Introduction to Automation and Process Control

An overview of automation, automation systems, and system engineering
Topics

- Automation Defined
- Automation Systems and Applications
- Automation System Components
- Project Engineering
- PLC Basics
  - A brief history of PLCs
  - PLC Components
  - Data and Data Types
  - The PLC Scan
  - Basics of Programming
What is Automation?

Automation Defined and Automation Applications
What is Automation?

- Industrial Automation is the use of computers to control industrial machinery and processes, replacing human operators.
- It is a step beyond mechanization, where human operators are provided with machinery to help them in their jobs.
Why Automate?

Some advantages of Automation are:

- Repeatability
- Tighter quality control
- Waste reduction
- Integration with business systems
- Increased productivity
- Reduction of labor..
Types of Automation Applications

Process Control is defined as the automated control of a process.
- Used extensively in oil refining, chemical processing, electrical generation and the food and beverage industries where the creation of a product is based on a continuous series of processes being applied to raw materials.

Machinery Control is defined as the control of individual industrial machines.
- These machines are used independently of one another or in succession to manufacture or assemble parts into a final product.

Machine Tooling is defined as the control of an individual machine that is designed to drill, grind, or otherwise shape a raw material into a finished part.
- These applications require very fine control with repetitive motions which need to be changed whenever the part is changed.
What is an Automation System?

- An automation system is a device or set of devices that manage the behavior of other devices or machines.
- The system is an interconnection of components connected or related in such a manner as to command, direct, or regulate itself or another system.
- Comprised of **Sensors** (inputs to the system), a **logic solver** (decision making device, usually a PLC), **final control elements** (outputs), and an **HMI** (human – machine interface), which provides a means for the operator to effect and monitor system operation.
Automation Systems in the Real World

Real automation systems involve a lot of equipment

- PLCs and distributed I/O
- CNC and motion controls
- HMI panels and computers
- Motors and drives
- Safety systems
- Computers
- Communications networks

Real automation projects require extensive engineering

- PLC programming HMI configuration and programming
- Drive system parameterization and engineering
- Network design and integration
- Integration of OEM machines into the process..
What is an Integrated Automation System?

An integrated control system ties together islands of automation into a complete automation production system. It includes:

- Full line of automation and drive products – Control, Networking, Visualization, Motion, Safety
- Data Transparency and Communications – From I/O level up to MES
- Integrated Engineering Tools – Device Configuration & Project Manager
All of the individual components of a control system are commercially available from several different manufacturers.

- Not all manufacturers supply all components of the automation systems.
- Using different manufacturers components creates a problem of getting all of the pieces to work together smoothly and to share information openly.

Siemens has the unique position in the industry of supplying many different automation system components.

- All of the automation system components Siemens supplies to an end user are designed to openly communicate with other manufacturers equipment using standard protocols.
- All of the components Siemens manufactures are also designed to easily integrate with one another and are managed from a single program known as Simatic Manager..
History of the PLC

The PLC was invented in response to the needs of the American automotive industry.

- Before the PLC, control, sequencing, and safety interlock logic for was accomplished using relays, timers and dedicated closed-loop controllers.
- The process for updating such facilities for the yearly model change-over was very time consuming and expensive, as the relay systems needed to be rewired by skilled electricians.
- In 1968 GM Hydramatic (the automatic transmission division of General Motors) issued a request for proposal for an electronic replacement for hard-wired relay systems.

The winning proposal came from Bedford Associates of Bedford, Massachusetts.

- The first PLC was born and a new company dedicated to developing, manufacturing, selling, and servicing this new product: Modicon, which stood for MODular Dlgiital CONtroller.
What is a PLC?

A PLC (Programmable Logic Controller) is a small computer used for automation of real-world processes, such as control of machinery on factory assembly lines. Where older automated systems would use hundreds or thousands of relays and cam timers, a single PLC can be programmed as a replacement.

- The PLC is a microprocessor based device with either modular or integral input/output circuitry that monitors the status of field connected "sensor" inputs and controls the attached output "actuators" (motor starters, solenoids, pilot lights/displays, speed drives, valves, etc.) according to a user-created logic program.
- The functionality of the PLC has evolved over the years to include capabilities beyond typical relay control; sophisticated motion control, process control, Distributed Control System and complex networking have now been added to the PLC’s list of functions.
- PLC’s have to have their hardware layout defined (to be discussed later) and their program created to define its overall function.
What is a Human Machine Interface?

