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ORIGINAL PAPER

Innovation and creativity in process control and manufacturing

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Abstract The industry and manufacturing processes are characterized by a variety of algorithmic methodologies and techniques that describe their function. Therefore; the methodology for teaching automatic processes control for innovating projects, build a profile of the student based on validated evidence of the professional comprehensive training solution, defined in learning skills (Tobón, in Formación basada en competencias, Pensamiento complejo, diseño curricular y didáctica. Bogota, Colombia, 2005) for the structured approach to the problem of controlling processes and workable solution, aimed to apply integration of management actions functional process controls, integrating threads and systemic responses of these.

Keywords Process control · Finite state machines · Innovation in automation · Process control protocols · Machine control

1 Introduction

Being ready to innovate it's available to overcome the creativity paradigms in process and industrial machines to get new products for the more unexpected applications or the most conducive man's service and the planet life. In control of process has application the complexity concept, utility and service of process respective, but in turn also it's the best application of best technologies to do control operations and generalizes toward technological progress [2].

The problems of innovation and control are associated with the context:

- Identify typical problems of automation and control as well as the specifics of your environment.
- Propose solutions to problems of automation and control.
- Synthesize complex processes in making innovative and viable solutions.
- Develop and implement tailored to the capabilities of the actuators and process controllers.

The innovator is the dreaming student able to see the products, technology services from other side and other zoom. With the challenge that if it wasn't donne he'll be the first in doing and learn from it, but if it was donne he'll seek to optimize the process, the execution and the results. It's the ability to move the puzzle systemic chips with best benefits and innovator products.

With tis work, we seek to rise the studen to another level with visualization, presentation and solution capacity of solving tecnology problems.

1.1 Comprehensive training

The skills training for the innovative development of processes control and manufacturing, relies on methodologies of student-centered learning as the axis of the process with social inclusion in leaders environment, it is based on human and personal integrity, being, knowing and doing [20,21]. The social, industrial environment, motivates the student to identify the processes that can be boarded and the solvable problems with ethical responsibility and progressive spirit, for this reason it is important to create integrated working teams under the discipline, ethical criteria and technical profile for the project development [11].

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The appropriation of knowledge transforms leaders into a teachers [1] to give answers and explanations supported with strategic capacity in the proposal of solutions to the suggested problems.

Innovation is an action that requires discipline and a dedicated team with an unbiased approach to learn from experimentation [10]. Teamwork is collaborative, trying to face the proyect from different perspectives, but everyone contributing to the same goal, so it is essential to establish performance roles of each team member [21] according to the aspects of leadership [11]. The meetings of socialization of progress, evaluation and feedback systems, the discussions to continue with the following stages make a democratic and enriching solution. Finally, the solutions have to be concreted and skillfully performed in order to generate a product of higher social service.

1.2 Innovative and creative learning

Being innovative is a step further to be competent and it is a mental discipline ability training, and use of methodologies to develop creativity. Discipline forges the responsibility to be methodical and constant in the projects development. There would still be important to the development and promotion deadlines, and excellent project planning.

Innovation based on ideas that apply directly to needs, usually in industrial processes, where the title of the project defines the objectives to be achieved. Innovation can also be seen as an added value due to the adaptability, adjust and improve of systems for particular applications, hence the need to make the a literature review related [19]. This inventory shall apply the concept of creativity and functionality should be in the detailed definition of the problem, covering the rationale, scope and limitations of the solution.

Now is opportunity for development supported within the framework of methodological reference, scientific and technological solution, validation and implementation with their documentation.

1.3 Interactive design

Design and interactive learning sugest the realation between the student continued loyalty and the lifetime of design project fase and make possible to provide future tools and support structures and continuous improvement of both the concepts and the processes objects of control. This interactivity in the design of automated control occurs under the concept that innovation allows different possible evolutions of the process due to the concepts of user requirement or technological alternatives available.

From a practical learning point of view, interactivity is made with reliable simulation tools which facilitate the validation of concepts, displaying corrections and improvements of the processes run.

2 Learning methodology

The automatic control problem is now a project of control and it is born from the need required by the industry, supported on a methodology and developed in the search and construction of solutions to problems related with the performance of the approachable processes from technical and technological capacity of the acquired knowledge and transmitted by the teacher to the student in the form of creativity and innovation of the proposes with solutions to the problems observable in the dynamic of actions and reactions of variables of the physics of processes, insurable on its implementation.

It could be thought that learning will occur when comparing between what is expected and what happened [10] for this, the methodology searches the construction of the systemic project functioning, formalized in: prior knowledge of the process like help in modeling and understanding the way it operates, study of the viability of intervention with a plan for evaluating progresses process, intervention strategy design, formulation of the solution with its implementation, validation and documentation.

2.1 Discipline

This methodology is developed to work activities under the supervision of compliance and achievement gains required in the performance. In the study learning activity reflected the benefit of the same student, hence the motivation for effort and compliance is proper and coordinated in the group. The educational work will have a component of motivation, need and joy of the goals achieved.

With experience of teaching once defined the problem should develop a schedule of activities, where individual tasks, reports, documentation and socialization of the fact, and expected difficulties are included.

2.2 Working groups

Group work starts from the classification of its members, the definition of their roles and the conviction of a collaborative work. This work will place greater emphasis on the methodological aspect.

Collaborative learning allows viewing more edges of the project is important and strategic distribution of work fronts in a group that has empathy toward goals. In a way it is important that the group is natural: among friends, colleagues,

neighbors. Management responsibility is assigned roles to each of the members

1. *Coordinator*. Set times and places of work and coordinates the work.
2. *Quality manager*. Ensures that the goals are reached.
3. *Dynamic*. Promotes performances and schedules set.
4. *Systematizer*. Addresses all information and documentation development.

2.3 Acompanying teacher

The teacher is the leader team and play several rolls that allowed, interaction, control and regulate of the student with him self, with the problem development, using the necesary tools to learn.

- *Guide*: because he is the knower of the learn reaches.
- *Instructor*: because he knows how to do it and where is the knowledge.
- *Auditor*: because he is who watch for the learn quality level.
- *Evaluator*: because he is who weighted the reached goals.

In the article development will show this interaction with the purpose of develop the knowledges abilities.

3 Control problem

The control problem searches as fundamental objective, to make the process behave according to the established desire defined in the process engineering [19] or algorithmic manufacturing, validated in the certainty of the capacity to control specifying the complexity and implementation of controls to the process. This premise opens the door to becoming innovative window control in a toolbox for creativity on processes, machines and artifacts. From the point of view systemic, the problem is reduced to identify the inputs, the environment, history and requirements to meet the output specifications [9].

The studente and teacher defined delivery parameters and how budgets should be a control problem, such that enable it to achieve its development learning achievement of competencies to certify:

"Select and describe a problem in a typical industrial process development event with activities involving sensors and actuators controllable (on/off and PID controllers—helped by the teacher)":

1. The typical process will process a structural line (emsamble, reaction, machining, etc. and fed this line the separate

threads. Between discrete and continuous actuators and sensors are binary or continuous identification.
2. Process activities must be executed sequentially, concurrently, partially synchronous.
3. Planning the system configuration data acquisition specifying implementation.
4. Specify targets actuating devices, which must have their respective transfer function, highlighting the technical specifications thereof and shall have its PID controller connected in a closed loop, which must be tuned to better respond to the step function.

3.1 Processes

The processes defined in this work are related to industry and manufacturing material and/or energy products, defined in elements of combinatorial logic operation, sequential discrete operation or continuous specified operation in a strict and severe protocol under a language of function specifications of the process, related to the natural concatenation of its performance and engineering concepts applied, while a suitable communication system operates the environment of subsystems, synchronizing them for integral outcome of the process [17].

Logical thinking is the engine spirit that makes processes acquires autonomous performance, to have life and properly function.

The processes of discrete feature, associate the management usually to an operational fractionated discontinuous level, in the realization of defined activities such as events, enabled by initial conditions and closed the fulfillment of final terms [17]. These activities are organized in a network of program execution according to the operation of the system in a gant chart (gant) called state machines, structured to achieve the process purpose. These events network performance can be classified according to the interopertivity: sequential, concurrent, cooperating, deterministic, stochastic or continuous operation.

In the context of plant control is the response to step functions generated by the state machines in a hybrid configuration [8], as command for subprocesses and/or actuators of continuous nature in his operating range.

