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A Review on Importance of PLC and Drive to Save Energy in the Process Industry

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***Abstract*— Programmable logic controller (PLC) is an electrical digital device that can be programmed through Codes and functions like as timing, logic, counting, and sequencing are stored in the PLC programmable memory. Machines and processes are controlled by these instructions. Variable frequency Drives are used in the industrial process for speed control and smooth start stop. As the need of automation increases significantly for the industrial processes, a control system needs to be easily programmable, flexible, reliable, robust and cost effective. It is human nature to always seek to improve the processes of its activities, in which Process automation has enabled industrial automation to make a major technological Advance. In view of this, the aim is to reduce the energy in the process manufacturing industries. In this paper a review on Importance of using PLC and drives to save energy in industrial process. Various applications of PLC and Drives in the energy research, industrial control, Application of monitoring and control of industries process are reviewed in this paper. Most industries are responsible for most of the percentage of GDP (Gross Domestic Product) movement in industrialized countries, at a time when companies seek to maximize their processes in an increasingly competitive market, always having to adapt any and all procedures with a view to technological advances, making a particular industrial process cleaner, which is of great importance to maintain the consumer market.**

***Index Terms*— PLC, SCADA, HMI.**

I. Introduction

PLC denotes "Programmable Logic Controller." A PLC is a robust computer specifically designed to function successfully in difficult industrial settings, such as steel and cement plants, characterised by severe temperatures and varying moisture and dust conditions. It is used to automate industrial processes, machine operations, or complete production lines, such as those in manufacturing plants and wastewater treatment facilities.[1] PLC reduces the extensive hard wire formerly linked to traditional relay control circuits. Relays were electromechanical devices that facilitated fundamental control logic inside cabinets. PLCs were originally designed to replace these devices. PLCs, unlike other control system designs, have evolved into standardised computers with distinct properties. Unlike many embedded systems, PLC hardware is not designed for a specific installation site.[2] A PLC is a modular, reusable, and often ruggedized component designed for installation in cabinets. PLC is essential in automation for regulating industrial processes. A PLC may be programmed according to theoperational requirements of the process. The advantageous soft wiring capability offered by programmable logic controllers was a commendable attribute. Soft wiring facilitates alterations in the control system, making them simple and adaptable. To alter the behaviour of any device inside a PLC system or to manage a different process element, one need just adjust the control logic programme. In a conventional system, implementing this alteration requires physically altering the cabling connecting devices, a process that is both expensive and time-intensive. An automated control system is a technology designed to manage and analyse large volumes of data rapidly.[3] The programmable logic controller (PLC) is a compact, economical, and autonomous electronic device designed for various industrial automation applications. This is often used to manage a straightforward, repetitive operation and is linked to numerous PLCs or a host computer to facilitate the management of a complicated process. The controller operations in various modes may be seen using a personal computer (PC). A standard PLC comprises a power supply, CPU, input/output (I/O) modules, and specialised modules.[4] Figure 1 illustrates a control system based on a PLC. It comprises a supervisory/programming computer, electronic field instruments, and various electro-mechanical devices, including switches, sensors, and contactors at the input module, as well as indicators, lights, relays, and control valves at the output modules. Contemporary structures integrate an increasing number of electrical appliances and technological systems, necessitating enhanced control mechanisms. The PLC enables the user to integrate its input/output (I/O) modules to create a control system, as seen in Figure 2 of the fundamental block diagram of the PLC.[5] The control programme for the particular application is stored in the memory inside this system. This programme is thereafter run as an integral component of the PLC's internal operational cycle. The PLC constantly scans memory to maintain control over the machine or process operation. Consequently, the controller consistently executes three steps: it acquires inputs from input modules, processes preprogrammed control logic, and produces outputs to the output module depending on the solutions derived from the control logic. The PLC's programmed automated functioning is initiated by an operator via the supervisory computer. Simultaneously, programme information may be documented and monitored by the Supervisory Control and Data Acquisition (SCADA) software.[6]

The PLC embedded software system differs from traditional computer programming software. It pertains to control signals for the interaction with physical surroundings

