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Study of the Automatic Filling and Capping System, using GRAFCET- GEMMA-PLC and WinCC flexible

Abdy Bouhamadi[1, 2], Mohamed Aboulfatah[1], Mohamed Ahmed ould Sid Ahmed[2]
Mohamed ould Mohamed Mahmoud[2]

[1] Laboratory of Systems Analysis and Information Processing (SAIP), Faculty of Sciences and Techniques, University Hassan I, B.P.: 577, 26000 Settat, Morocco.

[2]Laboratory of Industrial Systems and Information Technologies (ISIT), Faculty of Sciences and Techniques, University of Nouakchott Al Aasriya, Nouakchott, Mauritania.

ORCID: 0000-0001-8378-4901 (Abdy Bouhamadi).

Abstract

In many industries (such as pharmaceutical, beverage industries, etc.), the bottles must be filled with a predetermined amount of liquid. To meet the needs of industries, we have made a study of the filling and automatic capping system using the GRAFCET (GRAphe Fonctionnel de Commande des Étapes et Transitions) and the GEMMA (Guide d'Étude des Modes de Marches et d'Arrêts) that allow to obtain a reliable and fast machine with good precision. The target programmable logic controller (PLC) is Siemens S7-300. With regards to the software tools used, we used the Step 7 programming software, PLCSIM simulation software, and the WinCC flexible supervision software.

Keywords: Filling and Capping System, GRAFCET, GEMMA, Step7, PLCSIM, WinCC flexible.

I. INTRODUCTION

In The recent industry trend is the replacement of semi-automatic or manual systems with a modern automated system that ensures production profitability and reduces the time required for each cycle. Production automation involves transferring coordination tasks, previously performed by human operators, to a set of technical objects called Command Part (PC).

In the field of automation, the GRAFCET [1] and the GEMMA [2] are widely used as modeling language and as a natural extension to define the modes of operation respectively.

Notable contributions in this area have been made by several authors in the literature:

Sosa et al. [3] performed an academic-level industrial facility study using GRAFCET, GEMMA and Computer Integrated Manufacturing (CIM) Pyramid.

Pannu et al. [4] made a filling system of several bottles based on the color of the bottle.

Jovanny [5] applied an approach based on GEMMA and GRAFCET / SFC to obtain an automated design of the mechatronics system.

Alvarez et al. [6] combined GEMMA, the UML-use case diagram and the GRAFCET with a new PLCOpen organization that can convert an API programming file to an XML file.

Machado and Seabra [7] proposed a methodology based on GEMMA and GRAFCET but with a particular focus on synchronization aspects.

In this paper, we applied the GRAFCET and GEMMA by applying hierarchical structuring on the automatic filling and capping machine. The system design is carried out using Siemens Simatic software STEP7 and WinCC Flexible Advanced which are the main software used for HMI (Human-Machine Interface) and PLC programming [8].

The validation of finding results is done through the PLC, which is the most practical solution for process automation because it has less complexity than embedded systems and more reliability than logical relays [9].

II. METHODS AND TOOLS USED

A. GRAFCET (GRAphe Fonctionnel de Commande des Étapes et Transitions)

A GRAFCET is a mode of representation and analysis of an automatism. It was developed in 1977 by the AFCET (French Association for Economic and Technical Cybernetics). In 1982, it became a French standard (NF C 03-190 UTE) proposed by ADEPA (National Agency for the Development of Automated Production) and later an international standard (IEC-60848). In addition, this has been the basis for the development of a new IEC 61131-3 standard that validates five PLC programming languages including the SFC based on the GRAFCET.

GRAFCET / SFC (Sequential Function Chart) is a graphical tool that describes the different behaviors of the evolution of an automatism and establishes a sequential and combinatorial correspondence between the inputs, that is to say the transfers of information from the Operative Part to the Control Part and the outputs, transfer of information from the Control Part to the Operative Part [10].

Whatever the complexity of the sequential system, it can be modeled as a combination of three basic structures that are as follows [11]:

- Single sequence (linear structure): an automatism is described by a single-sequence GRAFCET when it can be represented by a set of several steps forming a sequence whose progression is always carried out in the same order.

- Multiple simultaneous sequences: When crossing a transition leads to activate several steps, the sequences resulting from these steps are called "simultaneous sequences". Simultaneous sequences always start on a single receptivity and always end with a unique receptivity. Indeed, the different sequences "start" at the same time and then evolve independently of each other.
- Multiple exclusive sequences: from one step, you can choose between several possible sequences conditioned by several exclusive receptivities.

Two particular cases of sequence selection are frequently encountered in most sequential automations. These are the step jump and the sequence restart.

B. GEMMA (Guide d'Etude des Modes Marche et Arrêt)

GEMMA is a "tool-method" for better defining the on/off mode, an automated industrial system. It consists essentially of a graphic guide which is progressively filled out during the design of the system [2].

As shown in Fig. 1, the GEMMA consists of two major parts:

- Control part out of energy: this zone of the GEMMMA, located at the extreme left, corresponds to the inoperative state of the control part. It only appears for the form. In this state, the operative part is not under the control of the control part. The operative part can be in energy or out of energy. The security is guaranteed by the technological choices, the procedure of putting in energy of the operative part.
- Power control and active part: this area is used to describe what happens when the Control Part (C.P) operates normally. It covers almost the entire graphical guide. This part will allow us to define the different modes of working and stopping of our machine and the conditions of passage from one mode to another.

 It is subdivided into three zones or three families of procedures:

- ➢ Family F: we group in this family all the modes or states essential to obtain added value. These modes are grouped together in the graphics guide in an F "Operating Procedures" box.
- ➢ Family A: we will classify in this family all the modes leading to (or translating) a stopping state of the system for external reasons. They are grouped together in zone A "Stopping procedures".
- ➢ Family D: we will group in this family all Modes leading to (or translating) a state of shutdown of the system for reasons internal to the system, in other
- ➢ words, because of failures of the operative part. These modes are represented in a Zone D "Failure Procedures".