The concept of automated factory leads to broader concepts of automation processes, such that the whole is an integrated system without topological constraints, multiple specificities of the processes, subprocesss and machines. This solution is achieved by building a higher level layer in the hierarchy of control with the same methodology of state machines, using distributed control concepts supported in communication networks for the development of remote control in real time (Fig. 1).
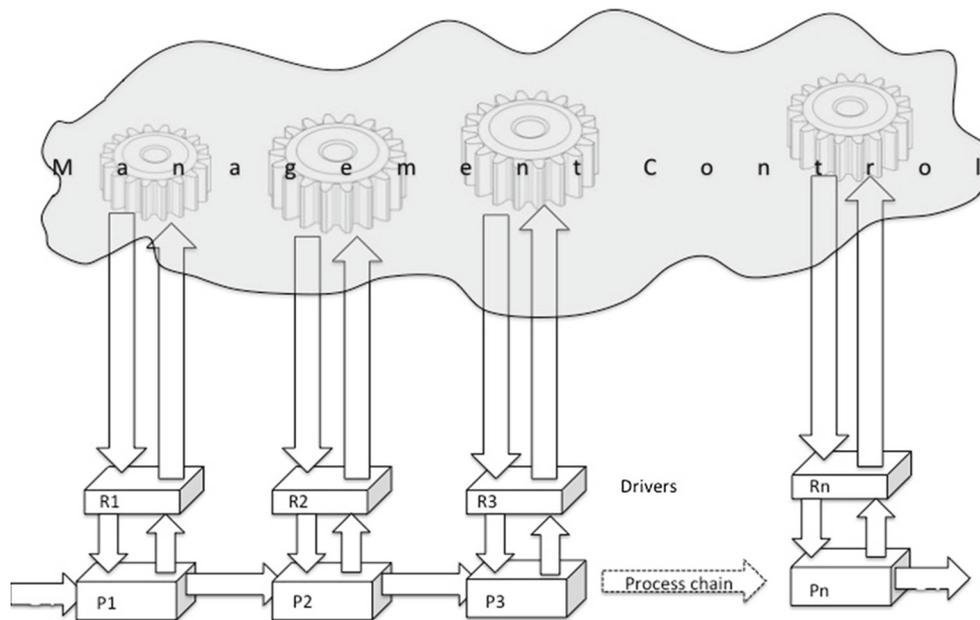
Fig. 1 Structure of plant systemic

3.2 The given problem

Control methodologies have emerged from the concept of observing the behavior of natural laws that govern the processes, then there have been developed strategies and actuator devices to intervene these natural behaviors and finally methodologies and control structures are developed, seeking the behavior the process to be governed by the man, for a desired purpose.

In order of that, the technological base is plentiful and with full capacity to meet any need for a typical industrial process, where actions are made by the dosification of mass and/or energy to feed processes. The methodology outlined here starts building the solution from industrial need to control processes by controlled actions over actuators integrating systemically related subprocesses in a management structure dedicated in real time to adress and manage the complexity of the problem. Finally actuators are those who confront the fine adjustments under strategies on energy and mass balances, on natural responses to processes, which in the concept of sublevels of closed loop control govern the behavior of system, process, or plant.

3.2.1 Language specifications

The action of control searches the exact conduction of the reaction process, for this gives the controller the possibility to interpellate accurately and precisely the actuators according to the dynamics of dosage required by the process engineer. Is the strategy of control engineer designing these strategies within specifications that address the functional complexity

of the process using in their favour the naturalbehaviors of the system and subsystems, which can be adjusted with the help of PID regulators to properly tune the expected reactions.

These language specifications SDL [4] must be very precise and concrete so that it can allow accurate modeling of task execution, operations and process reactions.

The work os divided in subprocesses determined by the accurate observation of typological, functional and dependent specificities in the fuctional logistics of the process. To help, it can be opted for the development of a data flow diagram where it can be topologically appreciated the areas of activity and data binding.

Innovation strategies are structured in event control of discrete feature in a higher level of hierarchy and its premises express the logical functional development of this control level in handling slogans of actuators on/off or setpoint signal levels.

Moreover continuous processes of continuos nature are involved in the systemic building several inter-related subprocesses defining a higher complexity due to the mutual variables interaction within the subprocess. This modeling is specified in the language of differential equations to define behaviors with continuous operational settings. His inter relationship is specified in the formulation of state equations whose solution defines the development of this type of process.

3.2.2 Protocol

The worded structured redaction of specifications language for the functional description of the control of a process

is called protocol and accords his functioning and the design concept, based in the processes algebra and communications that provide operational structures, supported by logical expressions defined in the Boolean algebra and seudocodes to define, model and control the operation of the processes involving safety, performance and optimization criteria; with adequate and comfortable interface between man and machine, according the technical specifications of the sensors, actuators, controllers and process equipment [9].

The concepts and actions are associated into logical algorithms defined by signals from the sensors of the process, by parameters, variables, times and the interaction between processes. The algebra of processes is developed with combinational and conditional logic to elaborate competition and synchronization criteria with cooperating and concurrent processes. Allocations are also made to availability of physical and logical resources to control of processes and subprocesses modules.

Typical procedures are specified for operations of actuators and advance of sub processes, of input, connection and disconnection, starts in extreme conditions, overomming of noises or difficult situations.

It may be that the protocol acquires certain apparent complexity associated with the complexity of the process. This complexity is addressed with look at the integral control scheme which is reflected in the redaction of the protocol. Elaborate a data flow diagram according to a good analysis of the premises of the protocol helped visualize and partiallize in control related areas. The minimum control unit will be associated with an actuator, but it is possible that a control may be responsible for multiple actuators. Although the recommendation is to assign a higher number of controls which makes the integral system looks simpler but multiplies the capacity as many controls, which makes the whole system, look simpler but multiplies the capacity of operating flexibility

3.2.3 Data flow diagram

It is the first sketch of the solution to process control, it allows a panoramic overall observation of systemic network of information flowing in the platform from the sensor signals defined as inputs to outputs, involving elements of execution in time real, both in hardware, software, the system modules and the data distribution network specified in the premises of the protocol data. Its usefulness lies in the visualization to identify sub processes and understand the description of the problem to assign the required control modules allowing greater reliability in the design of the solution.

3.3 Synthesis

The synthesis process is associated with the control system strategic solution, to build proper functionality and protocol described in the schematic diagram of the data flow, applying concepts of analysis, modularity, modeling and structural hierarchy levels abstraction.

The synthesis process can ask to adjust and refine the specification lenguje because the synthesize of problem is understood in more detail levels and clarity of more specific functional algorithms is made.

3.3.1 Finite state machine

The algorithmic solution of this methodology is framed in the theory called finite automats supported in the construction of logical networks called finite state machines (FSM) known as finite state automats, referred to the theory of networks of Petri [17], or their derivative methodologies such as Grafcet, that have proven their efficacy for representing such systems.

In a FSM, the states are represented by circles, that define events of concrete actions of the actuators and/or subprocesses that describe the different situations by which the process can go through when the conditions for starting the operation have been produced.

The state transitions signals that are logical expressions [23] of transient signals whose validation process generates competition of the triggers of movement from one state to another according to the behavior of the process ensured with the compliance of the conditions [16] reactives of the process makingfinite states machines are subjective and depend on each specific problem [24]. These transitions are represented as a line (arrow) indicating the name of the signal and the transition from one state to another.

The construction of the network of transitions is ensured in the structure described in the premises of the protocol and executed in the reaction of the sensors or the information of the development of other events according to the systemic structure of the solution to the problem, or by the validation of variables calculations or flags signals synchronization, or timing or progress counters. There will be a starting state depending on the input criteria in operating control, usually the initial state acts as a starting point is the off state and walks through validated states by the transitions of competition winning the defined network in the protocol rules as the management of priorities or algorithms of conflict resolution.

These transitions can lead to assignments associated of variables for registering, posting or droping flags of sync, configuration of timers or counters onset and dynamic variables of progression. Graphically, are represented after the logical expression of the transition followed by a slash and then the assignment expression. Deterministic processes generate a sequential machine from the activation of the first

rule to its completion. In stochastic processes is the factor of randomness that defines the navigation path in the network. In more complex systems these nondeterministic choices involve the application of other proven techniques in artificial intelligence such as fuzzy logic, called fuzzy state machine.

The changing levels during different stages of advancement corresponds to the application of steps on/off or reference values to the system input actuator so it is necessary to observe the consistency of the response of the actuator and the requirement of FSM both, time and type of response.

The analysis of a process may result in actions of redesign to increase efficiency, reduce costs, improve quality and shorten times by reducing production and delivery times. The interpretation of the protocol for the development of the FSM can lead to generate different functional solutions, with redundant states in which it may be necessary to analyze synthesis that optimizes development. In the same machine two states are equivalent if the machine can start in any of these states and generate the same set of possible sequences of output when any input sequence is provided. This makes that the set of control states of a machine can be minimized without changing the external behavior of the machine, replacing any set of equivalent states by a single state.

The abundance of actuators in a process allows to characterize it as multiprocessing systems where it is profitable to develop several simpler machines in finite state where each controls a smaller number of actuators, hopefully an actuator for each FSM, but also occurs the risk of duplicating reduncdant efforts with FSM.

The distributed nature under the concept of multitasking operation, allows to expand the solution and control the entire local process or geographically distributed by process sections. Takes importance as an essential part of the system the logistics of communications, within the complexity and the environment of performance, so that data from system sensors, actions that must decide to actuators and exchange of information and data synchronization on different machines.

