Chapter III : PLC Architecture

Chapter III: Architecture of a PLC

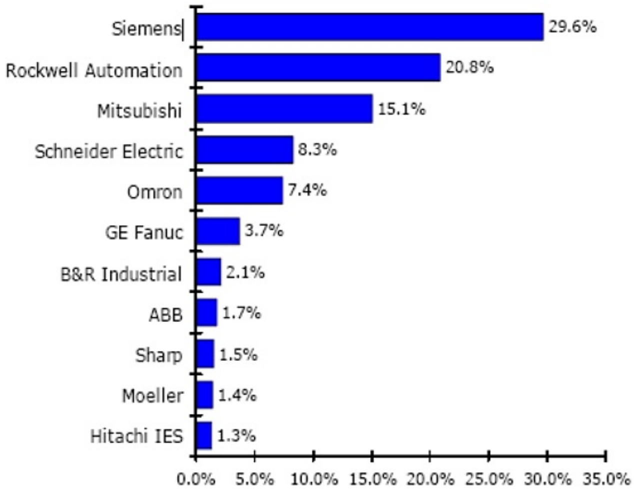
1 Definition of a Programmable Logic Controller (PLC)

A Programmable Logic Controller (PLC) is an electronic programmable device designed for controlling industrial processes through sequential processing. It sends commands to pre-actuators (operative part or **PO**, on the actuator side) based on input data (sensors) (control part or **PC**, on the sensor side), instructions, and a computer program.

PLCs emerged in the United States around 1969 in response to the automotive industry's desire to develop automated manufacturing lines that could adapt to advancements in technology and changes in manufactured models.

2 Most Popular and Widely Used PLC Brands in the Industrial Sector

Américains :	1. Allen Bradley 2. Gould Modicon 3. Texas Instruments 4. General Electric 5. Westinghouse 6. Cutter Hammer 7. Square D
Européens :	1. Siemens 2. Klockner & Mouller 3. Festo 4. Telemechanique
japonais :	1. Toshiba 2. Omron 3. Fanuc 4. Mitsubishi



3 Advantages and Disadvantages

3.1 Advantages

PLCs offer many benefits:

- The components are particularly robust, allowing them to operate in harsh environments (ambient dust, electromagnetic interference, vibrations, temperature variations, etc.).
- They feature optimized electronic circuits for interfacing with the physical inputs and outputs of the system, ensuring minimal execution time and effective real-time operation.
- Maintenance is easy, as modules can be replaced very quickly.

3.2 Disadvantages

- They are more expensive than traditional computing solutions, such as those based on microcontrollers.
- The cost depends on factors such as the number of inputs/outputs required, the memory available for programming, and the inclusion of industry-specific modules.

- Training is required, as PLCs require mastery of specific programming languages. However, these languages are often perceived by users as more accessible and visual than traditional programming languages.
- The variety of brands and models results in a diversity of languages and variable mappings, despite the existence of the IEC 1131 standard.

4 Types of Programmable Logic Controllers (PLCs)

There are two types of PLCs:

- The monoblock type
- The modular type

4.1 Monoblock PLC

The monoblock type generally has a limited number of inputs and outputs, and its instruction set cannot be expanded. Although it is sometimes possible to add input/output extensions, the monoblock type is primarily designed for solving simple automation tasks based on sequential logic.

Example:

Figure 3.2. Monoblock PLC Modicon M221 by Schneider Electric

The Modicon M221 is a monoblock PLC by Schneider Electric.

Main Specifications:

- **Power supply voltage**: 24 V DC
- **Number of binary inputs**: 24, including 4 fast inputs compliant with IEC 61131-2 Type 1
- **Number of analog inputs**: 2 (0...10 V)
- **Output logic type**: Transistor
- **Number of binary outputs**: 16 transistors, including 2 fast outputs
- **Logical output voltage**: 24 V DC
- **Logical output current**: 0.5 A

4.2 Modular PLC

The modular type, on the other hand, is adaptable to all situations. Depending on the requirements, analog input/output modules are available, in addition to specialized modules such as **PID**, **BASIC**, and **C Language**, among others. The modularity of PLCs allows for quick troubleshooting and greater flexibility.

