Cementing the relationship between DCS and PLC: A review of emerging trends in plant control systems.

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Abstract

This paper explores the changing roles of traditional distributed control systems (DCS) and programmable logic controllers (PLC) used to automate cement manufacturing processes. The two technologies initially served two different control requirements. However, improvements in microprocessor-based controllers created conditions for two technologies to merge. The shift toward commercial, off-the-shelf automation technology, software-based control versus hard control and use of non-proprietary networks has created a new class of systems called hybrid process automation systems.

In addition, the role of the plant control system has been expanded from just process visualization and control to include process optimization, plant asset management, energy management, and inventory control. Cement plants can now use the process control systems to improve operational and energy efficiency.

Control system vendors have adopted unique terms to differentiate their systems from the traditional definition of a DCS or PLC. Some have expanded their process control systems to offer vertical integration with IT systems and horizontal integration with intelligent drives, motors, process instrumentation and discrete control technologies. This paper addresses a number of requirements placed on the cement automation systems as a result of these developments and identifies technologies that offer the best solution to meet the challenges faced by cement producers.

Introduction

The process of manufacturing cement has gone through many changes over the years. The wide acceptance of the dry process of cement making rather than the wet and pre-calcinations processes are among these changes. In any case, the manufacturing process continues to have the most significant, quantifiable influence on overall cement quality and efficiency, sustainability, and environmental impact of the plant.

The automation requirements of the cement industry are unique, even though on the surface they may seem similar to other industrial processes. Legacy automation systems installed in existing cement plants have not kept pace with new technologies now available to the process industry. The growing size and complexity of the cement manufacturing process have placed new demands on automation system vendors. By understanding these requirements and the control and automation technologies available today, we can effectively select the best platform for the automation of applications in the cement industry.

Cement Plant Automation Requirements

What is unique about automating the cement manufacturing process?
Cement production involves the transformation of material through crushing and grinding. Limestone is the primary ingredient. The raw meal undergoes physical change through the calcinations process in the kiln where it is heated up to 1600° C. The automation systems convey material through different stages of the
process and routes. The automation system manages the starting and stopping sequences of the conveying and material handling systems.

Cement production can be considered as a combination of individual processes such as blending and preparation of raw meal, temperature and speed control of the kiln and kiln feed control. Clinker cooling process recovers the heat and lowers the temperature of the clinker so it can be stored. Speed control of pre-heater fan and the exhaust fan maintain negative pressure inside the kiln hood and ensure the correct flow of hot gases. Feed control of the Finish Mills to maintain throughput and blending of the cement with additives in the Finish Mills to produce different types of cement. Basic temperature, air flow and pressure control are very critical to the production process and are applied at various places in the process.

The cement industry also uses large motors and drives that control large pieces of mechanical equipment. Interlock requirements for this type of equipment are unique when compared to the equipment used in typical process industries, such as chemical. The motors and mechanical equipment needs to be protected from operator mistakes and incorrect operation. For this purpose two types of interlocks are programmed in the control systems. The first type is called soft interlocks, implemented using logic in the control system, and second type of interlocks are implemented using hard wiring and are called hard interlocks. There are also different types of interlocks effective in different modes of operation of the mechanical equipment.

Improving energy efficiency in the cement production is a big challenge for cement industry since it is a big consumer of electricity, oil, coal, and natural gas. The cement industry is also the third largest emitter of greenhouse gases globally.

**Division of the Cement Plant from Controls Perspective**

A cement plant’s control system can be divided into three sections or processes -- front-end where material is prepared, main section, and back end for packing storage and dispatching. There are also auxiliary systems and utilities providing essential materials and services to the main process.

The front end processes can also be called the preparation phase. In the preparation phase the raw material, which is mainly limestone, is ground and combined with other materials, such as shale and iron to give it specific chemical composition. After the final mix is prepared, it is stored in a raw meal silo until it can be fed into the pre-heater. In coal-fired kilns there is a coal mill, and it pulverizes the coal that is fed into the kiln using the burner.

