Chapter 1 : General Structure of an Automated System

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Objectifs

At the end of this course, the learner will be able to:

- Describe an automated production system (APS).
- Differentiate between the components of an APS.
- Create an APS.
- Describe the functioning of an industrial programmable controller.

Prerequisites:

- General electricity.

Introduction

In the late 1960s, an American car manufacturer decided to replace control systems based on wired logic (electrical relays) with programmed logic. Technological advancements in recent years led to the development of Programmable Logic Controllers (PLCs) and a consequent revolution in control engineering.

Definition of Automation

I

Automation consists of making operations automatic that previously required human intervention. In the industry, automation has become indispensable as it allows for the daily execution of the most tedious, repetitive, and dangerous tasks. Sometimes, these automated processes are so rapid and precise that they accomplish actions impossible for a human being. Automation, therefore, is synonymous with productivity and safety.

Automation consists of the study of industrial systems control. Automation techniques and methods are continuously evolving, incorporating technologies such as electromechanics, electronics, pneumatics, and hydraulics. Automation is present in all sectors of activity, including carpentry, textiles, food, automobile, and more.

1. Objectives of automation:

• Increase system productivity (quantity of products manufactured within a given time).

• Improve production flexibility.

• Enhance product quality.

• Adapt to specific contexts:

o Hostile environments for humans.

o Hard tasks that require physical or intellectual effort for humans.

• Enhance safety.

II

Description of an Automated Production System (A.P.S)

The objective of system automation is to produce high-quality products while minimizing the reliance on human labor and keeping costs as low as possible. An automated system is a set of interacting elements organized with a specific purpose: to act upon raw materials and provide them with added value.

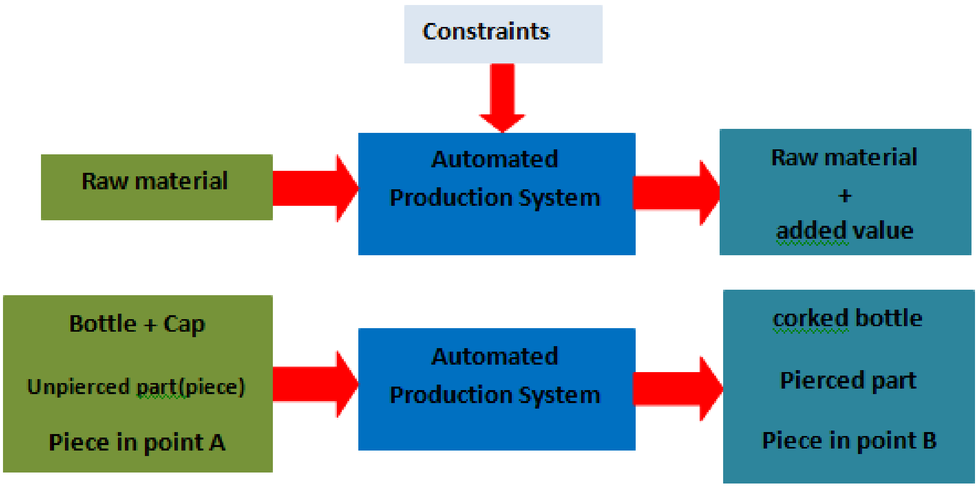


Figure 1. Automated Production System

1. Structure of an automated system

Automated systems, used in the industrial sector, have an identical basic structure. They consist of several more or less complex parts linked together:

• *Operative Part (OP): the process to be controlled*

• *Control Part (CP): the control system*

• *Supervison Part (SP): the operator (monitoring, start/stop) increasingly integrated into the control part*

Any automated system can be decomposed according to the following diagram:

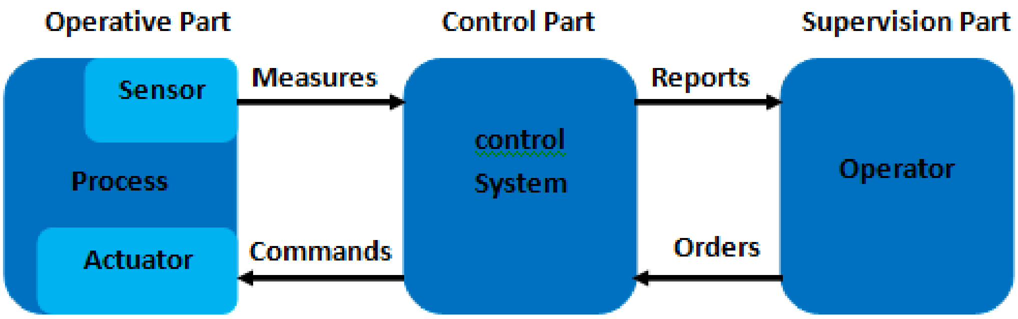


Figure 2. Structure of an automated system

1.1. Operative part

Also known as the power part, it is the visible part of the system (body). It acts on the raw material to give it added value. The actuators (motors, cylinders) and pre-actuators (distributors and contactors) act on the mechanical part of the system, which, in turn, acts on the raw material. Sensors are used to acquire various states of the system. To carry out movements, it is necessary to supply energy (electrical, pneumatic, and hydraulic) to the OP.

Fondamental : The actuators

These are elements of the Operative Part that receive "transportable" energy and transform it into "usable" energy for the system. They execute the orders received by acting on the system or its environment.

Actuators belong to three technologies:

a) Pneumatic actuators (cylinders, motors).

b) Hydraulic actuators (cylinders).

c) Electric actuators (electric motors).

Figure 3. Actuators (a. Pneumatic actuator (Cylinder),b. Electric actuator (ASM 3~))

Fondamental : Pre-actuator

The pre-actuator is the component that allows the transfer of energy from the external environment to the actuator. The pre-actuator distributes the necessary energy to the actuator according to the orders received.

The pre-actuator can be:

a) Contactors for electric motors

b) Variable speed drives for electric motors

c) distributors for pneumatic or hydraulic cylinders

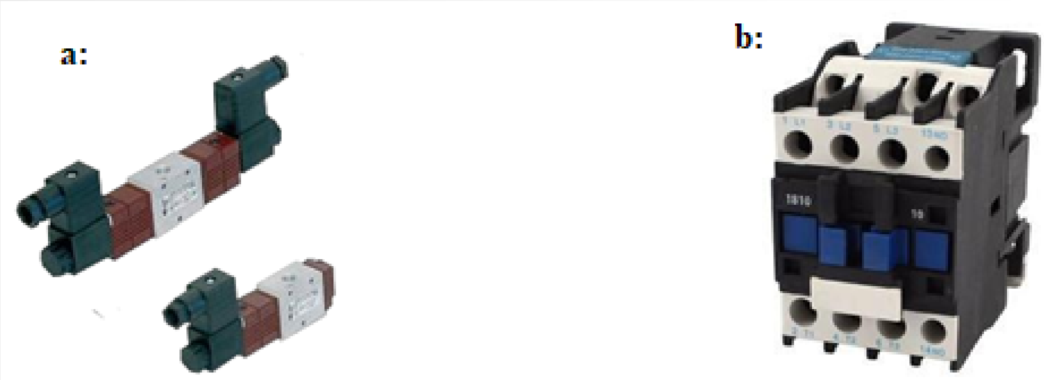


Figure 4. Pre-actuators (a. Pneumatic pre-actuator, b. Electric pre-actuator)

Fondamental : Sensors

The Sensors allow to take from the operative part, the state of the raw material and its evolution. They are capable of detecting various physical phenomena in their environment (movement, presence, heat, light, pressure, etc.) and then convert this physical information into coded data that can be understood by the control part.

As a result, sensors convert variations in physical quantities related to the automation's operation into electrical signals.

Figure 5. Sensors

1.2. Control part

It gives operating orders to the operative part. It is considered the “brain” of the system. The command part replaces the operator, the operator's know-how is translated into a program. It gives orders to the operative part according to:

a) Program it contains.

b) Information received by the sensors.

c) Instructions given by the user.

Figure 6. Programmable logic controllers associated with computer

1.3. Supervision part

Comprising control panels and signaling consoles, it enables the operator to control the system (start, stop, cycle start, etc.). It also provides visualization of various system states through indicators, dialogue terminals, or human-machine interfaces (HMI).

