Application of Programmable Logic Controller for Gases Monitoring in Underground Coal Mines

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Abstract— Nowadays mining industry is experiencing many changes. One of the many developments, looming on the horizon, having potential to change the fundamental nature of mining as it is practiced today: automation. Automation in mining industry would be useful for safety and large production. It is based on geographic location of operation, so naturally use of automation is to achieve operating goals such as maintaining required digging profiles, avoidance of hazards, obstacle, etc. Mining industry continuously strive to find better ways to increase output, improve quality and uphold the highest safety standards while decreasing cost and protecting the environment. This paper presents applications of programmable logic controller in underground coal mines for key activities of automatic mining operations and will focus on conveyor belt system, gas monitoring and control with help of different gas sensors, for automatic control and cutoff power supply of a particular area in underground mine when concentration of flammable gas exceeds more than the permissible limit.

Keywords- **Automation, PLC, Sensors, Underground Mine gases.**

I. INTRODUCTION

In the past, systems were controlled manually. Modern day machineries consist of electrical, mechanical, electronics and instrumentation parts. They use electricity, hydraulic, pneumatic and electronics controller for control and monitoring operations [1]. Therefore, all of these have been mixed as a branch, named "Mechatronics". Automation is a part of mechatronics. Automation means self-moving. It is derived from two Greek words Auto and Matos, Auto means itself and Matos means moving. Therefore, automation may be defined as the use of control systems and information technologies to reduce the need of human involvement in the production of goods and services, i.e. automation is the technology by which a process or procedure is accomplished to minimize human assistance and error. It is implemented using a program (a set of instructions) combined with control system that execute the instructions. To automate the process, power is required both to drive the process itself and operate the control system [2]. Automation has successfully been used in the field of automotive, aerospace, power, steel and process industries by providing maximum flexibility at minimal cost while maintaining benefits of increased quality, safety and control. Automation plays an increasingly important role in economy and daily experience. Some of the widely used automation tools are programmable logic controller (PLC), Supervisory Control and Data Acquisition (SCADA), Artificial Neural Network (ANN), Distributed Control System (DCS), Human Machine Interface (HMI), and Programmable Automation Controller (PAC). Whereas mechanization provides human operators with machinery to assist them with the muscular requirements of work, automation greatly decreases the need of human sensory and mental requirements as well [3].

In a traditional industrial control system, all control devices are wired directly to each other according to how the system is supposed to operate while using PLC system, wiring between devices is reduced. Thus, instead of being wired directly to each other, all equipment is wired to PLC. Then, the control program inside PLC provides the "wiring" connection between the devices. The control program is the computer program stored in the PLC memory that tells the PLC what is going on in the system [4]. This paper presents applications of PLC in mines for automatic mining operations. Applications of PLC in open cast mines industry are mine blasting, excavation, loading and transportation etc. For underground mines, applications of PLC will be suitable for controlling conveyor belt system, gas monitoring with the help of different gas sensors, ventilation and automatic cutoff power supply of certain areas in an underground mine when concentration of flammable gas exceeds permissible limit.

II. MINING METHODS

Coal is mined by two methods:

A. Surface or opencast mining
B. Underground or deep mining

The choice of mining method is determined by the geology of coal deposits i.e. depending on the depth of the seam or seam to be extracted. Underground mining currently accounts for a bigger share of world coal production than opencast. Approximately 60% of world coal production is produced from underground mines. India is the third largest coal producing countries [5, 6] but in India surface mining accounts for about 90% whereas only 10% comes from underground mining.

A. Surface Mining

Surface mining: - It is also known as opencast or open cut mining. Surface mining is only economically feasible when the coal seam is near the surface. The exposed coal is drilled and drill holes are filled with explosives for blasting. Then overburden is removed with large draglines, shovels and trucks or bucket-wheels and conveyors to the coal preparation facility. This method recovers a higher proportion of coal deposit than underground mining as all coal seams are exploited 90% or more of the coal can be recovered. Large opencast mines can cover an area of many square kilometers and use very large pieces of equipment, including:

- Draglines, which remove the overburden
- Power shovels
- Large trucks, dumpers
- Bucket wheel excavators
- Conveyors

The coal is then loaded on to large trucks or conveyors for transport to either the coal preparation plant or directs to where it is to be used [5].

