PROCESS CONTROL SYSTEMS

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Contents

Summary

As well as the structural design of an adequate automation strategy according to both the process and user specific requirements, another essential aspect is represented by its technical realization. Especially in that areas where a safety-oriented plant operation is of primary interest and - following from this - high demands on reliability are to guarantee, nowadays almost generally decentralized control systems (DCS) come into application.

After a brief description of the historical development leading to today's decentralized control systems, this chapter has considered the different functional levels of a modern DCS. Starting from the sensor and actuator elements at the field level the chapter covers signal processing components, the operating and observing level up to the process management and supervisory level.

Following that, the main structural aspects of a decentralized control system have been emphasized. Essential subjects are the hierarchical organization of the components concerned, as well as their mutual communication. In this context topic bus topologies and their specific fields of application are discussed. Another focal point was set to the description and the impartial rating of the reliability of a decentralized control system.

In view of the different areas that decentralized control systems can be applied, the varying environmental conditions, e.g. temperature, electromagnetic radiation, humidity etc., and their adverse influence on the DCSs functioning must be taken into consideration.

1. Historical Development

The field of process automation evolved in step with developments in technology of new devices and systems. Over the past five decades, control functions of process automation systems have grown in sophistication.

The 1940s and 1950s represent an age of pneumatic controllers which were installed in the relevant locations in plants and manually supervised in the field. Standardized transmission of pneumatic signals (0.2-1 bar) and electric signals (4-20 mA) made placement of the controllers in central control rooms possible. Thus process information centers were born.

Several developments in technology took place during the 1960s. Solid state technology became the new controller base. Consequently, continuous feedback control gained more facilities than the pneumatic systems of the 1950s. Binary control could be transferred from the electromechanical relay systems to electronic modules incorporating NAND-, NOR- (i.e. AND, OR with inverted outputs), memory and time functions which allowed greater flexibility than their electromechanical predecessors, especially in the context of sequential control. A further advantage of this technology was better connectability of components such as indicators, controllers, recorders etc.

One of the major events of the 1960s was the introduction of computer-based automation. The first minicomputers were installed for control purposes. The mode of their application was restricted to operator guidance and set-point-control (SPC). In the latter case there was always a conventional controller responsible for the closed loop with its set-point delivered by the digital computer. Since the digital computers of the 1960s were slow, expensive and unreliable, the scale of their applications in automatic control remained small. Nevertheless, the introduction of digital computers in process automation marked the beginning of an important development that continued through the next decades.

In the 1970s the first minicomputers were operating in the DDC-mode (Direct Digital Control). Here the minicomputer performs the controller function by itself, an additional conventional controller is no longer involved. To minimize the risk of a computer breakdown, the dual computer concept was introduced. The second computer dealt with a hot standby-function. Because the software efforts of the minicomputers were high this concept had no widespread application.

Even more important was the invention of a new class of computers based on the microcontroller technology introduced in the early 1970s: the PLCs (Programmable Logical Controllers). These were specialized to solve all problems of binary control (logical as well as sequential control). Because these PLCs were to replace the relay systems and the solid state systems of the 1950s and 1960s, they could be programmed in a similar manner to the two old techniques: the Ladder Diagram (LD) and the Function Block Diagram (FBD). Consequently, the PLCs were easy to program and in addition they were reliable and available at reasonable cost. These properties were the key to their rapid success all over the world.

At the end of the 1970s another application of mini and microcontrollers was introduced, and developed fully in the early 1980s: the Decentralized Control Systems (DCS), sometimes also called Process Control Systems (PCS), the first term being preferred here. These systems consist of many computer components having functions of their own and communicating with one another. The functions are predefined (e.g. signal processing, PID algorithms, supervision) and do not need to be programmed, only configured and parametrized. Hence, a lot of software effort can be saved in contrast to the minicomputers of the 1960s and 1970s. DCSs became the standard equipment in the 1980s when planning new plants.