- Human Machine Interface - The user interface: the device that allows interaction between the user and the machine.
- The terms HMI and "MMI" (Man Machine Interface) are typically used in industrial and process control applications, whereas "user interface" is the common term in business information systems.
- It consists of a combination of menus, screen design, keyboard commands, command languages and online help, which creates the way a user interacts with a computer.
- If input devices other than a keyboard and mouse are required, this is also included.
- HMI devices require programming in order to define their operating characteristics and what is information is presented to the operator.
And what about these things called Drives?

- Normally, electric motors run at a fixed speed that is determined by the motor design.
- A Variable Frequency Drive (sometimes abbreviated VFD) is an electronic device that allows an electric motor to be run at varying rotational speeds.
- This provides for more precise and more efficient control of a machine over a greater range of operation using linear controls.
- Drives require programming to define their operating characteristics and parameters.
How do I program all of these pieces?

- Each component of an automation system can be microprocessor controlled.
- Any device that is microprocessor controlled has the ability to have its specific method of functioning defined via software.
- All of the software for all of the individual components resides on a PC. This PC is referred to as the *Engineering Station* (ES), and is the central point in a system from where all programming can be done.
Engineering Setup

- Engineering Station
- Programming/Automation Network

- Power Supply
- CPU
- Expansion Card
- Expansion Card
- Expansion Card
Hardware Features

PLCs of the modular type have a limited number of connections built in for signals such as digital inputs, digital outputs, analog inputs and analog outputs.

- Typically, expansions are available if the base model does not have sufficient I/O.
- Rack-style PLCs have processor modules without I/O and separate I/O modules, which may occupy many racks giving thousands of discrete and analog inputs and outputs.
- Often a special high speed serial I/O link (or Ethernet) is used so that racks can be remotely mounted from the processor, thereby saving on wiring costs especially for large plants.
Data in a PLC

Each data value in a PLC has an address associated with it. The address is its location in the memory areas the PLC can access while running. Data can either be handled as a raw value (absolute) or interpreted as a specific kind of data (type).

- **Bit** – lowest data quantity – expressed as either “on” or “off”
  - Associated Data Type – “Boolean”
- **Byte** – a data quantity comprised of 8 consecutive bits (8 bits)
  - Associated Data Type – “Octal”
- **Word** – a data quantity comprised of two consecutive bytes (16 bits)
  - Associated Data Types – Integer, Time, BCD, Hexadecimal
- **Double Word** – a data quantity comprised of four consecutive bytes (32 bits)
  - Associated Data Types – Double Integer, Date and Time, Real
Digital signals behave as switches, yielding simply an on or off signal (logical 1 or 0, or “True” and “False”, respectively). These are interpreted as Boolean values by the PLC.

- Pushbuttons, limit switches, and photo-eyes are examples of devices providing a digital signal.
- Digital signals generally use voltage or current, where a specific range is denominated as ON (logical 1) and another as OFF (logical 0).
- Initially, PLCs had only digital (discrete) I/O.
System Inputs and Outputs

Analog signals behave as volume controls, yielding a range of values between zero and full-scale. These are typically interpreted as integer values by the PLC.

- Pressure, flow and temperature transducers, scales and gas leak detectors can provide analog signals.
- Analog signals generally use voltage or current as well, but do not have discrete ranges for On or Off.
- They define a range of valid values, typically the range in which the I/O device operates reliably.
- PLC models introduced in the last 20 years typically have functions for analog I/O.
Other Signals

- Other methods of signal I/O include serial communications, and proprietary networks like Allen-Bradley's Data Highway, Siemens’ MPI (Multi Point Interface), or open and standardized networks like Profibus or Profinet.

- Communication channels may be used to interface the PLC with human-machine interface devices such as printers, keypads, video terminals, and supervisory level computers.

- The interconnection between different components must be defined using software…each piece of the system must have each one of its interconnections between itself and other devices defined individually.
Logic controls

- Pure logic controls were historically implemented by electricians with networks of relays, and designed with a notation called ladder logic. Nowadays, most such systems are constructed with programmable logic controllers.

- Logic controllers usually respond to switches or photoelectric cells, and cause the machinery to perform some operation. Logic systems are great for sequencing mechanical operations in places like elevators and factories, but notably poor at managing continuous process controls in such places as oil refineries and steel mills.