C. Hierarchical Structuring

Automated Production Systems are more and more complex. In order to simplify the study, the implementation and the maintenance of the system, it is necessary to structure the control part and the operative part. The main objective of

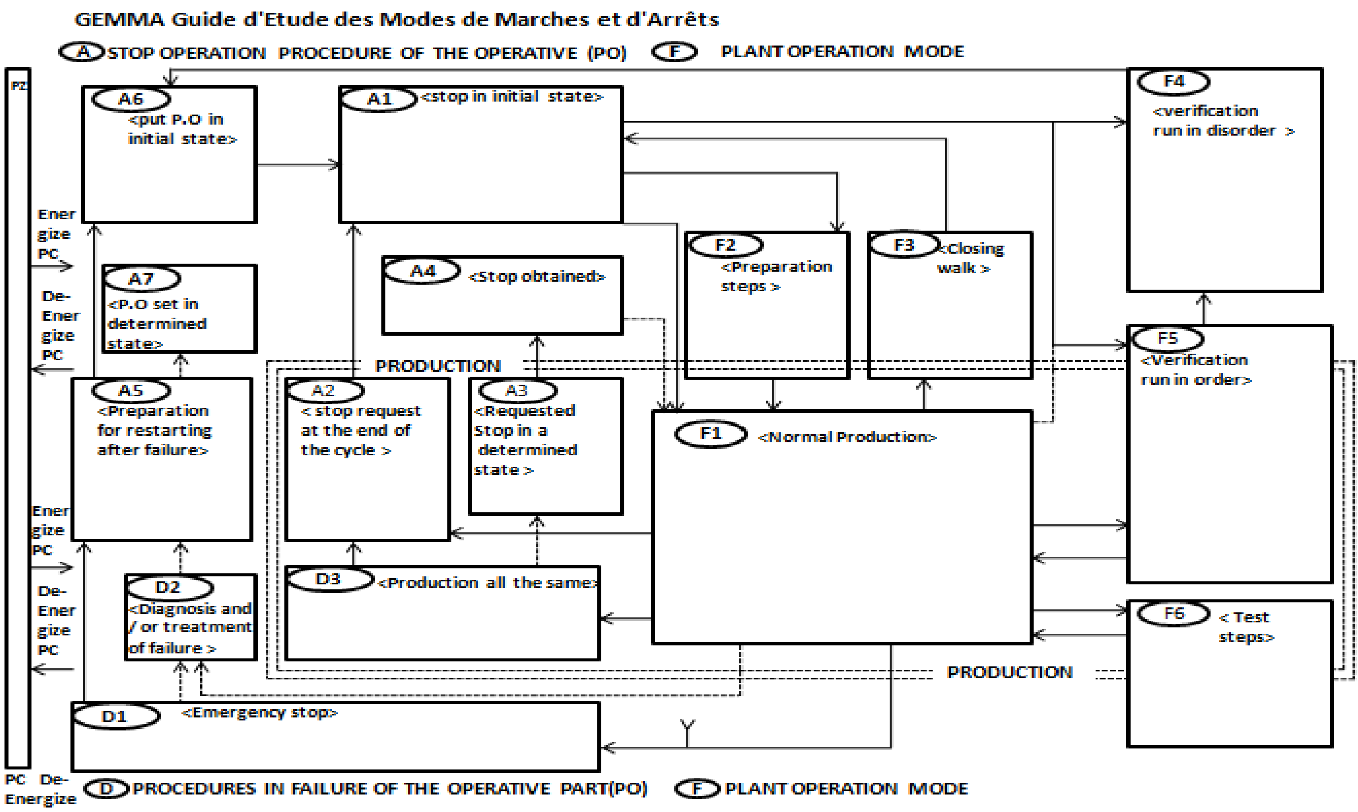

Fig. 1. Graphical notation of GEMMA

structuring is to allow a progressive approach to the functioning of an automated system, both at the level of analysis and at the level of representation. The structuring is either hierarchical (GRAFCET Master, GRAFCET Slave) or without hierarchy (communication between 2 positions).

Hierarchical structures can be organized as follows:

- Safety GRAFCET (GS): It manages the stops due to failures (emergency stops). Generally, the SG corresponds to the rectangle D1 of the GEMMA Guide. It is hierarchically superior to all other GRAFCETS. This hierarchy is achieved by forced command.
- Piloting GRAFCET (GC): it integrates the normal functions on / off modes. It can use specific GRAFCETS (initialization, preparation, closing ...).
- Normal Production GRAFCET (GPN): GRAFCET describing the normal operation of production of the system. It can use task or procedure GRAFCETS.

III. CASE STUDY: AUTOMATIC FILLING AND CAPPING MACHINE

The filling and automatic capping machine is composed of three stations that can work simultaneously.

✓ Station 1 is used for transfer and load. At first, the transfer cylinder B is pulled out to shift the conveyor from one position to the right. Then, cylinder A is used to load a new empty bottle.

✓ Station 2 is used for filling bottles. Cylinder C is released, while opening the valve D, to empty the content of the dosing container in the bottle. Then, valve D is closed and cylinder C is retracted to refill the dosing container.

✓ Station 3 is the capping station. The extension of the cylinder G presents a new cap on the screwing device composed of the cylinder E and the motor F. The cylinder E is then extended to grasp cork. Then, the cylinder E must be retracted at the same time as the cylinder G to retract the device having the cork. Finally, the cylinder E is extended at the same time as the pneumatic motor F rotates, to allow screwing the cap on the bottle.

A. Normal Production Cycle

In the present example, the technology chosen for the actuators is the pneumatic.

Here is the list of sensors:

- a0 : cylinder A completely retracted;
- a1 : cylinder A completely extended (bottle on the conveyor);
- b0 : cylinder B completely retracted;
- b1 : cylinder B completely extended (forward conveyor one step);
- c0 : cylinder C fully retracted (metering cylinder filled);
- c1 : cylinder C completely extended (dosing cylinder emptied into the bottle);
- e0 : cylinder E completely retracted (screwing motor at the top);
- e1 : cylinder E fully extended (screwing motor at the bottom or at the stop);
- g0 : cylinder G fully retracted;
- g1 : cylinder G completely extended (plug presented under the screwing device),

Here is the list of actuators:

- a-: retracts the cylinder A.
- a+: extends the cylinder A (push the bottle on the conveyor).
- b- : retracts the cylinder B
- b+ : extend the cylinder B (advance the conveyor)
- c- : retracts the cylinder C (fill the measuring cylinder)
- c+ : extends the cylinder C (fills the bottle)
- d : open the filling valve (single action).
- e- : retracts the cylinder E.
- e+ : extends the cylinder E.
- f : rotates the screw motor.
- g - : retracts the cylinder G.
- g+ : extends the cylinder G (introduce the new cap).