Another important application of microcomputers dating from the mid-1980s was their integration within the sensor and the actuator world. A steadily increasing number of sensors and actuators used microprocessors to improve quality or to perform some diagnostic tasks. It is perhaps a technical anachronism that the internal information processing in the sensors, the actuators and in the PLCs and the DCSs was digital, but information transfer between them was on the analog base. The transfer of digital signals between the components began in the 1990s, when the fieldbus technique became available.

In the 1990s the DCSs are still present, but the hardware and software has changed from special to standard components such as Personal Computers and Work Stations with their well-known software standards. The scope of automation has been widely enlarged. The DCSs are part of an integrated automation strategy, sometimes called CIM (Computer Integrated Manufacturing). This development is presented in more detail in the following sections.

2. Functional Aspects

Each DCS has to fulfil multiple functions such as continuous feedback control, logical and sequential control, observation and operation and so on. Of course, these DCS functions are the reason to use the DCS within the automation strategy. In some sense the DCS functions do not depend on the individual DCS structure chosen by a certain DCS producer. The functions can be performed by different structures. So it makes sense to discuss the functional aspects of a DCS apart from its structural aspects. The functional aspects are more general than the structural ones. The structure can change, for example for hardware reasons without changing the functions.

2.1. Hierarchy of Functional Levels

In attempting to understand a large and complex system, it is usual to represent the overall system in terms of interconnected subsystems. A diagram showing the subsystems and their interconnections will allow a deeper insight into system operation, since the details are hidden inside the subsystems.

In a particular case, suitable subsystems may already physically exist, in other cases they may be defined artificially. Such subdivision can be performed according to different criteria. For instance, geographical location, function within the system, function in a control system sense or relative time scale could be positive criteria for subdivision. An important characteristic of complex automated systems is the fact that they can be decomposed into a series of individual functional levels, resulting in a hierarchy of functional levels.

Although it is possible to define any number of functional levels in a hierarchy, a commonly accepted hierarchical structure consisting of five vertically arranged functional levels is illustrated in Figure 1. This hierarchical structure mainly corresponds to the structure used for plant automation in the processing industry. The functional levels of this system are: field level, process control level, process scheduling and supervisory level, production planning and control level, and enterprise management level.

