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Selection and application of advance control systems: PLC, DCS and PC- based system

Sanjeev Gupta[1,]* and S C Sharma[2]
[1]N V Patel College of Pure and Applied Sciences, Mota Bazar, Vallabh Vidya Nagar 388 120
[2]Department of Paper Technology, IITR, Saharanpur 247 001

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Very-large-scale-integrated (VLSI) chips have made a great impact on the development of advanced control systems. The paper highlights the basic features and architecture of Programmable Logical Controller (PLC), Distributed Control System (DCS) and Personnel Computer (PC) based system used in almost all industries like paper, chemical, petrochemical, sugar, and fertilizer etc. The factors affecting the selection of PLC, DCS, and PC-based control system are covered in the paper. The comparison between PLC & DCS, PLC & PC-based control system, and PLC, DCS & PC-based control system are presented. Fuzzy based controller and its importance in the industry are also discussed.

Keywords: Computer control, Programmable Logical Control, Distributed Control System, Personnel Computer, Fuzzy control

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Introduction

Prior to the introduction of computers for industrial control applications, the standard control system consisted of a large number of single loop analog controllers (electronic or pneumatic), where signals were not readily available to operator (Figs 1 & 2). Some of the PID controllers have a regular indication for the operators such as strip chart, pointer, alarm etc. Computers were first used in industrial plant not as controller but as monitor or data loggers[1]. The first controller in which the computer is used to change the set point of analog controller came in early 1960. Thereafter, different control modes were developed and used in the industries (Table 1). In early 1980's, management in many companies reacted sharply to use computer control in the process industries because of the following reasons: i) Most marketed before their designs were thoroughly proved or their programming aids were fully developed; ii) The vast communication system required in bringing the plant signal to centralized computer location and return control signals to field is very expensive, and it is prone to electrical noise; and iii) All of the control functions are located in one computer; failure resulted in demands for a complete analog backup system.

*Address for correspondence
E-mail: sanjeevgupta45@yahoo.com,
sc_sharma60@rediffmail.com

Types of Advanced Control Systems

Every company is seeking ways to cut product cost, upgrade product value and boost plant throughput. Now-a-days computer control (Fig. 3) and information system technology is applied widely in most of the process industry, because it may produce significant technical and economic benefits. Process control information systems assist operating personnel in producing the required throughput of products with minimum quality variations, least consumption of the raw material and energy, and maximum efficiency. Centralization process control combined with increased mechanization has resulted in improved