Figure 7. Control panel

III

Programmable logic controllers (PLC)

This section is an introduction to Programmable Logic Controllers (PLCs) as well as their general functions, hardware types, and internal architecture. PLCs are widely used for a variety of automation tasks in several fields, such as industrial manufacturing processes, chemical processes, domestic applications, etc.

1. Definition of programmable logic controllers

A programmable logic controller (PLC) is a programmable electronic device designed for controlling industrial processes through sequential processing. It sends orders to pre-actuators (operational part or OP on the actuator side) based on input data from sensors (control part or CP on the sensor side), setpoints, and a computer program. It is essential not to confuse a PLC with a microcomputer; although microcomputers can also control equipment by adding specific input/output cards, they are not as flexible to use as PLCs specially studied. The PLC receives information about the system's state and then controls the pre-actuators according to the program stored in its memory.

Figure 8. Example of programmable logic controller

2. Architecture of programmable logic controllers

A PLC generally consists of modules arranged side by side, such as a power supply, a central processing unit (CPU) based on a microprocessor with a memory card, input and output interfaces, communication interfaces, special cards, and a programming device. It can indeed be considered as a unit containing a large number of relays, counters, timers, and separate data storage units (usually EEPROM). The following figure shows the basic layout of a PLC:

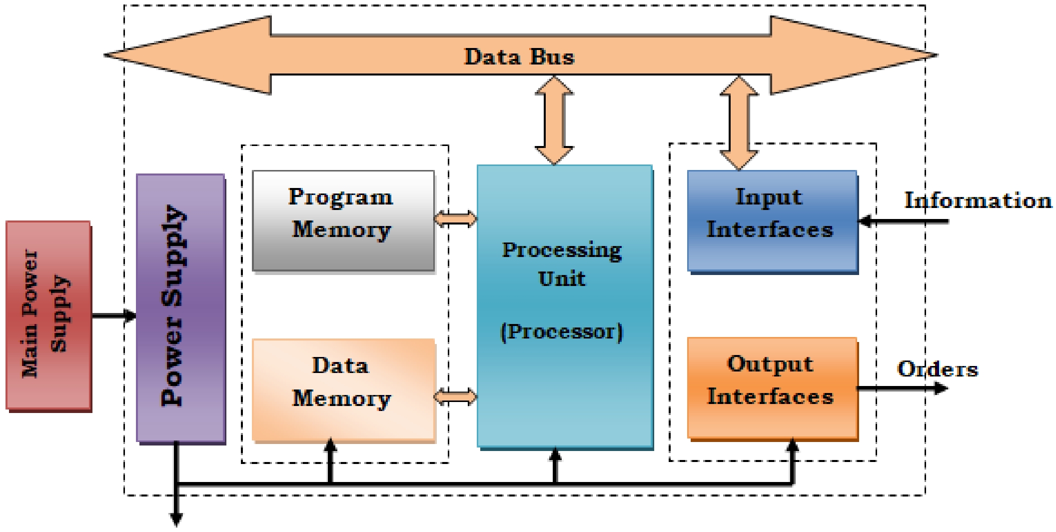


Figure 9. Internal structure of PLC

3. Areas of use of PLCs

A programmable logic controllers (PLCs) are used in all industrial sectors for controlling machines (conveyors, packaging, etc.) or production lines (automotive, agri-food, etc.). They can also perform process regulation functions (metallurgy, chemistry, etc.). Furthermore, they are increasingly used in the building sector (commercial and industrial) for controlling heating, lighting, security, and alarms.

4. Nature of the information processed by the PLC

The information can be of the type:

On/Off : The information can only take two states (true/false, 0 or 1, etc.). This is the type of information delivered by a detector, a push-button, etc.

Analog: The information is continuous and can take a value within a specific range. This is the type of information delivered by a sensor (pressure, temperature, etc.).

Digital: The information is contained in coded words in binary or hexadecimal form. This is the type of information delivered by a computer or an intelligent module

5. Constitution of programmable logic controllers

Power supply module: It ensures the distribution of power to various modules. It is essential as it converts an AC into a low DC voltage (24V) required for processors and other input-output modules.