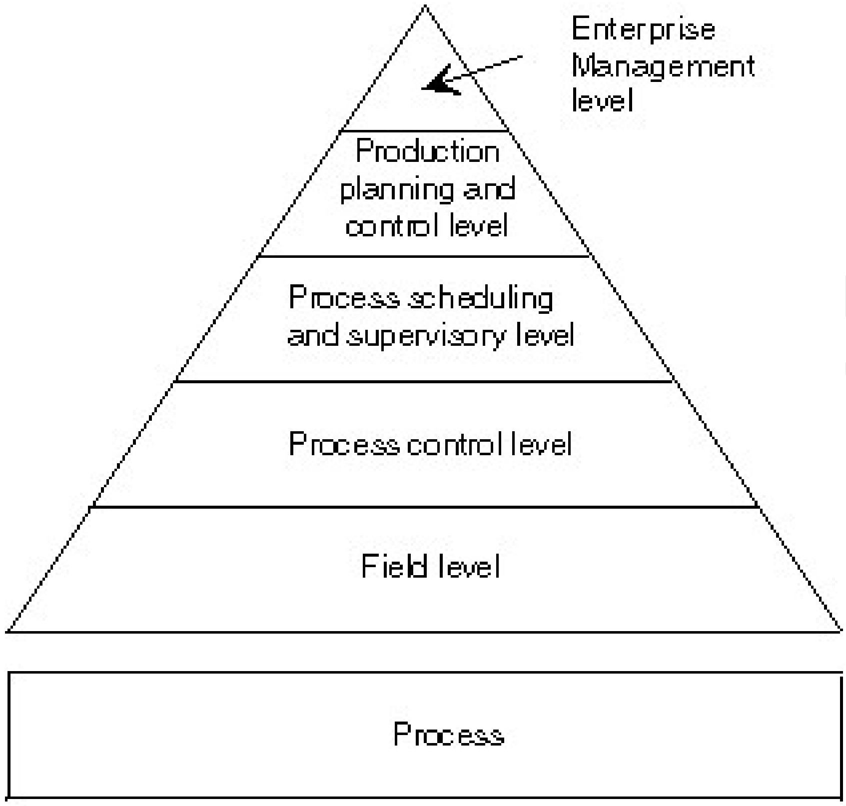

Figure 1. Hierarchical system levels**.**

At each level, some automation functions are implemented to operate on the next "lower" level. The execution of functions is initiated and controlled by the next "higher level". Beginning from the highest level, the tasks of each functional level of Figure 1 can be briefly summarized as follows.

The *enterprise management level*, apparently the "highest level", is responsible for managing the whole enterprise in the sense of planning the investment, the personnel, the finance and other functions, as well as in the sense of watching the turn-over, the profit and so on. This management is usually done by the board of directors. The highest level does not deal with the so-called "operative business" e.g. product quantity, product type, customer orders, delivery terms and so on, which are covered by the lower levels.

The functions of the *production planning and control level* belong mainly to the area of operations research and resource logistics. Production planning according to customer orders, stock on hand levels, energy costs, etc. are typical functions of this level. It is also responsible for a rough plan of production. The outcomes of this level will be provided as an objective to be fulfilled by the next lower level, which is responsible for making a detailed plan of production.

To handle this plan is one of the tasks of the *process scheduling and supervisory level.* It covers all resource planning such as personnel, material and apparatus required to fulfil an individual order. Optimal re-scheduling and flexible production changes are other functions which may be undertaken at this level.

Plant performance monitoring, failure-detection logging and procedures for failure avoiding (quality control), status reporting and standby are also within the responsibility of this level. In general, this level deals with the determination of optimal plant work conditions and generation of all relevant instructions to be transferred to the next lower level.

At the *process control level* all kinds of control (e.g. Section 2.4) are performed based on directives from the next higher level (e.g. setpoint and recipe control).

In addition, the process control level handles the tasks of data collection for higher members of the hierarchy, process monitoring, system check and diagnosis. The functions of this level are described in greater detail in the next sections.

The *field level* is in charge of acquiring information about the process with help of its sensors and is also responsible for acting on the process through its actuators. As a rule, the biggest part of investment for automation is needed for the field level. The availability of the plant depends highly on the availability of the sensors and actuators and this is discussed in the next section.

Clearly, there exists information flow both vertically and horizontally among the system levels. A vertical flow of information means the exchange of information between the levels. On the other hand, a horizontal flow of information takes place within a level.

As indicated in Figure 2, the extent of vertical flow of information increases as one moves down, where real-time data processing takes place, while the contrary holds with the horizontal flow of information.

As already discussed, the hierarchical structure depicted in Figure 1 corresponds mainly to the structure used for plant automation in the processing industry.

Regarding the automation of manufacturing plants, a similar structure is valid and a new concept was worked out in the late 1980s, known as CIM (Computer Integrated Manufacturing).

It is designed to integrate the information and control parts of a manufacturing plant and contributes highly to the increase of flexibility, productivity, and reliability. CIM provides a smooth adaptation to changes in manufacturing demand, an optimal use of manufacturing and transport facilities, a uniform product quality, etc.

