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# Automation of underground coal mines using PLC

*Underground coal mining requires advance instrumentation for sustainable growth and safety of miners. Many parameters, such as emission of gases, strata conditions, temperature, air velocity, humidity, etc., need to be monitored simultaneously using suitable sensors. This paper presents applications of programmable logic controller (PLC) to key activities of underground automatic mining operations is the prefered option for increasing output, with safety in gassy underground mines by way of switching off power supply when concentration of flammable gases exceed permissible limit and simultaneously raising alarm to help save miner's valuable lives and assets mines property. Beside, PLC can be used for monitoring strata conditions.*

*Large scale implementation of PLC to automation in mining operations is a grey area to be explored and there is a scope to design and develop instrumentation for mines for multiple output of PLC system.*

***Keywords:*** *Automation; PLC; gas sensors; underground coal mine; hazardous gas.*

## I. Introduction

Underground coal mines require modernization for safe and economical production of coal. In India, coal production is mainly from the conventional manual faces. For economic, environmental and safety considerations underground coal mining projects, mechanization and automation in the preferred option. Therefore, more underground mines are likely to adopt increasingly modern instrumentation to compete with the existing global challenges to enhance productivity along with safety [1]. In the past, mine machinery was mainly mechanical which was controlled manually by human being. Modern day machines consist of electrical, mechanical, electronics and instrumentation parts, which may be control automatically. They use electricity, hydraulic, pneumatic and electronics controller for control and monitoring of mining operations. 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 [2]. It is implemented using a programme (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 [3]. Large number of human causality and huge loses occur in underground coal mines during and after a disaster. The main source being, gas accidents, explosives, flood, caving, etc. It requires the development of a system that can help minimize the human and material loss that happen during rescue operations in coal mines [4]. Automation has been successfully 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. 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 [5].

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 programmable logic controller (PLC) system, wiring between devices is reduced. Thus, instead of being wired directly to each other, all equipment is wired to PLC. This paper presents applications of PLC will be suitable in underground mines for automatic mining operations such as mine blasting, excavation, loading and transportation, controlling conveyor belt system, monitoring of strata conditions, gas monitoring in gassy mines with the help of different gas sensors, ventilation system and automatic switching off power supply of particular areas in case of flammable gas concentration exceeds the permissible limit in an underground mines at the same time warning to mine management [2].

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## II. Mining methods

The underlying objective in selecting and implementing a particular mine plan is always to mine a mineral deposit so that profit is maximized given the unique characteristics of the deposit and its location and the limits imposed by safety, economy and environment. Coal mining in India is carried out by generally two methods; opencast and underground. As on dated 31st March 2013, there were 559 operating mines for coal in India, out of which 215 were opencast, 320 were underground mines and 24 were mixed collieries. Opencast mining contribute over 90% of total production whereas rest of the production (about 10%) comes from underground mining [6]. India is the third largest coal producing countries.

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 [7, 8].

### A. Surface Mining

It is also known as opencast or open cut mining. A mine in which the ore lies near the surface and can be extracted by removing the covering layers of rock and soil. 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/machinery for mining process [7,9]. Surface mining requires large capital investment.

### B. Underground Mining

The mining method used will depend on the characteristics of the orebody, particularly thickness and deep, and the competency of the surrounding rock. Different methods can be used in different parts of a mine. This type of planning is done continuously as mining proceeds and more data are required on the orebody configuration through underground drilling [9]. There are two main methods of underground mining:

*(i) 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 [10].

*(ii) 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 [7, 11].

Fig.1. shows flow chart of mining process and corresponding instrumentation/mining machinery [9]. In India, many underground coal mines are closed due to mine safety. In Indian coal 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. 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. The coal production cost is less in underground mines compared to opencast mines. In underground mines, mass production technology is used by introducing continuous miner.