Figure 10. Power Supply Module

Central Processing Unit (CPU): This is the electrical assembly that performs the tasks in the program memory. It contains the microprocessor and performs all logical, arithmetic, and digital processing functions (transfer, counting, timing, etc.).

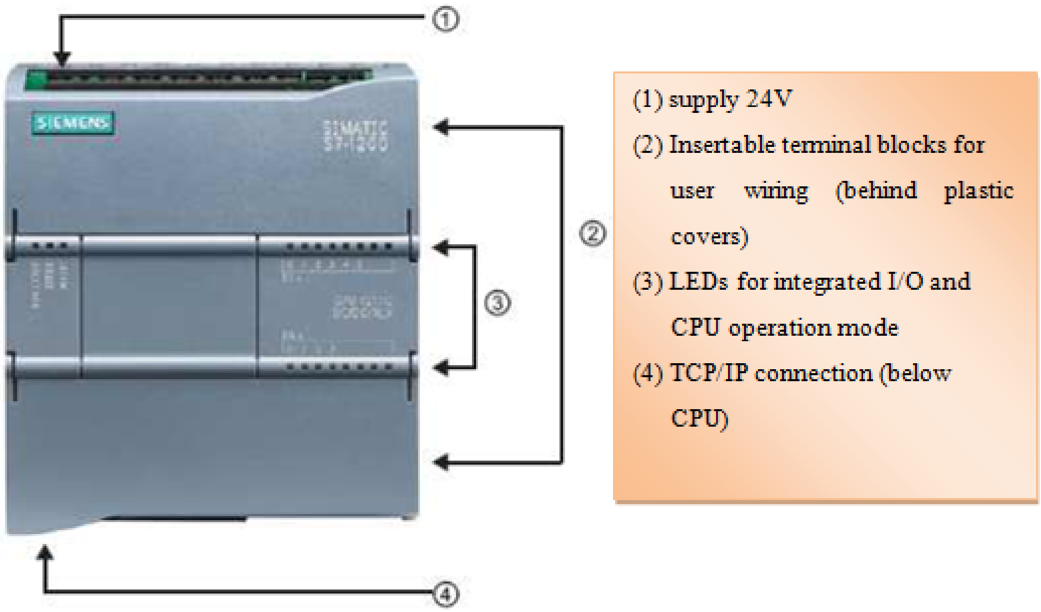


Figure 11. Central Processing Unit (CPU) modules with different capacities, integrated inputs/outputs, and a PROFINET interface.

Internal Bus: It is a set of conductors that establish the connection between the various elements of the PLC system and possible extensions. The bus is organized into several subsets, each intended to carry a specific type of information:

• Data Bus.

• Address Bus.

• Control Bus for service signals such as synchronization signals, direction of exchanges, exchange validity control, etc.

• Voltage Distribution Bus from the power supply block.

Memory Zone:

The memory zone serves the following purposes:

• Receive information from input sensors.

• Receive information generated by the processor and intended for controlling outputs (counter values, timing values, etc.).

• Receive and store the process program.

`Possible actions on memory:`

• WRITE : to modify the content of a program.

• DELETE : to remove information that is no longer needed.

• READ : to read the content of a program without modifying it.

`Memory Technologies:`

• RAM (Random Access Memory): Volatile memory in which data can be read, written, and erased (contains the program).

• ROM (Read-Only Memory): Non-volatile memory accessible only in read mode.

• EPROM (Erasable Programmable Read-Only Memory): Reprogrammable non-volatile memory, erasable using ultraviolet rays.

• EEPROM (Electrically Erasable Programmable Read-Only Memory): Reprogrammable non-volatile memory, erasable electrically.

Memory capacity is given in words of 8 BITS (Binary Digits) or bytes.

Input/Output Interfaces: These interfaces allow the processor to receive and send information to external devices.

`Input Interface:` It allows the reception of logical information from sensors and push-buttons of the console connected to the Programmable Logic Controller (PLC).

`Output Interface:` It allows the central processing unit to transmit orders to various pre-actuators (relays, solenoid valves, etc.) and signaling elements (indicators) on the panel while providing electrical isolation.

Generally, there are generally two types of I/O modules: digital I/O (DI/DO) and analog I/O (AI/AO).