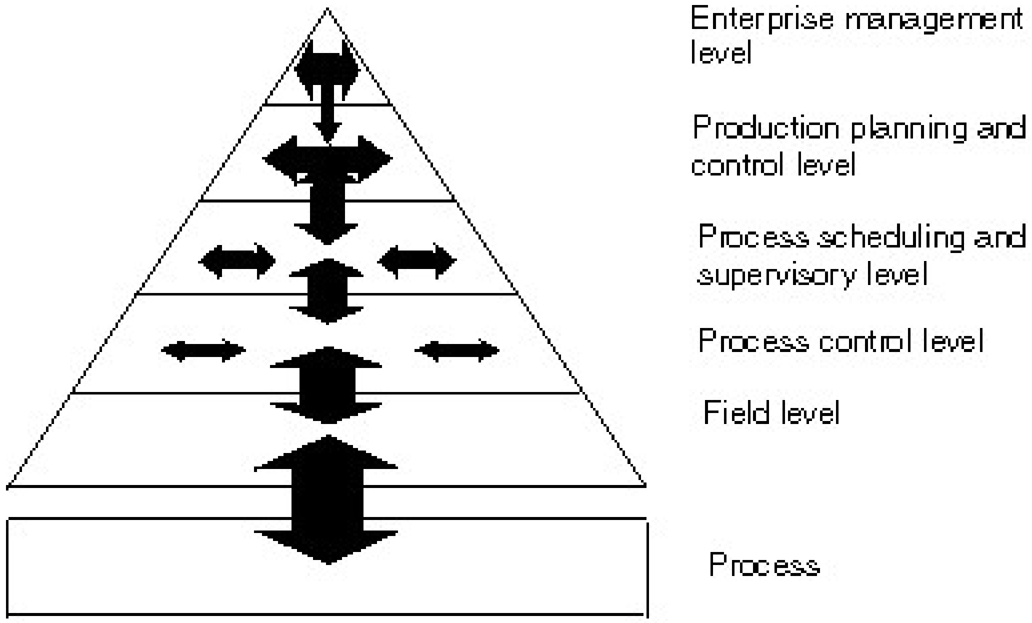

Figure 2. Information flow in the system levels.

A typical configuration of a CIM-system is shown in the example of Figure 3, which is employed in the manufacture of printing plates. Printing plates are aluminum plates coated with a photosensitive material. They are used in the production of mass printing as in the case of newspapers. The process involves electrochemical roughing (1), electrochemical anodizing (2), coating (3), drying (4), cutting (5), piling (6), packing (7), and dispatching (8). In this CIM-system, it can be seen that all levels, ranging from the field level up to the production planning and control level, are completely covered by dedicated components. They all have their own functions, but they work together, they are "integrated".

The field level involves a number of sensors and actuators, which are in charge of capturing information from the process and acting on it. The DCSs in conjunction with the PLCs have the task of controlling the process. The process scheduling and supervisory level contains an MES (Manufacturing Execution System) which facilitates tasks such as fine plan production, and an LIMS (Laboratory Information Management System) organizing and managing the quality assurance and performance tests. On the production planning and control level there is a so-called MRPII (Manufacturing Resource Planning being the further developed version of a former Material Requirement Planning). The MRPII collects the customer orders and produces a rough production plan, manages the stock, the material resources, the delivery terms and so on. A DTS (Driverless Transport System) is responsible for the product flow, mainly among parts 6, 7, and 8 of the process.

In the following sections, emphasis will given in particular to the field, the process control, and the process scheduling and supervisory level including process interface and operation and observation.