3.3.2 Synchronization

The implementation of a multi-processing system—several FSM-, suggests that among them may exist sync criteria of states due to competition or cooperation of sub processes [13], and from that the FSM are classified.

- *Synchronous machines*. These are machines in which all states must be executed simultaneously with states of other machines. Synchronization is done via synchronization signals and input signals indicating the occurrence of an event are used.

- *Asynchronous machines*. These are machines that are totally independent and do not require simultaneous execution of events.
- *Partially synchronized machines*. These are machines that require sync only certain events and others are indifferent at the time of execution.

3.3.3 Distributed control

Multi process systems can be associated with distributions of plant due to independence of processes, topology of the plant, extent and distribution of the plant. In these cases the control methodology for discrete events applies with the same premises with the consideration that control can be decentralized and being islands whose connections with the environment is made under mechanisms for real-time communications [14].

3.4 Continuous controllers

Control history began at level of the actuating devices, solving problems of handling or dispensing currents mass or energy in processes of continuous variability and possibly in the dependent systemic configuration. From managing projects synthesized with FSM, these subsystems can be seen as ACTUATORS parts of the process. The methodology for the solution of these subsystems consists in the identification of mathematical model of the subprocess [3,18], identifying the transfer function by the approach of energy or mass equations balance differential [12,15,19]. About this transfer function is identified the behavior or responses to actions that may be subject to process performance [4]. Obviously these answers are not the most ideal in execution behavior and it is therefore necessary to have items such as PID regulators that adjust the response to the best operative desire of the system [7].

In case you have no empathy between the demands of control and actuator responses tuned to the best functionality, seek consensus in the control adjusting to the demands of protocol specifications of the actuators.

4 Application

The theory explained above is illustrated with a classic and basic example of control implementation on a hot water tank. See Fig. 2.

The text of approach to the problem by the process engineer can be summarized in the following premise: you want to build a tub under atmospheric pressure, to heat water to a temperature between a minimum and maximum value, must also ensure a minimum supply hot water.
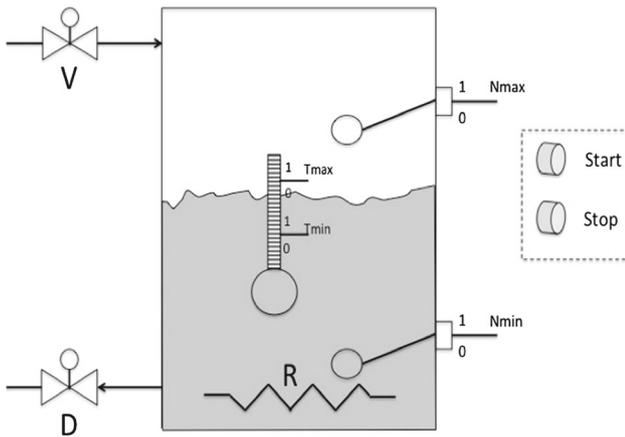
Fig. 2 Tank level and heating

Table 1 Planning of activities

Class topics	1	2	3	4	5
Protocol	x				
Synthesis		xxxx			
Prototype			xx		
Control targets				xx	
Sociallization					x

4.1 Planning

Success requires a careful control and culture of innovation [7]. From a first draft, where the feasibility of the solution to appreciate the innovative process must chart a development process areas to run. The following table 1 shows an example of programming the core activities in developing innovative shows.

This brings associated planning a series of deliverables defined in the planning (by date and type) and to help having control in the achievement of goals, strategies and objectives validation, assimilation of the learning process (know-how) also help development documentation.

The deliverables will be received by the teacher, who fed fixes, improvements, strategies, corrections; then these results should be socialized in the first instance in the innovative group. It is possible that more groups are associated with a more complex problem, for which it is necessary to socialization in plenary.

4.2 Development

The protocol-adjusted writing will be on the following premises.

A tub to which you will control its water level between the Nmin and Nmax value, by opening or closing a valve V to supply the liquid.
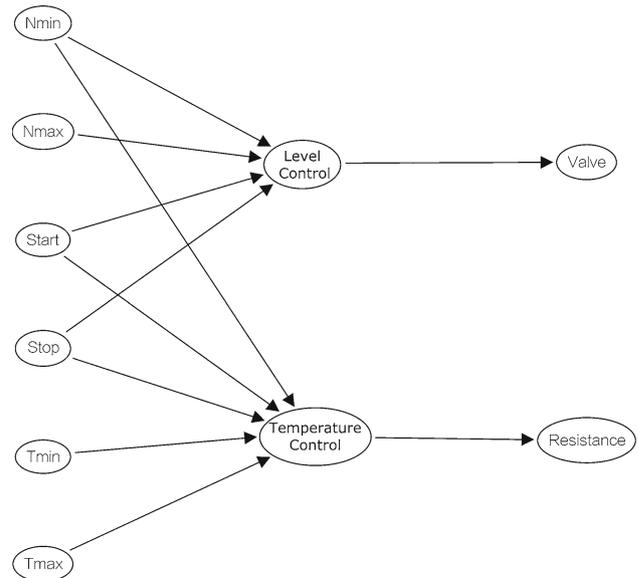

Fig. 3 Data streams

The internal temperature was adjusted between Tmin and Tmax value through an electrical resistance R, which is connected to heat, and disconnects when the maximum temperature has been reached.

For safety the resistance must be disconnected when the water level is below the minimum value.

The hot water tank has a starter button "Start" and a "Stop" control.

4.3 Synthesis

To approach the problem solution, which in some cases can be difficult to understand because of the systemic complexity of the problem a flowchart of data, which allows a zoom separate subsystems, and solutions is developed. This diagram identifies the part of the actuators of the process, in this case the fill valve and resistance. In the first instance to each actuator is assigned its respective control, level control to the valve and temperature control for resistance, then according to the premises of the protocol sensors are related with the respective controls. The following graph illustrates the data flow diagram of the problem of the boiler (Fig. 3).

A panoramic observation allow to appreciate that in this process are necessary two functional modules that correspond to level control that acting on the valve and temperature control acting on the resistance, where Nmin and Nmax are specific sensors for the level control and Tmin and Tmax for the temperature control (Figs. 4, 5). The relationship of these controls is given by the sign of Nmin which is also used for controlling temperature due to the premise of safety. The Start and Stop signs are generic signals for the two controls.
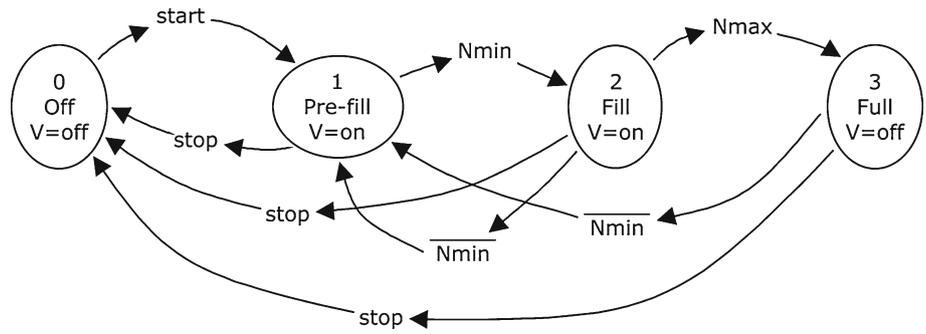
Fig. 4 FSM level control
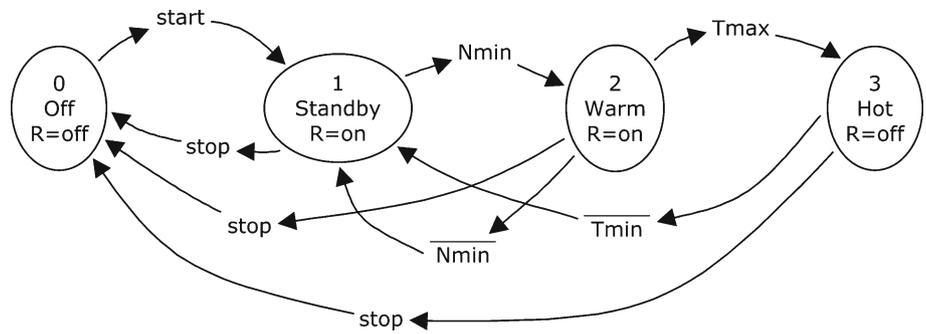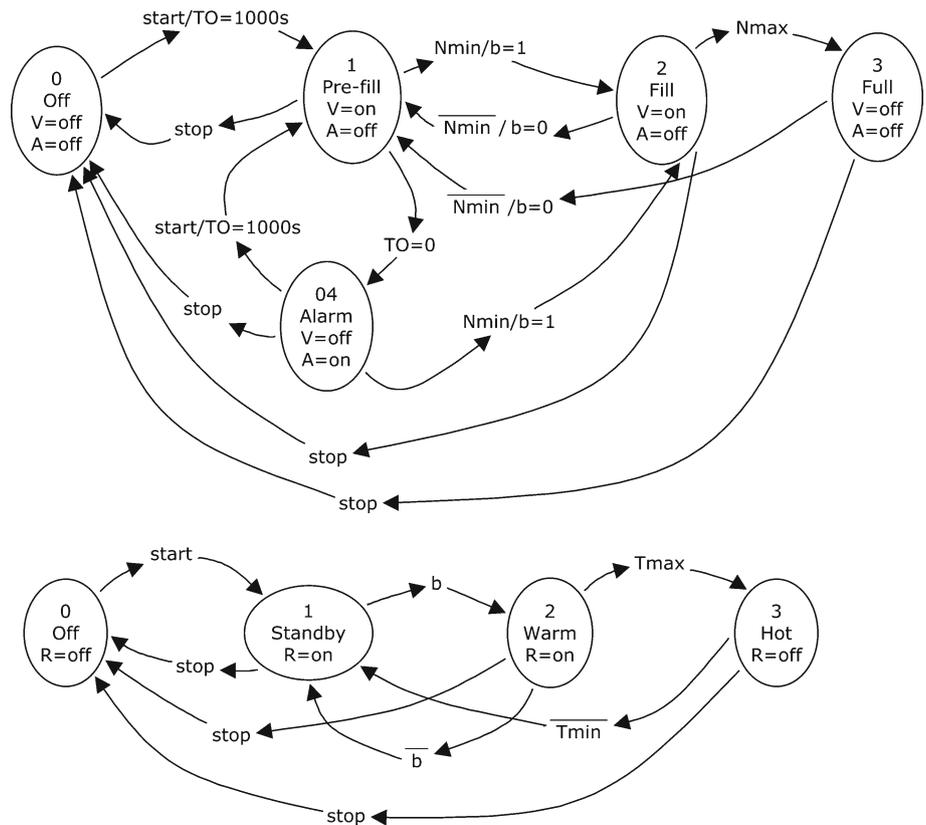