B. *Underground Mining*

There are two main methods of underground mining:-

1. *Room and Pillar Mining*

Room and pillar mining is generally used at shallow depths, where the geology of the coal seam is too complex for longwall mining. In room and pillar mining, coal deposits are mined by cutting a network of rooms into the coal seam and leaving behind pillars of coal to support the roof of the mine. Up to 60% of the coal can be recovered, with the remaining 40% forming pillars which support the mined out rooms. These pillars can be mined as the final stage in the extraction of the section [7].

2. *Longwall Mining*

Longwall mining comprises full extraction of coal from a section of the seam, or face using mechanical shearers. Longwall mining is almost a continuous operation involving the use of self advancing hydraulic roof supports, sophisticated coal shearing machine and armored conveyor, paralleling the coal face. Working under movable roof support, the shearing machine cuts and spills coal and rides on conveyor, for transport out of the mine. Longwall mining is a very efficient coal producing technique. Its productivity potential is higher than that of room and pillar mining, because longwall mining is basically a continuous operation require less workers. Over 75% of coal in the deposit can be extracted from panels of coal that can extend 3km through the coal seam. Almost all modern, high-production mines use a retreat longwall method of mining [5, 8].

III. STATUS OF COAL MINING INDUSTRY IN INDIA

Coal mining in the India is carried out by generally two methods; opencast and underground. Opencast mining contribute over 90% of total production whereas rest of the production (about 10%) comes from underground mining [21]. These mines are mostly semi-mechanized. The machinery commonly deployed is drill machines, load-haul dumper (LHD), ventilation fans, pump for dewatering, haulage for transport, etc. In underground mines, mass production technology is used by introducing continuous miner. Modern roof- bolting technology with flexibolts up to 5 m length; smart bolting for cost reduction of roof support; introduction of mechanised roof bolting using hydraulic bolts for difficult roof are new technology absorptions in Indian Underground Coal Mining. Mechanized Long wall mining (long wall powered support) has also been introduced in a limited scale which yields higher output with high percentage recovery (70-80%) [21]. Mining industry continuously strive to find better ways to increase output, improve quality and uphold the highest safety standards while decreasing cost and protecting the environment, which is possible by implementing PLC system and help for atomization.

IV. PROGRAMMING LOGIC CONTROLLER

Earlier, human operator used to control a system, which was later substituted by electrical relays. These relays allow power to be switched on and off without a mechanical switch. It is common to use relays to make simple logical control decisions. The development of low cost computer has brought the most recent revolution, the Programmable Logic Controllers (PLCs). The advent of PLC began in 1970s, and has become the most common choice for manufacturing controls [9]. A PLC is programmed to control the operation of plant/mines. The block diagram of PLC shows in figure 1. PLC is a digital industrial computer. It can be defined as a digital electronic device that uses a programmable memory to store instructions and to implement specific functions, such as logic, sequencing, timing, counting and arithmetic to control, through digital or analog input/output modules of various types of machines or processes. Modern control systems still include relays but these are rarely used for logic. Relay is a simple device that uses magnetic field to control a switch. When a voltage is applied to the input coil, the resulting current creates a magnetic field. The magnetic field pulls a metal switch (or reed) towards it and the contacts touch, closing the switch.