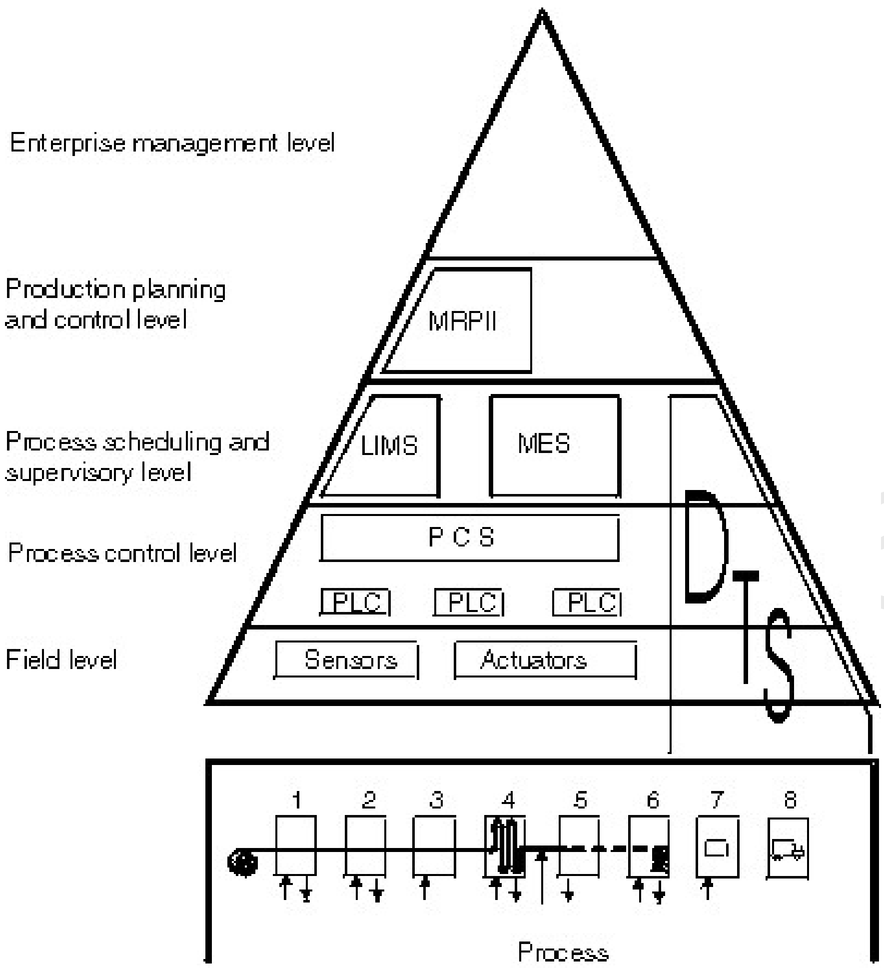

Figure 3. CIM-system for the manufacture of printing plates.

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Bibliography and Suggestions for further study

Berger R (1995) Quality assurance for process control projects. Single Report 02/3669 EN, PQ Hartmann and Braun, Frankfurt/Main.

Da Silva (ed.) 1986 Introduction to Data Communications and LAN Technology. London: BSP.

ESPRIT Project 5206 (1992) Fieldbus Integration with CIM, Implementation Guide, Extended Release. Fraunhofer Institute IITB, Karlsruhe.

Frydenlund M M (1993) *Lightning Protection for People and Property*. New York: Van Nostrand Reinhold.

Göddertz J (1990) *Profibus*. Bonn: Klöckner Moeller.

Halsall F (1992) Data Communications, Computer Networks and Open Systems, 3rd edn. Wokingham: Addison-Wesley.

IEC 1131-3 (1995) Programmable logic controllers - programming languages. IEC: Geneva/ Switzerland.

ISO (1983) Open Systems Interconnection Basic Reference Model. ISO/DIS 7498.

Jain B N and Agrawala A K (1990) *Open Systems Interconnection*. Amsterdam: Elsevier.

Leterrier P and Valentin T (1992) Implementation of a fieldbus into an automation device: the conditions for success. In *Integration of Design, Implementation and Application in Measurement, Automation and Control*. Interkama-Congress 92, Oldenbourg publishing house.

Levine W S (1996) *The Control Handbook*. CRC Press: Boca Raton.

Litz L (1995) Grundlagen der Bussysteme. In H J Forst (Hrsg.), *Bussysteme für die Prozeßleittechnik* pp. 9-38. Offenbach: VDE: Berlin.

MacKinnon D, McCrum W and Sheppard D (1990) *An Introduction to Open Systems Interconnection*. New York: Computer Science Press.

Morgan D (1994) A Handbook for EMC Testing and Measurement. London: Peregrinus.

Parr E A (1995) *Industrial Control Handbook,* 2nd edn. Oxford: Butterworth Heinemann.

Polke M (1994) *Process Control Engineering*. Weiheim: VCH.

Popovic D and Bhatkar V P (1990) Distributed Computer Control for Industrial Automation. New York: Dekker.

