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Development of Special Purpose Machine using PLC

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Abstract

This project focuses on the development of an SPM controlled using a Programmable Logic Controller (PLC) to enhance efficiency, precision, and reliability in production processes. The demand for automation in manufacturing industries has significantly increased, leading to the development of Special Purpose Machines (SPM) tailored to specific industrial needs. The proposed system integrates PLC technology for seamless automation, minimizing human intervention while ensuring high-speed operations with reduced errors. The machine is built to execute specialized tasks with optimized logic programming, enabling real-time monitoring and adaptive control mechanisms. By utilizing sensor inputs, actuator control, and logical sequencing, the PLC ensures smooth operation, adaptability, and real-time monitoring. Additionally, a Human-Machine Interface (HMI) is incorporated to enable user-friendly interaction and control adjustments. This study explores the PLC programming logic, signal processing, and overall electrical automation strategies that drive the SPM. Comparative analysis with traditional control systems highlights the advantages of PLC-based automation, such as higher flexibility, improved system diagnostics, and reduced downtime. The results demonstrate that an efficient electrical and PLC-driven control system can significantly enhance the performance of SPMs in industrial applications, setting the stage for smarter and more automated manufacturing solutions.

Keywords: *PLC, Industrial Automation, VFD, Servo Motor, HMI, SPM.*

1. Introduction

Industrial automation has revolutionized manufacturing by integrating computer-controlled systems, robots, and PLCs to boost productivity, precision, and efficiency. The shift from manual operations and traditional relay-based controls to PLC automation has minimized human intervention, enabling faster, more reliable, and high-quality production. A key player in this transformation is Special Purpose Machines (SPMs), designed for specific industrial tasks with greater accuracy and consistency. In the past, industries relied on either manual operations or relay-based control systems, which came with several drawbacks—high labor costs, inefficiencies, and an increased risk of human error. Relay-based systems, while effective, had their own challenges, such as complex wiring, troubleshooting difficulties, and limited flexibility for control modifications. Similarly, manual machines required constant supervision, often leading to inconsistent output and errors due to fatigue. To overcome these limitations, this project focuses on developing an SPM with a PLC-based control system, replacing outdated relay logic and reducing the need for manual oversight. By integrating sensor-based monitoring, actuator control, and a Human-Machine Interface (HMI), the system becomes more efficient, flexible, and user-friendly. PLC programming enables logical sequencing and automation, providing real-time monitoring, improved diagnostics, and smooth operation—making it far superior to traditional systems. This approach makes the proposed SPM highly scalable, efficient, and cost-effective—an ideal solution for industries aiming to modernize their production. The study highlights how PLC programming, electrical automation, and system optimization contribute to building a reliable and advanced industrial automation system, helping shape the future of smart manufacturing.

