-IOM4711-0	6	2	3	4	2		
MS-IOM1711-0		4					
MS-IOM2711-0	2					2	2
MS-IOM2721-0	8				2		
MS-IOM3711-0	4					4	4
MS-IOM3721-0		16					
MS-IOM3731-0		8	8				

Remark:
1. UI can act as AI or BI (dry contact input)
2. UO can act as AO or BO (dry contact output)

Table 5: Selection of controller and IOM based on required IO points (indicative example)

Total number of points	AI	15
	AO	1
	BI	37
	BO	10

Select the combination of IOMs connecting to SA bus to fulfill the BMS point requirement

Point Type DDC	Number	UI	BI	BO	CO	AO	UO	RO
Required		15	37	10	1			
MS-NCE25xx-0	1	10	8	7	4	4		
MS-IOM2721-0	1	8					2	
MS-IOM3721-0	2		16					

In a BMS, tons of data and information flow around and many controllers and automation engines share data and network. This requires a Communication Protocol to define the communication behavior of each component in the network. These rules define the content and format of messages to be exchanged, error detection and recovery, addressing, when a device may transmit a message, electrical signaling characteristics, and details of the communication medium such as wire type and pin connections, etc.

Protocols are often defined by dividing the complex problem into several simpler problems that, when solved in a particular order, meet the overall communication needs. Component parts of the overall solution are called layers. A protocol may provide the functionality of a particular layer or group of layers, or address the entire communication process. Let us look at a few of the most commonly used protocol elements.

RS-Series Serial Communication (Physical Layer)

The ITU (International Telecommunications Union) has defined standards for serial communications like RS-232, RS-422, RS-423 and RS-485. In RS-232, the user data is sent as a time-series of bits - 1 bit at a time. RS-232 has a bit rate of 19,600 bps for a maximum distance of 20 meters and has only one transmitter and receiver. The currently used popular RS-485 port has a maximum bit rate of 10 Mbps, can have 32 transmitters per receiver in a single line, with maximum cable length of 1.2 km.

Common Data Exchange Terminology

LAN (Local Area Network) refers to a group of computers or DDCs on a network. LAN uses coaxial cable or fiber-optic cable, which are faster in data transmission. Some LANs could also be wireless, using infrared or radio transmission. These have slower transmission rates and limited distances between nodes (transmission points).

Ethernet is a common network protocol for exchanging information across a LAN. Ethernet networks are used for many applications, including e-mail, file transfer, web browsing and building control systems.

For other common terms that are frequently referred like TCP/IP, internet, intranet, FTP, VoIP, P2P, etc., please refer standard IT books or web sites.

Modbus

This protocol was published in the late 1970s and is based on a master-client architecture. It uses a standard message structure which is recognized and implemented by all Modbus controllers, regardless of network type. Modbus communicates over RS-485 physical layer. Each Modbus message has the same structure – using four basic elements and in the same sequence. Refer *Table 6*.

Table 6: Modbus message structure

Field	Description
Device address	Address of the receiver
Function code	Code defining message type
Data	Data block with additional information
Error	Numeric check value to test for communication errors

Table 7: BACnet message structure

<table>
<tr><td colspan="5">BACnet Application Layer</td></tr>
<tr><td colspan="5">BACnet Network Layer</td></tr>
<tr><td>TCP/IP</td><td></td><td rowspan="2">MS/TP</td><td rowspan="2">Dial-up PTP</td><td rowspan="3">LonTalk</td></tr>
<tr><td colspan="2">ISO 8802</td></tr>
<tr><td>ETHERNET</td><td>ARCNET</td><td>RS 485</td><td>RS 232</td></tr>
</table>

In Modbus network, a conversation is always started by a master and a slave takes action and responds to it. Addressing in the message header is used to define which device should respond to a message and all other nodes, with different addresses, simply ignore that message.

Other than wired serial connections, Modbus can use wireless communication and TCP/IP networks as well.

Lon Works

This is a network automation and control solution for commercial buildings, industrial, transportation, home markets, etc. It does not have central control or slave-master architecture. Intelligent control devices called nodes communicate with one another using Lon Talk protocol. Each node includes a physical interface (transceiver) that couples the node micro controller with the communication medium.

Lon Works supports multiple communication media such as twisted pair, power line, coaxial cable, infrared, optical fiber, radio frequency etc.

BACnet

This is the currently used and most popular protocol. ASHRAE and ANSI developed this communication and data protocol BACnet (Building Automation and Control Network), which was launched in 1995. This open protocol was supported by almost all BMS manufacturers. It gave the end-users a large benefit in terms of vendor-independence and forward compatibility with future generation systems.

The two terms regularly used in BMS are BACnet IP and BACnet MS/TP. BACnet IP uses a standard UDP/IP stack to send and receive messages (UDP: User Datagram Protocol). UDP/IP operates in parallel to TCP/IP. For the most part, the same packet that would be found on an MS/TP link is encapsulated in a UDP/IP packet and called BACnet IP. Devices use IP addresses and Ethernet MAC addresses just like other UDP/IP network devices. There is no concept of a master-slave token passing since Ethernet is automatically peer-to-peer in nature. Devices simply transmit to their intended recipient at will, and let Ethernet deal with packet collisions and retries as needed.

MS/TP stands for Master Slave Token Passing. Each device on the link is considered the 'master' when it has the token. If it does not have immediate need to use the token, it is required to pass the token along to the next device. This is the 'token passing' part. All devices on the link that do not currently have the token are regarded as slaves, and are expected to listen to any messages the current master may have for it. Because all devices take turns being master, the link is effectively peer-to-peer.

BACnet uses five lower level communication media – namely ACRENET, Ethernet, Lon Talk, RS-485 MS/TP and RS-232 point-to-point. If two BACnet compliant devices are connected together on a network, but use Ethernet and RS-232 respectively, gateways are required to do certain translations.

BACnet protocol works on a client-server model and its messages are called client requests. A client machine sends a service request to a server machine, which performs the service and reports the result to the client. BACnet provides a tiered architecture as shown in *Table 7*. All the compliant devices from every manufacturer are required to have a PIC statement (Protocol Implementation Conformation statement). The PIC statement helps the BMS engineers while trying to integrate different make BACnet devices for commissioning. BTL (BACnet Testing Laboratories) is a certification body that verifies correct implementation of object type by the manufacturer and runs a conformation test to certify the controllers. The certified controllers and control systems can be seen in the link *http://www.bacnetinternational.net/btl*

Gateways and Routers

It is common to see different devices in a building having different protocols, which need to be brought on a common network, mostly onto BACnet network. A gateway is used as a translator between Modbus/ASCII/TCP devices and BACnet, facilitating them to show up as BACnet-compliant devices on the BACnet network.

The BACnet standard also specifies how to build routers. 'Routers' are simply devices that connect multiple networks together. The networks may be of the same or different types. e.g. a few DDCs on Ethernet and a few on MS/TP. Router is a device that passes a message from one network to another without changing the form or content of the message. Though in the BMS field, the terms gateways and routers are used interchangeably, they are different.

BACnet has emerged as the most-adopted open network protocol. Choosing field devices and systems, which can be networked on BACnet, may be a way to maintain a flexible position as products and standards continue to develop over the years.

References

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2. Intelligent Building Systems, Albert Tingpat So and Wai Lok Chan, Johnson Controls.
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In the Part 5 of this classroom series, in the May-June 2016 issue of the *Journal,* we shall discuss Supervisory Controllers and Use-Interface.