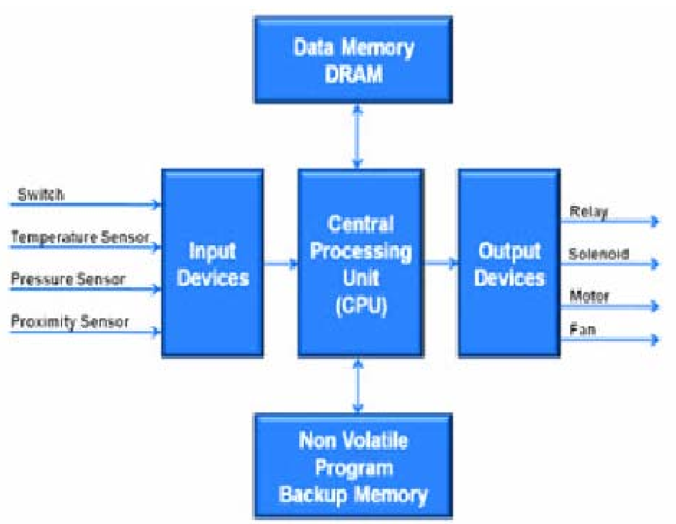

Figure 1. Block diagram of PLC

The contact that closes when the coil is energized is called normally open. The normally closed contacts touch when the input coil is not energized. Relays are normally drawn in schematic form using a circle to represent the input coil. The output contacts are shown with two parallel lines. The term logic is used because the programming is primarily concerned with implementing logic and switching operations. The input devices (e.g. switches, sensors, gas sensors, limit switches, inclinometers and push buttons etc.) and output devices (e.g. motor relay, contactor etc.) being controlled are connected to PLC, and then to the controller monitors and the inputs/outputs according to the program stored in PLC by the operator to control the machine or process. Originally PLCs were designed as a replacement for hard-wired relay, timer, and counter logic control system. PLCs have a great advantage that it is possible to modify a control system without having to rewire the connections to the input/output devices, the only requirement being that an operator has to key in a different set of instructions. The result is a flexible system, which can be used to control systems, which vary quite widely in their nature and complexity.

The soft wiring advantage provided by programmable controllers is tremendous. In fact, it is one of the most important features of PLCs. Softwiring makes changes in the control system which is easy and cheap. If you want a device in a PLC system to behave differently or to control a different process element, all you have to do is change the control program. In a traditional system, all control devices are wired directly to each other according to how the system is supposed to operate, making any changes would involve rewiring between the devices which is a costly and time-consuming endeavor. PLC system eases maintenance and troubleshooting. In PLCs the relations between inputs and outputs are determined by user program. By using advanced programming technologies it is much easier to implement complex control algorithms than in any hard-wired solutions. The significant advantages of using a PLC over conventional relays, timers, counters, and other hardware elements are as follows:

- Programming the PLC is easier than wiring a relay control panel and is often scrapped during rewiring.
- It has easy maintenance and higher reliability.
- PLC can be connected to the plant computer systems easily.
- PLCs can be used with robots to perform hazardous industrial operations, making it possible for humans to perform more intellectually demanding functions.
- PLC is low cost automation system.

A. Basic structure of PLC system

PLC contains mainly two parts- hardware and software. A schematic architecture of PLC shows in figure 2. The basic components of the PLC are as follows:

- Input module
- Output module
- Processor
- Memory
- Power supply
- Programming device
- Programming software
- Connector cable

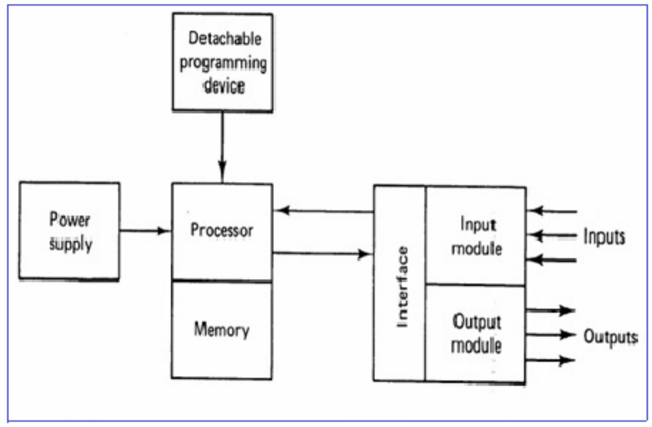

Figure 2. Architecture of PLC

The input and output modules are connections to the industrial process that are to be controlled. Inputs to the controller are signals from limit switches, pushbuttons, sensors, and other on/off devices. In addition, larger PLCs are capable of accepting signals from analog devices of the type modeled. Output from the controller is on/off signals to operate motors, valves, and other devices required to actuate the process. The processor is the central processing unit (CPU) of the programmable controller [10]. The processor of PLC is very similar to microprocessor/microcontroller and those used in personal computers and other data-processing equipment. Thus, PLC consists of central processing unit (CPU) similar to computer, memory, and input/output modules. However, a logic control system has no memory and does not consider any previous values of the input signals in determining the output signal. The CPU controls and processes all the operations within the PLC. It is supplied with a frequency and a clock. Frequency determines the operating speed of PLC and provides timing and synchronization for all elements in the system. A bus system carries information and data to and from the CPU, memory and input/output units. PLC is designed for multiple input and output arrangements extendable to further required modules. There are several memory elements: a system ROM to give permanent storage for the operating system and fixed data, RAM for the user's program, and temporary buffer stores for the input/output channels. The automation process also has flexibilities in programming and control techniques [11]. The PLC is designed to provide flexibility in control based programming, executing logic instruction and realization of complex control algorithms. PLC allow for shorter installation time and faster commissioning through programming rather than wiring [12]. In order to create or change a program, the following items are needed:

- PLC
- Programming Device
- Programming Software
- Connecting Cable

The basic operation of PLC system shows in figure 3.