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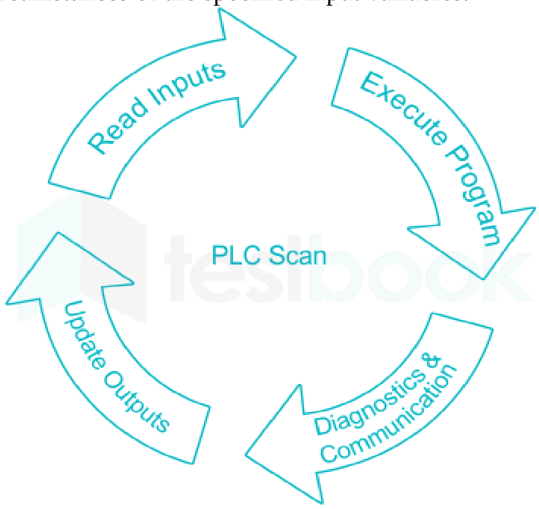
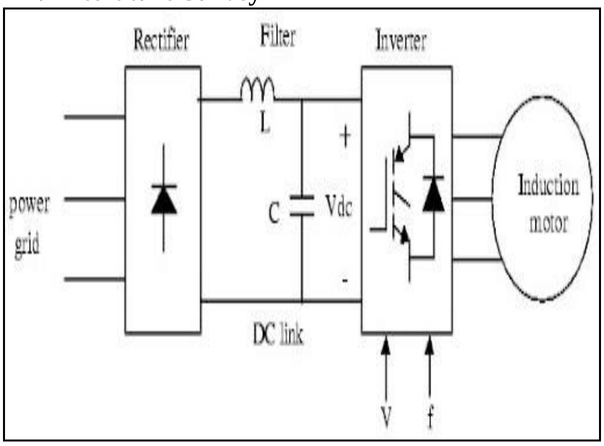
rather than data processing. The creation of the intelligent power supply switching control programme is predicated on the logical requirements specified in Truth Table I.[7] This table identifies Mains Power Supply input (MPS I/P) and Diesel Generator Supply input (DGS I/P) as two input variables to the PLC, while the four output variables are MPS, Solar Power Supply (SPS), DGS, and DGS Starter (DGSS). The logical condition 0 is regarded as the OFF state, whereas the logical condition 1 is deemed the ON state of the variables. The Output Power to the Load (OPL) must be activated by the output variables, contingent upon the automated switching circumstances of the specified input variables.



2. Literature Survey



PLC Working

The working of a PLC can be better to understood as a cyclic scanning method called, scan cycle. Operating system starts cycling and monitoring of time, The CPU starts reading the data from the input module and it checks the status of all the inputs, Executing the user or application program which is written in different language of PLC like ladder logic, Function block diagram, and structured text, Instruction list. CPU performs all the internal diagnosis and communication tasks. [11] The output will update in the output module according to the programme and continues the cycle.

Advantages of the Programmable Logic Controller

The benefits of using the PLC go far beyond what was thought of in its creation, being the replacement of relay panels, resulting in a range of improvements in all industrial environments, such as the quality and space optimization that is used [16]. In an attempt to solve the problem of industries with electromechanical relays, one of the most important equipment for technological advancement was created, which is essential for industrial automation, the installation of the PLC in the industrial environment, brought benefits to all, reducing hard work, repetitive work, which brought major problems to the health of the employee.

Variable Frequency Drive

The variable frequency drive, or VFD, is primarily used to drive and control the speed and torque of the motor so that it can adhere to the needs of the application. This is accomplished by adjusting the supply voltage and frequency.

A VFD is a device used in a drive system consisting of three main sub systems which are induction motor, main drive controller assembly and drive operator interface. They are all are used for variable speed application. [12] The speed revolutions per minute (rpm) of the driven shaft need to be increased or decreased depending on load changes. Speed of three phase induction motor can be controlled by PLC and Drive integration and control the motor speed as well as other parameters.

Speed of induction motor

$N_s = 120F/P$

Where,

N_s = the synchronous speed of the stator magnetic field in RPM

P = the number of poles on the stator

F = the supply frequency in Hertz

The speed of the induction motor is directly proportional to the supply frequency and is inversely proportional to the number of poles of the motor. As the no. of poles are constant by design itself, thus the speed of induction motor is varied with the supply frequency. Thus Speed control of a 3-phase induction can be achieved using VF control. [17]

Inverter drive is a type of adjustable-speed drive used in electro-mechanical drive systems to control AC motor speed by varying motor input frequency and voltage. VFD is a system made up of active/passive components of power electronics devices, high speed central controlling unit & sensing devices. The basic function of VFD is to act as a variable frequency generator in order to vary speed of motor as per the user setting.[18]

A variable frequency drive is a system equipped for controlling the rotational speed of an alternating current (AC) electric motor by controlling the frequency of the electrical power supplied to the motor.