5 Structure of a PLC

A PLC is structured around:

- A **processing unit** or CPU (Control Processing Unit)
- A **power supply** (PS: Power Supply)
- Modules that vary depending on the needs of the application.

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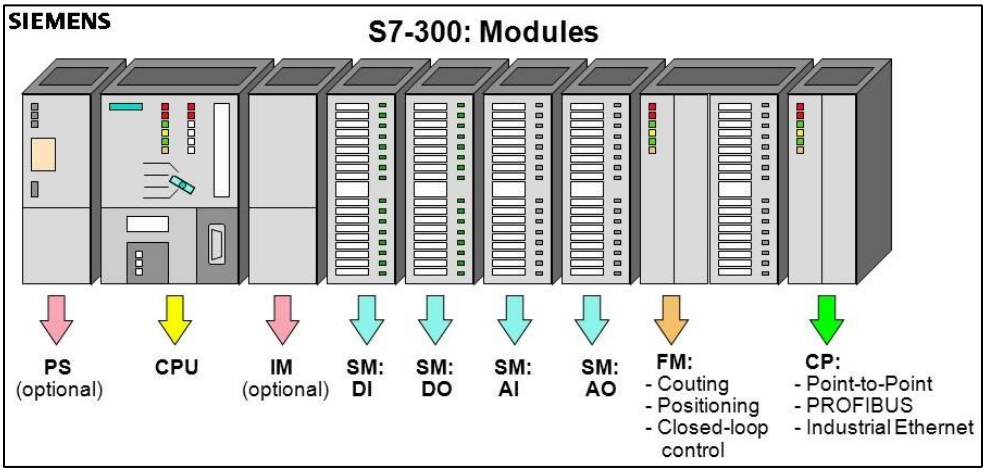

Figure 3.3. Structure of the Simatic S7-300 PLC by Siemens

5.1 Signal Modules (SM: Signal Modules)

Signal modules serve as the interface between the PLC and the process.

5.1.1 Binary Input/Output Modules (TOR):

These modules allow the connection of binary signals (sensors and digital actuators) to the PLC.

a) Digital Input Modules (DI: Digital Input):

They are designed to receive information from sensors and adapt the signal by shaping it, eliminating noise, and electrically isolating the control unit from the operative part.

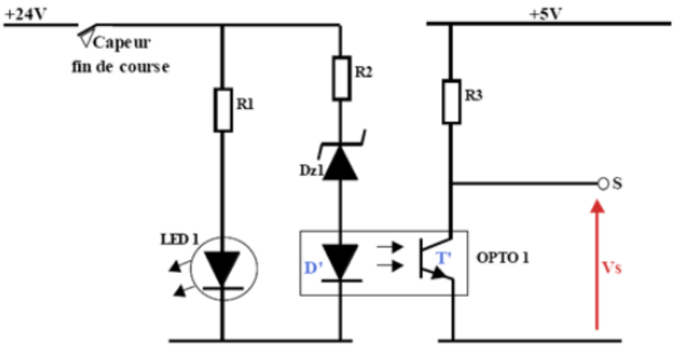

Figure 3.4. Example of a Typical Input Card for a PLC

b) Digital Output Modules (DO: Digital Output):

These modules are designed to control pre-actuators and signaling elements of the system. They adapt the voltage levels of the control unit to those of the operative part of the system while ensuring galvanic isolation between the two.

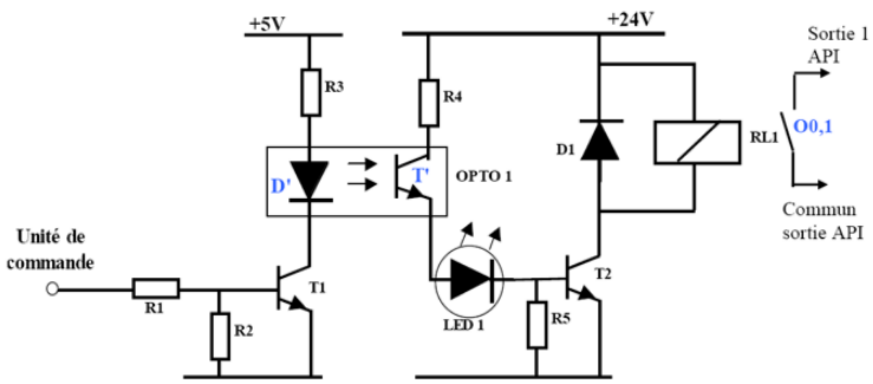

Figure 3.5. Example of a Typical Output Card for a PLC

5.2 Analog Input/Output Modules

These modules are connected to continuously varying signals.