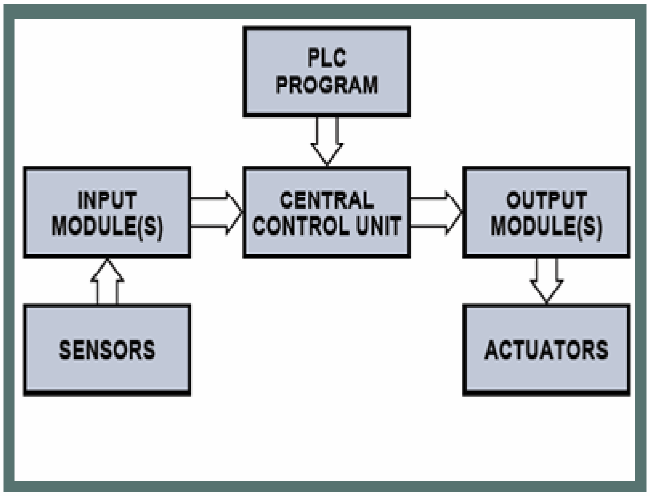

Figure 3. Basic operation of PLC system

The configuration of PLC with computer shows in figure 4. The program is created in a programming device and then transferred to the PLC. A software program is required in order to tell the PLC what instructions it must follow. Programming software is typically PLC specific. A software package for one PLC, or one family of PLCs, such as the S7 family, would not be useful on other PLCs. PLC Software supports different operating system like windows XP, vista, Win 7 etc.

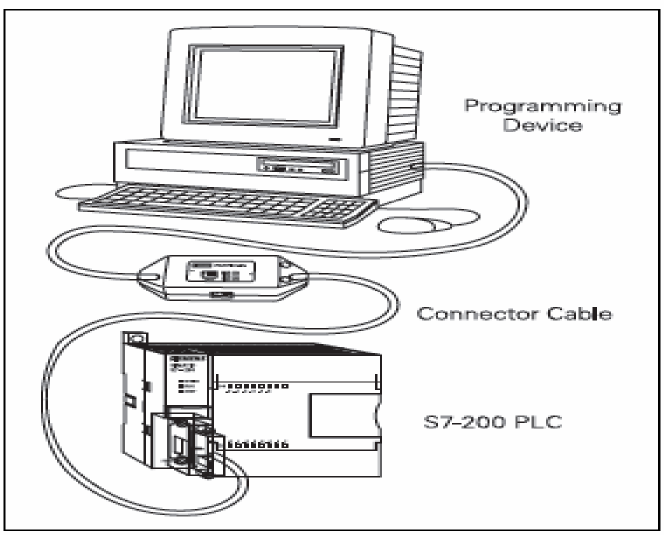

Figure 4. Configuration of PLC with computer

PLC software is installed on a personal computer in a similar manner to any other computer software. PLC programs may be write in any of three forms, namely ladder logic diagram, statement list and function block diagram. Generally, PLC is programmed using ladder logic method. The ladder logic diagram writes in PLC software which is stored in a computer. Connector cables are required to transfer data from the programming device to the PLC. Communication can only take place when the two devices speak the same language or protocol.

B. *PLC in mining automation technology*

Nowadays the mining environment has changed dramatically; and has seen many new developments in technology, automation, communications systems, and computerized process control and worker safety monitoring [13]. Automation works mechanically and controlled electrically. PLC controls many electrical and mechanical devices, such as sensors, gas sensors, relay, contactor, switches, motors, hydraulic and pneumatic valves, solenoid valves etc. A sensor can be defined as a device capable of converting energy from one form into another. Sensor senses the desired physical quantity and converts it into another energy form. The function of a Safety System is to monitor and control conditions on a machine or process that are hazardous in them or, if no action were taken, may give rise to hazardous situations. The Safety System runs in parallel with the Control System. The safety system is often referred to as "safety control" while the PLC system controlling the devices that produce the end product is often referred to as the "standard control" [14]. The major issue in the use of PLC in mining automation technology requires an understanding of various aspects of the selected area such as geological site, hydrology, mining, drilling, exploration, electrical power supply and thermodynamics of the gasification reactions in the cavity are important parameters for successful operation. An exchange of knowledge between the various fields is necessary. A Safety system is designed with PLC to protect;