2. Literature Survey

Chiranthan et al developed a Digital MCB which automatically detects the location of the fault and also rejoins the power supply. It offers completely autonomous and have a quicker response [1]. Dongqi et al designed and simulated filling speed of gray iron EPC is controlled by Siemens PLC. The equations of filling speed and pressurization speed of EPC are deduced, and the influence of external factors on casting quality is analyzed. The tracking error of the filling speed is simulated and compared to that controlled by PI [2]. Fang et al developed Human-Machine Interface Based on FANUC 0IMF CNC This paper uses FANUC PICTURE as the development tool to develop a special human-machine interface for machining shaft parts facing FANUC CNC system. Using this human machine interface can greatly reduce the skill requirements for CNC operators [3]. Fu et al researched on Discernment of Rectangular Controls in Human-Machine Interactive Interface. the detection and classification methods of controls based on image processing and machine learning are studied. The experimental results demonstrate that the proposed rectangular boxes in the human-machine interface can be easily captured by using the image morphology processing algorithm [4]. Ghate et al designed and fabricated a Special Purpose Winding Machine appropriate for winding 1:1 prototype edge-localized mode (ELM) coils of the Joint European Torus (JET)[5]. Jiayin et al analyzed about Design of Three Degrees of Freedom Pneumatic Manipulator Based on PLC Control for eliminating the use of manipulator in the big factory[6]. Joy et al have develop a Switch Mode Power Supply (SMPS) that integrates with a battery that is charged by solar energy. The battery provides standby power of the requisite quality to the PC. Personal Computers (PC) need stable power inputs that can deliver rigidly regulated and isolated DC outputs of high power quality at different levels. [7]. Mohammed Islam et al have designed VFD Motor Controller for Ship Service Auxiliaries. This chapter illustrates the VFD applications in an electrical system where the power generation is limited to a few megawatts [8]. Patel et al have designed Special Purpose Winding Machine (SPWM) is capable of winding up to 30 mm 30 mm square cross section NbTi and Nb3Sn based cable-in-conduit-conductors (CICC) in both circular and non-circular (D shape) winding pack geometries [9]. Patnaik et al have designed and developed a special purpose machine for glass insertion in plastic frame for spill guard glass shelf assembly of commercial refrigerators using Creo 2.0 and Catia V5 to accommodate the assembly operation for high production rate and zero tolerance for rejection. [10]. Uzunov et al developed PLC system for motor speed stabilization performed on a dynamometric test bench. This allows the recording of various steady-state engine parameter characteristics, such as: torque, fuel consumption, etc. [11]. Vasavada et al designed automatic MCB and ELCB system is able to detect, diagnose, interrupt and reclose the circuit breaker in order to ensure power supply continuity along with safety [12]. Wang et al designed an intelligent book sorting system based on PLC and touch screen control, comprehensively applies PLC technology, RFID technology, touch screen technology [13]. Wijaya et al developed a pneumatic system with PLC control for the elimination of conventional tofu press machine [14].

3. Problem Definition

Old-fashioned relay-based control systems and manual machines in industries face complex wiring, high maintenance, limited flexibility, and frequent human errors. Constant supervision leads to inconsistent quality, reduced efficiency, and higher labor costs. filling speed and pressurization speed of EPC are deduced, and the influence of external The main disadvantages of the traditional system are:

- Time-consuming process
- Lack of precision and consistency
- High labor dependency
- Increased production costs