In addition to these modules, there are special I/O modules (PID card, fast counting card, etc.), this type of card equipped with microprocessors, in order to simplify tasks and relieve the CPU module.

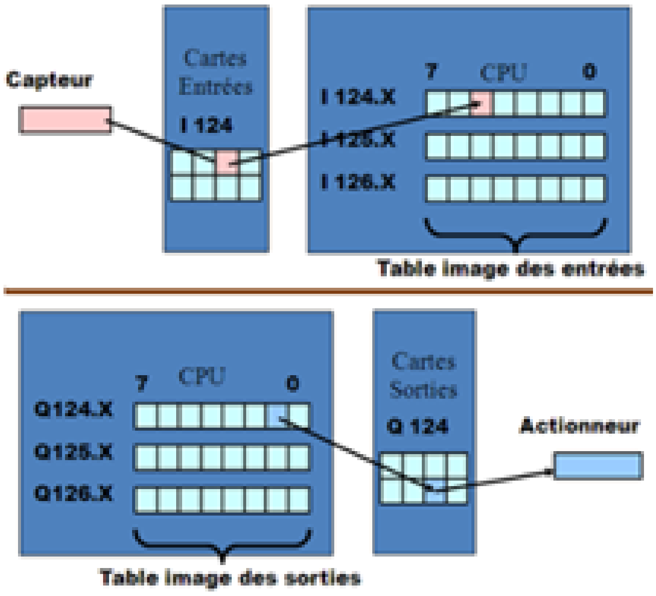


Figure 12. Input/output interfaces

Programming Device :

The programming device is used to introduce the desired program into the processor memory. This program is developed on a PC or a specialized console provided by the manufacturer and then transferred into the memory of the Programmable Logic Controller (PLC).

Figure 13. Programming device

Communication Module :

The communication interface is used to receive and transmit data over communication networks that connect the Programmable Logic Controller (PLC) to other distant PLCs. It concerns actions such as device verification, data acquisition, synchronization between applications, and managing the connection.

Figure 14. Communications Modules

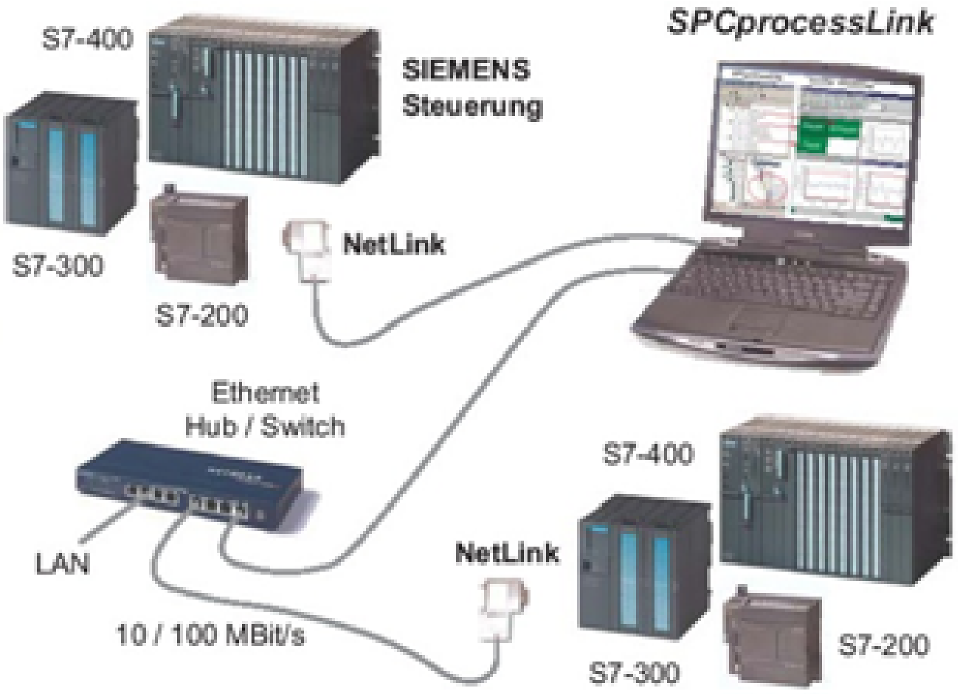


Figure 15. Industrial communication networks

6. PLC programming

Programming languages :

There are 5 programming languages for programmable logic controllers (PLCs) that are internationally standardized by the IEC 61131-3 standard. Each PLC can be programmed using a proprietary programming console or a computer equipped with the specific software provided by the manufacturer.