The mass production and safety of underground mines increases with reducing production cost by implementing of automation technology and its upgradation of machinery in

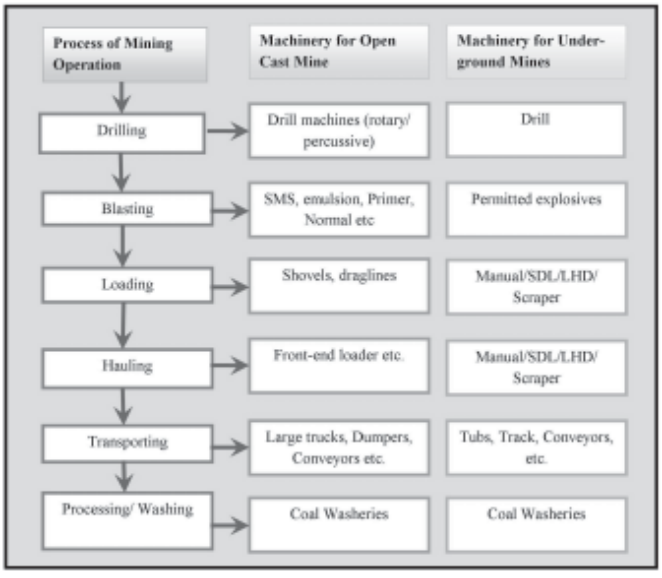


Fig.1 Flow chat of mining process and corresponding mining machinery

mining operations. PLC can play a vital role for automation of mining industry.

### III. Sensors for mining operations

Mining operation involves a variety of heavy rotating machinery that is used for exploration and processing of precious metals, minerals and material extracted from the earth. The underground mining operations can be automated and fully mechanized with the help of different types of sensors and controllers, instruments and machinery. The measurement of a motion through acceleration, tilt or vibration is extremely important and widely used in mining and drilling. For monitoring of environmental parameters like, hazardous gases generally found in gassy underground mines, ambient temperature, air velocity and humidity are required gas sensors, temperature sensor (thermistor), real-time vortex type air velocity sensor and humidity sensor respectively; and for monitoring of strata conditions require mainly roof support, convergence indicator, load cell, stress and strain meter, extensometer, pillar pressure indicator, etc. For this purpose different electro-magnetic sensors along with some mechanical arrangements are installed at different prefixed positions [1]. However application of respective instruments provides point to point information in the space but can be made continuous in time with the help of a programmable logic controller.

### IV. Programming logic controller

Control engineering has evolved over time. In the past humans were directly involved in controlling a system. More recently electricity has been used for control and early electrical control was based on 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 [12]. A PLC is programmed to control the operation of plant/mining operations, which contains mainly two parts; hardware and software. The basic components of the PLC hardware are input module, output module, processor, memory, programming device, programming software, power supply, connecting cable, etc., which connected in a systematic manner. The block diagram of PLC hardware system is shown in Fig.2. PLC 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. It is also known as a digital industrial computer [13].

Modern control systems still include relays but these are rarely used for logic. PLC system can automatically switch on/

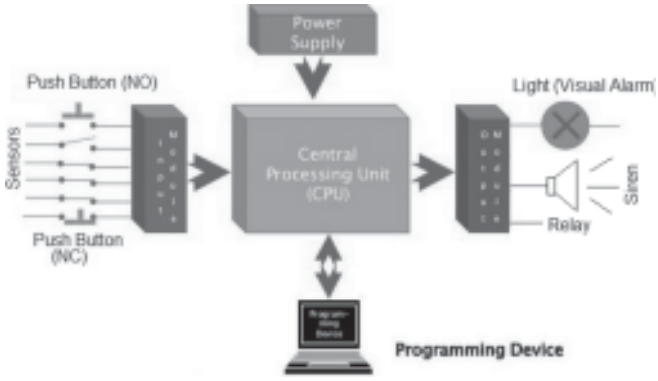


Fig.2 Block diagram of PLC system

off with the help of relay arrangements. Relay is a simple electromagnetic device that use 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 towards it and the contacts touch, i.e. closing the switch. 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. The term logic is used because the programming is primarily concerned with implementing logic and switching operations.