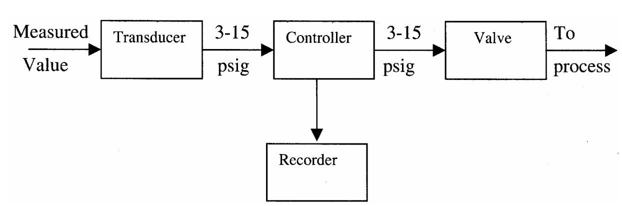

Fig. 1 — Block diagram of pneumatic control system

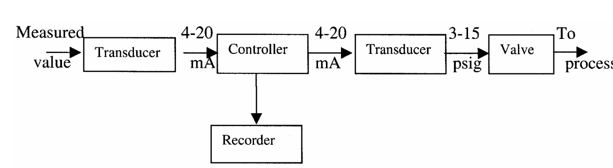

Fig. 2 — Block diagram of electronic control system

Table 1—Different types of control modes

Symbol	Description	Mathematical exp.	Properties
P-Proportional control mode	The basic continuous control mode is proportional mode in which the controller output is algebraically proportional to the error signal.	$P= P_0+ K_P E$ Where P= controller output P_0 = output at zero error (4-20 mA or 3-15 psi) K_P = proportional gain. E = error signal	• It is characterized by a continuous linear relationship between controllers I/O. • Exhibits off set. • Low stabilization time. • When used alone it provides sufficiently large deviation.
I-Integral control mode	This mode is often referred to as reset control mode. In this mode value of the controller o/p changes at a rate proportional to the error.	$dp/dt = K_I.E$ $P(t)=K_I \int E\, dt + P_0$ $K_I =1/T_I$ K_I = Integral gain T_I = Integral time	• It eliminates offsets. • It shows oscillatory behavior. • Large stabilization time.
D- Derivative control mode	It is also called as rate control mode, the controller output is proportional to the rate of change of error.	$P = K_D\, dE/dt+P_0$ where K_D = Derivative gain	• Reduces oscillation. • Improve dynamic performance. • It provides no output when error is zero or constant.
PI - Proportional Integral control mode	This mode is the combination of P and I control mode.	$P= K_P E + K_P K_I \int E\, dt + P_0$	• Zero offset. • Max. deviation produced is larger than that produced by proportional but less than that of integral mode. • Eliminates offsets.
PD -Proportional Derivative control mode	This mode is the combination of P and D control mode.	$P = K_P E + K_P K_D dE/dt+P_0$	• Lowest deviation. • Small offset. • Lowest stabilization time. • It increases the overall stability.
PID - Proportional Integral Derivative control mode	This mode is formed by the combination of P, I and D control mode. In PI controller, integral part completely removes steady state error and a proportional part provides adequately fast response. The process capacity needs some form of additional kick for fast response, which is provided by the derivative action.	$P= K_P\ E+ K_P\ K_I \int E\ dt + K_P K_D\ dE/dt$	• It produces maximum deviation which is larger than that in PD • No off set. • Stabilization time is longer than that of PD but smaller than PI. • Best control mode

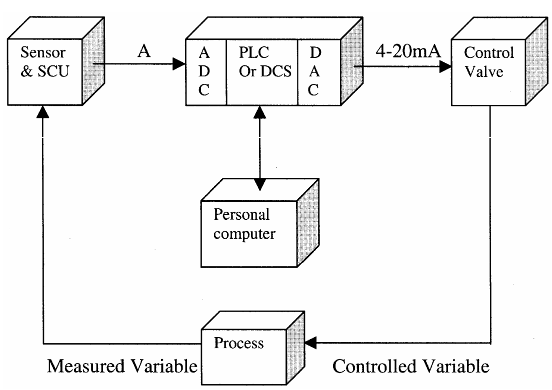

Fig. 3 — Basic block diagram of computer control system

productivity[1]. Investment in process control system has been an important factor in improving product quality and lowering production cost, while providing a competitive edge to mills. This in turn has forced the other mills to improve their process control technology. Now-a-days advanced control systems (PLC, DCS, PCs) are extensively used in the industries.

Programmable Logical Controller (PLC)

PLC, developed in 1968 by the General Motors for relay replacement, is usually located in the field, close to the process unit. PLCs are small and operator interface may be as simple as a push-button switch or status light. In second generation, PLC suppliers have added analog to digital conversion capability and provided sufficient logic to configure simple control loops. Presently, there are at least two recognized PLC sizes: (i) Small PLC, which is a relay replacement unit and provides a reliable control to stand-alone section of a process; and (ii) Medium-sized PLC that performs all the relay replacement functions expected of it, and also performs functions like counting, timing, and complex mathematical applications. Most medium-sized PLCs can perform PID, feed forward, and control functions as well. PLCs now have data highway capabilities and can function well in DCS environments[2].

Distributed Control System (DCS)

DCS, developed in 1975, was first used by pulp and paper mills. It consisted of distributed microprocessor-based single loop controllers connected to a shared video-based operator station. It has substituted analog controllers with Direct Digital Control (DDC). The video-based operator station eliminated the need of large instrument panels, which were important prerequisites for operators. For the replacement of proportional control (P), proportional-integral control (PI) and proportional-integral-derivative control (PID), the DCS is the best choice. DCS system is complex and expensive, but provides various control functions and other reliability features[3-5].

Personal Computer (PC)

PC has a superior ability to perform monitoring/supervising functions such as report generation, historical trending, calculations and storage of data. Whatever may be the size and nature of the applications, PC can play an important role. For small pilot projects, where the control is usually undefined, the PC with its flexibility and true programmability is the proper tool. Real-time multitasking environment tailored for PC-based control systems ensures that the information path between field input/output (I/O) modules and the host is always open or strictly speaking never closed long enough to interfere with the process under control.

Architecture and Application of PLC, DCS and PC-based Control System

The rapid technological development of computers during last 10 years coupled with significant reduction of their cost has revolutionized the use of computers in controlling the process. The expected future improvement, together with the growing sophistication of control design techniques, made the computer the centerpiece for the development of a control system for industries. It is observed that computer has substituted the analog controllers in the conventional control loop and the program residing in computer now controls the action that is produced by the analog controller. Owing to the tremendous computational power of computers, it is possible to implement control strategies which can improve the quality of control and which are otherwise difficult or impossible to implement with conventional hardware. The major benefits achieved by using computer as controller are flexibility, multiplicity of functions and the ability to make use of advanced design and analyses techniques.