Fig. 5 FSM temperature control

Fig. 6 Control of tank level and temperature alarm system and synchronization

With these features and according to a specified performance protocol on the premises is developed the control engineering solution about the concept of FSM.

It is important to look at these two FMSs, synchronized states running off in both MEF and the state of prefill level control with standby temperature control. The remaining states of both FMSs run without synchronization. The mechanics of synchronization is done by signal sensors or human machine interface. For example to get out of the off state the *Start* signal is used and arrives with the *Stop* sig-
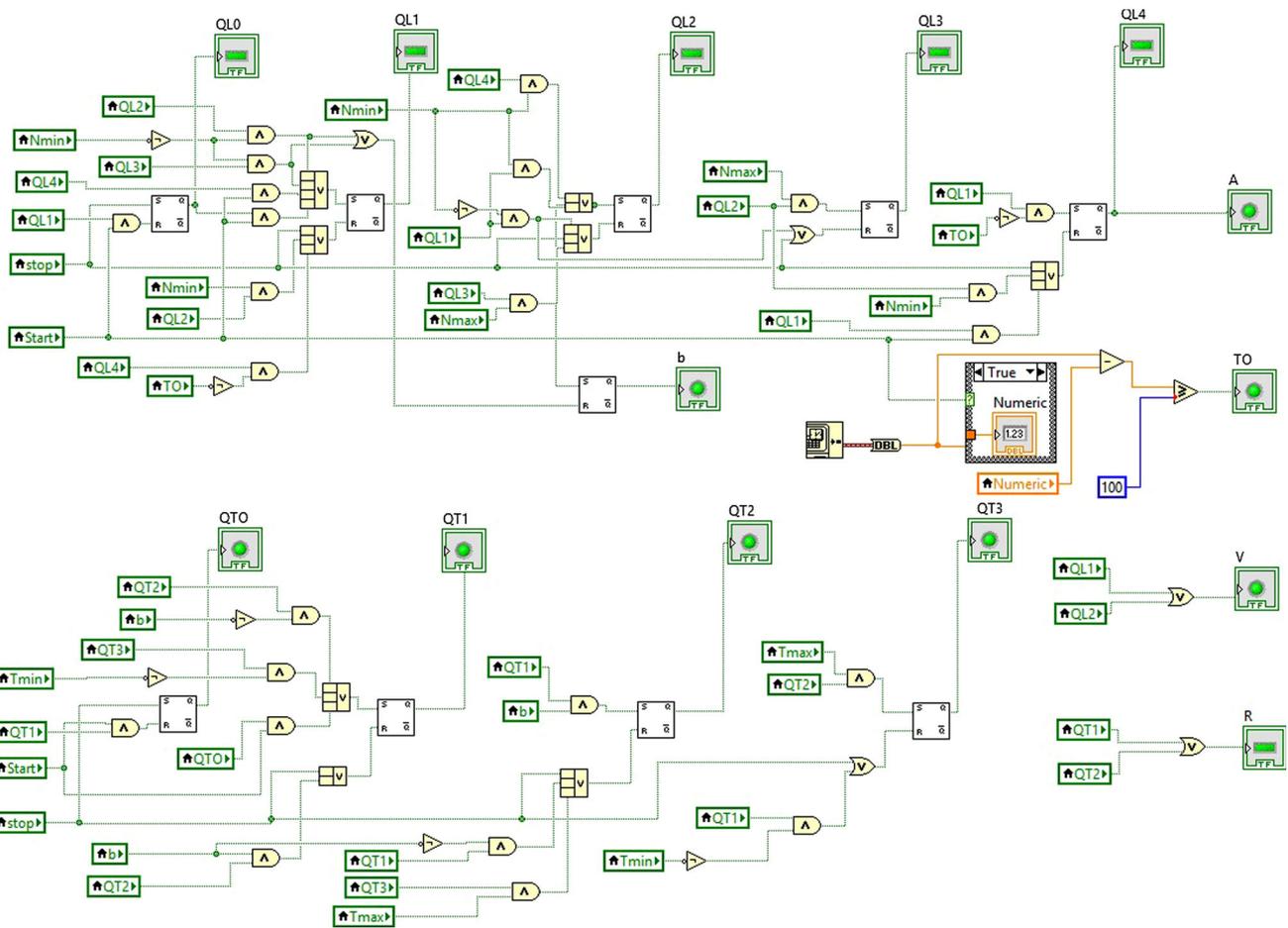
Fig. 7 Control of tank level and temperature with flip-flop set reset

nal, the states of pre-filled and waiting comes with *Start* and $\overline{Nmin}$ signals and gets away with signals *Stop* and *Nmin*. In Fig. 6, another method of synchronization is displayed by using the allocation flag in the FMS and reading level flags in FSM temperature.

It is very normal that processes are subject always to improvement and redesign, in this case there are going to be placed alarms to the system in case the water level input has a lower flow than established, so the time to reach the minimum value it will have to extend for a longer time in this case an alarm time-out is activated, with which you can have an intervention operator who act possibly opening a pre-entry system or by maintenance activities manual valve. The system will take these adjustments by an exceeded level or the operator may again press the Start button.

4.4 Simulation interactive of FSM

There are many technologies available to develop prototypes, which are based on process instrumentation systems where

the characteristics of sensors and actuators to be used are defined.

This simulation is done with the evolution from the first conceived in the design structure. It is normal at the beginning to detect errors in concepts of work processes, which will interactively corrected until to reach the desired improvement and increase design quality.

The machine corresponds to programming, as a multi-tasking system must simultaneously meet all FSM running. The programming and implementation of the control must include elements of reading sensors, record the current state, actions of states, state transitions, handling of timers, actions applied to the actuators, among other hardware and drivers. These programming languages are formed by symbol structures, syntactic and semantic rules, which express strictly protocol performance. The most practical ways is using programming languages such as; the PLC ladder pair in pseudo code for processors, and other graphical programming, hardware and FPGA programming. In Fig. 7 programming problem with heating tank shown using graphical programming set reset flip flop.