Raw meal is fed into the pre-heater where it gradually gains temperature as it enters the kiln. The fine powder of raw meal due to the rotation of the kiln, and the heat transforms into circular grey stones called clinker. Clinker is passed into a clinker cooler where it is cooled to a temperature where you can actually hold it into your hand. Inside the cooler, heat from the hot clinker is recuperated and fed back into the process. The clinker is stored in the clinker silo.

The back-end processes mainly involve the finish mills areas. In the finish mill section, the raw clinker is grounded finely and is mixed with different additives to produce different kinds of cement based on customer requirements. This material is finally stored in different silos. The material can be bagged or loaded onto trucks, rails cars or barges for bulk distribution.
Operations and Plant Control

The job of the control system operator is to ensure that the plant keeps running at maximum throughput and fuel efficiency. Operators control the sequence of belts and select the routes for material transport. These conveyor belts move material from one process section to the next. Operators take actions on alarms related to the equipment they control such as large drives and motors. Interlocks protect the equipment from damage and are visualized as alarms for the operators. Operators also take action on alarms that disrupt the main process and use trending data to ensure that key process variables are within their operational limits.

Operators use main plant control system to control kiln feed, as well as fuel input. A fuel injection system may use coal, oil, or a combination of combustible materials. Sometimes advanced process control (APC) oversees all the process variables. APC also provides optimized control through schemes based on MPC, fuzzy logic, or neural networks. Similar controls schemes are used for raw mill and coal mill operations. Cement mill areas include hydraulic systems for ball mills, mill feeding circuits, blending systems to produce different type of cement, material separator systems, and silo discharge systems.

Cement plants also have specialized systems for water injection in ball mills, cooler hydraulic grate control systems, circular Stacker and Reclaimer systems, longitudinal Stacker and Reclaimer, and lab automation systems. Additionally, more and more plants are using nonconventional fuels such as tires and industrial and residential waste products in addition to oil, gas, and coal.

Overall Plant Control Strategies

There are two strategies to implement overall control in cement plants. The distributed approach uses individual PLCs to control auxiliary tasks, including lab automation, cooler grate control, hydraulic power packs, Reclaimer and Stackers, water treatment, compressed air, and bag houses. These auxiliary systems are usually controlled through dedicated PLCs supplied with mechanical equipment. These auxiliary systems are, in turn, controlled by the plant’s main control system that is typically a DCS type system.
The main plant control system interfaces to these individual PLCs via network interfaces or hardwiring and provides the overall command and process control environment. This control approach is used when the plant control system cannot meet specific auxiliary applications requirements. This approach is also partly driven by the need of equipment suppliers to guarantee performance. They must provide control systems with their equipment so that the control logic functions are properly implemented to ensure correct operation and control of the equipment. The suppliers usually develop their solutions based on the product capabilities of a single automation vendor. It is cost effective for the process OEM to use a single PLC vendor, because it does not require them to develop, maintain, and support their programs on multiple PLC platforms.

The main disadvantage with this approach is that there is always a level of ambiguity between the auxiliary systems and the main plant control. One disadvantage is that maintenance and control personnel treat these systems as black boxes, since only the equipment vendor knows the why and how of the logic inside the PLC, or if the control is based on a dedicated controller. In most cases the tools and software used to implement these systems are very different from main plant control software, requiring the maintenance people to learn several different programming packages from different vendors. Managing the different programs and versions of software packages and keeping them updated over the life cycle of the plant is very costly.

In the centralized control approach, the control system must meet the overall plant control requirements, such as plant asset management, energy management and advanced process control, and interface with CMMS and ERP systems. The system must also be able to meet the process control requirements of the analog control and be able to execute portions of the logic in a faster cycle to meet the speed control requirements of the sub controls. The system must be able to support various types of programming languages including function blocks, structured programming languages, and ladder logic. The systems that have these capabilities combine the features of both DCS and PLC, sometimes called hybrid control systems. In the central approach, the main plant control system provides the overall logic for the main process and the auxiliary systems. The auxiliary systems have remote I/Os that are connected to the main plant control system; the logic for the control of the auxiliary system resides in the central controller.