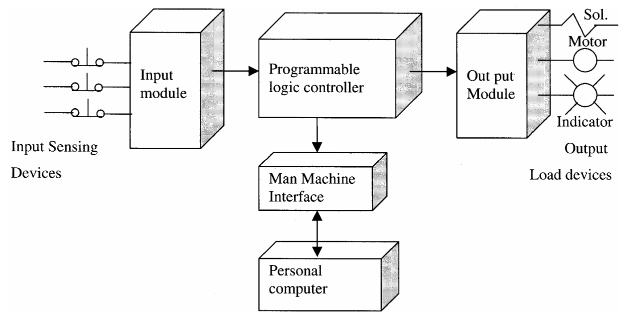

Fig. 4 — Basic block diagram of PLC system

PLC

PLCs were designed to eliminate assembly-line relays during model changeovers (Fig. 4). PLC is easier to change than relay panels; this has reduced the installation and operational cost of the control system compared with electromechanical relay systems. PLC offers the following advantages: (i) Ease of programming and reprogramming in the plant; (ii) Programming language is based on relay wiring symbols familiar to most plant electrical personnel; (iii) High reliability and minimal maintenance; (iv) Small physical size; (v) Ability to communicate with computer systems in the plant; (vi) Moderate to low initial investment cost; and (vii) Modular designs are also available.

DCS

DCS is miniaturized version of the multitasking, multivariable, multi-loop controller used for process control (Fig. 5). It is functionally and geographically

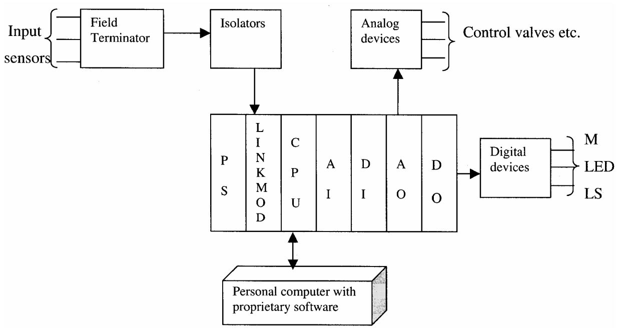

Fig. 5 — Basic block diagram of DCS

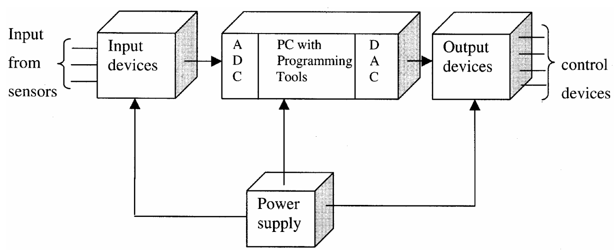

Fig. 6 — Basic block diagram of PC- based control system

distributed system. Equipment making up a DCS is separated by function and is installed in two different work areas of a processing installation. Equipment for operator to monitor process condition and to manipulate the set point of the process operation is located in a central control room; from where operator can view information transmitted from the process area and displayed on a video display unit (VDU), and can change control condition from a keyboard. DCS are suitable for the following processes: (a) Where a single centralized system is not adequate (Power, Steel, Fertilizer and Pulp & Paper plants); (b) Which can be divided into different and functionally independent sections, based on functional scope and geographical distribution; and (c) Processes of different level of hierarchy.

DCS have the flexibility of a compact platform with digital and analog processing as single tool for configuration of automation functions and process graphics, global data base capabilities, intelligent I/O, easy documentation of system, wide graphics and communication, open system architecture with no interface between system bus and operator station, and automatic system diagnostics. It offers following advantages: (i) Compact to contain ON/OFF controllers; (ii) Control algorithm changes do not call for hardware changes; (iii) Reduced complexity and easy expandability; (iv) High speed of the control processing; (v) Continuous trend data are available; (vi) Plant data are transparent on the network; (vii) Sequential, batching, and feedback control are possible; and (viii) User friendly but higher data security.