- **Analog Input Modules (AI: Analog Input):** Designed to receive continuous signals.
- **Analog Output Modules (AO: Analog Output):** Designed to send continuous signals.

5.3 Communication Modules (CP: Communication Processor)

These modules operate under various protocols and were introduced to facilitate communication between:

- Multiple PLCs.
- A PLC and remote inputs/outputs.
- A PLC and Human-Machine Interfaces (HMI).

Examples of communication protocols: Modbus, Modbus Plus, Profibus, InterBus, RS232, RS-485, Ethernet, DeviceNet, LonWorks, FIPIO, FIPWAY, CANopen, etc.

Example: The ASi bus (Actuators Sensors interface) is a Master/Slave type sensor/actuator bus that connects up to 31 slaves (sensors/actuators) on a two-wire cable.

5.4 Interface Modules (IM: Interface Module)

Interface modules play a crucial role in automated systems, particularly in configurations where the PLC must manage inputs and outputs (I/O) across extended sites. These modules enable flexible expansion of available I/Os, integrating specialized functions such as variable speed drive control, high-speed counter management, and other domain-specific equipment (industry-specific modules).

Using interface modules as slaves in a decentralized peripheral system provides several advantages:

- Reduced wiring costs.
- Increased flexibility.
- Improved performance.

Example:
A beverage production line consisting of two units, filling and mixing, controlled by a single PLC (see figure below). Since the PLC is located far from the mixing unit, the use of longer cables becomes necessary, resulting in higher cabling costs.

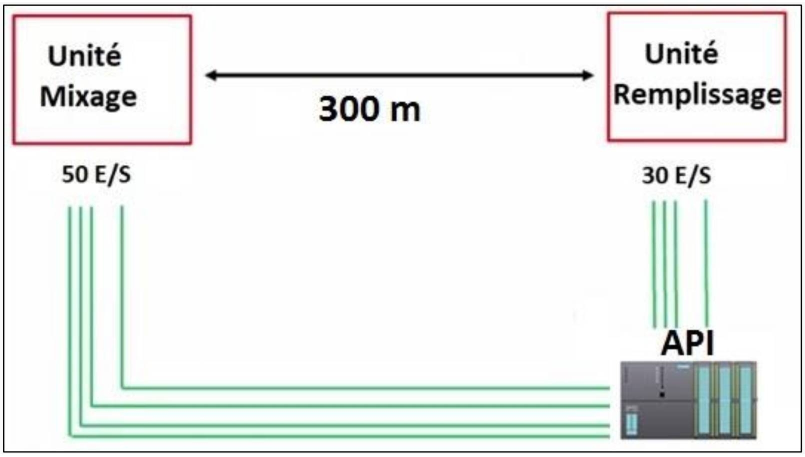

Figure 3.6. Wiring Diagram Between the PLC and Two Production Units

The solution to this problem is to use a **decentralized Input/Output (I/O) peripheral** placed near the mixing unit. By doing so, less cabling will be required, and maintenance operations will be easier to perform.

In this setup, communication between the control PLC and the decentralized I/O module is established via the **Profibus-DP protocol** (Decentralized Peripherals). The PLC acts as the master, while the decentralized I/O module functions as the slave.