**PLC - Programmable Logic Controllers**

Programmable logic controllers initially emerged as a replacement of the relay control systems. Before PLC, control, sequencing, and safety interlock logic for manufacturing processes was accomplished using hundreds of relays, cam timers, drum sequencers, and dedicated closed-loop controllers. The process for updating such facilities to make changes to the process was very time consuming and expensive, as the relay systems needed to be rewired by skilled electricians. PLCs eliminated the need to physically rewire the relay systems as it can now be done by modifying the software. Hence software in the PLC became the brain of the manufacturing process.

The basic concepts of PLC programming are common to all manufacturers. Differences in I/O addressing, memory organization, and instruction sets mean that PLC programs are never perfectly interchangeable between different vendors. Even within the same product line of a single manufacturer, different models offer different levels of programming capability, resulting in programs being non-interchangeable.

The IEC 61131-3 specification is an effort to standardize the PLC programming languages and define common instruction sets and programming languages. IEC 61131-3 currently defines five programming languages for programmable control systems: FBD (function block diagram), LAD (ladder diagram), SCL (structured text, similar to the Pascal programming language), STL (instruction list, similar to assembly language), and SFC (sequential function chart). These techniques emphasize logical organization of operations with a program.
In PLC-based systems, logic control and programming works in the same ways as relay logic. PLCs are programmed in ladder logic, which strongly resembles a schematic diagram of relay logic. Modern PLCs can be programmed in a variety of ways, from ladder logic, to more traditional structured programming languages, C and function blocks. It is no wonder that ladder logic is the preferable form of programming language for electricians and technicians responsible for the maintenance of manufacturing facilities. Since not much change in the thinking process is required to program ladder logic, it was the natural first step for the electricians who were familiar and had experience working with relays.

![Typical PLC architecture](image)

The elements used in PLC programming, such as inputs, are called contacts. Outputs are called coils, as in relay coil. This kind of language is found in almost all the PLC programming software. Programs are divided into multiple rungs of ladder. Each rung of ladder language typically has one coil at the far right. Some manufacturers may allow more than one output coil on a rung.

--( )-- a regular coil, true when its rung is true or normally open relay contact close

--(\)-- a "not" coil, false when its rung is true or normally close relay contact opens

--[ ]-- A regular contact, true when its coil is true (normally false)

--[\]-- A "not" contact, false when its coil is true (normally true)

The coil may represent a physical output that operates a device, such as a motor contactor, connected to the PLC output. It may also represent an internal storage bit to use elsewhere in the program. The limitation with the PLC way of thinking is that it gives a programmer a very limited view of the overall plant sequence control. It also makes the logic very complicated to troubleshoot if a large number of contacts and coils are used. This is also known as the bottoms up approach to programming. It is very easy to look at the individual pieces of the equipment and their interlocks. However, it is very difficult to understand the complete plant control logic, because the ladder logic quickly becomes very complicated as the number of devices and their interactions increase. Ladder logic does not provide the kind of interface that a process control engineer can easily understand, because his view of the plant is in the form of groups, routes, and individual objects such as motors, PID, and diverters.

Drum sequencers are sometimes programmed in ladder logic to implement process sequences. Drum logic can be implemented in many different ways, depending on how a particular programmer approaches a problem. Keeping the drum logic separate from the rest of the interlocking and control scheme is very difficult, and most programs do not maintain this separation. As a result, trouble-shooting the program at a
later point becomes very difficult, especially for a person who is not familiar with the functional details of the particular equipment and protection interlocks.