The choice of technologies is necessary for each automated system which allowed us to more precisely determine the normal production of the machine. This is the operation state for which it was designed. This state can often be referred to as a GRAFCET called basic GRAFCET or normal production GRAFCET (GPN). It is shown in Fig. 2.

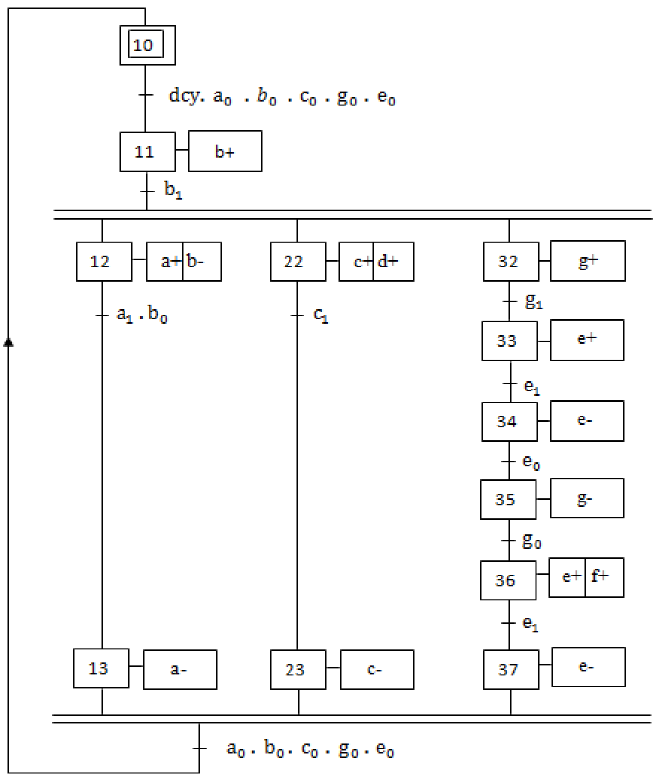

Fig.2. Normal Production GRAFCET of the machine (GPN)

In the GPN in Fig. 2, it was assumed that no bottles were missing, that there would be no failures and that the three stations would work together.
We seek to build a reliable machine in all possible and imaginable conditions. For this we will apply the GEMMA to the automatic filling and capping system.

B. GEMMA

The GEMMA graphic guide in Fig.3 makes it possible to determine the run/stop states required for this machine:

A5- After emergency stop, cleaning and checking are often necessary: this is the purpose of rectangle A5 "Preparation for restarting after failure".

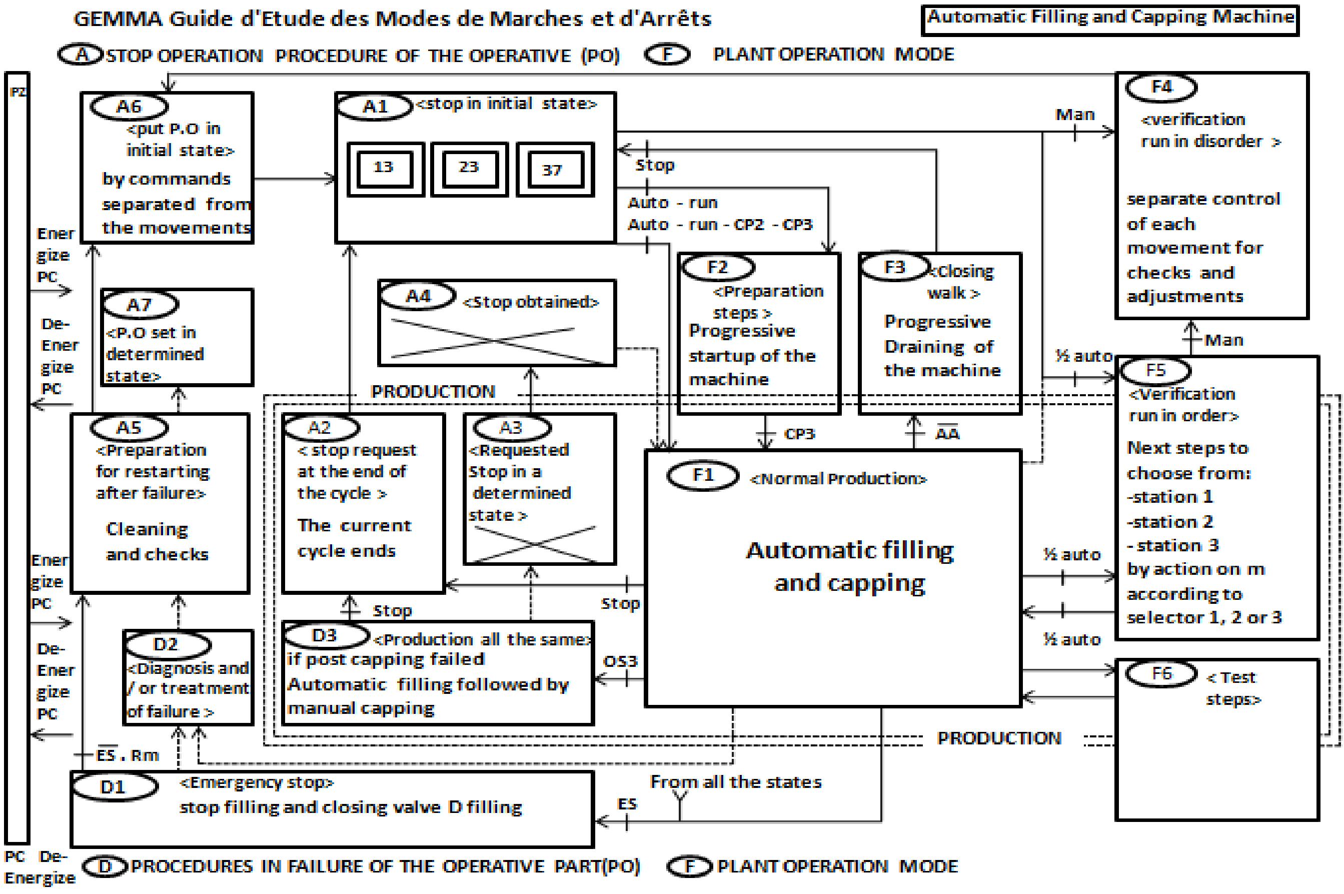

Fig.3. GEMMA applied to the filling and capping system

A1- The rectangle A1, "Stop in the initial state", represents the state of the machine defined by the sketch opposite.