Fig. 8 Filling, emptying and heating tank
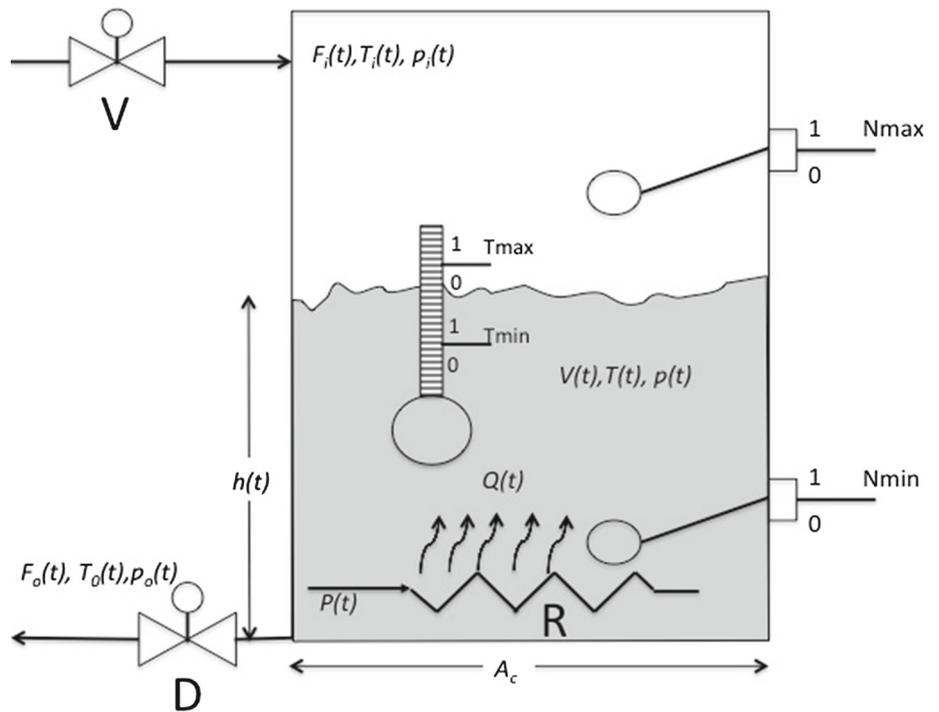
4.5 Actuator response

The actuators involved in this process are the valve and the resistance and the desire is that your response satisfies the conditions of the problem. Basically you can say that there are two models that define the behavior of tank heater: the model mass associated with the volume of water accumulated in the tank and manifested in the high level and the energetic pattern associated with water temperature [3]. In Fig. 8, the model associating the physical variables related with fluids and temperature is shown. The mathematical approach is associated in two equations of mass and energy balance. Since thermal energy is stored in the mass, can be referred to the system as state equations.

The *mass balance* equation will allow to build the model of tank fill [7].

Whereas $\vec{\rho}_i, \vec{\rho}_o$ average water densities and $\vec{F}_i, \vec{F}_o$ average flow values in an instant Δt.

The accumulated volume

$$\rho(t) V(t)|_{t+\Delta t} - \rho(t) V(t)|_t$$
$$= \vec{\rho}_i(t) \vec{F}_i(t) \Delta t - \vec{\rho}_o(t) \vec{F}_o(t) \Delta t$$

whereas $\Delta t \rightarrow 0$ and the density of water is the same throughout the process, the average value of the input and output streams are their instantaneous values, plus the tank is rectangular then the occupied volume is $V(t) = A_c \cdot h(t)$, we get to the following ordinary differential equation.

$$A_c \frac{dh(t)}{dt} = F_i(t) - F_o(t) \qquad \text{EC1}$$

The *energy balance* model makes a relation to the amounts of thermal energy expressed in temperature measurement of input, output and the amount of heat generated by the electrical resistance [7].

The energy input: $\rho C_p \vec{F}_i(t) \vec{T}_i(t) \Delta t$
The energy output: $\rho C_p \vec{F}_o(t) \vec{T}_o(t) \Delta t$
The energy transferred to the resistance: $\vec{Q}(t) \Delta t$
ρ y C_p are constant in density and specific heat
The accumulation of energy in the tank is a result of the energy balance.

$$\rho A_c C_p \left[h(t) T(t)|_{t+\Delta t} - h(t) T(t)|_t \right]$$
$$= \rho C_p \vec{F}_i(t) \vec{T}_i(t) \Delta t - \rho C_p \vec{F}_o(t) \vec{T}_o(t) \Delta t + \vec{Q}(t) \Delta t$$
$$T_o(t) = T(t).$$

With this development leads to the following differential equation:

$$A_c h(t) \frac{dT(t)}{dt} + A_c T(t) \frac{dh(t)}{dt}$$
$$= F_i(t) T_i(t) - F_o(t) T(t) + \frac{Q(t)}{\rho C_p}.$$

Substituting in the above equation, the equation of mass balance is reached

$$A_c h(t) \frac{dT(t)}{dt} + F_i(t)\, T(t) = F_i(t)\, T_i(t) + \frac{Q(t)}{\rho\, C_p}. \qquad \text{EC2}$$

The initial conditions define the behavior of the system in the future. In EC1, the height of level depends on the initial conditions at t = 0, being worth h (0) = h$_s$. In EC2 are the equations that define the behavior of the system, where the initial conditions T (0) = T$_s$ adjust the actual value of the variable. This equation has as associated variables: altitude, temperature, flow and heat. For problems regarding tanks, here is formulated an innovative question: what is to be controlled? And the answers may be.

1. The height of tank level.
2. Flow at the outlet.

For this problem the answer is the first option, supposing that the control is made by the manipulation of the inflow F$_i$(t), whereas the rat outflow, then you should have a look to the output stream.

According to Torricelli's law the flow drain from a tank through a hole in the bottom of the tank is: F$_o$(t) = $\sqrt{2gh(t)}$, where g is the gravitational force. This option generates a nonlinear differential equation,

$$A_c \frac{dh(t)}{dt} = F_i(t) - \sqrt{2gh(t)}.$$

4.5.1 Linearization at the equilibrium point

The controllability of the process, depend access to the input variables, they are looking for linear access.

In the *filling process*, a good alternative to artificially linearized, is to place a drain valve designed for flow linear output with height $F_o(t) = \propto h(t)$, then the differential equation model of mass EC1 is:

$$\frac{A_c}{\propto} \frac{dh(t)}{dt} + h(t) = \frac{1}{\propto} F_i(t)$$

$$\frac{dh(t)}{dt} = \frac{1}{A_c} F_i(t) - \frac{\propto}{A_c} h(t). \qquad \text{EC3}$$

In seeking to control the filling system have an equilibrium point h (0), a value that is set according to the zone level control capability. Is recommended that this value is a level on top of the tank. If H = 1 m is the maximum values of filling the tank when this to Nmax, assume that h (0) is 80 % of this height. Addition it will be assumed that the flow rate of the system in equilibrium, equal to the input output is 10 l/min, then

$\frac{dh(t)}{dt} = 0$ then $F_i(0) = F_o(0)$ and $\propto = \frac{F(0)}{h(0)}$. Then $\propto = 0.0125 \left[\frac{m^2}{min} \right]$.

Combining and evaluating terms

$$\frac{dh(t)}{dt} = \left[\frac{1}{m^2} \right] F_i(t) - 0.0125 \left[\frac{1}{min} \right] h(t).$$

In the *thermal processing,* the differential equation of the model energy EC2 is not linear in terms of the $T(t)$:

$$\frac{dT(t)}{dt} = \frac{F_i(t)}{A_c h(t)} [T_i(t) - T(t)] + \frac{Q(t)}{A_c \rho C_p h(t)}. \qquad \text{EC4}$$

The controllability is required to be linear in the change in temperature of the tank contents. Applying theorem Taylor to the expression EC4.

$$\begin{aligned}
\frac{dT(t)}{dt} &= \left[\frac{F_i(t)}{A_c h(t)} [T_i(t) - T(t)] + \frac{Q(t)}{A_c \rho C_p h(t)} \right]_0 \\
&+ \left. \frac{T_i(t) - T(t)}{A_c h(t)} \right|_0 (F_i(t) - F_{i0}) \\
&+ \left. \frac{F_i(t)}{A_c h(t)} \right|_0 (T_i(t) - T_{i0}) - \left. \frac{F_i(t)}{A_c h(t)} \right|_0 \\
&\times (T(t) - T_0) + \left. \frac{1}{A_c \rho C_p h(t)} \right|_0 (Q(t) - Q_0) \\
&- \left[\frac{F_i(t)}{A_c} (T_i(t) - T(t)) + \frac{Q(t)}{A_c \rho C_p} \right] \left. \frac{1}{h^2(t)} \right|_0 \\
&\times (h(t) - h_0).
\end{aligned}$$

Combining and evaluating terms

$$\begin{aligned}
\frac{dT(t)}{dt} &= \frac{Q_0}{A_c \rho C_p h_0} + \frac{T_{i0} - T_0}{A_c h_0} F_i(t) + \frac{F_{io}}{A_c h_0} T_i(t) \\
&- \frac{F_{io}}{A_c h_0} T(t) + \frac{1}{A_c \rho C_p h_0} Q(t) \\
&- \left[\left(\frac{F_{i0}}{A_c} (T_{i0} - T_0) + \frac{Q_0}{A_c \rho C_p} \right) \frac{1}{h_0^2} \right] \\
&\times (h(t)). \qquad \text{EC5}
\end{aligned}$$

4.5.2 Mathematical model

To observe the behavior of this process has been modeled in simulink the previously developed equations. In Table 2, the parameters are assigned to the model so as to adjust to an actual process variables and Fig. 8 shows the model.