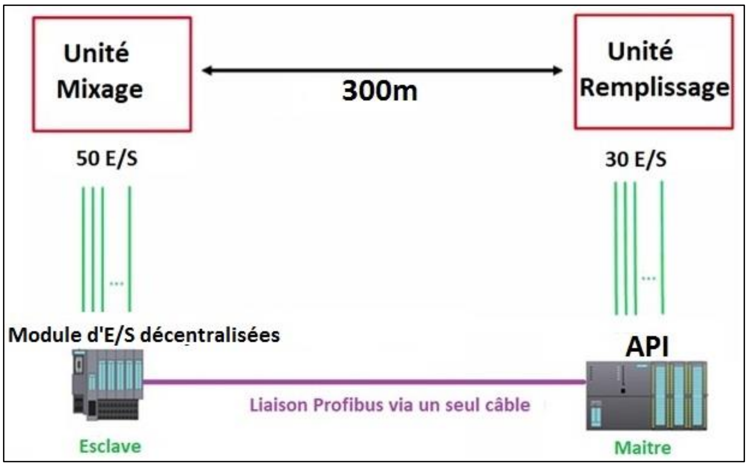

Figure 3.7. Wiring Diagram Between a PLC and a Decentralized I/O Module

5.5 Function Modules (FM: Function Module)

Also known as industry-specific modules, these are intelligent modules that independently execute technological tasks such as counting, measuring, cam control, PID control, and motion control. They reduce the load on the processor and are used in applications requiring high precision and dynamic response, such as high-speed counting and weighing.

5.6 Local Human-Machine Interface Modules (HMI: Human-Machine Interface)

These include devices such as a control panel (touchscreen or with a keyboard) or a maintenance terminal. These are connected to the PLC via an industrial network (proprietary or open) and display messages or a representation of the process.

6 Internal Architecture of a PLC

The internal structure of a PLC is similar to that of a simple computer system. The central unit combines the processor and central memory, managing the interpretation and execution of program instructions. Instructions are executed sequentially, driven by a clock.

The PLC also includes input/output interfaces, and all its components are typically powered by a DC power supply unit.

Below, we define each of the elements that make up the PLC:

- **Processing Unit (CPU)**.
- **Input/Output Interfaces**.
- **Power Supply**: 230 V, 50/60 Hz (AC) - 24 V (DC).

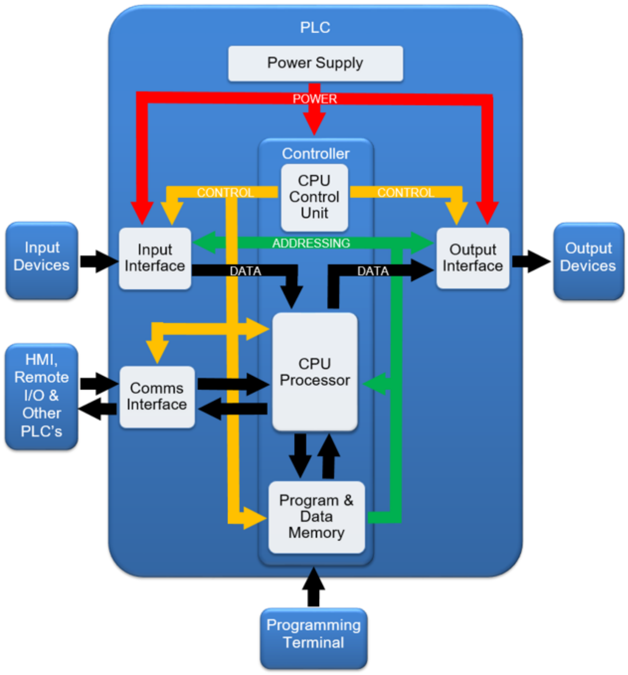

Figure 3.8. Internal Architecture of a PLC

6.1 The CPU

The CPU is often referred to as the brain of a Programmable Logic Controller (PLC) because it coordinates all the essential functions of the system. It executes the user program, manages inputs and outputs, processes data, and ensures communication with other devices or networks. The CPU typically consists of two main components: the processor and the memory, each playing a crucial role in the PLC's operations.

6.2 The Processor

The processor is the core of the CPU. It can be a microprocessor or a microcontroller. It oversees all system operations and performs all the necessary tasks (logical and arithmetic functions) required for program execution.

