The Gap From Scientific System Approach Down To Industrial Power Plant Control Engineering

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Summary : the aim of this paper is to highlight some process control competitiveness deposits to improve process control engineering. Rationale scientific foundations should be a significant contribution to improve process control of the future. To anticipate control systems through control engineering, we focus our interest in the definition of process control requirements and the definition of perennial control and document requirements, whatever the implementation into off-the-shelves I&C devices should be.

Introduction

This paper is an attempt to point out productivity deposits to improve process control engineering. Currently process control engineering is mainly a company made activity. One way to improve the competitiveness of control engineering (cost, project duration, quality, availability and safety) should be to develop explicit and rigorous method standing on scientific basis such as system theory.

The aim of this paper is to point out some current difficulties engineering companies have, Academic should overcome.

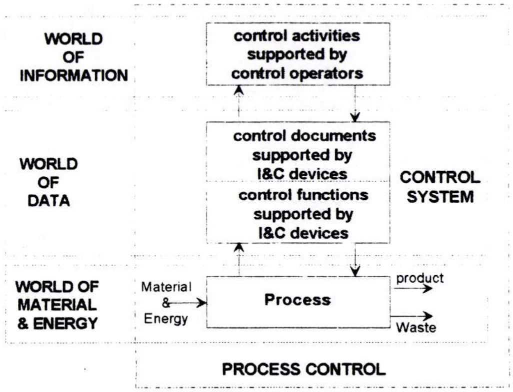

Figure 1: A control system and its environment.

Currently there is no universal definition for the words "process", "process control",

"control function", "control system"... We should define a control system as a set of control functions and documentation, embedded into Instrumentation and Control (I&C) devices (in the world of data) interacting with a process (in the world of material and energy) and control operators carrying out control activities (in the world of information), as summarized on figure 1.

N. Wiener said "information is information not material nor energy", we should paraphrase "data are data not material nor energy".

The distinction between data and information is not trivial. G. Bateson [1] said "a data is a track of an event (a footprint of a dinosaur), an information is a difference generating a difference".

We should distinguish world of data and world of information.

From figure 1, it appears that a control system is in fact a subsystem of a process control. The definition of a control system should depend on the process to control (whose representations stand on scientific foundations such as mathematics, physics, and chemistry) and the activities assigned to control operators (whose representations stand on scientific areas such as psychology, sociology).

The difficulty of control system is the lack of a unique and unanimous scientific reference. Currently the definition of a control system is often a forum standing on the know how of engineering companies, the skill of engineers and the return of experience of existing control systems.

For new engineers entering within control system area, the way from the definition up to the erection and commissioning of a control system is not fully explicit.

The control functions are defined from mechanical engineering studies, in general implicitly, furthermore, control functions and control documents are defined as programming schemes and mimics depending on the selected I&C devices. Here is a competitiveness deposit.

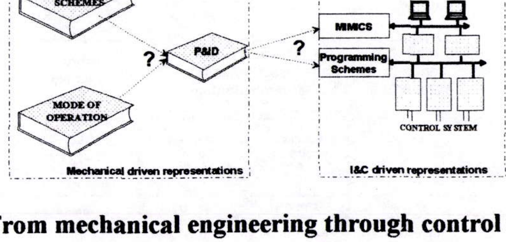

Figure 2: From mechanical engineering through control engineering

Defining control functions as programming schemes and control documents, as mimics should not be a problem if I&C systems are perennial. Unfortunately, technology evolution is very fast and I&C systems disappear due to the «Monopoly» between I&C suppliers: I&C obsolescence is fast (less than 10 years). In general, it is difficult to reuse control design on new I&C systems.

One way to improve control systems should be to explicit and to unify the life cycle of control system, in particular to achieve perennial and reusable control function and document requirements whatever the evolution of I&C systems should be.

We used the word "control" with several meanings. Among the scientific material we read and tried to understand, we could re-present the life cycle of control systems as a balance between the three points of views of the structuralism paradigm, with reference to J. Piaget [4,5].

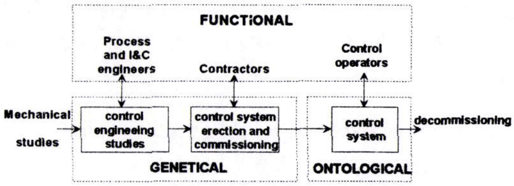

Figure 3: Control system life cycle.

- The genetic point of view should be the control engineering studies, the erection and the commissioning of the control system,
- The ontological point of view should be the control system itself,
- The functional point of view should be the activity engineers are carrying out for the genesis of a control system and the activities of control operators using a control system to control a process.

As suggested on figure 3, in the following sections we will focus on the possibility to anticipate control systems through control engineering improvements, in particular:

- A better representation of the process operation,
- The definition of process control requirements from the process operation representation,
- The definition of perennial control functions and control documents from process control requirements.