- People
- Environment
- Machinery

V. MINE GASES

Gases that appear in underground mines are highly toxic and some are dangerously flammable when mixed with air. Methane and CO are the most common dangerous gas found in underground coal mines. Methane (CH_4) is produced during coalification (the process of coal formation). Only a fraction of these remains trapped under pressure in the coal seam and surrounding rock strata. This trapped methane is released during the mining process when the coal seam is fractured. Methane released in this fashion will escape into the mine area, and will eventually escape into the atmosphere. Underground coal mining releases more methane than surface or open-pit mining because of the higher gas content of deeper seams. The amount of CH_4 released during coal mining depends on a number of factors, the most important of which are coal rank, coal seam depth, and method of mining [17]. Carbon monoxide (CO) is a deadly, colorless, odorless, poisonous gas. If the methane gas from the coal seams is accumulated in underground spaces, a high risk of explosion may arise. So, sensor must sense such accumulation and the ventilation system should eradicate the gas when crosses the permissible limit using PLC system. Methane is measured in percentage by volume between the ranges of 0-5%. CO concentration is measured in parts per million (ppm). Gas sensors are used to detect the presence of Carbon Monoxide gas at concentrations from 0-300 ppm measuring range (standard). In mines the permissible concentrations of CO gas is 0-50 ppm [18]. PLC system performs monitoring, analyzing and controlling using sensor capable to give both analog and digital output. Sensor makes use of serial interface port to communicate with PLC system.

VI. GAS MONITORING AND VENTILATION SYSTEM

Gas sensors monitor carbon monoxide, methane, carbon dioxide, oxygen and differential pressure at ventilation splits throughout the coal mine. In India many coal mines are closed due to presence of hazardous gases (CO, CO_2, CH_4, SO_2 etc.). Thus, it is important to use PLCs for gas monitoring and control of ventilation system in those mines for efficient removal of gases and provide a safe working zone. There are two kinds of Risk Zones, namely, Explosive Risk Zones (ERZ) and Negligible Explosive Risk Zone (NERZ). These are defined as:

- ERZ0 is "an underground mine, it is identified by a risk assessment as likely to be, greater than 2%". These areas are typically sealed off and inaccessible areas with no ventilation.
- ERZ1 is "an underground mine, where the general body concentration of methane is known to range, or is shown by a risk assessment as likely to range from 0.5% to 2%". These areas are typically face or coal cutting areas and return airways.
- NERZ is "part of underground mine, where the general body concentration of methane is likely to be less than 0.5%". These areas are typically fresh air intakes and referred to as Zone 2 in IECEx certified systems.
- These boundaries are typically only valid while the mines ventilation system is operational. When no ventilation is present the whole mine is considered to be an ERZ0.

In an underground coal mines, gas monitoring and ventilation control system with different gas sensors are installed at air outlets forming zone boundaries and provide local visual indication:

- Healthy when the methane level is below 0.25%.
- Warning when the methane level is between 0.25% and 0.49%.
- Alarm when the methane level is above 0.49% [19].

A. Process Description

PLC takes real time decision depending upon the various field level input signals from various gas sensors placed at different critical points and sends decision to the output devices after processing. A process variable, such as flow rate or gas concentration in underground coal mines, is monitored via the input module. The information is processed by the central control unit; and relevant action is taken by the output module, which, for example, drives an actuator. Gas sensor determines the concentration of gas accumulated in a protected area and transmits the information to an input module of PLC system. Gas sensing system shows in the figure 5.