PC

PCs, which provide a powerful low-cost means for process control (Fig. 6), are not in direct competition with PLC or DCS. However, they are limited by their architecture and programming. A PC offers lowest hardware cost for implementing programmable logical controller, but it may not be correct tool for many applications. PC-based systems are improving because of their familiarity with system, as well as increased networking capability, software availability, faster CPUs and larger storage space. The use of industrial PCs and workstations that provide a hardened platform for using PC-based systems on the plant floor is increasing. Operator interface stations provide a pre-packaged platform designed around the shock, vibration, airborne particulate and temperature considerations encountered on a plant floor.

For small processes, where response time is slow, PC can easily perform the control functions. Process controls that require fast response time of 10 loops or more, together with other discrete control, should use stand-alone loop controllers or small DCSs. Other applications with distributed process control functions where each loop should have its own processor cannot use PC with a single microprocessor. PC can be used as an engineer/operator station using a proven communication link.

Selection of Different Computer Control Systems

PLC and DCS functions include ON/OFF control (motor starts/stops, timing/counting, sequencing, etc.), data acquisition (status, analog, identification), regulatory control (feedback, feed forward), programmed control (batch, grade changing) etc. (Table 2). PLCs are typically chosen for small discrete applications where high level of ruggedness and reliability is required. They offer high-speed sequential and logical control capabilities and are very good control solutions for real time applications. They have been successfully used in applications for weighing, welding, painting, packaging, coating, mixing etc. DCS is better suited for more complex, slower function and where large numbers of I/Os are used. Both DCS and PLC are designed to satisfy the needs of a wide spectrum of process industries

Table 2 — Differences between PLC and DCS based systems

S No.	PLC	DCS
1	It is used for low loop count.	It is used for any loop count.
2	Performance drops with increasing loop count.	No change in performance with increasing loop count.
3	Individual database for every node.	System-wide global database.
4	Purely free running mode.	Highly efficient multitasking mode.
5	Redundancy not possible or limited.	Redundancy possible at every level.
6	Communication on low speed serial Bus-9600 Bauds maximum.	Communication on high-speed serial bus IEEE802.3 Ethernet – 10 MBps.
7	Manual documentation.	Automatic documentation.
8	Multiple engineering tools.	Single engineering tool.
9	Analog processing simulated through digital computer.	Analog processing done in real frequency domain function.
10	Typical performance: 100 PID loops/sec.	Typical performance: >1000 PID loops/sec.
11	Large engineering efforts required in case of expansion.	Re-engineering efforts reduced by 75% in case of expansion.
12	No interplant connectivity.	Fully functional interplant connectivity.

Table 3 — Differences between PLC and PC - based systems

S No	PLC	PC
1	PLC really shines in its I/O capabilities.	In PC the analog and digital I/O cards are better suited for lab.
2	In PLC the I/O cards are mounted on racks, so that diagnostic lights are easily visible. Noise is also more.	In PC, the I/O cards are not mounted on the racks, so that electrical noise and catastrophic mishap are less.
3	The connections are rugged, accessible and organized.	Very small room for cable connection.
4	Simple processor architecture.	Much more complicated I/O architecture than PLC.
5	It is used in controlling industrial process and control logic programming is subjected to adjustment by MMI.	PC is less optimized for control task and high-level language is used for programming.
6	It has simple devices such as indicator or push buttons on its I/O lines.	It lacks truly and good interface.

including oil, gas, chemical, pulp & paper etc. For P, PI, PID and straightforward loop control, DCS is the best choice but it is complex and expensive.

PCs can provide direct digital control. PLC has not only replaced relay but has also extended the logic capabilities of the system (Table 3). As PLC requires real-time communication capability with the PC or other host computer, some PLC suppliers have added analog to digital conversion capability and provided the sufficient logic, to configure at least simple control loops (Table 4).

Fuzzy Controller and its Applications

Fuzzy logic is a human concept, potentially applicable to a wide range of processes and tasks that require human intuition and experience. In computer, truth-values are either 1 or 0, which correspond to true/false duality. In fuzzy logic, truth is the matter of degree, thus truth-values ranges between 1 and 0 in a continuous manner. Fuzzy logic is a method for representing information in a way that resembles natural human communication. It is a rule-based system. It consists of if…then rules. Fuzzy logic control can be applied by means of software, dedicated controllers, or fuzzy microprocessor embedded in digital products. Application flexibility combined with inherent simplicity and a wide range of capabilities give fuzzy logic technology a great potential for growth[6].