The three basic components of the VFD are:-

- Rectifier
- DC Bus/DC link
- Inverter

The induction motor used along with the PLC for automation in industries provides better Efficiency. PLC & VFD are interconnected with each other with different types of communication protocol like Ethernet, profinet, serial and optical fibre. Study shows that variable speed operation of induction motor leading to high energy saving [14].

Energy Saving with Variable Speed Drives

One of the major costs incurred by most industry worldwide is energy. Therefore in the competitive markets of today where reducing costs is an important part of surviving, any methods of reducing the amount of power used in the processes that industry performs will be advantageous. With induction motors so widely used they account for a significant part of the energy requirements of many companies. Study shows that the feasibility of adding ac variable speed drives to control the existing pumping and fan applications in industrial reduce the running power of the motor and per unit energy consumption of the process [20].

Advantages of Variable frequency Drive

[1] Make Process Controllable

A VFD allows you to control the motor at any speed throughout its entire range. By adding transducers and or controllers a VFD allows you to control just about any process or application you may have that uses a motor.

Built in application on VFD's allows for easy quick programming for just about any control need.

Built in communication protocols allow the VFD to talk to most automation system for control and feedback information.

[2] Decrease stress on equipment

A VFD will be "soft start" a motor with adjustable ramp times this is when the motor would have the most stress.

A VFD always monitors the motor to control it to its maximum efficiency and protect the motor from working too hard.

When the motor is slower the entire system belts, pulleys, coupling, bearing, fans, impellers any part of the system the motor touches has less stress on it with a VFD controlling the motor.

[3] Saves Energy

VFD reduces the voltage and hertz there for amperage follows along with total energy used.

Proposed Work

When metallic can is placed on start point of conveyor the proximity sensor 1 (inductive) senses the can and signal PLC to start the motor thus conveyor start moving.

- Now metallic can is detected by proximity sensor 2 and it signal PLC to stop the motor thus conveyor stop and bottle filling start after a short delay.
- If sensor 1 detects another metallic bottle still it don't send any signal to the PLC so there will be no interference.
- When the filling process is done by the help of electric valve then PLC send the signal to start the motor again thus conveyor start moving further. Now when filled bottle is moved and come to the end of conveyor a push button to stop the conveyor is pressed so that filled bottle can be easily removed from the process.

PLC has evolved as a main controller in industries nowadays. This is because of the simplicity and robustness of the PLC.A programmable logic controller is a digital, industrial computer which is made up of integrated circuits. PLCs can store instructions like counting, timing, arithmetic manipulations and communication to machines and different control instruments. PLCs have many input and output ports therefore many instructions can be followed at a time with great accuracy. PLC's have replaced automated systems consisting of hundreds of sensors, timers, counters, etc. Its ability to redesign and reform the programming allowed flexibility in performing different processes also in different ways. Various domains like motion control, networking, sequential relay control, distributed control systems have been adjoined in PLC functioning since its inception.[22] The abilities of storage, processing speeds and communication possibilities have made the modern PLC's complement to the desktop computers. [25]