F1- in rectangle A1, when you start the machine you go to rectangle F1 "Normal Production". That is, "Automatic filling and capping" according to the GRAFCET described in Fig. 2.

A2- Production stop can be requested at any point in the cycle. The current cycle ends.

F2- When the machine is empty; it must be started gradually, each position starting when the bottle is present. This is the "Preparation step" of rectangle F2.

F3- The "Closing march" of rectangle F3 allows the opposite operation. That is to say the progressive stop of the machine with emptying of the bottles.

D3- Delicate point of the machine, the post "Capping" is sometimes defective. It may then be decided to continue production, by capping manually as and when filling; this is the subject of rectangle D3 "Production all the same".

D1- In case of emergency stop, rectangle D1 "Emergency stop" is reached. It provides for a stop of all movements in progress and the closing of the valve D to stop any flow of liquid.

A6- After any failure or verification, a reset to the initial state is necessary: rectangle A6.

F4- For the adjustment of the measuring container, the verification of the cork dispenser, a command to separate movements is provided: rectangle F4.

F5- For verification, a semi-automatic command (only one cycle at a time) is required for each station and for the whole system: rectangle F5, "Verification run in order".

By determining these conditions of evolution, we become aware:

- Of the need for additional sensors detecting the presence of bottles under each station: CP1, CP2, CP3 which will allow the gradual start required in F2 and progressive drain requested in F3.
- Of the needs at the console level: buttons providing the evolution conditions given by the operator.
- That the completion the basic GRAFCET with marching and stopping is required.

C. Hierarchical Structuring of GRAFCETs

For this, we have proposed new hierarchical GRAFCET based on the enrichment method which are: Safety GRAFCET (GS), Piloting GRAFCET (GC), Normal Production GRAFCET of station 1 (GPN1), Normal Production GRAFCET of station 2 (GPN2) and Normal Production GRAFCET of station 3 (GPN3).

- The GS in Fig. 4 is the most hierarchical GRAFCET. When the step 101 of the GS is active, it allows:
  - The GRAFCETS named GC, GPN1, GPN2 and GPN3 are forced in the situations where they are at the moment of forcing. This order is also called "freezing".
  - The closing of the filling valve (d +).

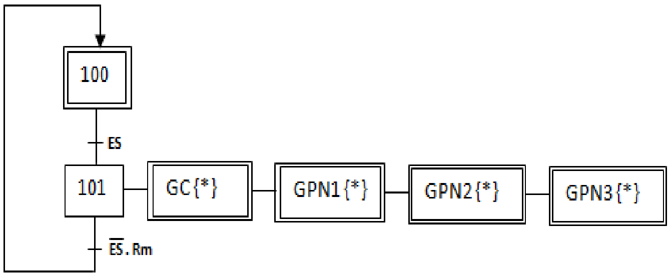

Fig.4. Safety GRAFCET of the machine (GS)

- Since we talked about hierarchy earlier, the Piloting GRAFCET (GC) in Fig. 5 is always higher in the hierarchy than GPN1, GPN2 and GPN3. It is GC that decides when they start

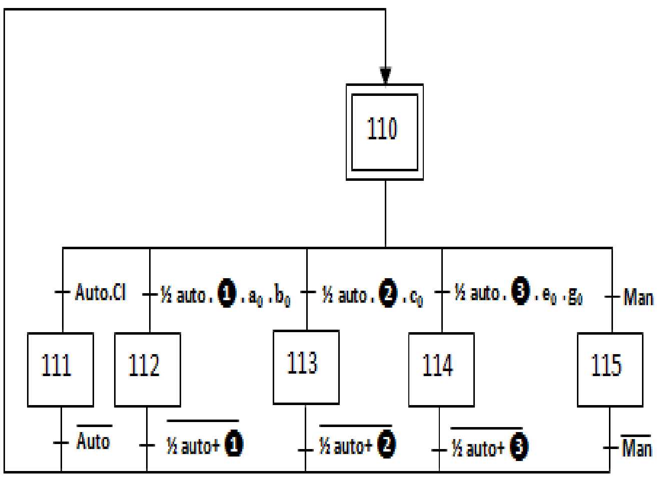

Fig.5. Piloting GRAFCET of the machine

$$CI = a_0 \cdot b_0 \cdot c_0 \cdot g_0 \cdot e_0$$

- As the machine has a complex automatic step, we have made a normal production GRAFCET of each station to facilitate the structure of operation. The GRAFCETS are GPN1 in Fig. 6, GPN2 in Fig. 7 and GPN3 in Fig. 8. These three GRAFCETS communicate with each other with horizontal coordination.

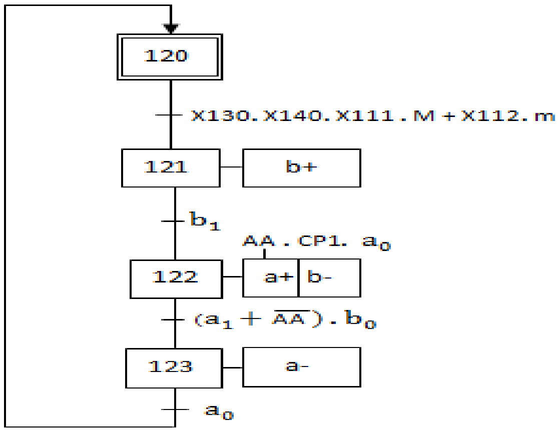

Fig.6. Normal Production GRAFCET of station 1(GPN1)

