Chapter 3

Control equipment

This chapter gives an overview over various kinds of commercial control equipment.

3.1 Process controllers

A *process controller* is a single controller unit which can be used to control one process output variable. Figure 3.1 shows an example of a process controller (ABB's ECA600). Today new process controllers are implemented digitally with a micro processor. The PID controller function is in the form of a program which runs cyclically, e.g. each 0.1s, which then is called the time step of the controller. Earlier, controllers were build using analog electronics, and even earlier, pneumatic and mechanical components were used. Such controllers are still in use today in some factories since they work well and are safe in dangerous (explosive) areas.

Here is a list of typical characteristics of process controllers:

- The front panel of the controller has vertical bar *indicators and/or numeric displays* showing, see Figure 3.1,
  - the process measurement signal (a common symbol is PV – Process Value),
  - the setpoint (symbol SP),
  - the control variable (MV – control variable).

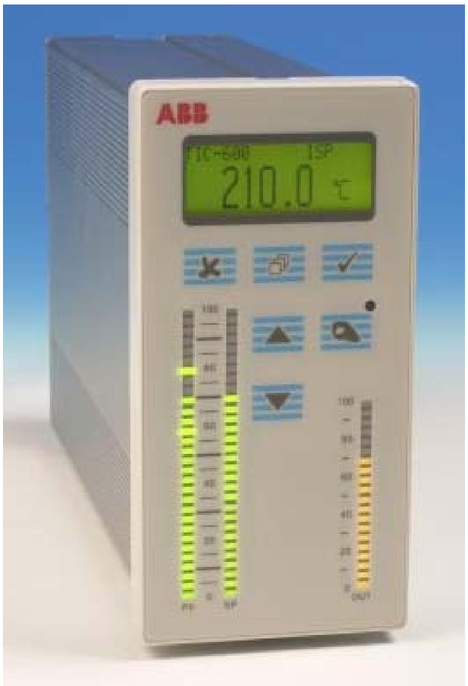

Figure 3.1: A process controller (ABB ECA600)

- The controller has *analog input* (AI) (for measurement signals) and *analog output* (AO) (for the control variable). The input signal is a voltage signal (in volts) or a current signal (in amperes). The output signal is a current signal. In general, current signals are preferred before voltage signals, because:

  – A current signal is more robust against electrical noise.

  – With long conductors the voltage drop along the conductor may become relatively large due to the internal resistance in the conductor.

  – A current signal of 0 mA is abnormal and indicates a break of the conductor.

  The standard current range is 4–20 mA (also 0–20 mA is used). There are several standard voltage ranges, as 1–5V[1] and 0–10V. The physical measurement signal in A or V is usually transformed to a percent value using a linear function. For example, the transformation from the a signal y_A in the range 4-20 mA to a signal

[1] 4–20 mA may be transformed to 1–5 V using a resistor of 250 Ω.

$y_{\%}$ in the range 0-100% is realized using the following formula:

$$y_{\%} = K\left(y_A - y_{A0}\right) + y_{\%0} \tag{3.1}$$

where $y_{\%0} = 0\%$, $y_{A0} = 4\text{mA}$ and $K = 100\%/16\text{mA} = 6,25\%/\text{mA}$. The most important reasons to use 4 mA and not 0 mA as the lower current value, is that the chance that the actual measurement signal is drowned in noise is reduced and that the base signal of 4 mA can be used as an energy source for the sensor or other equipment.

- The controller may have *pulse output*, which may used to implement analog output using a binary actuator, typically a relay. The technique is called *PWM - Pulse Width Modulation*. The PWM-signal is a sequence of binary signals or on/off-signals used to control the binary actuator. See Figure 3.2. The PWM-signal is kept