Most technicians and maintenance people do not understand why a particular piece of logic was implemented. They will, however, use software and hardware jumpers to bypass the logic. This can damage the equipment and pose serious safety risks to workers. Some equipment control programs for equipment (circular stackers and grate hydraulic control) are very complicated and require mathematical computations. These calculations must be performed in the specific amount of time (10ms or less). Such stringent execution requires controllers with high speed computation capability. Once these sub-controls are programmed, their logic rarely needs to be modified or changed; only modification in the process parameters is required.

**DCS – Distributed Control Systems**

DCS evolved within the process control industry. DCS are known for regulatory control capability and redundancy. The DCS architectures were centrally orientated with main control room as a meeting point for long cables for the input and output. They were based on proprietary components - operating systems, networks, hardware, and configuration tools with all the hardware located centrally in a controlled environment. Traditional DCS were not designed with open interfaces thus restricting the communication within the system boundaries. Communication interfaces with other vendors equipment requires expensive and time consuming hardware and software development process.

The earlier days of process control was mainly isolated to a certain number of loops or PID controllers (Proportional Integral and Derivative) to control temperature, pressure, steam, and flow. As the electronics technology developed and the PLC-based systems became pervasive, it becomes possible to program a number of PID loops in a single controller in a rack away from the field. The PID controllers that were initially made of dedicated electronic hardware in the earlier DCS systems can now be implemented in a cost-effective way in a single, microprocessor-based controller. Some of the fieldbus based technologies, such as Foundation Fieldbus, still support the concept of “Control in the Field,” where a single, independent control loop can be implemented in the field away from main controller.

The programming environment for the traditional DCS was based on function blocks commonly understood in the process control industry. There is not a big need to program the complicated logic operations that required high speed program execution, since most of the temperature and pressure loop’s response time is in 100ms or higher. In process plants, motors and drives were programmed and controlled via the PLC.

As the microprocessor became faster and cheaper, it became possible to implement some of the PID loops in the software, since software-based controllers were able to meet the input to output cycle time requirements of the overall process control loop. High speed control loops, such as those used in metal processing, still use dedicated control hardware due to performance reasons, but most of the process loops in a cement plant can be programmed in a single controller/PLC using software.
Typical DCS architecture

Understanding the PLC vs. DCS divide

Now let us look in more detail at the key attributes of the PLC vs. the DCS type of control.

Manufacturing applications involve assembly of specific items – “things” a PLC was originally used in this case. A typical characteristic of this type of process is that the operator can usually monitor the “things” visually as they progress through the manufacturing line. The manufacturing process is very logic control intensive, often with high-speed requirements. Higher speed means more things can be produced per shift which translates into more production. This type of process is often controlled by a PLC and Human Machine Interface (HMI) combination. The primary goal is to make the equipment perform certain steps, and the control is only needed to manage the exception to these tasks; in such cases, PLC is the right choice.

Process automation applications typically involve the transformation of raw materials through the reaction of component chemicals or the introduction of physical changes to produce a new, different product – “stuff.” The plant is composed of one or more process unit operations connected together. One key characteristic is that the operator can’t see the product. There is usually a large amount of simple to complex analog control (i.e. PID or loop control), and the response time is not that fast (100ms or greater). This type of process is often controlled by a DCS, although the analog control capability of a PLC may be more than adequate in some applications. A determining factor in the selection process is often how large in scope the control application is (i.e. plant-wide versus single unit and number of I/O points). Some of the examples of PLC type control in cement are cooler grate hydraulic control, hydraulic system for ball mills, circular Stacker, and Recalimer.

The value of the product and the cost of downtime is another way of looking at the automation requirements. The cost of downtime is the loss of production, but it can also lead to other costs. For example, in the Pyro processing section, the restart of kiln requires more fuel to bring the production to pre-failure stage. It also requires a lot of operator intervention and damage to the equipment may occur. Those plant sections should be handled by systems which are highly available due to the redundancies built into the system, such as in a DCS type system. In contrast the barge loading systems or the bagging systems can be shut down easily and restarted in matter of minutes for system maintenance, troubleshooting, or upgrades, with very little impact on the bottom line.
Visualization of the manufacturing process is a critical part of the cement plant control system. In a typical PLC application, operators focus more on dealing with exceptions to the manufacturing process. The machines continue to work until a failure occurs or a product with defects is produced. In this case the system takes the action and rejects the product.