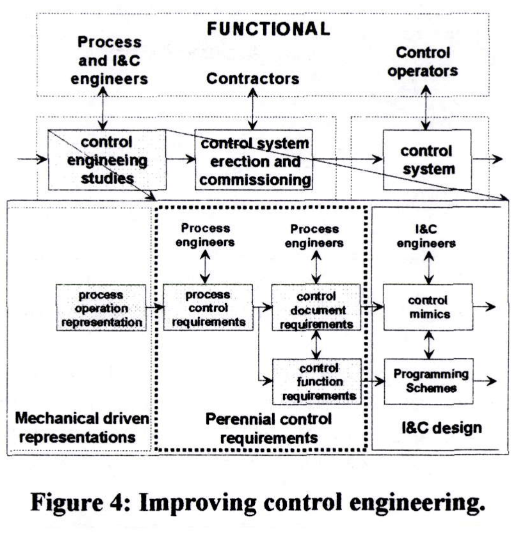

Figure 4: Improving control engineering.

Life Cycle Of A Control System

Academics have proposed system theories. To make short, if we try to apply this concept to a control system, we have to identify the limit of scope of a control system, a boarder between a control system and its environment.

From the genetic point of view, it is rather difficult to define a boarder because the control system doesn't yet exist, through engineering studies it is a virtual artifact. It becomes a real artifact through erection and commissioning.

On the basis of an explicit process operation representation, process-engineers should establish the process control requirements as a set of monitoring and control activities taking into account experience feedback and requested performances (safety, availability).

On the basis of the process control requirements, process-engineers should study and optimize the share of monitoring and control activities between control operators and a control system.

Once monitoring and control activities devoted to a control system should be identified; process-engineers should describe perennial control function and document (as human machine interface) requirements, taking into account process operation constraints (safety, availability, performance).

We point out that the control document requirements proposed by process-engineers should not be complete. The control documents should be completed and adapted in site to the real life process control gained during the commissioning.

The limit of scope of process-engineer studies should include the process control requirements, the control function and document requirements. The boarders of process engineer studies with their environment are virtual. To make short, as inputs, process-engineers need a process operation representation from mechanical engineering, as outputs process-engineers should deliver the control function and document requirements to I&C engineers.

Once the requirements of control functions and documents are set up and validated, I&C-engineers should design a control system (selecting off the shelves I&C devices), compliant with the control function and document requirements. The control functions requirements should be translated into programming schemes, distributed and implemented into the I&C devices of the control system. The control document requirements should be translated into mimics and implemented into the I&C devices of the control system.

The limit of scope of I&C-engineer studies should include the design of the control system, the translation of the control function and document requirements into programming schemes and mimics, the distribution and the implementation of the programming schemes and the mimics into the control system. The boarders of the control system design studies are virtual. To make short, as inputs, I&C-engineers need the control function and document requirements, as output, I&C-engineers deliver a validated design of the control system.

Once the control system is designed, contractors erect the control system from I&C devices in conformance with the control system design. The control system is commissioned in conformance with the process control requirements. The boarders of the control system are becoming real from the erection down to the commissioning. To make short, as inputs we have the control system design and off-the-shelves I&C devices, as output we have a control system ready to use.

From the ontological point of view, a control system is existing and we can describe it as hardware and software. It is an artifact control operators use to control a process. The boarders of the control system are «real». To make short, as inputs we have data from transmitters and control operators, as outputs we have data to actuators and to control operators.

From the functional point of view, we point out that the limit of scope of a control system is different for process-engineers, I&C engineers, contractors and control operators.

We point out that there is a rupture between the world of mechanics and the world of process control. Here is a difficulty to explicate the definition of control functions and documents from mechanical engineering studies. We will try in the following section to highlight this difficulty.

For engineering companies, anticipating the control system through engineering studies is important. The objective of reducing the cost and improving the quality of control engineering should be satisfied through explicit and standardized studies standing on reusable library of generic elements.

From Academic system theories, a system is presented as a set of elements interacting together and with the environment.

The question we will try to answer is: what are elements and interactions of control systems and how to define them?

The aim of a control system is to help control operators to control a process. Before defining a control system, we have to identified what must be controlled within the process.

Process Operation Representation From Control Point Of View

The intention of this section is to highlight what should be a representation of the process operation dedicated to control needs.

Here is a difficulty. To represent an objet means to be directed by an intention, see H. Putmann [6]. The intention of the representation of process operation (to know what and how to control) should be directed by control engineering, unfortunately the description of any process operation needs knowledge from mechanical engineering. In general this representation should be carried out by mechanical engineering to satisfy control engineering. In fact, we need a common representation understandable in these two worlds.

To describe the representation of the process operation, we should interpret the work of P. Delattre [2] pointing out that a process must be represented from three points of views (the structure, the operation, the behavior) or any association of these points of view.

We should define a process as a network of operations supported by a structure and evolving with the time.

A structure should be any process equipment (pipes, tanks, pumps,…).

Mechanical schemes are representing the structure but from the point of view of structure dimensioning and topology. From mechanical engineering an element should be a piece of the structure, the interactions should be the ordered network interconnecting the pieces of structure.

From the control point of view, process-engineers are interested by the operation on material and energy to monitor and to control.

We point out that operations on material and energy can't be monitored and controlled directly on material and energy, but only through the structure (transmitters and actuators).