This project is a framework illustrating an automated bottling factory using PLC technology. The whole process is under SCADA supervision. The many sensors used in the system prevent superfluous operations like as overfilling or underfilling of the bottles. The system is fully monitored by SCADA, allowing for the plant to be halted or operated via SCADA in emergencies. The facility is managed by a programmable logic controller. The PLC serves as the central component of the whole automated system. Instructions to the PLC are inputted via Ladder Logic programming language. [27] The programming software used is RS LOGIX ENGLISH, whereas the communication software employed is RS LINX Classic for Windows operating systems. Once the programme is composed and effectively executed in OFFLINE mode, it is then downloaded onto the PLC using the communication software in accordance with the specified programme. Upon detection of the bottles at the input side, the conveyor motors activate, causing the conveyor belt to move ahead. The motor ceases operation when the bottle attains the precise position under the valve. [28] The solenoid valve in the tank activates, initiating the filling procedure. When the liquid level attains a certain height, the high-level valve deactivates, and a matching signal is sent to the PLC to initiate the conveyor drive. A 24V solenoid valve is used for this function, while a proximity sensor is utilised for detecting the bottle. Our project uses a DC motor drive system, while industries employ AC motor drive systems. Upon detection of the bottle by the sensor, a signal is sent to the PLC, which halts the drive motors. Once the filling process concludes, the PLC reactivates the drive motors to advance the conveyor. [29] At the terminus of the conveyor, an additional mechanism is installed to remove the full bottle off the conveyor belt. The conveyor operates until the proximity sensor detects the presence of another bottle. A sensor is positioned at the conveyor's terminus to tally the number of filled bottles, so determining the plant's output rate. The various phases of the bottle filling process may be monitored via the SCADA system on the computer. The whole procedure may be modified directly from the SCADA interface, including the initiation or cessation of conveyor motors, operation of various proximity sensors, or activation of an emergency stop. This is facilitated by the use of the RS 232 communication wire.This cable establishes a connection between WonderwareInTouch software and the used PLC.[25] Consequently, SCADA enables comprehensive control over the project without direct interaction with the hardware components, functioning as a remote control. This is a crucial aspect of automation, because any problem or disturbance may be remedied or halted only via SCADA.[26]

II. COMMUNICATION BETWEEN DRIVE AND PLC

A PLC is a solid state, industrial computer that performs discrete or sequential logic in a factory

environment. it was originally developed to replace mechanical relays, timer, and counters [27].

A Variable Frequency Drive (VFD) is used for applications wherein speed control is of an essentialbimportance due to load changes wherein the speed needs to be increased or decreased accordingly.[28]

A numbers of VFDs are connected to Communication module and this communication module is attached from PLC CPU. The communication module can be Modbus/Ethernet etc.

From PLC Ladder Logic Diagram we can decide whether we want to read the parameter of VFD or we want to write the parameter to VFD.

Applications of PLC and VFD in the Industrial Process

Paper mainly focuses on efficient cooling system designed for overcoming heating and insulation losses. With the implementation of smart grid and smart cities, the traditional control mode of transformer's cooling system cannot meet the new demand. Ideally PLC is used for online monitoring and data recording.

In our paper, we have proposed an intelligent cooling system based on Programmable Logic Controller (PLC) which eradicates the problem of manual transformer cooling control system by automatically switching between the cooling banks. The cooling system in our paper comprises of three cooling banks, each having a fan and a pump. [29]

At a time, two out of three cooling banks will be operating. In case of failure of any one of the operating banks, the third bank

will automatically switch on in place of the faulty bank. Hence third bank will continue to operate until faulty bank is repaired. This switching between cooling banks is PLC controlled and thus eradicates the errors caused by human intervention. Along with this, continuous monitoring and data recording is simultaneously done. We have also focused upon proper utilization of standby

bank by means of periodic switching. PLC logic is used for controlling all the components which are involved in the protection of transformer and also using the component only when needed eradicates the wastage of power and unnecessary operations. Human Machine Interface (HMI) can also be used for complete visualization of the process in the control room.

Limitations

1. Initial Cost and ROI Concerns

High Initial Investment: The installation of PLCs and drives requires a significant upfront investment, both for the hardware and the integration with existing systems. While the long-term energy savings can justify this, the initial cost may deter some companies from adopting them, especially small to medium-sized enterprises.

Return on Investment (ROI) Delays: Even though these systems can save energy over time, the payback period might be long, making it difficult to justify the investment in certain economic conditions.

2. System Complexity and Maintenance

Complex Configuration: PLCs and drives require proper configuration to function optimally. Poorly configured systems can lead to inefficiencies that negate potential energy savings.

Maintenance and Expertise: These systems require skilled personnel for regular maintenance, troubleshooting, and optimization. If the maintenance is not up to standard, energy savings may not be maximized, and operational inefficiencies can arise.

Potential for Misuse: If not set up or programmed correctly, PLCs and drives could lead to improper energy usage. For instance, a motor controlled by a VFD might not be optimized for the load, leading to unnecessary energy consumption.

3. Limited by Process Dynamics

Incompatibility with Some Processes: PLCs and drives are more effective in systems where process parameters (such as flow, temperature, or pressure) can be easily adjusted. However, in more complex or less predictable systems, their ability to save energy might be limited.

Not Suitable for All Equipment: Certain equipment may not benefit from the use of variable drives. For instance, applications where constant speed or precise control is required may not see a significant improvement from VFD implementation.