To optimize the process, in a typical DCS system the operators have to make constant changes in the material feed, fuel supply, and combustion air. The operator also decides which material routes and process paths are to be used for the material. The operator will change set points, open/close valves, or make adjustments to the process to keep the plant throughput and performance at its peak. Within the process visualization, faceplates and analog trends provide a critical view into what is really happening in the production process, while the alarm management system focuses the operator's attention on areas where he must intervene to keep the process running within its target performance. In such an environment, only a system with a well designed and defined HMI can reduce operator error and take the guess work out of the decision-making process. DCS type systems usually offer more highly developed and consistent HMI environments than PLC/SCADA-based systems. For example, in a typical DCS motor, valves, and diverters in one area of the plant looks and functions in the same way as the other areas of the plant.

In a typical process application, you tend to have a more systemized approach to the control model, as opposed to the individual machines. The greatest difference is the speed and time constants. Generally, in process, you maintain temperatures, pressures, and flow which change over time at a much slower rate in matter of minutes or seconds than a high-speed packaging line where everything occurs at micro seconds. If high-speed logic operations are required, PLCs are usually a better choice. Typically the program execution range in a PLC-type system can be as fast as 10 to 5ms. PLC-type control is mostly suited to the design of the system that requires customization. Machine builders usually look for PLC-type systems so they can efficiently program the logic, resulting in faster execution of the overall program.

PLC-type systems use HMI panel and displays that offer a development environment that is open to customization. Equipment vendors make sure that their proprietary knowledge about the machines is preserved. PLC-type systems, with their bottoms up approach to programming, are suitable for this type of application. Engineering expectation is another way to look at the PLC vs. DCS divide. Technicians and traditional electricians are more comfortable with ladder logic. Operations and control people, on the other hand, like programming tools that provide a view that matches their process control environment. A system
where programming system logic relates to what an operator views on the HMI is very useful and helps in understanding problems and speeds up the troubleshooting process. The programming environment of a PLC-based on ladder logic is more suitable to the programming of the inner functions of the objects such as motors or diverters. The internal functions implemented by using ladder logic must be encapsulated in the form of function blocks.

Conclusion - Beyond the DCS vs. PLC divides

It is clear that both PLC and DCS were designed to meet two different application requirements. It is also clear that both kinds of system attributes are required to provide effective control of the process systems and automation needed for the cement industry.

Increasingly, the programming languages that use function block logic allow us to view the plant equipment as functional objects in the control program. This is very similar to the operator’s view of objects on the HMI, including motors, dampers, and valves. Additionally, combining these objects in the form of groups and routes to start and stop sequences is very useful. The group includes all the objects, and the routes include objects specific to that particular path. The multiple routes within each group decide which path the material is going to be routed through.

The systems with a high level of operational information in their configuration and visualization environment have proven to be very useful once operators, electricians, and process supervisors are properly trained. This top to bottom programming approach allows plant operators to look at the HMI screens and identify a faulty object such as a motor or a valve. The maintenance personnel can immediately reference the object in the program, understand the issue, and then take corrective action to solve the problem. The functionality of the multiple objects, such as motors and their interlocks, is defined, documented and consistently applied throughout the plant control system. This helps to quickly identify the problem and find the right resource to solve it.
Energy efficiency and asset management are two emerging trends where process control systems are now playing a critical role. The latest versions of process control systems now include higher level advance process control, energy management, and plant asset management capabilities.