These languages are classified into three families:

• *LITERAL Languages*

IL (Instruction List) Language: List of instructions

ST (Structured Text) Language: Structured literal language

• *Graphical Languages*

LD (Ladder Diagram) Language: Contact-based language (Ladder)

FBD (Function Block Diagram) Language: Functional diagram (logic diagram)

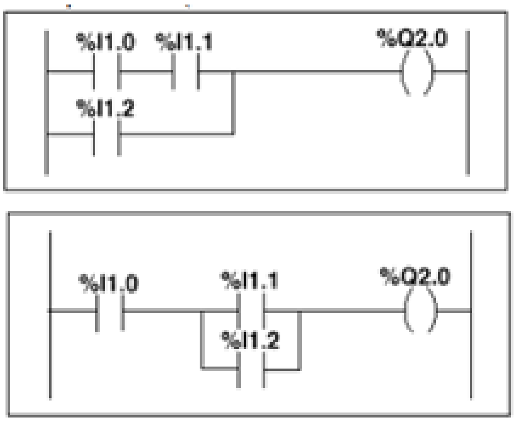
• *SFC (Sequential Function Chart) Language:* Sequential functional diagram (GRAFCET)

- *Instruction List (IL) :*

Textual language of the same nature as assembler (programming of microcontrollers). Very rarely used by automation specialists.

Line N°	Instruction	Operand	Comment
00	LD	%I0.01	Testing the address input **0.01**
01	AND	%I0.02	**AND** between input **(I0.01)** and input (I0.02).
02	ST	%Q0.02	Give the logical result of the **AND** operation at output **Q0.02**.

Table 1. Examples of instruction fields.




```
LD      %I1.0
AND     %I1.1
OR      %I1.2
ST      %Q2.0

LD      %I1.0
AND(    %I1.1
OR      %I1.2
)
ST      %Q2.0
```

Figure 16. Example of a program in IL and its equivalent LD language.

- *Structured Text Language (ST) :*

It is a higher-level language than LADDER. It allows the programming of any type of algorithm more or less complex. It is convenient for mathematical calculations, which can be tedious to write in LADDER. It is also used for processing character strings.

```
! (*Instruction de sortie de boucle EXIT*)
  WHILE %MW1<124 DO
       %MW2:=0;
       %MW3:=%MW100[%MW1];
       REPEAT
              %MW500[%MW2]:=%MW3+%MW500[%MW2];
              IF(%MW500[%MW2]>32700) THEN
                     EXIT;
              END_IF;
              INC %MW2;
       UNTIL %MW2>25 END_REPEAT;
       INC %MW1;
  END_WHILE;
```

Figure 17. Example of ST program

- Ladder Diagram Language (LD) :

It is the most commonly used programming language for automation and the programming of programmable logic controllers (PLCs). This language is composed of a sequence of contacts (switches that can be either closed or open) and coils that allow to translate the logical states of a system.

Figure 18. Example of a LD program

- Function Bloc Diagram (FBD) :

This is a graphical language (flowchart type) where functions are represented by blocks with inputs on the left and outputs on the right. It allows the manipulation of all types of variables.