The input devices such as switches, sensors, gas sensors, limit switches, inclinometers, extensometer, load cell, push buttons and others environmental parameter monitoring sensors, etc. are connected to input module and gives current status/signal to PLC system. The output devices such as relay, contactor, siren, visual alarm, motor, ventilation fan, mine machinery, etc. are connected to output module of PLC system. The processor is the central processing unit (CPU) of the programmable controller. The input and output modules are connected to the PLC system that are to be controlled. The PLC system sends command to output devices according to input signal through the PLC programme stored in computer/ programming device by the operator to control the machine or process. PLCs are capable of accepting both types of signals, (i.e. analog and digital) and provide decision according to actual occurrence. Output from the controller is on/off signals to operate relay, motors, solenoid valves, buzzer, indicating devices and other devices required to actuate the process [14]. Originally PLC were designed as a replacement for hardwired 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 [15].

#### A. Architecture of PLC

The processor of PLC is very similar to microprocessor/ microcontroller and those used in personal computers and

other data-processing equipment. 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 read only memory (ROM) to give permanent storage for the operating system and fixed data, random access memory (RAM) for the user's programme, and temporary buffer stores for the input/output channels [15]. The block diagram of PLC architecture shown is in Fig.3 [16]. The automation process also has flexibilities in programming and control techniques. The PLC is designed to provide flexibility in control based programming, executing logic instruction and realization of complex control algorithms. PLC allows for shorter installation time and faster commissioning through programming rather than wiring [17].

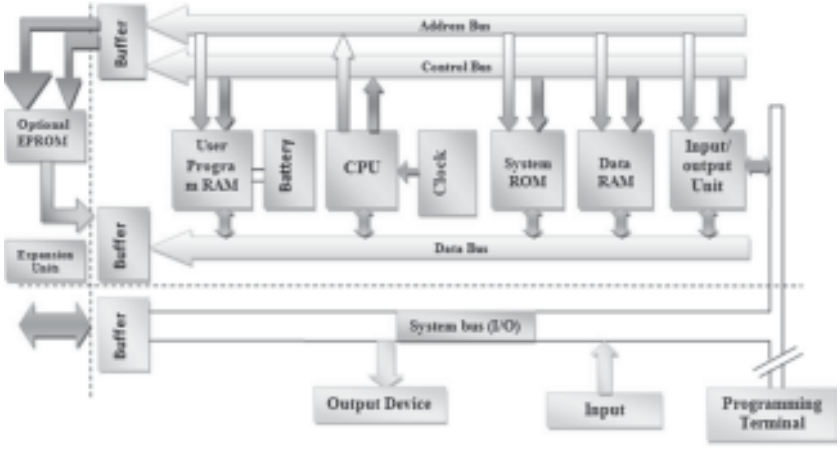


Fig.3 Block diagram of PLC CPU architecture

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 make PLCs. PLC software supports different operating system like windows XP, vista, Windows 7, 8 and 10 etc. PLC software is installed on a personal computer/laptop in a similar manner to any other computer software. PLC programmes may be written in any of three forms, namely ladder logic diagram, statement list and function block diagrams. Generally, PLC is programmed using ladder logic method. The PLC programme (ladder logic diagram) written on computer which have PLC software installed and it can be stored in PLC memory. Connector cables are required to transfer data from the programming device to the PLC. PLC system can be communicated to programming device via various communication cables, namely RS232/RS485/Ethernet/ PROFINET/PROFIBUS, etc. Communication can only take place when the PLC hardware and software are of same make and two devices speak the same language or protocol [2]. The configuration of PLC with computer is shown in Fig.4. The programme is created in a programming device and then transferred to the PLC. A software programme is required in order to tell the PLC what instructions it must follow.