**Energy Management using process control system**

Energy management and energy efficiency mean different things for different people. What does it mean for cement producers? The cement industry utilizes a variety of fuels such as coal, oil, natural gas, industrial and consumer waste and electric energy. The efficient utilization of these different forms of energy can lead to lower cost of production. Understanding where energy is used in the manufacturing process is a key first step in the development of strategies to minimize energy consumption and optimize the energy mix. Process control systems that are capable of integrating process and power system information can be a valuable resource to the conservation of energy in process manufacturing. Energy management systems do not replace human involvement in the decision-making process, but should be looked at as a real-time tool to keep energy consumption in check. Through understanding of the energy consumption for each individual process unit, experts can create better designs that are focused on improving energy consumption.

Process optimization techniques, together with real-time energy consumption information, all play a part in enabling manufacturing processes to be operated at maximum profitability and with greater energy efficiency. The fact is that none of these activities can be justified financially until we know when, where, and how much the impact of the energy savings will be. The main idea is that "you cannot improve what you cannot measure." The process automation systems today offer the possibility of integrating energy usage information in a process control system. This capability provides the platform for the manufacturers to understand the energy usage within their manufacturing facilities, by helping them tie the energy usage information to their production processes.

Smart MCCs enable the power consumption of different parts of the plants to be collected within the process control system. This information can be displayed for the operator to monitor the KWh consumption of the manufacturing process alongside other key process parameters. The information can be further passed into a historian or an MES (Manufacturing Execution Systems) for reporting purposes. This information can be used to implement different energy management strategies, allowing plants to optimize energy usage and production output simultaneously.

The energy management topic is evolving, and customers are embracing the idea of integrating electrical systems in a process control system. Using process control systems as the central point of their energy management scheme, manufacturers can save and manage the use of electrical energy. Cement industry producers can achieve the objectives of energy optimization through the integration of process control and energy usage information.

**Plant asset management using a process control system**

Plant asset management is an emerging area where the traditional definition of DCS and PLC does not apply. The plant assets in a typical control system include mechanical equipment, computers, networking, drives, motors, and process instrumentation. Process control systems today have the capability to act as the center point to gather, store, and manage health information about these plant assets. Asset management means the most beneficial operation of these assets from the time a piece of equipment is commissioned to when they are finally replaced or decommissioned.

According to ARC:

“Plant Asset Management (PAM) is a combination of hardware, software, and services used to assess the health of plant assets by monitoring asset conditions periodically or in real time to identify potential problems before they affect the process or lead to a catastrophic failure.”

*Plant Asset Management Systems Worldwide Outlook, ARC Advisory Group, 2007*
The integration of asset management in a process control system is a recent development, and this capability has been defined and expanded over a number of years. NAMUR and ISA are playing a critical role in the definition of the specification for the Plant Asset Management standards. Initially HART and then the digital fieldbus technologies played a critical role in expanding the role of the process control system to include PAM. Fieldbus technologies, such as PROFIBUS and FF, enable not only the communication of the process data, but they also provide the capability to get useful information about these assets.

A typical example is diagnostic information about the broken sensor wire in a temperature transmitter or loss of compressed air in a pneumatic valve. This diagnostic information is transmitted from the instrument to the process control system via the digital fieldbus. The Plant Asset Management system interprets this information and presents it to the operator in an easy-to-understand format. A Plant Asset Management package also recommends corrective actions that can be performed to fix the problem.

The detail diagnostic information enables the maintenance technicians to quickly understand the problem and take appropriate maintenance actions. This leads to improved productivity and minimizes the unplanned down time. Asset Management is a "process" not just diagnostics and software. The integrated
asset management system in a process control system acts as a critical interface between the actual plant assets and higher level computerized maintenance management systems (CMMS) and helps in the implementation of different maintenance management strategies.

Summary

The implementation of the new capabilities of the integrated process control systems will allow cement producers to optimize their energy consumption and improve operational efficiencies throughout their facilities. The integration of energy and asset management information is now available in one central location, increasing operability and streamline plant cost of operation. It is not a question of whether or not cement plants will embrace new technologies; the plant economics will make it inevitable. Those facilities that will embrace new technologies will be in a better position to accelerate market share and increase profit margins.