4. Energy Savings Potential Depends on Application

Variable Load Systems: The real energy-saving potential of drives is most evident in systems where the load varies (e.g., pumps, fans, compressors). In contrast, fixed-load systems may not benefit as significantly from energy savings when using drives.

Energy Savings Capabilities: While drives can reduce energy consumption by adjusting motor speeds to meet actual demand, in some cases, the energy-saving potential might be limited depending on the characteristics of the system (e.g., if the equipment operates at full load most of the time, savings will be less significant).

5. Integration and Compatibility Issues

Compatibility with Existing Infrastructure: Integrating PLCs and drives into existing process systems can be challenging, particularly in older plants where legacy systems are in place. Retrofitting might require additional modifications, making the process more expensive and time-consuming.

Communication Problems: PLCs need to interface with sensors, actuators, and drives to function optimally. Communication issues (e.g., protocol mismatches, signal interference) can reduce the efficiency of these systems and hinder their energy-saving potential.

6. Over-Reliance on Automation

Risk of Over-Automation: Sometimes, the drive for energy savings can lead to over-reliance on automated systems. In cases where human intervention might be needed for optimal energy management, too much automation can overlook practical, real-world variables.

Lack of Continuous Monitoring: Energy savings require continuous optimization. PLCs and drives can automate processes, but without a robust monitoring system or human oversight, these systems might not adjust to changing conditions or optimize energy usage in real-time.

7. Limitations in Energy Recovery

Regenerative Energy Recovery: While certain drives can recapture energy during braking or deceleration (e.g., regenerative drives), not all drives or systems are designed with energy recovery in mind. This limits the extent to which energy can be recaptured and reused within the system.

Storage and Distribution of Saved Energy: In some cases, saved or recovered energy might not be stored or distributed efficiently, thus reducing the overall impact on energy savings.

8. External Factors

Environmental Variability: Changes in external factors such as temperature, humidity, or power supply stability can influence the performance of PLCs and drives, leading to suboptimal operation or reduced energy efficiency.

Grid Stability: PLCs and drives typically depend on a stable electrical grid. Fluctuations in grid power, such as voltage dips or surges, can affect the performance of these systems and limit their energy-saving potential.

III. FUTURE SCOPE

1. **Integration with IoT and Industry 4.0 Smart PLCs and Drives:**

The future of energy savings will see PLCs and drives becoming more integrated into the Internet of Things (IoT) and Industry 4.0 systems. These systems will allow real-time data collection from sensors and actuators, which will be processed and analyzed to optimize energy consumption.

Predictive Maintenance and Analytics: IoT-enabled PLCs and drives will not only help reduce energy consumption but will also facilitate predictive maintenance. Sensors will provide early warnings of potential issues, ensuring that equipment operates efficiently, preventing breakdowns, and avoiding energy waste caused by malfunctioning equipment.

2. Advanced Control Strategies

Model Predictive Control (MPC):

Future PLCs may integrate Model Predictive Control (MPC) strategies, which can predict future system behavior and adjust the control parameters for energy optimization in real time. This will allow PLCs to make decisions based on long-term performance projections rather than reactive adjustments, providing more significant energy savings in dynamic environments.

Adaptive Control Algorithms: Future PLCs and drives will likely use more adaptive control algorithms that automatically adjust to changes in operating conditions, such as varying load demands, environmental factors, and energy prices, further improving efficiency.

3. Energy Recovery and Regeneration Regenerative Drives: The development of more energy-efficient regenerative drives will continue to evolve. These drives capture excess energy during braking or deceleration and return it to the system or grid, reducing the overall energy demand. Future developments will expand the applications of regenerative drives to more types of industrial processes.

Energy Storage Integration: Advanced PLCs will be able to integrate with energy storage systems, enabling industries to store excess energy generated during off-peak hours or by renewable sources for later use, further reducing reliance on the grid and lowering energy costs.

4. Edge Computing and Real-Time Optimization Edge Computing: As PLCs and drives become more connected, they will likely adopt edge computing capabilities. This allows for real-time processing of data at the source (near the equipment) rather than relying on centralized cloud systems. This will speed up decision-making processes for energy management, enabling quicker adjustments to optimize energy use based on changing operational conditions.