Substituting in EC2, the thermal equilibrium $\frac{dT(t)}{dt} = 0$, besides the variables as initial conditions will be assumed in this state. Whereas at $t = 0$ gives the total balance and evaluating the expression at the equilibrium point, the value .

$$Q_0 = -F_{i0} \rho C_p (T_{i0} - T_0) = 2.5116 \times 10^6 \left[\frac{J}{min} \right].$$

Table 2 Parameters of the model

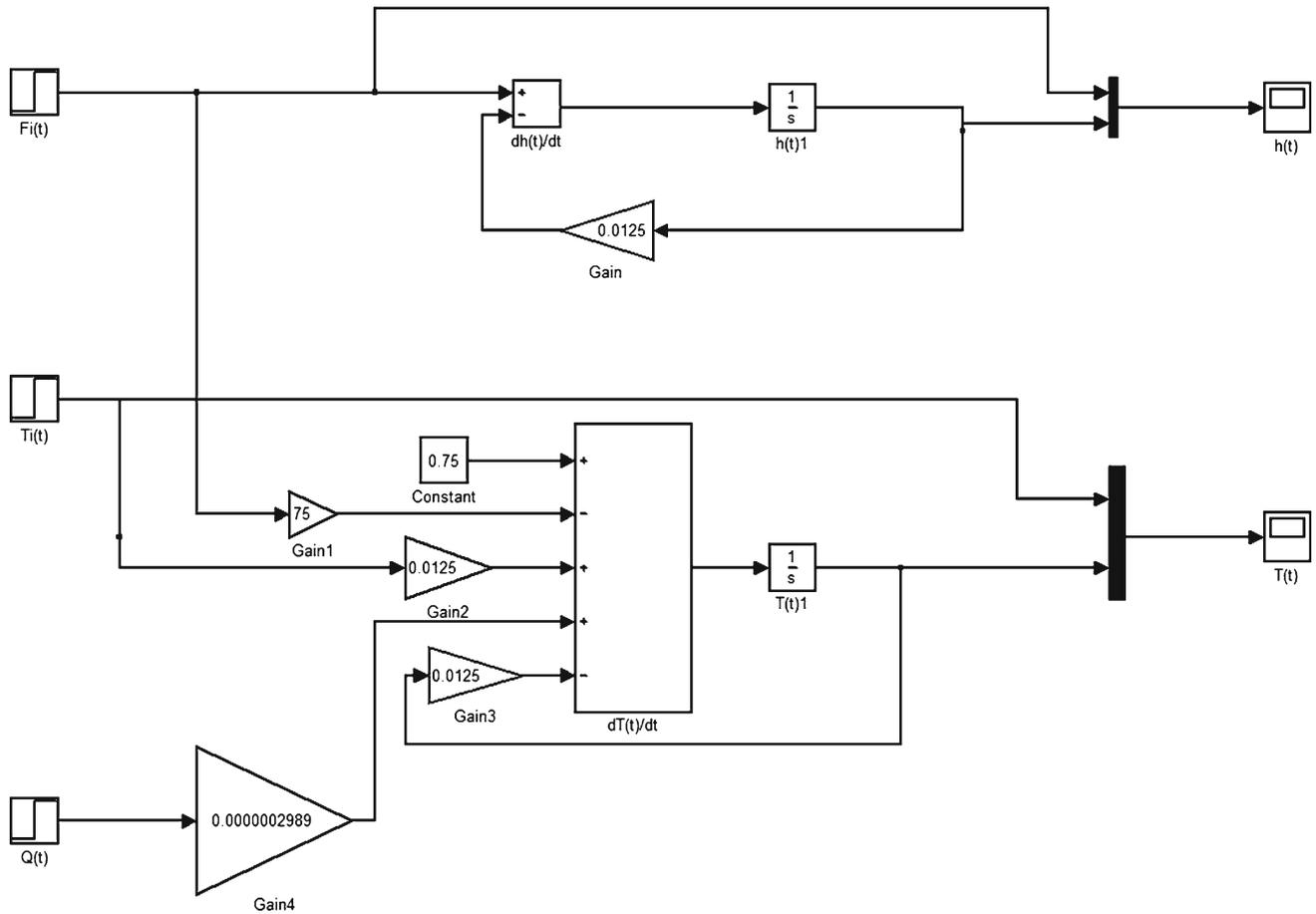| $Nmax$ (m)	h_0 (m)	A_c (m²)	F_{i0} (m³/min)	ρ (kg/m³)	$C_p \left(\frac{j}{(kg\,K)}\right)$	T_{i0} (°C)	T_0 (°C)	$Tmin$ (°C)
1	0.8	1	0.01	998.2	418.18	20	80	20

Fig. 9 The mathematical model

Assigning parameters in EC5

$$\frac{dT(t)}{dt} = 0.750 \left[\frac{°C}{min}\right] - 75 \left[\frac{°C}{m^3}\right] F_i(t)$$
$$+ 0.0125 \left[\frac{1}{min}\right] T_i(t) - 0.0125 \left[\frac{1}{min}\right] T(t)$$
$$+ 0.2989 \times 10^{-6} \left[\frac{°C}{J}\right] Q(t).$$

4.6 Interative model of simulation

The mathematical model for simulation of these expressions is shown in Fig. 9; has been implemented with simulink

The outputs correspond to the values of height and temperature of the liquid. The process defined inputs with controllable inflow of liquid and the heat supplied by the heat source. The inlet temperature of the liquid is a parameter that affects system performance.

The external heat can come from any source of alternative energy, such as steam heat exchanger, an electric heater or simply others. Suppose that the amount of heat transferred from the resistance is proportional to the electric power supplied. If this heating is controlled by current $i(t)$, the expression is:

$$\frac{dQ(t)}{dt} = I(t)^2 \cdot R.$$

This expression is cumulative over time and can say that the rate of thermal energy transfer is proportional to i^2, so if you want to make current temperature control should be built on a linear element in a range where is performance control action [3].
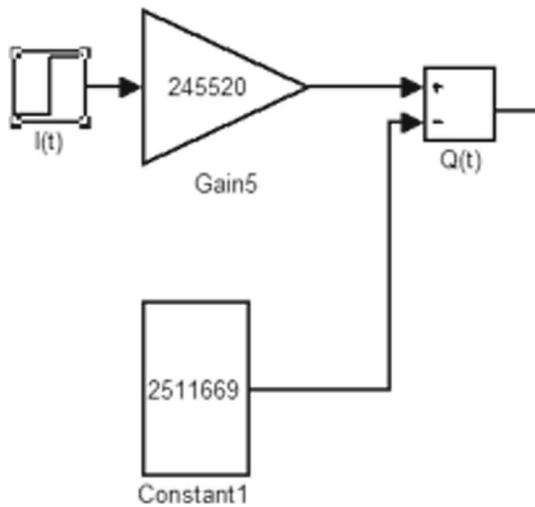
Fig. 10 Electric heat generator

$$R \cdot I_s^2 = 2.5116 \times 10^6 \left[\frac{J}{min} \right]$$

If $R = 100\,\Omega$ then $I_s = 20.459$ Amp
  Linearizing $R \cdot i(t)^2 = -R \cdot I_s^2 + 2R \cdot I_s \cdot i(t)$

$$Q(t) = -2511669 + 245520 \cdot I(t).$$

4.6.1 Time response

The time response allows us to observe the dynamics of the actuator or processes to stimuli presented at its inputs. The main observations refer to delays to stimuli when the input is stimulated with a step function. Other responses are considered as a sum of functions step, if it is LTI systems, the answer is the sum of each of the answers (Figs. 10, 11, 12).

In the FMSs has been given a maximum prefill time TO = 10 s, is expected that the fill the system would be able to meet this requirement. The student will then be able to play with the control parameters and so determine system constraints.

In the graph of response in time it is shown that the system has a response about time 150 s to 80 % of level and temperature, which guarantees the proper functioning in the system.

The temperature response of the system is observed aswell.

4.6.2 Frequency response

The frequency response makes relative to the dynamic capability of the components of the response time and proves so the Fourier transform of a function when expressed in time series as a function of frequency. Laplace helps calculate the behavior of systems and Bode frequency shows the relationship of inputs and outputs in frequency and phase (Fig. 13).

$$G_p s = \frac{H(s)}{F_i(s)}$$

4.7 Actuator controllers

The action of controllers is to force driver actuator response, such that the requirements expressed in the state machine is satisfied. Going back then to the protocol the requirements correspond to the responses h(t), T(t) just like the times the process takes to answer and most demanding form of response (Fig. 14).