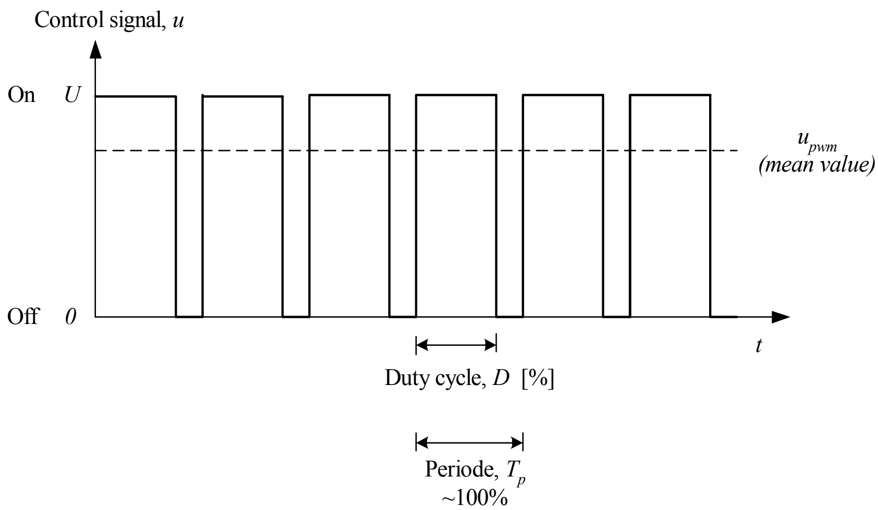

Figure 3.2: Pulse Width Modulation

in the on-state for a certain time-interval of a fixed cycle period. This time-interval (for the on-state) is called the duty cycle, and it is expressed as a number in unit percent. For example, 60% duty cycle means that the PWM-signal is in on-state in 60% of the period (and in the off-state the rest of the period). The duty cycle is equal to the specified analog control signal which is calculated by the PID controller function. In the mean the PWM-signal will become equal to the specified analog control signal, if the cycle period is small compared to the time constant of the process to be controlled.

- In addition to the analog inputs and outputs the process controller typically have *digital inputs* (on/off-signals) to detect signals from switches, buttons, etc., and *digital outputs* which can be used to control relays, lamps, motors etc.

- The process controller typically have ports for serial (RS-232) *communication* with another controller or a computer.

- The controller can be programmed from a panel on the front or on the side of the unit or from a connected PC. The programming includes combining function modules (see below).

- One of the function modules is the PID controller. You will have to enter values for the PID parameters, typically being K_p, T_i and T_d, but other parameters may be used in stead, as the proportional band, PB, which is equal to $100\%/K_p$, cf. Chapter 2.6.5.

- Other function modules include logical functions as AND, OR, SR-flipflop, etc., and arithmetic functions, as addition, multiplication, square root calculation, etc.

- In addition to the common single-loop PID control, the process controller may implement more advanced control methods, as *feedforward control* (cf. Chapter 9.1) *gain scheduling PID control* (4.9.2), *cascade control* (9.2) and *ratio control* (9.3).

- The operator can adjust the setpoint *internally* (locally) on the controller, but it is usually possible to use an *external* setpoint, too, which may come from another controller (as in cascade control) or from a sensor (as in ratio control) or from a computer which calculates the setpoint as a result of a plantwide control strategy.

- The operator can take over the control by switching the process controller from *automatic mode* to *manual mode*. This may be necessary if the control program is to be modified, and at first-time start-up. In manual mode the operator adjusts the controller output (which is used as the manipulating variable of the process) manually or directly, while in automatic mode the control output is calculated according to the control function (typically PID control function).

- Many controllers have the possibility of *auto-tuning*, which means that the process controller – initialized by the operator – calculates proper values of the controller parameters based on some automatically conducted experiment on the process to be controlled. An even more advanced option which may be implemented is an *adaptive PID controller* where the PID parameters are calculated continuously from an estimated process model.

- The operator can define alarm limits of the measurement signal. The alarm can be indicated on the front panel of the controller unit, and the alarm limits can be used by the control program to set the value of a digital output of the process controller to turn on e.g. an alarm lamp.

Figure 3.3 shows a section of the data sheet of the controller ECA600 shown in Figure 3.1.

Controller	
Control functions	P, PD, PI, PID, pPI
Gain	0.01–99.99
Integral time	0.1–9999.9 seconds
Derivative time	0.0–9999.9 seconds
Control action	Direct, reversed
Set point	Internal, external, ramp
Control output	Analogue, pulse
Alarms	Process value, deviation.
Sample time	30–500 ms
Analogue Inputs	
Input ranges	0–20 mA, 4–20 mA, 0–5 V, 1–5 V, 0–10 V, 2–10 V.
Input types	Differential or single ended (jumper selectable).
Input impedance	Current 250 Ω Voltage 200 kΩ
Alarm function for out-of-range signal	Yes, for 4–20 mA, 1–5 V and 2–10 V, when the signal drops below the lower limit.
Functions	First-order software filter, linear / square root.
Resolution	12 bits
Inaccuracy	Max. ± 0.2% of FS within 5–55°C.
Temperature stability	0.01% FS per °C within 5–55°C.
Analogue Outputs	
Output ranges	0–20 mA, 4–20 mA.
Type	Current source
Max. output current	22 mA
Load resistance on current output	Max. 650 Ω
Short circuit protection	Yes
Resolution	12 bits
Output signal break detection	Yes
Inaccuracy	Max. ± 0.2% of FS within 0–50°C.
Communication	