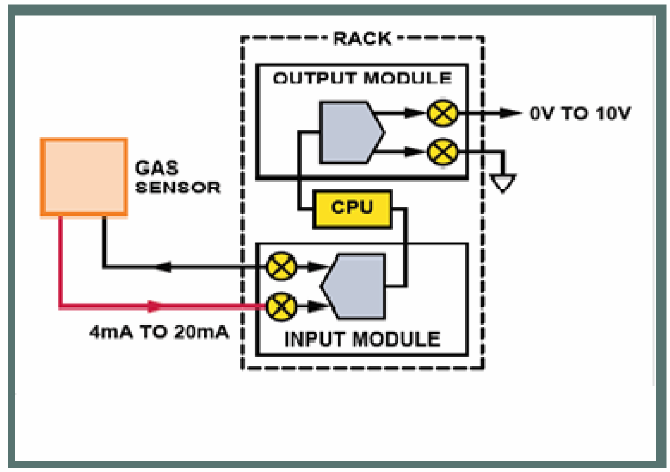

Figure 5. Gas sensing system

PLC consists of an analog input module that reads the 4 - 20 mA signal from the sensor, a central processing unit, and an analog output module that controls the required system variable. The current loop can handle large capacitive loads-often found on hundreds-of-meters long communications paths experienced in some industrial systems. The output of the sensor element, representing gas concentration level is transmitted over the current loop. This simplified example shows a single 4 - 20 mA sensor output connected to a single channel input module and a single 0 - 10 V output [20]. Figure 6 shows a typical gas monitoring and power cut-off system through PLCs in running gaseous underground coal mines. All gas sensors are connected to the input module of PLC and alarms, and actuator are connected to the output module of PLC. CH_4 and CO gas are most commonly found hazardous gas in underground mines.

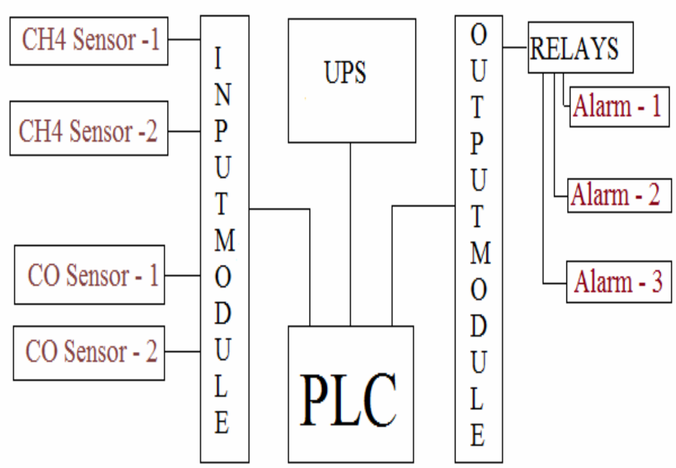

Figure 6. Block diagram of automatic gas monitoring and power cut-off system

When methane gas sensor detects the concentration below 0.25% then PLC gives no alarm and indicates safe working condition. When methane level in between 0.25% and 0.49% is detected, PLC gives warning alarm and increases ventilation through various methods like increasing speed of exhaust fan and pumping fresh air. When methane level is above 0.49%, the system turns alarm ON, automatically cutoff supply to all working machines, working miners are removed and blocks human entry from adjacent zone boundary. Miners may enter only after alarm goes OFF and normal working condition is ensured.

VII. FUTURE INNOVATIONS IN MINING AUTOMATION

Coal mining industries are emphasizing on modernization & upgradation of technology, optimization of operations and increased application of automation and information technology. Now-a-days PLC is limited only to gas monitoring systems, conveyer system and some other small applications in mine. In future PLC system may be used in many others applications and operations which are done manually at present, to increase the quality and quantity of production, reduce human efforts and errors and saving lives.

VIII. CONCLUSION

Automation not only reduces human involvement but also reduces energy consumption, production cost and increases production speed. So this paper is appropriate to fulfill those requirements of the coal mines. This innovative automation process is highly flexible and easily adaptable to new and existing situations. Automation provides some form of monitoring capabilities and provisions for programmable troubleshooting which reduces the downtime. The automation process also has flexibilities in programming and control techniques. The field environment of coal mines is highly polluted with extensive dust. So the mining automation is highly required which provides most accident free environment to the workers and prevents them to come in direct contact with the various noxious gases and dust that are emitted during coal mining. As the PLC does intelligently the overall operation and as it has centralized control. PLC is a device that is capable of being programmed to perform a controlling function. The PLC is designed to provide flexibility in control based programming and executing logic instruction, realization of complex control algorithms. PLC allow for shorter installation time and faster commissioning through programming rather than wiring.

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