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4. Methodology

4.1 Block Diagram

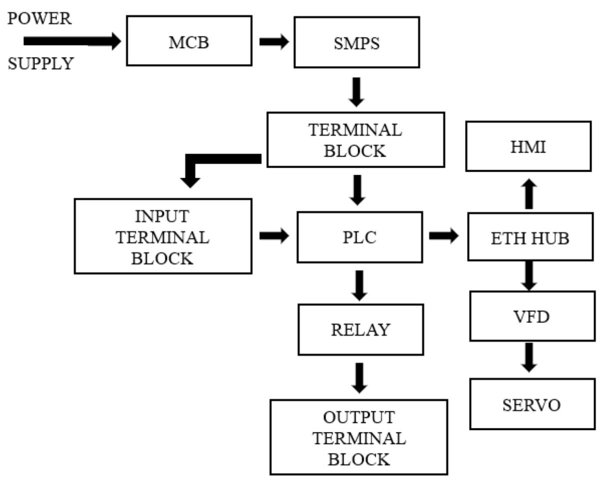

Figure 1 Block Diagram of System

4.2 Flow Chart

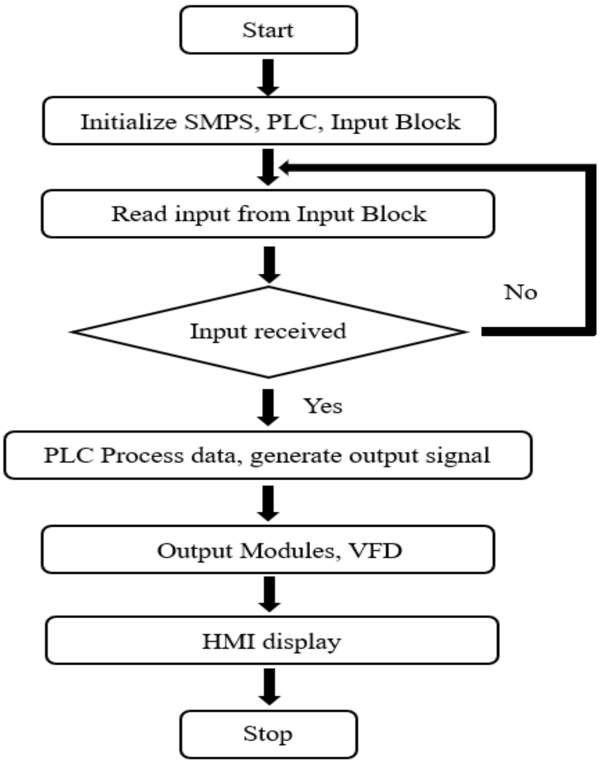

Figure 2 Flow chart of System

4.3 System Operation / Working

The flowchart shown in Figure 1 & 2 provides a clear understanding about the various processes involved in the Development of Special Purpose Machine using PLC. The Special Purpose Machine (SPM) operates through a well-coordinated electrical and control system, ensuring safety, precision, and automation in industrial applications. The process begins with an AC power supply being fed into the system through an MCB (Miniature Circuit Breaker), which acts as a protective barrier against electrical faults. The MCB ensures that only the rated power supply is allowed to pass through, and in the event of an overvoltage or short circuit, it instantly trips, cutting off power to protect the system from damage. Once the MCB approves the power flow, it is directed to the SMPS (Switched-Mode Power Supply), which plays a crucial role in converting 230V AC into a stable 24V DC supply. This regulated DC power is essential for operating the PLC, sensors, relays, and other control components. From the SMPS, the 24V DC supply is distributed via a terminal block, which acts as a central hub to provide power to multiple blocks, including the input terminal block, PLC, and output components. At the heart of the system is the input terminal block, which reads signals from various sensors, switches, or external devices and transmits them to the PLC (Programmable Logic Controller) as shown in Fig-1. The PLC, specifically the Siemens S7-1200, functions as the central unit of the system, where it receives input data, processes it according to the pre-programmed logic, and generates the necessary output signals to control different machine operations. These output signals are then directed towards different control components for execution. One major output path from the PLC is to the relay module, which controls various output devices by acting as an electrically operated switch. Another key path is towards the VFD (Variable Frequency Drive), which is responsible for regulating the speed and operation of the servo motor. The VFD ensures that the servo motor operates at the precise speed and torque required for the given industrial process, enhancing efficiency and accuracy in machine operation. Once the PLC processes and sends the necessary commands, the relay transmits signals to the output terminal block, which then activates the required outputs such as actuators, motors, or other electrical components, enabling the machine to perform its intended tasks. Throughout the entire process, the HMI (Human-Machine Interface) acts as the primary interaction point for the operator, displaying real-time data regarding system performance, input and output status, and fault alerts. The HMI provides users with full control over the system, allowing them to monitor, adjust, and switch between automation and manual operation modes. In manual mode, the user can override the automated process and directly control the machine using the HMI screen, providing flexibility and ease of operation when required. This intelligent automation system ensures that the machine operates with high efficiency, minimal downtime, and maximum accuracy. By replacing traditional manual and relay-based control systems, the PLC-based automation significantly enhances productivity, reduces human intervention, and improves overall system reliability, making it a modern, scalable, and cost-effective industrial solution.