6.3 The Memory

The CPU memory in a PLC is essential for storing and retrieving the data and instructions necessary for system operation. This memory can be organized into different areas or segments, each serving a specific role in data processing and management. While the precise classification may vary depending on the manufacturer or the specific PLC model, the memory is generally divided into four main parts:

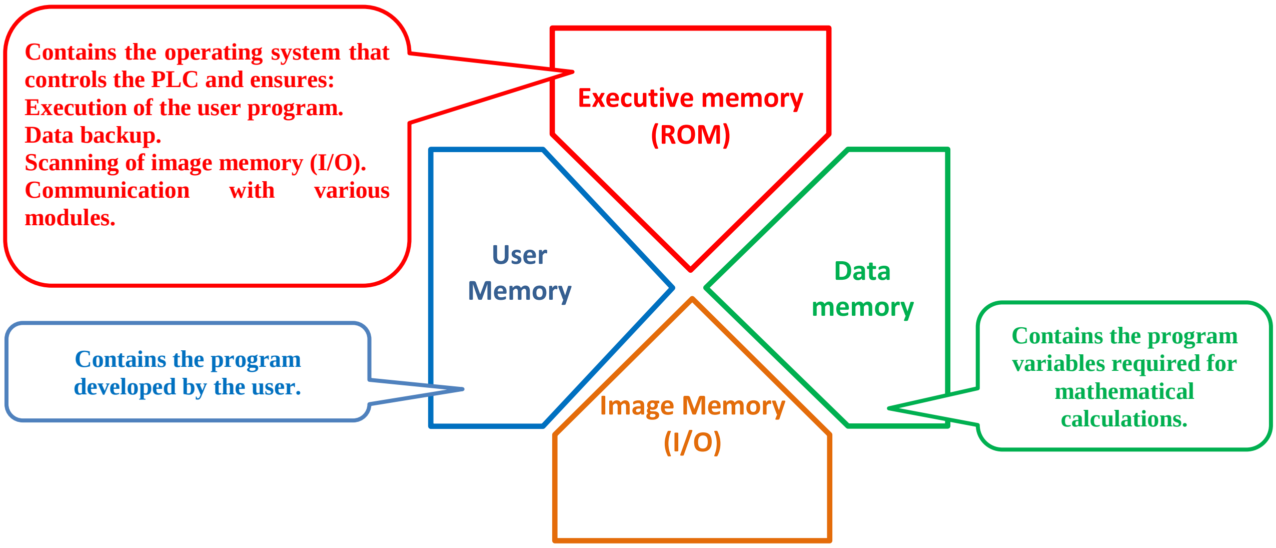

Figure 3.9 Organization of the CPU Memory

a. Input/Output Image Memory

- The **Input Image Memory (IIM)** consists of memory locations used to maintain the ON or OFF states of each input variable.
- The **Output Image Memory (OIM)** contains memory locations that store the ON or OFF states of the output variables. Data is saved in the OIM after executing the user program and waits to be transferred to the output modules.

b. Data Memory

Used to store numerical data required for mathematical calculations, logical functions, etc.

c. User Memory

Contains the user program.

d. Executive Memory

Used to store an executive program or system software. A PLC operating system is a special program that controls the CPU's actions and the execution of the user program. The PLC operating system scans the image memory, interprets, and executes the instructions of the user program stored in the main memory. It is provided by the PLC manufacturer and permanently stored in ROM.

6.4 Input/Output Interfaces

The interfaces of the PLC handle the reception and formatting of signals from external sources (sensors, push buttons, etc.) and the transmission of signals to external devices (control of pre-actuators, signaling lights, etc.). The design of these interfaces with galvanic isolation or optoelectronic decoupling ensures the PLC's protection.

6.5 Power Supply

The power supply provides power to the memory system, processor, and I/O modules. It converts high-level AC line voltage into various operational DC voltage levels.

7 Operating Principle of a PLC

PLC programs are processed in a specific cycle, typically as follows:

1. **Input scan**: Digital and analog inputs are read and stored in the Input Image Memory (IIM) to ensure a stable image of input states during the cycle.
2. **Program Processing**: The PLC executes the user program, processing input data to determine output actions.
3. **Output Update**: Program results are used to update the outputs by transferring data from the Output Image Memory (OIM) to the output modules.
4. **External Communications**: The PLC manages data exchanges with external devices to coordinate between PLCs, supervision systems, and other necessary communications.
5. **Self-Diagnosis**: Regular checks are performed to ensure proper operation of the PLC, with the capability to log diagnostics and report anomalies.