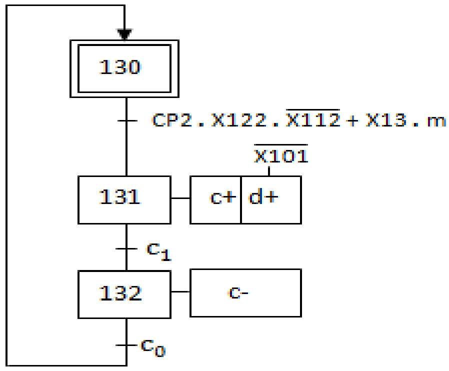

Fig.7. Normal Production GRAFCET of station 2(GPN2)

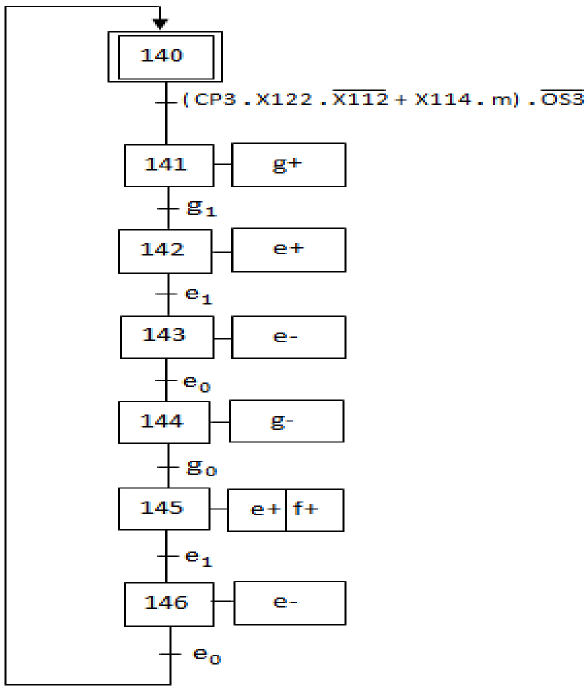

Fig.8. Normal Production GRAFCET of station 3(GPN3)

D. System conception

The automatic filling and capping system is designed by WinCC flexible Engineering System (part of WinCC flexible) with which we carry out all required configuration tasks. The

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WinCC flexible edition determines the operator panels of the SIMMATIC HMI range that can be configured [12].

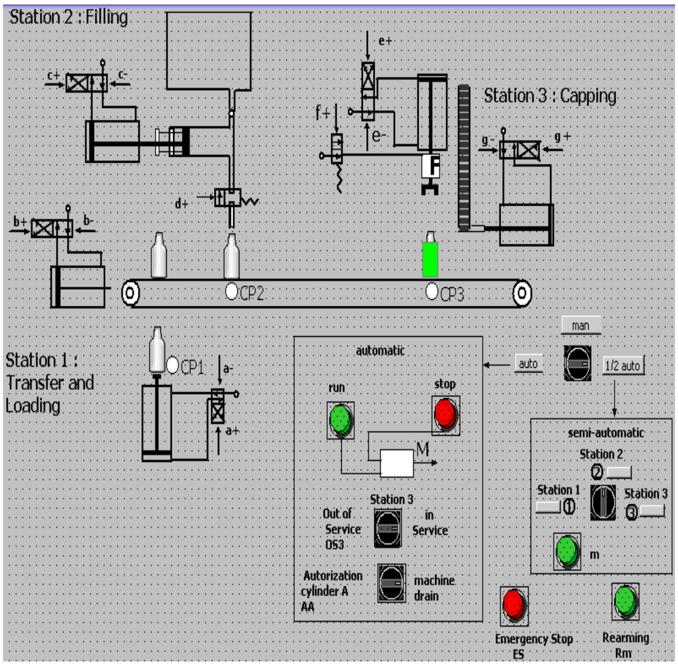


Fig.9. Automatic filling and capping machine developed on WinCC flexible

On the control panel in Fig. 9, a main selector is used to choose between the "automatic (auto)", "semi automatic (½ auto)" and "manual (Man)" options.

- The "automatic" option correspond to:
  - 2 buttons "on" and "off" whose action is stored (M signal).
  - An HS3 selector linked to station 3: "in service" or "out of service".
  - A selector AA of authorization of cylinder A, to allow emptying the machine.
- To the option "semi-automatic" which allows, by pressing the button m, the exploration of the cycle in a single post (1 or 2 or 3) depending on the position of the «semi-automatic» selector in ❶ or ❷ or ❸
- To the "manual" option which require the separate control of the movements (by direct action) on the distributors or by pressing buttons if provided.
- The emergency stop button ES allows to switch to D from all states.
- The Rearming button Rm .

STEP7 is the basic software package for configuring and programming SIMATIC S300 automation systems [13]. For programming, we have chosen the ladder language which is one of the 5 standard languages of the IEC 61131-3 standard defined by the International Electrotechnical Commission (IEC). Ladder language is a graphical programming language that is easy to understand and to learn. It is most commonly used for PLC programming and consists of a sequence of contacts (switches that are either closed or open) and coils that translate the logic states of a system.
The simulation of the program is done by:

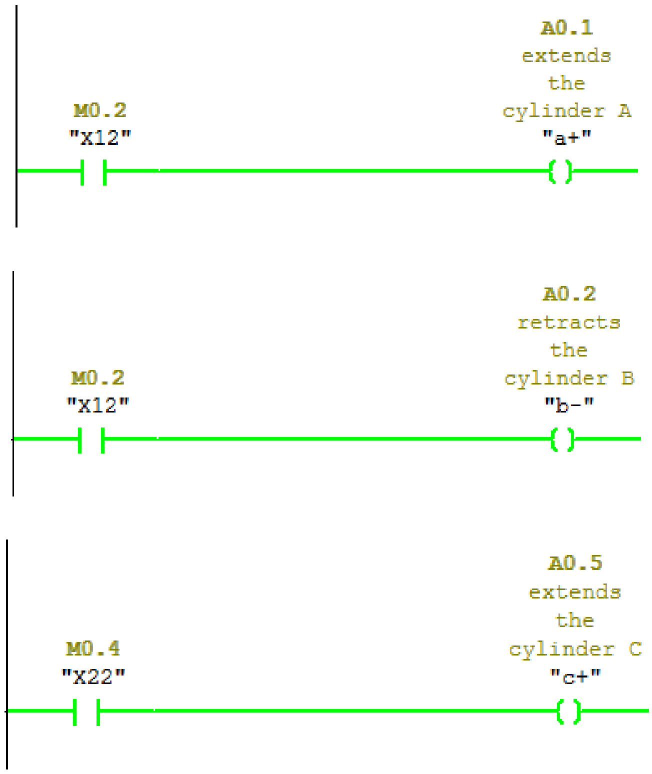
- PLCSIM under STEP7 consisted of simulating the program via SIMATIC S7-PLCSIM which is a controller for the functional tests of blocks and user programs for S7-300. The simulation is completely realized within the STEP7 software, it is not necessary that a connection is established with any S7 hardware (CPU or signal module). S7-PLCSIM has a simple interface for viewing and forcing the various parameters used by the program.
- WinCC flexible Runtime (part of WinCC flexible) is the process visualization software. In Runtime, the operator can perform process control. The following tasks are then performed :
  - Communication with the PLCs.
  - Display views on the screen.
  - Process control.