- Logic systems are quite easy to design, and can handle very complex operations. Logic systems may be designed with a system similar to Boolean logic.
Relay Logic Components

- Relay – an electromechanical device where a electrical coil receives power and causes its mechanical contacts to change states.
- “Normally Open” refers to contacts that are open (non-conducting) when the coil is off.
- “Normally Closed” refers to contacts that are closed (conducting) when the coil is off.
- When the coil is energized, all of the contacts associated with the coil reverse states.
- Special coils have been built to implement different functions such as sequencing and timing operations.
Start with Boolean Arithmetic, and a “First Law of Boolean Math”.

Addition (OR Function)  |  Multiplication (AND Function)
---|---
0 + 0 = 0  |  0 × 0 = 0  
0 + 1 = 1  |  0 × 1 = 0  
1 + 0 = 1  |  1 × 0 = 0  
1 + 1 = 1  |  1 × 1 = 1  

< Makes sense  |  < Makes sense  
< Makes sense  |  < Makes sense  
< Makes sense  |  < Why not 2

*There are only two numbers in Boolean math, 0 and 1*
The “OR” function (Addition)

0 + 0 = 0

1 + 0 = 1

0 + 1 = 1

1 + 1 = 1
The AND Function (Multiplication)

- $0 \times 0 = 0$
  - False
  - Off

- $1 \times 0 = 0$
  - False
  - Off

- $0 \times 1 = 0$
  - False
  - Off

- $1 \times 1 = 1$
  - True
  - On
The “NOT” function (Inversion)

Every boolean variable has a “complement” (or inverse), and since there are only two values in boolean math, 1 and 0, then:

If: \( A = 0 \)
Then: \( \overline{A} = 1 \)

If: \( A = 1 \)
Then: \( \overline{A} = 0 \)
Examples of Boolean Logic in a PLC Program

- **AND**
- **OR**
Additional Program Functions

- PLCs have built-in functions to support a variety of control requirement other than simple Boolean on-off applications:
  - Edge Detection (one shot)
  - Timers
  - Counters
  - Latches

- Newer PLCs also include operations for a variety of mathematical and technological functions as well

- The programmer uses these instructions in a myriad of different combinations to create a custom program to control the attached equipment.
Introduction to Programming
How a PLC Operates – The “Scan”

- Read Inputs
- Diagnostics and Communications
- Execute Program
- Update Outputs
General Program Structure

In a PLC, the overall program can be organized into several routines:

- Main Program – the major portion of the program that is executed every scan.
- Initialization Routines
- Error Handling Routines
- Time-based Routines
- Process-initiated Routines
- Hardware Fault Routines

- In addition, there are typically many other subroutines that perform specific functions, and are called by these routines.
Detail of the S7 CPU Memory Areas

User Memory
- Work Memory: Parts of code required for operation, Parts of data blocks required for operation
- Load Memory: System Data Blocks (configuration data online), Code Blocks, Data Blocks (user program online)

System Memory
- Memory Bits
- Timers & Counters
- Communications Buffer
- Diagnostic Buffer
- Process Image: Input Table, Output Table
- L-Stack, I-Stack, B-Stack

Programming Device
- Hardware Configuration (offline), User Program (offline)

Signal Modules
- Input Signals
- Output Signals

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Assigning Tags to Addresses

Each storage in the PLC memory area is accessed via its “absolute” address.

Examples:

I20.0, which points to Input Area Byte 20, bit number 0.
QW72, which points Output Area Word 72
MB0, which points to Memory Area Byte 0

“People” prefer logical names for these addresses, known as “tags”:

“Motor Start Pushbutton” for IB20.0
Drive Speed Setpoint” for QW72
“Conveyor System Status” for MB0
Relays and Contacts and Ladder Logic

Contacts and coils that are “linked” share the same name, or reference. This is true in electrical drawings and in Ladder Logic, the most commonly used PLC programming language.

Ladder Logic was designed from its inception to closely follow electrical diagrams that electricians were accustomed to reading.

The multiple horizontal lines give the appearance of a “ladder”, which is where the language gets its name.
I/O Module Data and Process Image
Tables

Input Module Configured as IB 0 and 1
Output Module Configured as QB 4 and 5

I 0.2
S 1
O 1
K 1
Q 4.3

PII

Byte 0
Byte 1
Byte 2
... Byte x

PIQ

Byte 0
Byte 1
Byte 2
Byte 3
Byte 4
Byte 5
... Byte x

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