5. Practical Implementation

5.1 Working Components

- **SMPS:** A Switched-Mode Power Supply (SMPS) is an electronic power supply unit that efficiently converts electrical power from one form to another using high-frequency switching technology. Unlike traditional linear power supplies, SMPS provides a stable and regulated DC output with higher efficiency, reduced heat generation, and compact size. It converts 230V AC into a steady 24V DC supply, which is essential for powering various low-voltage industrial automation components. In this project, the Switched-Mode Power Supply (SMPS) is used to convert the 230V AC supply into a stable 24V DC output, which is required to power the control system. After passing through the MCB for protection, the SMPS ensures that all low-voltage components, including the PLC, input/output terminal blocks, sensors, relays, and HMI, receive a consistent and reliable power source.
- **Relay:** A relay is an electromechanical switch used to control high-power devices using low-power signals. It works by using an electromagnet to open or close circuits, allowing safe and efficient control of electrical components. In this project, the relay is used to control output devices based on signals from the PLC. When the PLC processes input data and generates an output signal, the relay acts as an intermediary, switching on or off the connected devices. It ensures proper isolation between the control circuit (PLC) and high-power output devices, preventing electrical damage and enhancing system safety.
- **Servo Motor:** A servo motor is a type of actuator designed for precise control of position, speed, and acceleration. It works as part of a closed-loop control system, combining a motor with a position sensor to ensure accuracy. In industrial automation, the servo motor drives mechanical components based on commands from the PLC. The PLC sends signals to the Variable Frequency Drive (VFD), which adjusts the motor's speed and position as needed. This setup allows for highly precise and consistent movements, improving the accuracy and efficiency of machine operations.
- **MCB:** An Miniature Circuit Breaker (MCB) is a safety device designed to protect electrical circuits from overcurrent, short circuits, and overloads. It automatically trips and disconnects the power supply when the current exceeds a safe limit, preventing damage to equipment and reducing fire risks. In this project, the MCB is used as the first line of protection for the system. It allows power to flow only when the voltage is within a safe range.
- **Variable Frequency Drive (VFD):** A Variable Frequency Drive (VFD) is a motor controller that drives an electric motor by varying the frequency and voltage to the electric motor. Frequency has a direct relationship with the motor speed. That is, the higher the frequency, the higher the RPMs. If an application does not require an electric motor to be at full speed, the VFD can be used to reduce the frequency and voltage to the level required by the electric motor load. Since the motor speed requirements

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of an application change, the VFD can simply turn up or down the motor speed to meet the speed requirement. It saves energy consumption and energy costs, increase production with more precise process control. Also, it extends equipment life and reduce maintenance. VFD is used in this system to control induction motor.

- **Other Components:** Apart from the main parts, the system comprises various other parts for added functionality. An Ethernet hub enables seamless data exchange between PLCs, HMIs, and VFDs, ensuring efficient industrial automation and control. Input Terminal Block is used to receive signals from various input devices, such as sensors, switches, and push buttons. It serves as a connection point between the input devices and the PLC, ensuring proper signal transmission. Output Terminal Block is responsible for transmitting signals from the PLC to outputs, such as actuators, relays, and motors. Once the PLC processes the input data and generates an output signal, the Output Terminal Block ensures that the appropriate devices receive the signals for execution. The Power Block is used to distribute electrical power to various components in the system. It takes the regulated 24V DC output from the SMPS and supplies power to essential units like the PLC, relays, sensors, and terminal blocks, ensuring smooth and stable operation of the entire system. All these parts together make for an automated, efficient and accurate special purpose machine.