IV. RESULT

First, we must load the program into the PLCSIM virtual simulator and check the initial conditions before starting the system.

A. Results of the simulation Normal Production

The simulation of the GPN program shows that the operator will give the starting command for each operating cycle and that the three stations operate simultaneously as shown in Fig. 10 and Fig. 11. This solution is not practical to meet the needs of modern industries that require the flexibility and cost-effectiveness of the system.



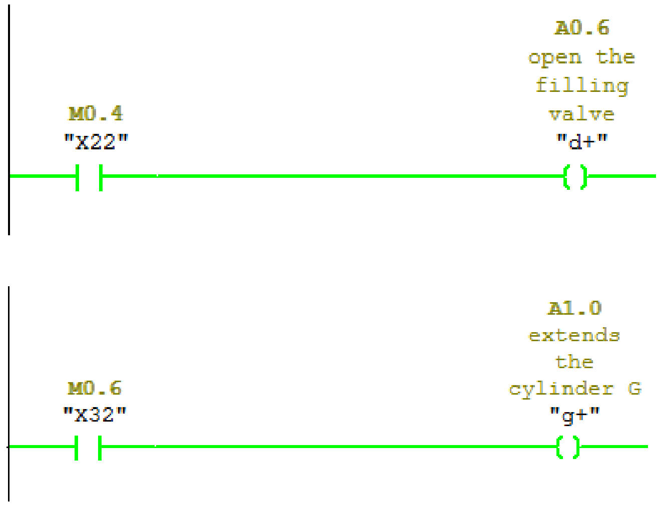


Fig.10. stations operating simultaneously/ Ladder language of the GPN

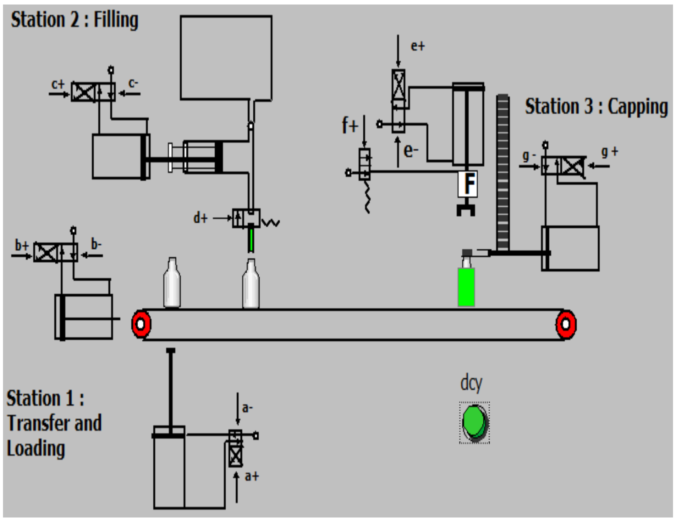


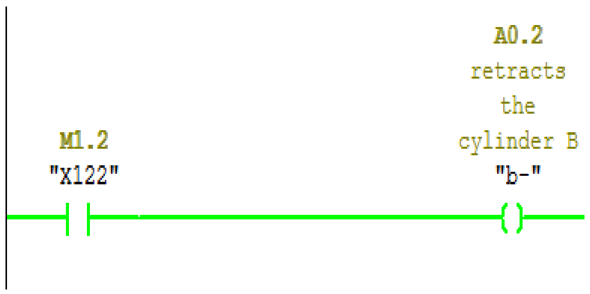
Fig.11. stations operating simultaneously/ of the GPN

B. Results of the simulation Structuring GRAFCET

The functionality of the machine is tested so that during operation the main selector will be positioned in the mode chosen by the operator.

From the control panel we can select the operating mode and give the order of the running and stopping of the system.

- The choice of the automatic mode by pressing the Start button allowed us the possibility that the three stations can operate simultaneously by the presence of a bottle for each station in Fig. 12 and Fig. 13.