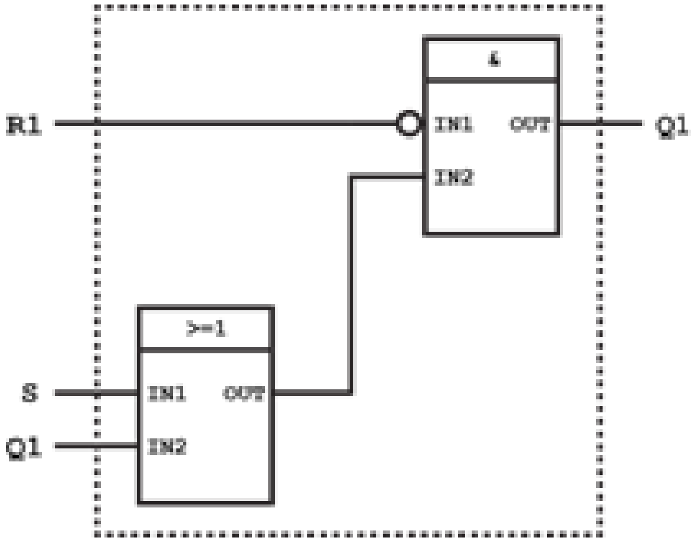


Figure 19. Example program in FDB

- SFC (« Sequential Function Char »):

It is a graphical language derived from GRAFCET, and it is a high-level language that allows easy programming of all sequential processes.

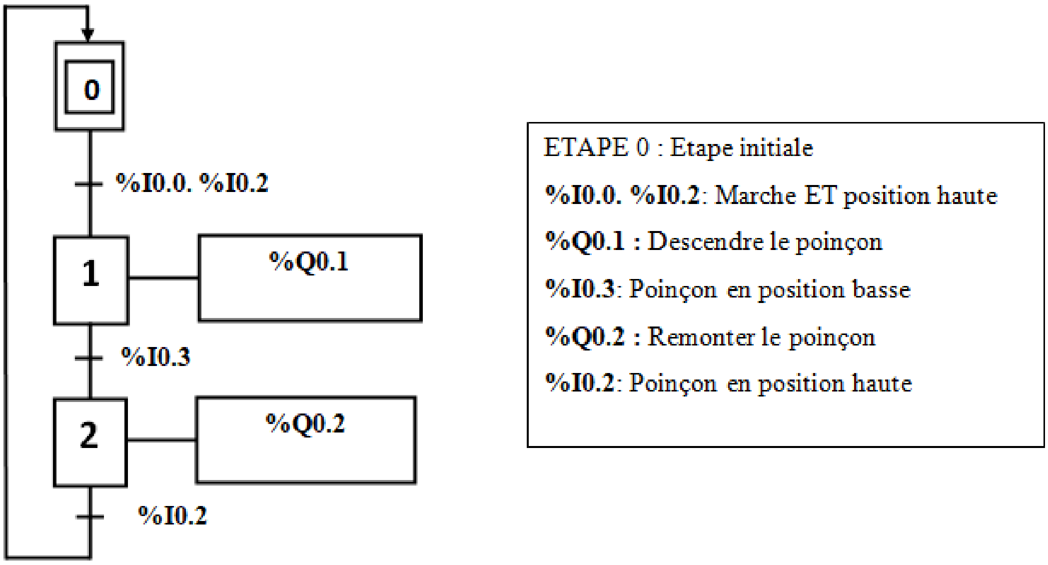


Figure 20. Example of an SFC program

Comparison of PLC programming languages :

LANGUAGE	ADVANTAGES	DRAWBACKS
LD	easy to read and understand by the majority of electricians basic language of any PLC	requires well-structured programming
FBD	Very visual and easy to read	Can become very heavy when equations get complicated
ST	High level language (pascal language) To do algorithms	Not always available in software workshops
IL	basic language of any PLC assembler-type	very cumbersome and difficult to follow if the program is complex Not visual.
SFC	Description of operation Not very flexible (sequential) of automation. Management of market modes Not always accepted in the industry…	little flexible

Table2 : Comparison of PLC programming languages

7. Security

Automated systems are, by nature, a source of many dangers (voltages used, mechanical movements, jets of material under pressure, etc.). Placed at the heart of the automated system, the PLC must be a reliable element because:

- Malfunctioning of the PLC could have serious repercussions on the safety of individuals.

- The costs of repairing the production equipment are usually very high.

- A production stoppage can have significant financial consequences.

Also, the PLC (Programmable Logic Controller) is subject to numerous measures to ensure safety:

• The PLC is designed to withstand the various constraints of the industrial environment and has undergone numerous standardized tests (resistance to vibrations, etc.).

• Power interruptions: The PLC is designed to handle power outages and, through programming, ensures proper operation upon re-powering (cold or hot starts).