The PLC system can easily create or change a programme with the help of programming device (computer/laptop) with

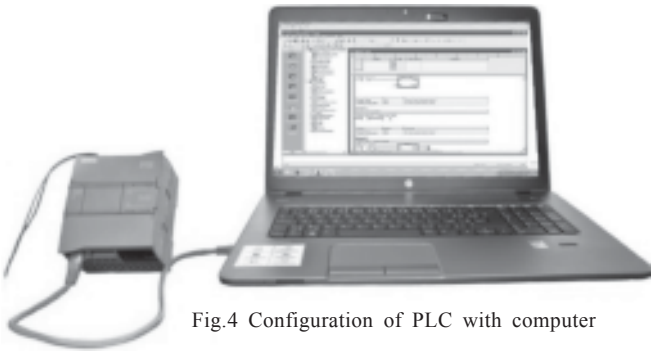

Fig.4 Configuration of PLC with computer

installed PLC software and connecting cable (i.e. RS232/RS485/Ethernet/ PROFINET/ PROFIBUS, etc.).

PLC programme writing is in the PLC software on programming device/computer. After writing a programmes it downloads/save in PLC via communication port and then run.

### B. Programme scan

During each operating cycle, the processor reads all inputs, takes these values, and energizes or de-energizes the outputs according to the user programme. This process is known as a scan. In PLC system, each new creation or change in programme requires scanning process which is shown in Fig.5 [18].

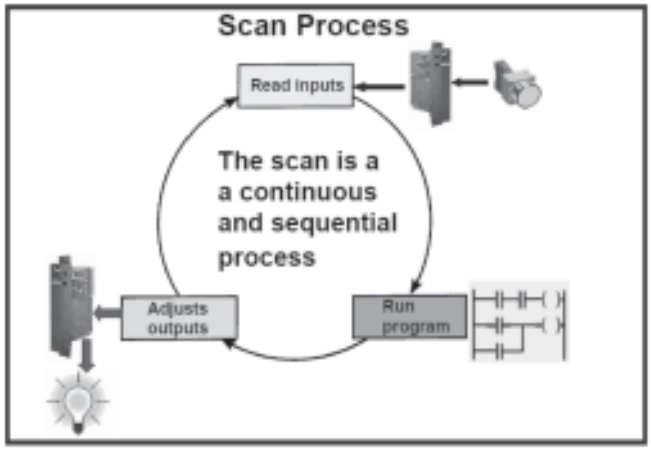


Fig.5 Scaning of PLC programme

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 that would involve rewiring between the devices which is a costly and time consuming endeavour. PLC system eases maintenance and troubleshooting. By using advanced programming technologies it is much easier to implement complex control algorithms than in any hard-wired solutions and easily determined relations between inputs and outputs [2]. By only changing the PLC programme (i.e. without change in any connection of hardware), PLC system can be made to behave differently to control a different process element. PLCs have been gaining popularity on the factory floor and will probably remain predominant for some time to come. Most of this is because of the advantages they offer:

- Cost effective for controlling complex systems.
- Flexible and can be reapplied to control other systems quickly and easily.
- Computational abilities allow more sophisticated control.
- PLCs can be used with robots to perform hazardous industrial operations, making it possible for humans to perform more intellectually demanding functions.
- Troubleshooting aids make programming easier and reduce downtime.
- Reliable components make these likely to operate for years before failure.
- PLCs system can communicate to sensors with wire as well wirelessly

## V. Automation technology in underground mining operations

Automation technology can save mines up to 80% on labour and labour related costs. Nowadays the mining environment has changed dramatically; and has shown many new developments in technology, automation, communications systems, computerized process control and worker safety monitoring [19]. Automation works mechanically and control electrically.