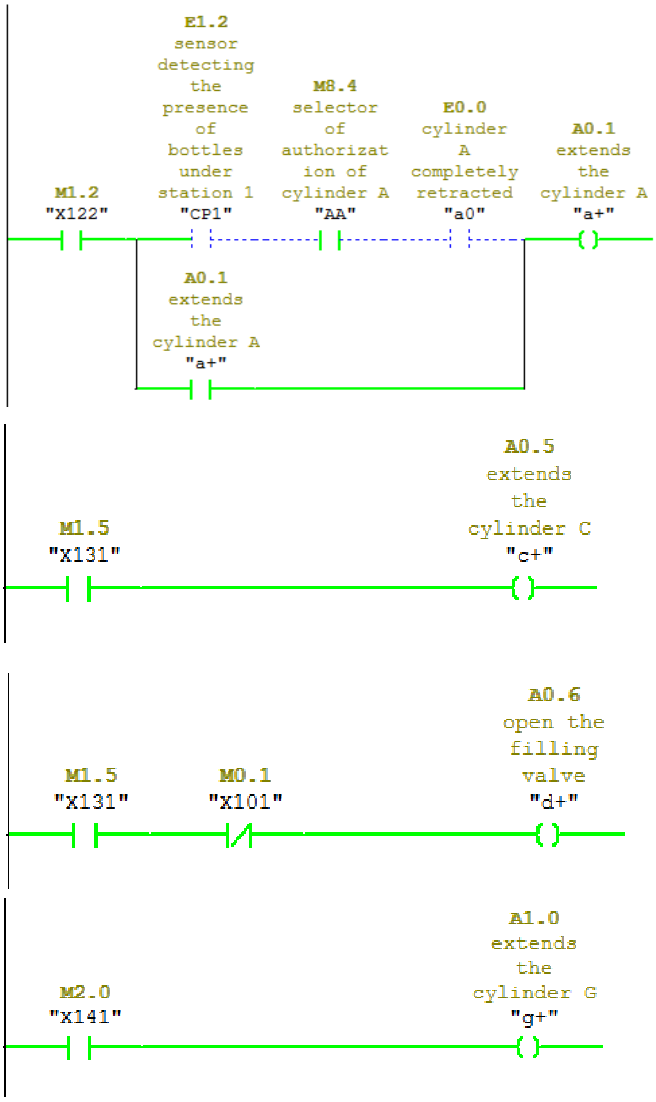


Fig.12. stations operating simultaneously/ Ladder language of Structuring GRAFCET

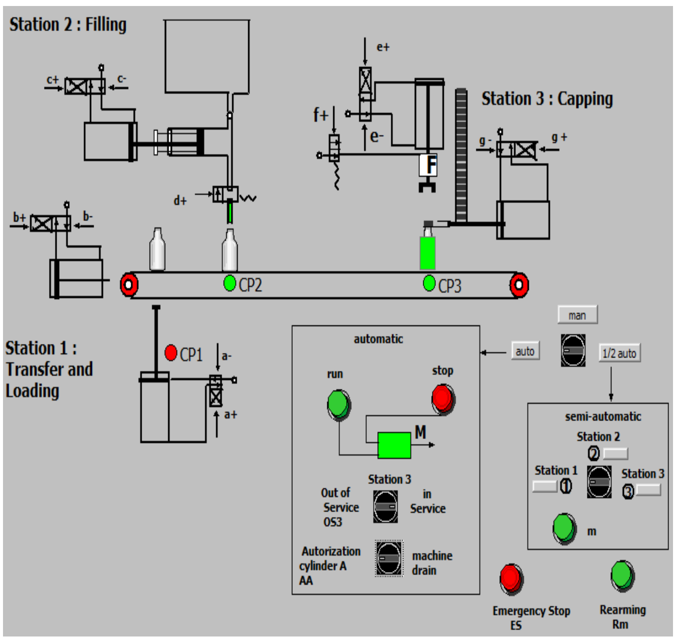


Fig.13. The 3 stations operating simultaneously

On the other hand, in the automatic mode, it is possible to have the operation of a single station in Fig. 14 or two stations in Fig. 15 according to the states of the program. This shows that the machine works with good precision.

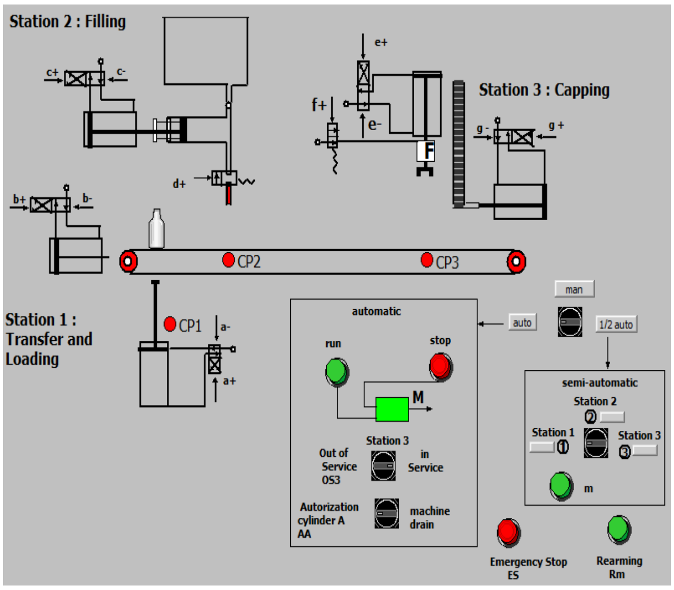


Fig.14. Transfer of bottle by station 1

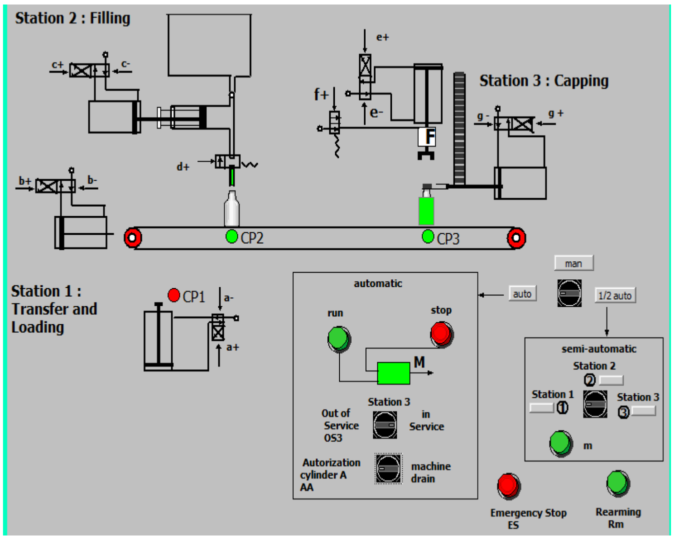


Fig.15. Stations Filling and Capping operating simultaneously / automatic mode

In case of failure, the operator will press the emergency stop button to block the program in the current state and close the filling valve as shown in Fig. 16 and Fig.17. The reset button will give permission to continue the operation of the system after the correction of the fault.