Digital Inputs	
Type	24 V DC, common digital input ground, current sink, opto-isolated.
Voltage	Max. 35 V, min. -0.5 V.
Logic levels	0 < 3 V (IEC 1131-2, type 1) 1 > 15 V (IEC 1131-2, type 1).
Digital Outputs	
Type	24 VDC, current source.
Load current	Max. 250 mA per output, max. 500 mA total.
Short-circuit current	Max. 500 mA transient current during 1 µs.
Power supply	
AC	115/230 V AC ± 10%, 50–60 Hz, 20 VA or 19 V AC ± 10%, 50–60 Hz, 1 A.
DC	24 V DC ± 10%
Protection	Secondary side of transformer and direct supply fused via thermo type fuse.
Transmitter	Max. 24 V DC/150 mA.
Environmental specifications	
Operating temperature	+5 to +55°C (IEC 68-2-1/2).
Non-operating temperature	-25 to +70°C (IEC 68-2-1/2).
Non-operating damp heat steady state	93% relative humidity at +40°C (IEC 68-2-3).
Protection class	IP20 generally. IP65 for front. IP65 for front against IP65 compliant panel with panel mounting kit.
Electrical environment	Fulfils ElectroMagnetic Compatibility, EMC, directive 89/336/EEC
Order codes	ECA 06–0000 ECA 60–0000 ECA 600–0000 EMA 60–0000

Figure 3.3: A section of the datasheet of the controller ECA600 shown in Figure 3.1.

3.2 PLCs and similar equipment

*PLC*s are common in industrial automation. Figure 3.4 shows a PLC system (Mitsubishi FX2N). PLC is short for Programmable Logical

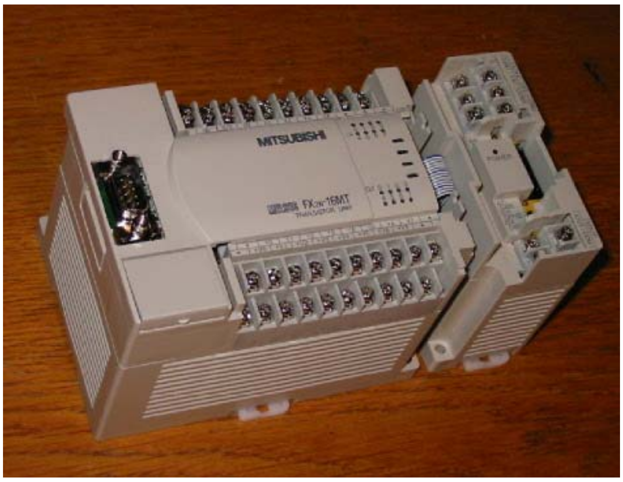

Figure 3.4: A PLC (Programmable Locical Controller). (Mitsubishi FX2N)

Controller. PLC-systems are modular systems for logical (binary) and sequential control of valves, motors, lamps etc. Modern PLCs includes function modules for PID control. The programming is usually executed on a PC, and the PLC-program is then downloaded (transfered) to the CPU in the PLC-system which then can be disconnected from the PC. The program languages are standardized (the IEC 1131-3 standard), but the actual languages which are implemented on commercial PLCs may differ more or less from the standard.

There exists alternatives to PLCs. Figure 3.5 shows National Instruments' Compact FieldPoint, which is denoted a *PAC* - Programmable Automation Controller. This is a modular system similar to a PLC in several aspects. Both logical and sequential control and PID control can be realized in the PAC. The control program is developed in LabVIEW on a PC, and then it is downloaded to the PAC, where it runs independently of the PC.

3.3 SCADA systems and DSC systems

3.3.1 SCADA systems

SCADA systems (Supervisory Control and Data Acquisition) are automation systems where typically PCs are used for supervision and control, but the execution of the control program takes place in a PLC or some other control equipment. In this way the SCADA system implements