The student now has a laboratory to test and validate the classical theory of continuous control (ref), changing the level of the input signals flow both as heat energy or pro-
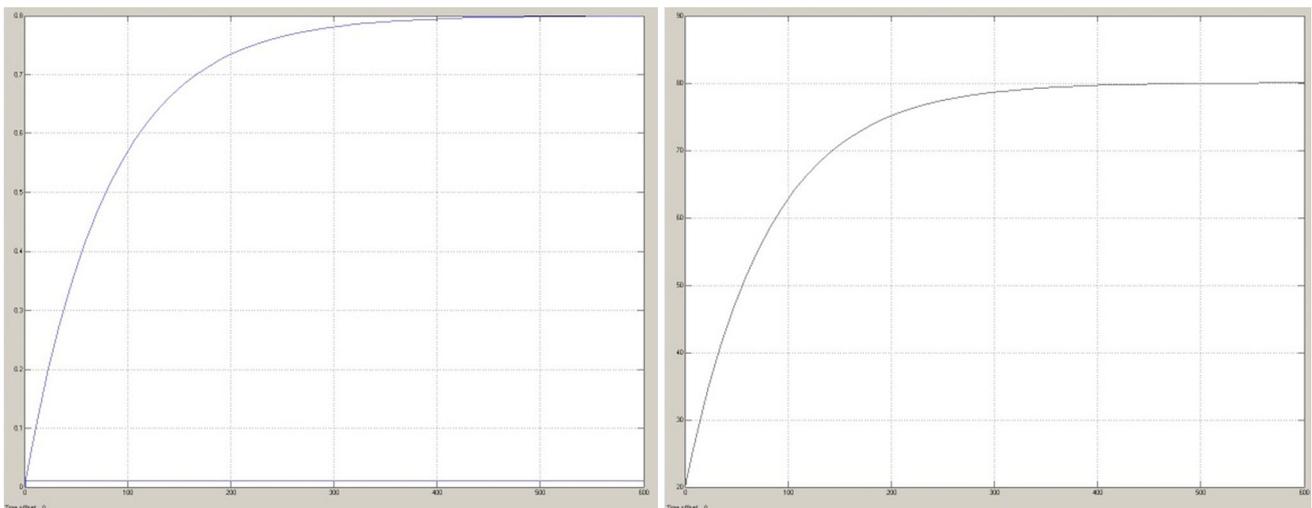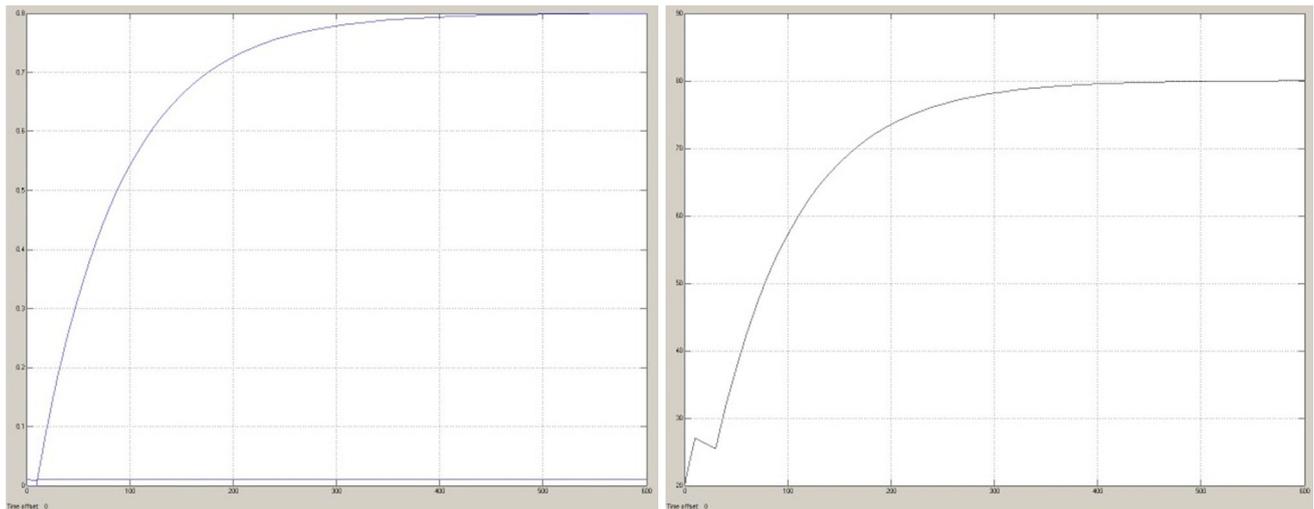

Fig. 11 Response breakeven

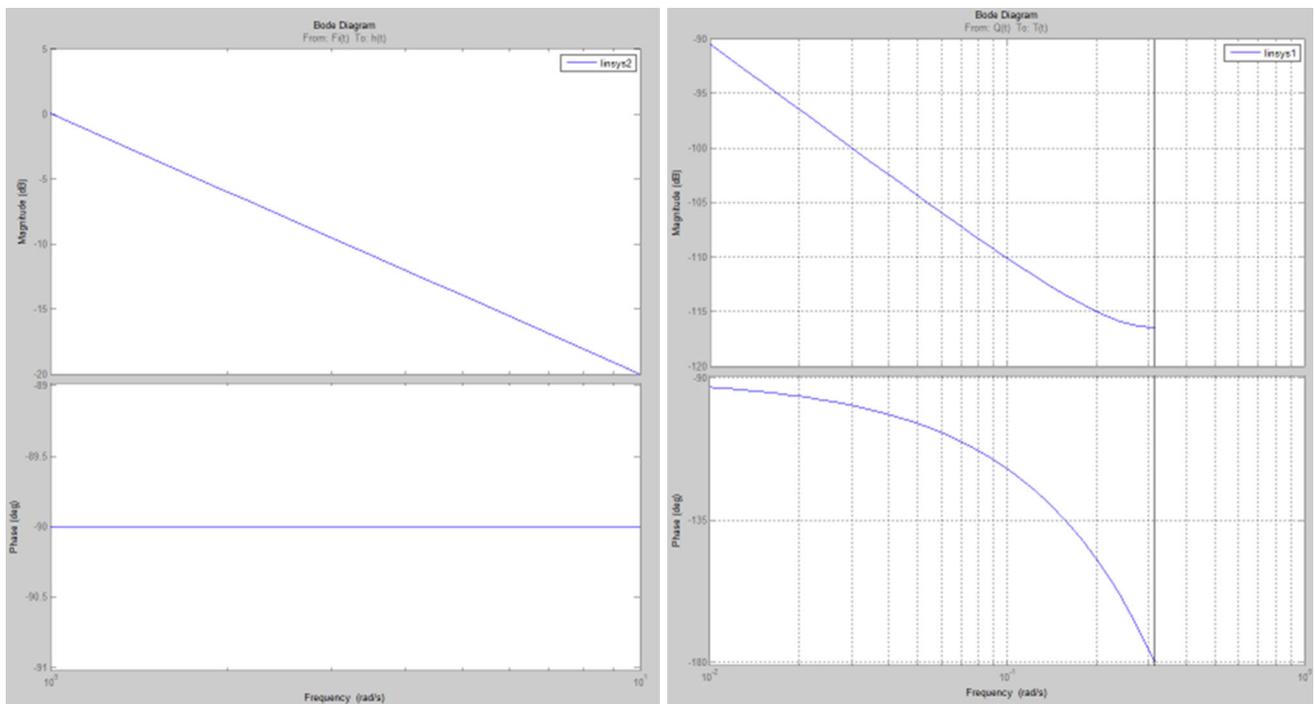**Fig. 12** Step response delay (level 10 s, temperature 30 s)

Fig. 13 Frecuency response of level (L) and temperatura (R)

duce disturbances in the inlet water temperature and make the respective analysis .

An example would be increasing the inflow by 50 %, in the graphs of Fig. 15 the changes observed in the levels of temperature output has been reduced by 30 % and the level value has grown by 40 % producing an overflow tank level.

With this objective in connection model of closed loop is added a PID controller device, which aims to force the behavior of the actuators for the best answer. Model has been included in the electrical resistance heating due to water. All

these variables are related among them for which is required a cautious and strategic program controller tuning, many authors present different methodologies for this procedure. The reference [7] shows the equations derived for this tune. The procedure developed in matlab following graphics shows the result of a tuning procedure (Figs. 15, 16).