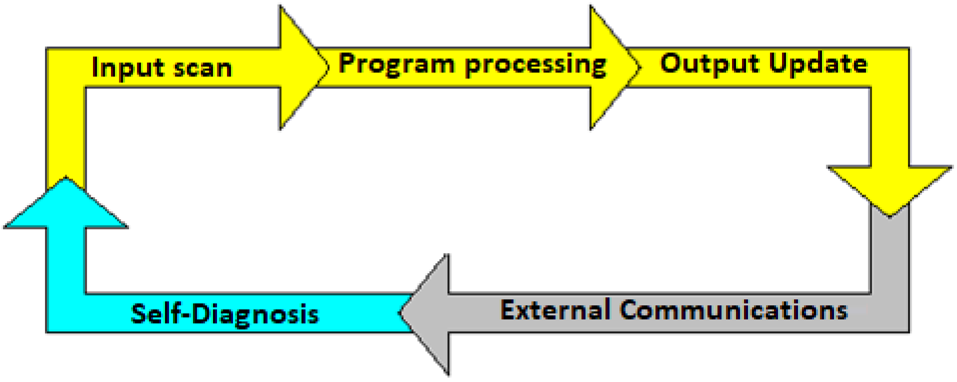

Figure 3.10. Operating Principle of a PLC

8 PLC Cycle Time

The cycle time of a PLC varies depending on:

1. **Program Size**: A longer and more complex program increases execution time due to the higher number of instructions and data to process.
2. **Calculation Complexity**: Operations requiring complex calculations extend the cycle time due to higher computational demands.
3. **Number of Inputs/Outputs**: A large number of I/O operations can slow the cycle, as each operation requires additional checks and communications with external devices.
4. **CPU Power**: The speed of the processor directly impacts the cycle time. A more powerful CPU reduces the time required to complete a cycle by executing instructions faster.

5. **Process Requirements**: The specific industrial process being controlled can dictate cycle time requirements, with some processes requiring near-instantaneous responses for safety and efficiency.

The cycle time typically ranges from a few milliseconds to tens of milliseconds.
Sensor readings and actuator commands are performed through polling.

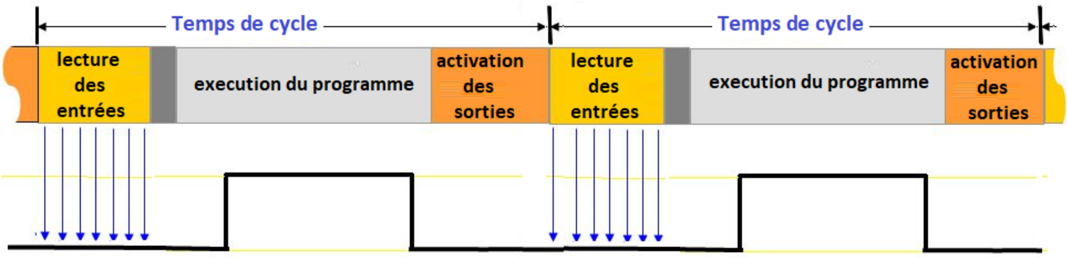

Figure 3.11. Execution Time of a Program in a PLC

9 Operating Principle of a Siemens Simatic S7 Program

Siemens PLCs are recognized as the most widely used control systems globally in the industrial sector. Their predominance is attributed to the reliability, flexibility, and advanced performance of Siemens PLCs, which effectively meet the complex demands of modern industrial environments.

In this context, we chose a Siemens PLC for our practical automation work. Specifically, we selected the **S7-1214C DC/DC/RLY** model from the **S7 1200 series**. The S7-1214C is designed to provide high flexibility and efficiency in managing industrial processes, with integrated inputs and outputs that support direct current (DC) for both inputs and outputs, as well as relays (RLY) for controlling external devices.

9.1 Main Organization Block (OB1):

Cyclic OBs (Organization Blocks) are fundamental to the structuring of Siemens PLCs. These code blocks play a crucial role in program organization, as they are processed cyclically, ensuring the sequential execution of automated tasks.

The repeated execution of the OB allows continuous monitoring and response to changes in the state of inputs and outputs, as well as variations in the internal data of the program. Within these blocks, a variety of logical, mathematical, or data management instructions can be programmed, defining the behavior of the automated system under various operational conditions.