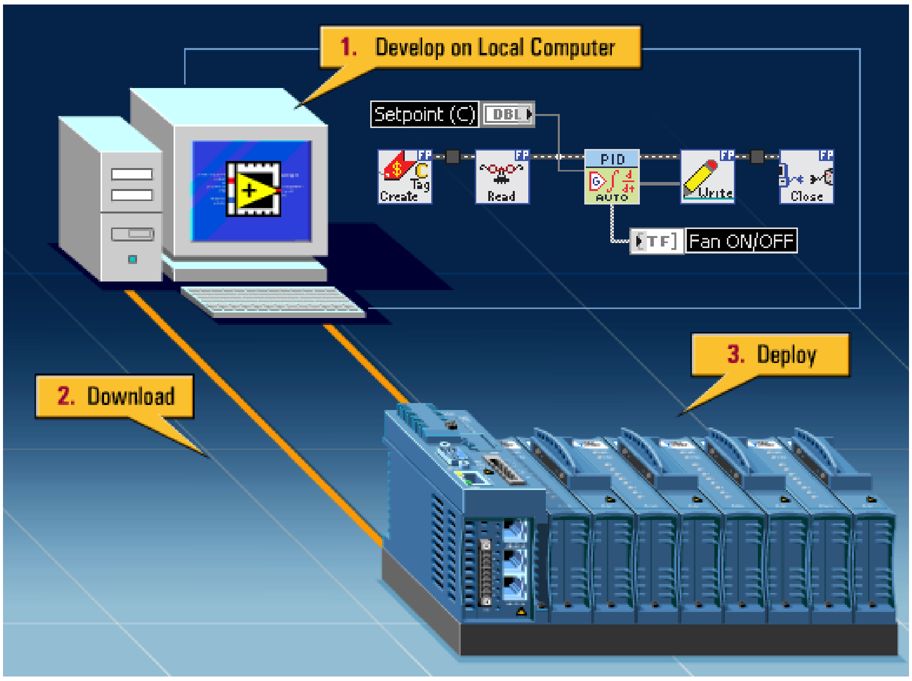

Figure 3.5: Modular control equipment: Compact Fieldpoint, denoted *PAC* - Programmable Automation Controller. (National Instruments)

a distributed control system architecture. Figure 3.6 shows an example of a SCADA-system.

Here are some characteristics of PC-based control systems:

- A set of function modules are available in the SCADA program on the PC, as arithmetic and logical functions, and signal processing functions. The setpoint to be used by the connected PLC or other control equipment may be calculated by the SCADA program according to some optimal control strategy.
- The user can build the screen contents containing process images of tanks, vessels, valves, etc., and bars, diagrams, numeric displays, alarm indicators etc.
- The PCs can communicate with other PCs or other kinds of computers via standard communication means, as RS-232 cables or Ethernet etc.
- The SCADA system has driver programs for a number of PLC-systems (from different vendors) and other I/O-systems

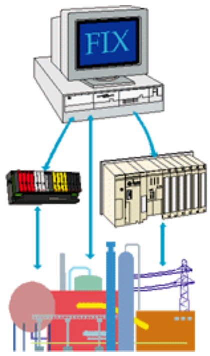

Figure 3.6: SCADA system (FIX, Novotek)

(systems for analog and digital Input/Output). The number of drivers may exceed 100.

- Data can be exchanged between programs in real-time. The OPC standard (OLE for Process Control)[2] has become an important standard for this.

3.3.2 DCS

DCS (Distributed Control Systems) are similar to SCADA systems in that the control equipment is distributed (not centralized) throughout the plant. Special process stations – not standard PLCs or process controllers – executes the control. DCSs can however communicate with PLCs etc. The process stations are mounted in special rooms close to process. The whole plant can be supervised and controlled from control rooms, where the operators communicate with the distributed control equipment, see Figure 3.7.

3.4 Embedded controllers in motors etc.

Producers of electrical and hydraulic servo motors also offers controllers for the motors. These controllers are usually embedded in the motor drive system, as separate physical unit connected to the motor via cables. The controllers implement speed control and/or positional control. Figure 3.8 shows an example of a servo amplifier for DC-motor. The servo amplifier

[2] OLE = Object Linking and Embedding, which is a tecnology developed by Microsoft for distributing objects and data bewteen Windows applications.

Figure 3.7: Control room of a distributed control system (DCS)

have an embedded PI controller which the user can tune via screws on the servo amplifier card.

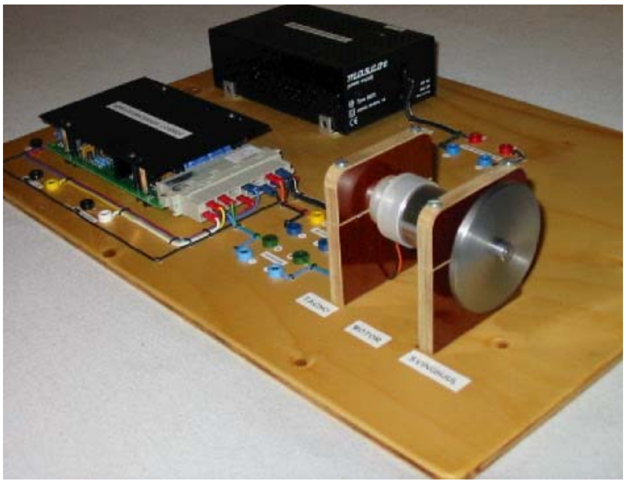

Figure 3.8: DC-motor with servo amplifier (shown behind the motor) implementing a PI-controller