Rose M T (1990) The Open Book: A Practical Perspective on OSI. New Jersey: Prentice-Hall.

Samad, T. (ed.) 2001 *Perspectives in Control Engineering*. New York, Institute of Electrical and Electronic Engineers. 503pp. [This book provides a broad review of the state-of-art in control science and engineering, with particular emphasis on new research and application directions.]

Santina, M. S.; Stubberud, A. R.; Hostetter, G. E. 1994. *Digital Control System Design*. Fort Worth, Saunders College Publishing. 797 pp. [This book presents a broad introduction to modern digital control systems.]

Sderstrm, T.; Stoica, P. 1989. *System Identification*. New York, Prentice Hall.. 612 pp. [This book provides a profound understanding of the subject matter as well as the necessary background for performing research in the field.]

Seborg, D. E.; Edgar, T. E.; Mellichamp, D. A. 1989. *Process Dynamics and Control*. New York, John Wiley. 717 pp. [This textbook incorporates process dynamics, computer simulation, feedback control, measurement and control hardware, advanced control strategies, and digital control techniques.]

Shinners, S. M. 1998. *Modern Control System Theory and Design*. New York, John Wiley. 720 pp. [This book presents a unified treatment of conventional and modern continuous control systems.]

Siljak, D. D. 1978. *Large-Scale Dynamic Systems*. Amsterdam, Elsevier North-Holland Scientific Publishers. 416 pp. [The aim of this book is to show the relationship between complexity, stability, and reliability of large-scale dynamic systems.]

Sinha, N. K.; Rao, G. P. (eds.) 1991. *Identification of Continuous-Time Systems*. Dortrecht, Kluwer Academic Publishers. 637 pp. [This book serves as a broad source of information to researchers and practising engineers.]

Sinha, P. K. 1984. *Multivariable Control*. New York, Marcel Dekker. 688 pp. [This is a textbook which introduces systematically to the problems of multivariable control systems.]

Stefani, R. T.; Savant, C. J.; Shahian B.; Hostetter, G. H. 1994. *Design of Feedback Control Systems*. Boston, Saunders College Publishing. 819 pp. [This book provides a broad introduction to classical and modern feedback control systems.]

Takahashi, Y.; Rabins, M. J.; Auslander, D. M. 1970. *Control*. Reading, Ma., Addison-Wesley. 800 pp. [This book presents control systems on a broad spectrum as well as in depth.]

Tzafestas G S (1993) Applied Control: Current Trends and Modern Methodologies. New York: Marcel Dekker.

Unbehauen, H. 2001. *Control Engineering* (in German). 3 Vols. Braunschweig, F. Vieweg & Sohn Verlagsgesellschaft. 1273 pp. [These are widely used textbooks that present the broad spectrum of classical and modern control systems.]

Unbehauen, H.; Rao, G. P. 1987. *Identification of Continuous Systems*. Amsterdam, North-Holland/Elsevier Science Publishers. 378 pp. [This book shows several advantages in retaining the models of real dynamical systems in continuous time-domain.]

van der Schaft, A. J.; Schumacher, J. M. 2000. *An Introduction to Hybrid Dynamical Systems*. London, Springer-Verlag. 174 pp. [This book gives a deep introduction into the field of hybrid dynamical systems.]

VDI/VDE 3542 (1995) Safety terms for automation systems: qualitative terms and definitions, Part 1-3. Berlin: Beuth.

Williams T (1995) *EMC for Product Designers*. Oxford: Newnes.

Wolovic, W. A. 1994. *Automatic Control Systems*. Fort Worth, Saunders College Publishing. 450 pp. [This introductory text focusses on the classical and modern design of linear controllers for single-input/single-output systems.]

Wood G G (1988) International standards emerging for fieldbus. *Control Eng*., 22-25.

Zhou, K.; Doyle, J. C.; Glover, K. 1996. *Robust and Optimal Control*. Upper Saddle River, N. J., Prentice Hall. 596 pp. [This book gives a fairly comprehensive and step-by-step treatment of the state-space control theory.]