9.2 Startup Organization Block:

The processing of startup OBs occurs once when the CPU transitions from **STOP** to **RUN** mode. The processing of the startup OB100 is followed by the cyclic OB (OB1).

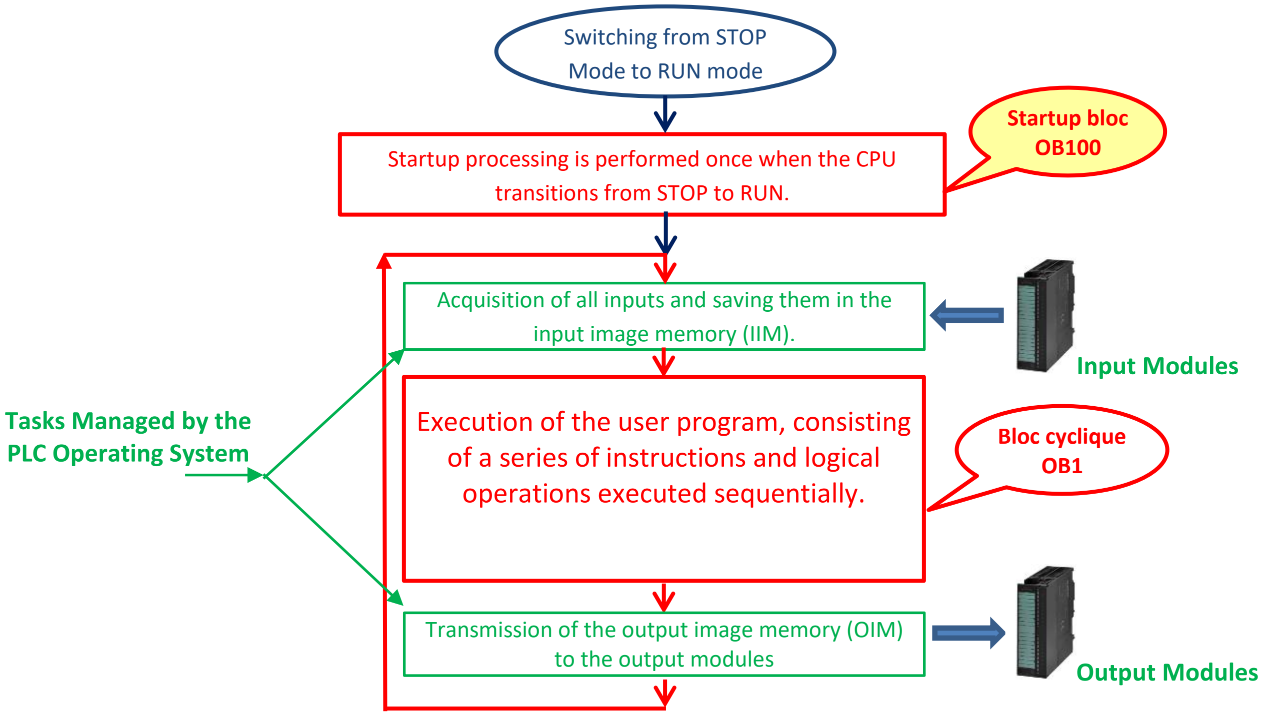

Figure 3.12. Operating Principle of a Simatic S7 Program

10 Criteria for Choosing a PLC

The criteria for selecting a PLC can vary depending on the individual and the project. The choice of a PLC will mainly depend on the specifications and technical requirements of the project. Most PLC manufacturers offer a range of PLCs to suit a variety of projects. Below are some criteria to consider when choosing a PLC:

a. Cycle Time:

Some PLCs have faster cycle times compared to others, making them better suited for systems requiring quick responsiveness.

b. Cost:

For small automation projects, it is preferable to choose micro or mini PLCs.

c. Development Software:

Some PLCs come with development software equipped with tools for program simulation, saving time during the development phase.

d. Availability of Native Communication Interfaces:

The PLC should be able to communicate with other systems. It is preferable to choose a PLC that supports this communication natively, avoiding the need for additional modules.

e. Availability of Replacement Components:

Some PLC brands have greater market presence, allowing them to offer better after-sales services and customer support.