Underground coal mines are well recognized hazardous areas which are prone to accidents due to roof fall, collapse of gallery sides, gas poisoning, gas and coal dust explosions, etc. Therefore, it requires suitable instrumentation and sensors to overcome this problem for sustainable growth and safety of miners. By using PLC system in underground mining operations we can easily save miner's lives, mine machinery and mine property. PLC controls many electrical and mechanical devices, such as sensors, gas sensors, relay, contactor, switches, motors, alarming device, extensometer, buzzer, hydraulic and pneumatic valves, solenoid valves, load cell, convergence meter, temperature sensors, etc. Sensor senses the desired physical quantity and converts it into another energy form. 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 [20]. The major issue in the use of PLC in underground mining automation technology requires an understanding of various aspects of the selected area such as geological site, hydrology, mining, drilling, exploration, electrical power supply. An exchange of knowledge between the various fields is necessary.

## VI. Hazardous gases in underground mines

In India many underground coal mines are affected by hazardous gas. Underground coal mines in the country have been declared as gassy mines in three types, namely degree I, degree II and degree III. The degree III gassy mines are considered most dangerous [21]. Gases that appear in subsurface of underground mine atmosphere may be highly toxic and some may be dangerously flammable when mixed with air. But concentration of mine gases found at any time and location may vary by factors like diffusion, turbulent dispersion and leakage paths in subsurface ventilation systems. Methane ($CH_4$) and CO are the most common dangerous gases found in underground coal mines. Methane 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 [22]. Carbon monoxide (CO) is a colourless, odorless and poisonous gas. If the methane gas from the coal seams is accumulated in underground spaces, a high risk of explosion may arise. Therefore, gas sensors must be required with automatic alarming and power cut-off system. In PLC system, sensor must sense such accumulation and the ventilation system should eradicate the gas when crosses the permissible limit.

In Indian mines, generally portable devices (methanometer, CO meter, anemometer, thermometer, etc.) are used for environmental monitoring and recording huge data in recording device/record book for future use [23]. To overcome existing problems, different sensors based PLC system can be used for monitoring, analyzing and controlling of different parameters in a single monitoring system. Sensor makes use of serial interface port to communicate with PLC system.

### A. Gas Monitoring and Alarm System

For monitoring of various gases present in subsurface of underground coal mine atmosphere require different gas

sensors, namely carbon monoxide, methane, carbon dioxide, nitrogen dioxide, sulphur dioxide and hydrogen sulphide which can be controlled by PLC system. In India many coal mines are closed due to presence of hazardous gases (CO, $CO_2$, $CH_4$, $H_2S$, $NO_2$, $SO_2$ etc.). In general following alarm levels and necessary precautionary actions are taken in underground mines: (i) for methane - at 1% isolate electricity and at 2% removal of personnel; (ii) for carbon monoxide - 0.005% time weighted average (TWA), 0.04% short term exposure limit (STEL), and 200 ppm ceiling limit (CL); (iii) for carbon dioxide – 0.5% TWA, 3% STEL and 1.5% CL; (iv) for oxygen - greater than 19.5%; (v) for hydrogen sulphide – 10 ppm TWA, 15 ppm STEL and 15 ppm CL; (vi) for nitrogen dioxide - 3 ppm TWA and 5 ppm CL; and (vii) for sulphur dioxide - 2 ppm TWA, 5 ppm STEL and 10 ppm CL [24]. 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) [2]. In an underground coal mines, gas monitoring, alarming and ventilation control system with different gas sensors are installed at air outlets forming zone boundaries and provide local visual indication [25]:

- 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%.

B. 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. Individual gas sensing system is shown in Fig.6. PLC consists of an analog input module that reads the 4-20 mA signals 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 0-10V output [26].