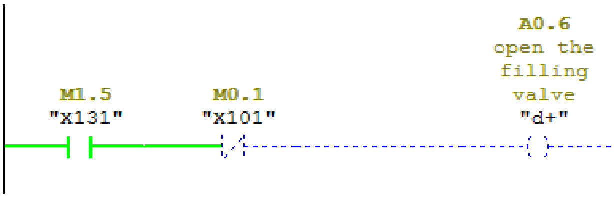


Fig.16. Closure of the filling valve by forcing in Ladder language

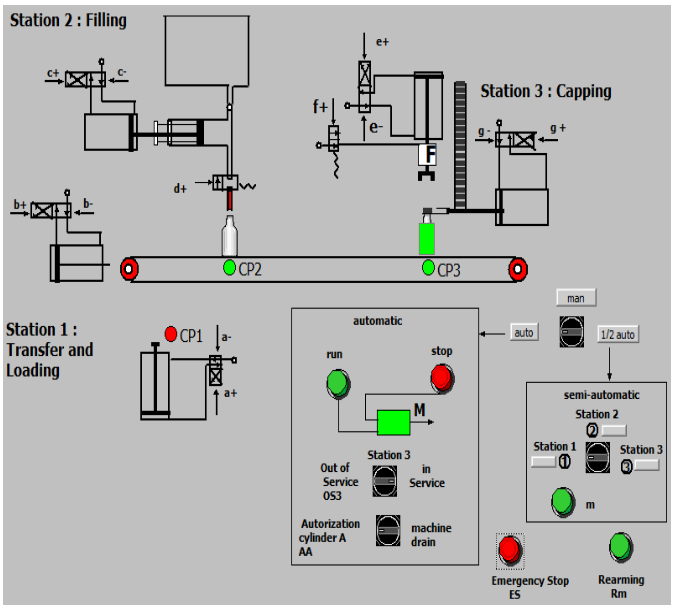


Fig.17. Closure of the filling valve by frozen type forcing

The instruction to stop the operation is done by pressing the stop button but the system will be stopped after the end of the cycle.

- Simulation in semi-automatic mode requires the operation of a single station according to the choice of the operator. To test the operation of one of the stations, simply set the "semi-automatic" selector to the chosen station and press the push button m for each cycle as shown in Fig. 18 and Fig. 19.

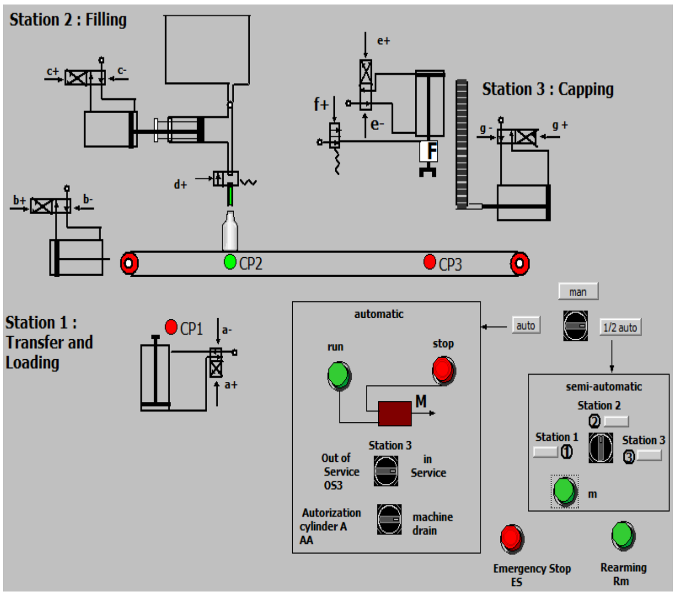


Fig.18. The filling station is only worked / semi-automatic mode

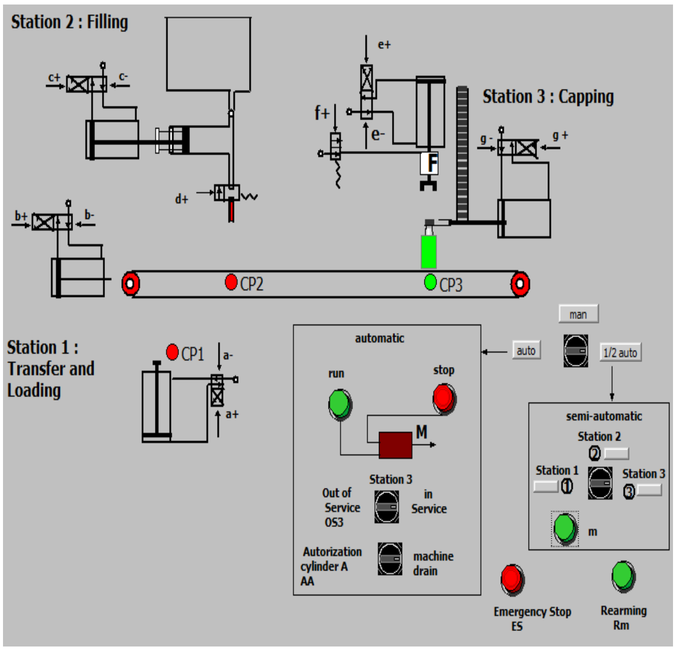


Fig.19. The capping station is only worked / semi-automatic mode

- For manual mode the operator will give a command to actuate

V. DISCUSSION

The obtained results from the simulation of the Normal Production GRAFCET (GPN) show that despite the lack of a bottle that would cause the liquid to be poured into the vacuum, the system continues the production process. This solution is not valid; we need to make a rectification using GEMMA and Hierarchical Structuring.

For the results obtained by hierarchical structuring have met our objectives for the design of a reliable and secure machine which can works in all conditions. This approach solves the problem of the GPN because the operation of each station depends on the chosen mode and requires the presence of bottle that which was detected by a sensor. The automatic, semi-automatic and manual operation modes are available according to the choice of the operator by a main switch on the control panel. Automatic operation is guaranteed without any human intervention.

The communication between the HMI and the PLC optimizes the layout of the workstation and limits the risks of working on the screen.

VI. CONCLUSION

This article presented a study to develop a filling and capping system using GRAFCET and GEMMA. In this way, GEMMA and GRAFCET formalisms were first systematically developed for the structure and specification of the system behavior. We made an implementation on the automatic filling and capping machine. The proposed solution is processed by a basic GRAFCET enrichment method with hierarchical structuring to respond to European security directives. The results obtained by simulation with WinCC flexible software and STEP7 show that the adopted approach is adequate for the design of a reliable machine.

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