5.2 System Control Components

- **Programmable Logic Controller (PLC):** A Programmable Logic Controller (PLC) is an industrial control computer system that reads input devices continuously and makes decisions at real-time based on a pre-programmed program, thereby controlling the status of the output device. Such a control system can significantly improve the efficiency of production lines, machine operation and industrial processes. One of the biggest benefits of using a PLC is that it is extremely flexible – easy modification and duplication of operations or processes and gathering and sending critical data in real-time. Additionally, PLC systems are modular and users can mix and match input and output devices to match a particular application to the optimal level. In this system, as indicated in Fig-1, The PLC (Programmable Logic Controller) serves as the main control unit in the development of the Special Purpose Machine (SPM). The selected PLC for this system is the Siemens S7-1200, a powerful and flexible controller designed for automation applications that require high precision, scalability, and real-time control. It offers advanced processing capabilities, high-speed digital and analog input/output handling, high execution performance, seamless networking through PROFINET, and built-in PID control functions that enhance the accuracy and efficiency of industrial operations. Additionally, its expandability through signal and communication modules allows for future system upgrades, making it adaptable to changing input/output requirements.
- **Human Machine Interface (HMI):** Human Machine Interface (HMI) software is an integral part of modern automation systems through its provision of an intuitive mechanism for operators to control and operate machine command panels. The exchange of information is done through a graphical user interface (GUI), which makes information exchange and communication between two kinds of HMI supervisory and machine-level effortless. Although HMI software can be expensive to buy, it pays for itself over the long term by eliminating redundancies and reducing operations. Even in lower-tech applications, where machine interaction depends mainly on pushbuttons and switches, entry-level HMIs are becoming popular for their capacity to reduce interface component counts and ease control processes. For more sophisticated systems, HMIs offer advantages through greater control, monitoring functionality and visualizing complex processes in real-time. In this system, the HMI (Human-Machine Interface) serves as

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the central control panel, allowing the operator to monitor and control various aspects of the Special Purpose Machine. Through the HMI, the operator can start and stop operations, switch between manual and automatic modes, and monitor real-time system parameters such as motor speed, relay status, and sensor inputs. The HMI provides clear visual feedback, displaying crucial data like operational status, fault alerts, and system diagnostics, ensuring smooth and efficient process control. Additionally, the HMI software can be integrated with other components, allowing dynamic adjustments based on operator inputs. This user-friendly interface enhances productivity, reduces manual errors, and improves overall operational efficiency, making system management intuitive and responsive.

5.3 Programming Used

- Ladder Programming: Ladder Logic is the most commonly used programming method adopted for PLCs, also referred to as "relay logic" due to its derivation from relay-controlled devices. It graphically represents the relay contacts utilized in such systems and is quite similar in appearance to the schematics of electrical circuit diagrams, with "rungs" of logic read sequentially from left to right. Each rung illustrates a specific action controlled by the PLC, starting with input devices contacts that trigger corresponding outputs coils. The graphical aspect of Ladder Logic makes it easy to implement and understand compared to many other programming languages, especially for electrically or mechanically inclined persons. This programming language is highly modular and scalable, allowing engineers to add or modify logic with minimal effort, making it suitable for various automation applications. Since it mimics traditional electrical control circuits, it becomes an intuitive choice for technicians transitioning from relay-based systems to PLC-based automation. Moreover, Ladder Logic supports troubleshooting with real-time monitoring, enabling quick identification and resolution of system faults. The sequential execution of rungs ensures logical processing of control actions, improving reliability and efficiency in industrial automation. Its compatibility with diverse industrial components, such as sensors, relays, and motors, makes it an essential tool for programming complex automated systems. Use of relay logic diagrams for PLC programming was a conscious decision, as it allows for easy representation and modification of complex processes in an uncluttered, organized manner. In this setup (as illustrated in Fig-3).