• RUN/STOP mode: Only a technician can start or stop a PLC, and the restart is performed through an initialization procedure (programmed).

8. Cyclical Controls

Memory self-check procedures, clock, battery, power supply voltage, and input/output .

Verification of the scan time at each cycle called Watchdog, and triggering an alarm procedure in case of exceeding it (set by the user).

Visualization: The PLCs offer a display screen where the evolution of the inputs/outputs can be seen.

As the failure of a PLC could have serious safety repercussions, standards prohibit the management of emergency stops by the PLC; this must be done using wired technology.

9. Criteria for choosing a PLC

Several criteria exist for the choice of a PLC, citing, for example:

• Quality/Price ratio.

• Ease of programming that offers a language intended for the automation engineer following the IEC 61131 standard.

• Simulation and visualization capabilities that provide the user with effective support for development and operation, for example, S7-PLCSIM from SIEMENS.

• Processing power and a set of specialized cards allowing easy development of specific applications: communication, axis control, regulation, etc.

• Expansion possibilities in terms of inputs and outputs.

• Standardization of communication protocols.

10. Types of PLCs

According to the number of inputs and outputs (I/O), there are two types of PLC: the monobloc PLC intended for simple applications with a small number of inputs and outputs. This type is characterized by low cost, less complexity, and not extensible comparing by the second type, which is the modular type, this latter is significant in terms of the number of inputs and outputs, complexity, price, and expandability.

11. Advantages of PLCs

PLCs have several advantages compared to basic controllers for the same system. To change a control system and the rules to be used, it is enough for an operator to enter a different set of instructions. This makes the system flexible, economical, and robust to environmental conditions (temperature, vibration, etc.).

Bibliographie

SIEMENS, SIMATIC S7 Automate programmable S7-1200, Manuel système 11/2011 A5E02486682-05.

Automates programmables industriels ; Philippe LE BRUN., Lycée Louis ARMAND, 173 Bd de Strasbourg, 94736 NOGENT sur Marne, Décembre 1999.

Programmable Logic Controllers; W. BOLTON., Elsevier Newnes, Fourth Edition 2006.

Systèmes Automatisés; Bacem JRAD., Support de Cours, Institut Supérieur des Etudes Technologiques de Djerba, Tunisie, 2012.

Les Automatismes industriels; BEN HAMMED Sofiene., Cours et travaux dirigés, Février 2015.

Les Automates programmables, tome 1 ; Caractéristiques et méthodologie de programmation ; Dr. Ir. H. LECOCQ., Université de Liège ; Faculté des Sciences Appliquées, 2005

Automates Programmables Industriels, Description et programmation; Support de cours, Dr. Aboubakeur HADJAISSA., Université Amar Telidji de Laghouat, Algérie; Faculté de Technologie, Département d'Electronique, Mars 2019.

SIEMENS, SIMATIC, Faites connaissance avec le S7-300S, petit Manuel illustré C79000-G7077-C500-01.

SIEMENS, SIMATIC, Langage LIST pour SIMATIC S7-300/400, Manuel de référence, 05/2010 A5E02790284-01.

Programmable Logic Controllers , Totally Integrated Automation (TIA) ; Automation System S7-1200, Birmingham Metropolitan College.

Utilisation de l'automate programmable, Résumé de Théorie et Guide de travaux pratiques, OFPPT/DRIF /CDC_GE.

Automates Programmables Industriels ; L. BERGOUGNOUX., POLYTECH' Marseille Département de Mécanique Energétique 2ème Année Option S.I.I.C, 2005.

Les Automatismes, La programmation; L. Lycée L.RASCOL 10, Rue de la République BP 218. 81012 ALBI CEDEX.

Les Systèmes Automatisés de Production, Abdellatif MTIBAA., Université de Monastir, Ecole Nationale d'Ingénieurs de Monastir; Département de Génie Électrique, 2012.

AUTOMGEN 7, Manuel de référence du langage, www.irai.com; 2002.

Les Automates Programmables Industriels ; Cours et TD Master 2, Filière Electronique, Lahouaoui LALAOUI, Université Mohamed Boudiaf de Msila, Département d'électronique faculté de technologie, 2017.