4.8 Implementation of the solution

The implementation of this solution corresponds to the application and the technology platform that is available, eg with
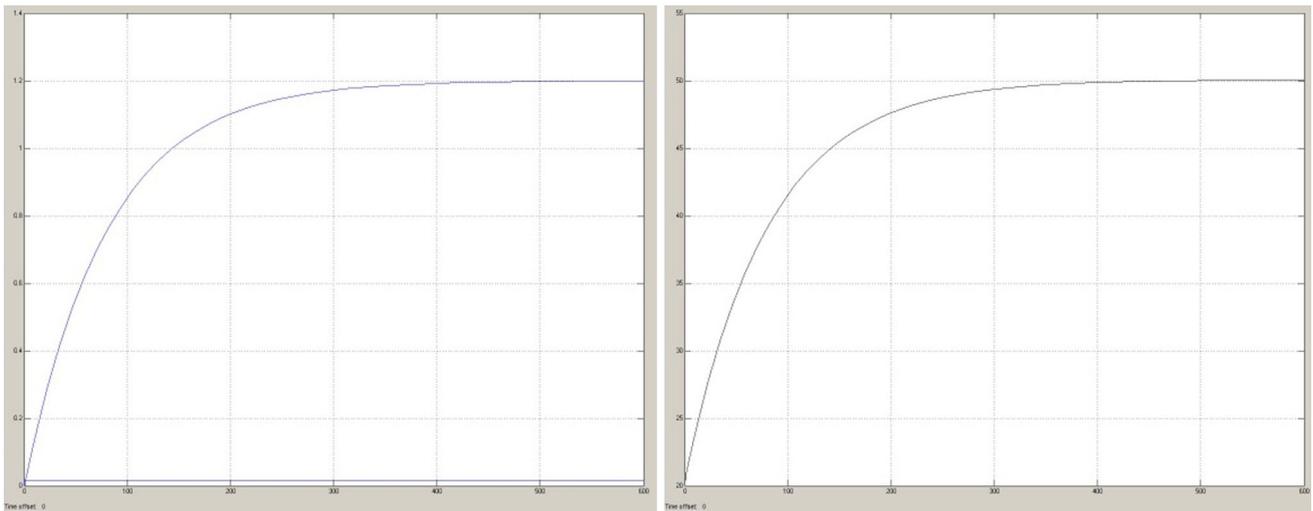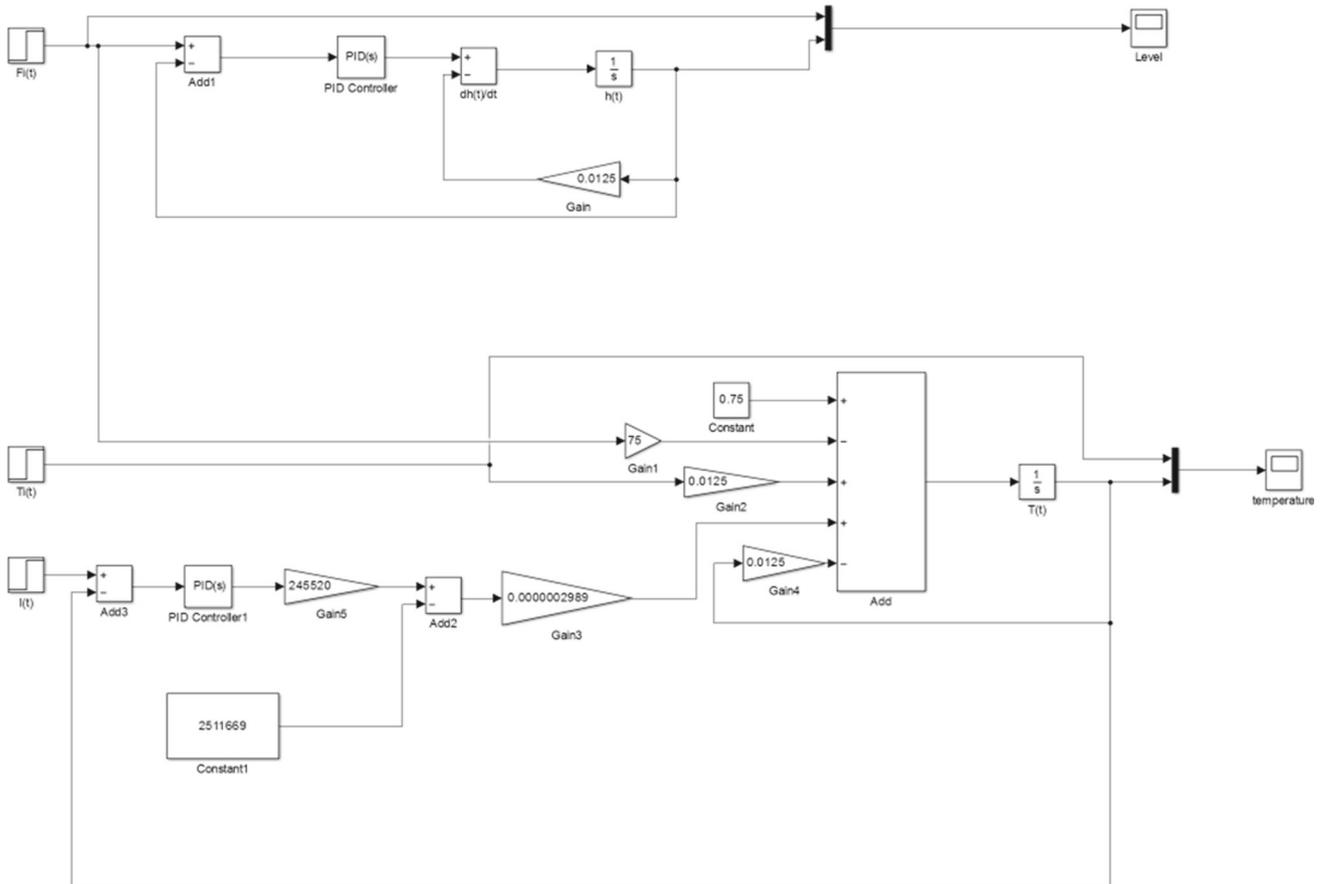
Fig. 14 Response to signal changes

Fig. 15 Model with PID controllers

a PLC, or pseudo-code programming or for graphic programming for processors or micro-controllers, or can also be implemented in hardware reset flip flop set–reset.

5 Results

This methodology has been used for several semesters teaching automatic control processes. The results are seen in the
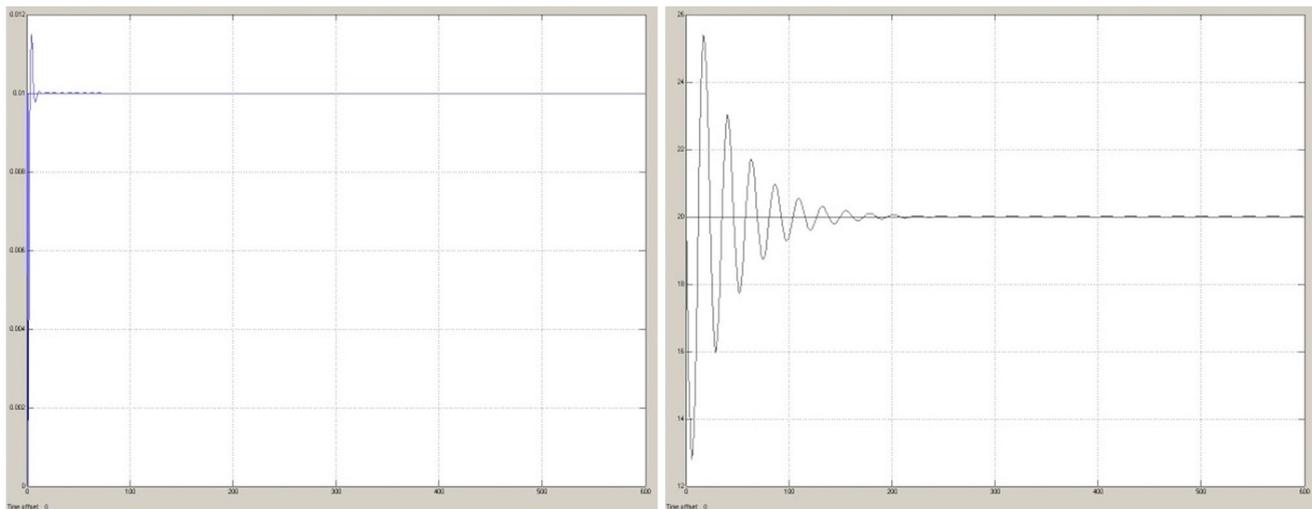
Fig. 16 Response controladores

concept of competency-based training in the contexts of being, knowing and doing.

Group work with defined roles, socialization projects, search and learning theories of knowledge and control, training in innovative processes are characterized by competitive affinity of the modern professional.

Experience has shown improved learning elements such as motivation, creativity, observation and flexible specification of its limitations.

System evaluation of a learning process innovation methodology ensures the result to the success and achievements are measured in quality aspects of the project from initial conception of the problem and the scope that the solution be sought. Here some students are more innovative than others, generating protocol specifications and limitations of the process which are successful that are designed with the logic that demands the interpretation of the problem. The non-logical concepts or errors are important because they contribute to learning in the case of failures but the solution generation soar. The methodology also provides search capabilities and understanding of traditional knowledge recorded in the books.

The typical problems the the students approach are related with the beer industrial plant control, milk pasteurization, food automatic dispenser, administration and industrial plant logistic control

Finally consistency is ensured when the group of students can do modeling or prototype solutions.

6 Conclusions

My students and I define them control the discipline that allows processes, machines or actuators work as I want in

physical, economic or technological limitations. This definition opens the door to innovation and creativity in the process industry.

The concept of innovation applied to projects that still have particular characteristics that make them unique, in that the processes take those characteristics, but to the extent that these processes repeat their solutions, controls acquire generic features, and develop a policy allowing industry around the problem of automation applied.

The control management structure is closely related to pedagogical teaching methodologies in innovation skills and creativity.

Being human in front of the user controlled processes simplicity and convenience of the man machine interfaces and looking forward to reflect on their being and consciousness to put things and technology for human.

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