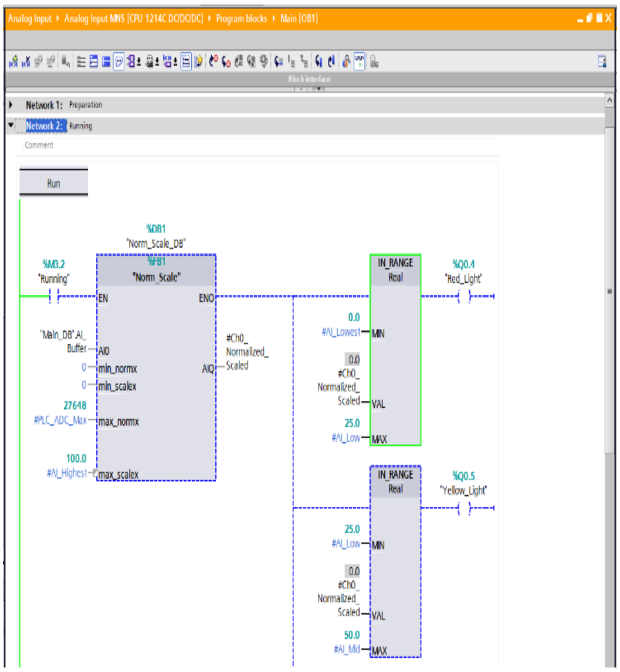

Figure 3 Ladder Programming

- Ladder Logic is used to control and automate the operations of the Special Purpose Machine by managing various components such as servo motors, relays, VFDs, and sensors. The PLC continuously monitors inputs from the input terminal block, processes the data, and triggers corresponding output actions to ensure smooth and precise operation. The relay controls output devices, while the VFD regulates the servo motor’s speed and position based on PLC commands. Additionally, the HMI provides real-time feedback and allows manual control when needed. The use of Ladder Logic ensures

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flexibility and scalability, making it easy to modify or expand the system for future upgrades or additional automation requirements, Shown in Figure 3.

- **HMI Programming:** Human Machine Interface (HMI) software is one of the main components of contemporary automation systems since it offers the operator an easy means of operating and commanding machine control panels. The connection is through a graphical user interface (GUI), and thus information exchange and communication between two forms of HMI—supervisory and machine-level—becomes highly convenient. Although the HMI software is expensive to purchase, it is cost-effective in the long term by avoiding duplication and optimizing operation. Even for low-technology applications, where the interaction with machines is mostly in terms of switches and pushbuttons, low-end HMIs are becoming popular since they can save interface component counts and simplify control operations. In high-end systems, HMIs are a great boon by offering higher control, monitoring functionality and visualization of complex processes in real time. In this system (as shown in Fig-4), the HMI serves as the main control panel, allowing the operator to perform multiple functions with ease. These include starting and stopping operations, selecting different machine settings, and switching between manual and automatic modes. The HMI also provides real-time feedback on system parameters such as motor speed, relay status, sensor inputs, and overall machine performance. This user-friendly interface allows operators to efficiently monitor and control the process while receiving critical alerts. Additionally, HMI software integrates with system components for automatic adjustments, ensuring seamless operation and improved responsiveness. The implementation of HMI technology improves productivity, minimizes human error, and ensures optimal process control, making the system more efficient and reliable, Shown in Figure 4.

Figure 4 **Control Panel of System**

Conclusion

In this system, the integration of PLC-based automation has significantly improved the efficiency, accuracy, and reliability of the Special Purpose Machine. The use of an HMI as the master control panel allows operators to monitor and control various system parameters effortlessly, ensuring seamless operation and real-time adjustments. The automation of processes through PLC programming, relay control, and servo motor integration has eliminated the limitations of traditional manual and relay-based systems, reducing human error and increasing productivity. Additionally, the modularity of the system allows for future scalability and adaptability to evolving industrial requirements. By implementing this advanced control system, the project successfully enhances operational efficiency, minimizes downtime, and optimizes overall process control, making it a highly effective and sustainable solution for industrial automation.

Future Scope

This project further in future can be used for enhancing automation, efficiency, and adaptability in industrial applications. With advancements in Industry 4.0 and smart manufacturing, the integration of IoT (Internet of Things) with the PLC system can enable remote monitoring and real-time data analysis for predictive maintenance and performance optimization. The system can also be upgraded with AI-driven decision-making algorithms to improve process control and adaptability. Additionally, expanding the machine's functionality by incorporating more sensors, advanced HMI interfaces, and robotic arms can further enhance precision, flexibility, and automation in various industries. The modular design of the system allows for easy scalability, making it adaptable for different manufacturing requirements. Ultimately, the project sets a strong foundation for future innovations in industrial automation, contributing to increased productivity, reduced operational costs, and improved product quality.

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