Real-Time Energy Monitoring: Enhanced real-time monitoring will provide detailed insights into energy consumption at granular levels, allowing for more precise adjustments. This will help in identifying and eliminating inefficiencies more effectively, contributing to significant energy savings.

5. Artificial Intelligence (AI) and Machine Learning AI-Driven Optimization: AI and machine learning (ML) will play a pivotal role in optimizing energy use. PLCs and drives can use AI algorithms to analyze vast amounts of operational data, predict energy demand, and optimize equipment performance autonomously. AI can identify patterns that human operators might miss, leading to even greater energy savings.

Energy Efficiency Algorithms: Future systems will incorporate advanced AI algorithms to continuously adjust the parameters of motors, pumps, fans, and other equipment based on real-time energy efficiency assessments, optimizing their operations to minimize energy consumption without compromising productivity.

6. Renewable Energy Integration

Hybrid Systems with Renewables:

PLCs and drives will increasingly be used in systems that integrate renewable energy sources (e.g., solar, wind) into industrial processes. PLCs will control the switching between renewable and conventional energy sources to optimize energy use and reduce costs. Drives will regulate motor speeds to match the variable output of renewable energy sources, ensuring efficient energy consumption.

Energy Grid Integration:

Future PLCs may also be more integrated with local or regional energy grids. By optimizing both local energy use and contributing to grid stability, industrial facilities could better manage energy flows, reduce peak demand, and lower energy costs.

7. Decentralized Control Systems

Decentralized Energy Control:

Future systems may move away from centralized control and implement decentralized control where multiple PLCs and drives are networked and operate autonomously. This would allow more granular control over energy consumption across various parts of the plant, improving the overall efficiency of the entire process.

Distributed Energy Resources (DERs): The concept of DERs, such as solar panels, battery storage, and wind turbines, will likely be integrated into the industrial energy ecosystem. PLCs will manage the flow of energy between these distributed sources, optimizing their use to balance consumption, storage, and energy generation.

8. Cloud-Based Energy Management Systems Cloud Integration:

The future will likely see more PLCs and drives connected to cloud-based platforms for remote monitoring and energy management. These systems will provide plant managers with detailed energy reports and insights into consumption patterns, enabling smarter decision-making for energy reduction.

Cloud-Connected Optimization: With cloud computing, industrial systems will have access to advanced analytics and optimization tools that can process vast amounts of data from multiple locations. This will allow companies to optimize energy use across different plants and facilities, providing more significant cost savings at the enterprise level.

9. Sustainability and Regulatory Compliance Energy Efficiency Regulations:

As global energy efficiency regulations become stricter, PLCs and drives will play a more crucial role in helping industries comply with sustainability goals and environmental standards. This could include optimizing processes to reduce emissions, water usage, and overall environmental impact.

Carbon Footprint Reduction: With the increasing focus on reducing carbon footprints, PLCs and drives will be a vital part of sustainable manufacturing. By optimizing energy consumption, these systems can contribute to reducing a facility's overall environmental impact.

10. Collaboration with Smart Grid Technologies Smart Grid Communication:

PLCs and drives will increasingly communicate with smart grids to enable dynamic demand response. When the grid signals high demand or energy shortages, PLCs and drives can adjust operations in real time to reduce energy consumption or shift usage to off-peak periods, improving energy efficiency and reducing costs.

IV. CONCLUSION

After a survey, it was realized the importance that automation has in human life, always seeking improvements in their lifestyle, facilitating the different branches of activities. In an attempt to solve the problem of industries with electro-mechanical relays, one of the most important equipment for technological advancement was created, which is essential for industrial automation, the PLC. The benefits of using the PLC go far beyond what was thought of in its creation, being the replacement of relay panels, resulting in a range of improvements in all industrial environments, such as the quality and space optimization that is used.

It can be concluded that the PLC was created in the 60's to replace electromechanical panels, is responsible for the great technological advance and will be part of industry 4.0.

The accomplishment of the study contributes to the professional of the area, deepening the knowledge about the determined subject for agenda, knowing better about the subject of its area of operation, knowing terms that are part of its experience.

The soft wiring advantage provided by programmable logic controllers was an excellent feature. Soft wiringmakes modifications in the control system were easy and flexible. If any device in a PLC system to behave differently or to control a different process element, all have to do is modify the control logic Program. In a traditional system, making this type of modification would involve physically changing the wiring between the devices, a costly and time-consuming procedure.

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