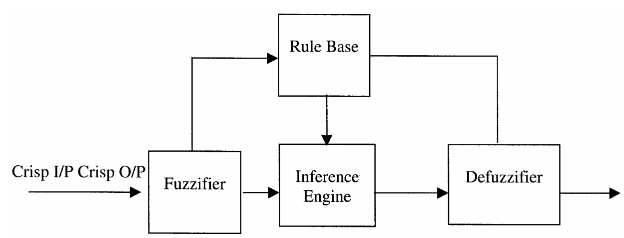

Fig. 7 — Model of Fuzzy controller

Fuzzy systems are rule-based with a strong mathematical basis. A fuzzy system is basically made of a fuzzifier, a defuzzifier, an inference engine, and a rule base (Fig. 7). The role of the fuzzifier is to map the crisp input data (a collection of distinct elements) value to fuzzy sets defined by their membership functions depending on the degree of "possibility" of the input data. The goal of the defuzzifier is to map

Table 4 — Differences between PLC, DCS and PC - based control systems

S No	PLC	PC	DCS
1	It is designed to operate in a real time control environment	The term real time is not well defined. A system that responds to key entry, as any multi-user system, may not be necessarily "real time".	The analog processing is done in the real frequency domain.
2	I/O signals are in digital forms.	In the PC-based control analog and digital I/O cards are better suited.	I/O signals are in analog form.
3	Communication is on low speed serial bus.	PC generally have RS-232C, RS-422 token ring, collision detected and perhaps other electrical and low-level logic protocol.	Communication is high speed through IEEE802.3 Ethernet- 10MBps .
4	It has limited interfacing capabilities.	It can rely on PC based alternatives and operator interfaced devices. Sophisticated control system.	DCS system is easy to handle and has free interface.
5	It has multiple project files	It has limited project file.	It has single project file.
6	Limited scalability and expandability.	It has great flexibility, higher reliability due to distributed processing function.	Highly scalability and expandable.
7	It has manual networks addressing configuration.	Its I/O devices are attached to hardware bus.	It has automatic network addressing generation.
8	It has ladder programming.	It has microprocessor programming.	It has FBD, SFC, LD programming.
9	It has PC with CPU 2K to 3K RAM memory, and its cost is $600-$2000 only.	The pre point cost of I/O can be estimated as follows: For DI and DO, it is $100.	The cost of DCS depends on I/O cards. The cost per I/O card, it is $5000.

the output fuzzy sets to a crisp output value. It combines the different fuzzy sets with different degrees of possibility to produce a single numerical value.

Fuzzy inference engine defines how system should infer through rules in the rules base to determine the output fuzzy sets. Fuzzy technology has already contributed to some industrial control applications. Future sensors applications for fuzzy logic might include flow and proximity sensors. Additional control applications for fuzzy logic will be in the chemical processing industries in near future.

Conclusions

DCS with host computer is preferred for cell control/area control, because it features exceptional operator interfaces, optimization capabilities and with hosts, excellent reporting capabilities. However, PLCs can be used as cell controller where they are the fundamental regulatory control element, and addition of a DCS serves no distinct purpose. DCS is preferred to control critical loops, since they require redundancy, and moreover analog input and output requires more processor time to scan. PLCs are used to control the discrete devices and interlocks. PLC has either no computer-based operator interface or the PLC operator interface does not have the processor power and capacity for an entire plant.

DCS system is complex and expensive but provides various control functions and other reliability features. For the straightforward control loop, DCS is usually the best choice. PLC is used for fast turn ON/OFF of motors, sequencing etc. and for low loop counts. PCs are not much used for the process control applications because they are limited in their ability to deal with real-time I/O, especially on a large scale. PCs cannot offer powerful software solutions for control applications. In their pure form, PC-based control systems are vulnerable to computer failure, in the event there are no loop controllers or other intelligent devices on line. They are also not suitable for industrial environment.

PLC can work similar to DCS with MMI interface but in this case the engineering efforts increase tremendously. The performance of PLC drops with increase in loop count, low speed communication and limited scalability and expandability. DCS is preferred where interplant connectivity, redundancy at every level and online real time updation of control loops is required.

Fuzzy control is still in its infancy stage, not much popular in industries. Fuzzy logic can incorporate nonlinear relationships or knowledge gathered from experience early in the control system design. For some processes, fuzzy logic in design control systems may reduce application development time. In some instances, individuals who are not expert in mass material balance equations, differential equations, Laplace transformations, or sophisticated engineering skills may develop control system.

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