Fig.7 shows a typical gas monitoring and power cut-off system using PLCs in running gaseous underground coal

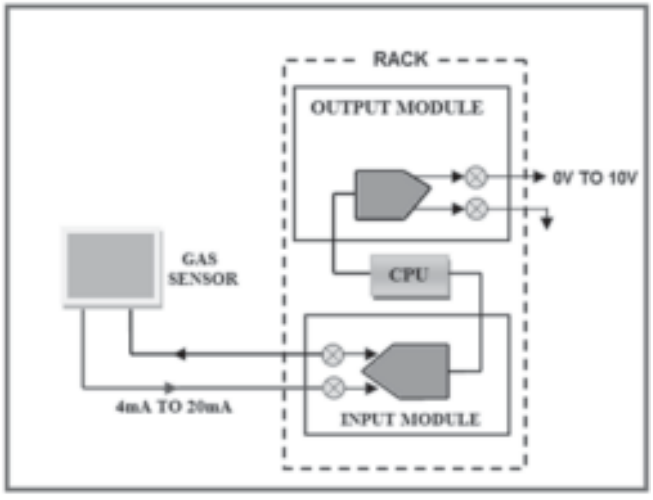


Fig.6 Gas sensing system

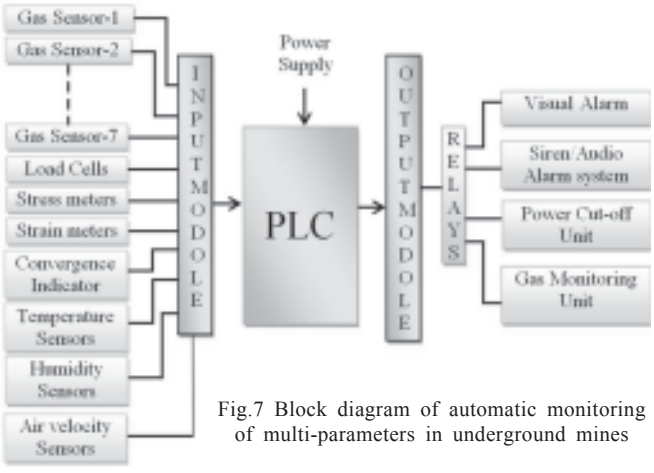


Fig.7 Block diagram of automatic monitoring of multi-parameters in underground mines

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. The gas sensor continuously measured concentration of gas present in underground mine atmosphere. CO sensor will be installed in roadways, working areas, return line and goaf areas. It is deadly poisonous gas and it's monitoring also help in early fire detection. Air velocity and methane sensors will be mounted at exit end of air route (return) inside the time. Continuous monitoring of methane is essential as concentration of methane from 4.8% to 14% form explosive mixture [27].

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 gas concentration exceeds the permissible limit gas sensor gives electrical signal (4-20 mA) to input module of PLC and PLC system can

automatically switches off power supply of particular area of mines and at the same time raise loud audio alarm which prompts mine authorities to evacuate miners as well as mine machinery from the danger zone resulting in saving of valuable human lives as well as mine's property. 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 and upgradation of technology, optimization of operations and increased application of PLCs and information technology. Nowadays PLC is limited only to gas monitoring systems, conveyor 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. PLC system, supervisory control and data acquisition (SCDA) and distributed control system (DCS) can be used in surface mining operations for modernization and atomization. PLC system also can help for coal production monitoring, automation of weighbridge for accurate weighing and coal transportation systems.

## VIII. Conclusions

Automation not only reduces human involvement but also reduces energy consumption, production cost and increases productivity. This paper enumerates the requirements of the coal mines. The innovative automation process is highly flexible and easily adaptable to new and existing mines. PLC 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. PLC is a device that is capable of being programmed to perform a controlling function. The PLC is designed to provide easy ways in control based programming and executing logic instruction, realization of complex control algorithms. PLC allows for shorter installation time and faster commissioning through programming rather than wiring.

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*(Continued on page 186)*

machine design parameters (the vane spacing, pick spacing, angle of wrap, etc.) and operating parameters (cutting speed, inclination, etc.).

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