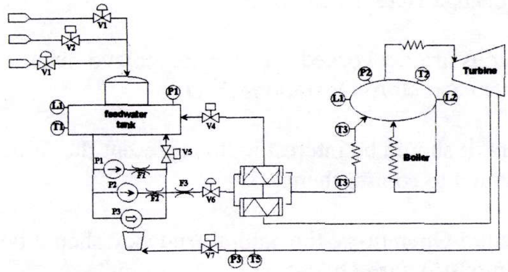

Figure 5: Structural scheme of a process.

A representation of the structure of a process, suited to process-engineers, should be a scheme describing a process as an ordered network of main structural equipment, indicators and transmitters (used to monitor) and actuators (used to control). Figure 5 should be an example of structural scheme suited to process-engineers.

We point out that, in general, each piece of structure is supporting a dedicated operation, for example a pipe is designed to contain a flow of energetic material, a tank is designed to store energetic material.

Within a process the structure and the operations on material and energy are tightly coupled, in general not separable. We suggest to highlight this link between the structure and the operation and to introduce the composed word "structure-operation" ("s-o").

A process should be a network of structure-operations evolving with the time.

We point out that the structure-operations are not networked anyhow. The process is organized as an ordered network of structure-operations taking into account laws of physics and constraints of the structure.

The identification of the organization of the ordered network of structure-operations is of key importance to monitor and to control a process.

From the control point of view, a process element should be a structure-operation; the interactions should be the exchanges of material and energy between the Structure-Operations.

A structure-operation should be a linear causal element within the range of operation. For the same material and energy as inputs, for the same operation within the same structure, we have the same product and waste as outputs.

Within a process, we can distinguish different types of structure-operations:

- Pipes allow to contain flows of energetic material, pumps allow flows of energetic material to be transported. Valves allow energetic material to flow or not,
- Tanks allow to store energetic material,
- Exchangers allow to cool a primary water flow and to heat a secondary water flow,
- Boilers allow to change water into steam...

The structure-operations are networked together to achieve macro structure-operations, we propose to call them Structure-Operations (S-O).

For process-engineers, it should be interesting to represent the Structure-Operations and the means to monitor and to control them.

To identify the Structure-Operations, the natural tendency should be to partition directly a structural scheme into Structure-Operations.

P. Watzlawick [8] points out that the reality, for human beings, is emerging from the visual sensations mainly capturing the topology, the structure of any system.

For process control, the difficulty is that the point of interest is not in the structure of the process, as summarized on figure 5, but it is the ordered network of Structure-Operations of a process.

The following figure 6 should be an example of a structure scheme of a electric system as a network of a grid, hydro plants and thermal plants.

The natural tendency should be to partition the electric system in Structure-Operations as suggested with the doted lines on figure 6: one Structure-Operation for the grid, one for the hydro plant and one for the thermal plant.

But in our example, the behavior of the frequency of the grid is depending on the inertia of the electrical generators of the plants, which is not accessible to visual perception but to the process control know-how. It means a partition of the electric system into Structure-Operations is not a partition of the structure but a partition as an ordered network of Structure-Operations as suggested with the full lines on figure 6.

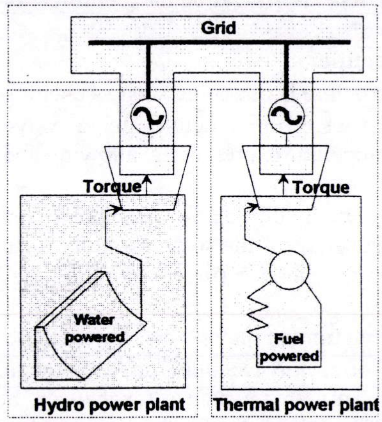

Figure 6: Structure-Operation scheme of an electric system.

We point out that on figure 6 the Structure-Operations are emerging from the equilibrium between mechanical production and consumption, upstream and downstream the mechanical torque.

The boarders of any Structure-Operations should be defined on the same principles of equilibrium within the different domains (electrical, mechanical, hydraulic, thermal, chemical…).

A Structure-Operation scheme should be a representation adapted to control needs, this representation is different of the mechanical schemes aiming at representing the dimensioning and the topology of the structure.

The difficulty of the identification of Structure-Operations is to define a boarder for each Structure-Operation and to achieve a consistent network of structure-operations.

Note: Currently there is no rigorous and unanimous terminology nor academic-based theory or method to identify Structure-Operations of a process.

Nevertheless, we should try to pave the way for a representation of a process as an ordered network of structure-Operations to monitor and to control.

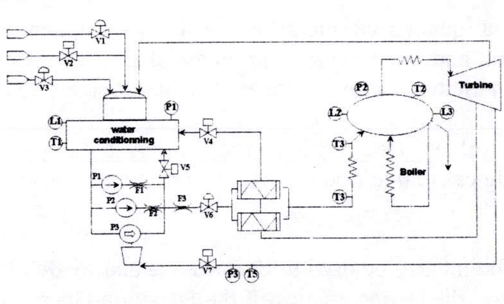

Figure 7: Structure-Operation scheme.

Figure 7 should be an attempt to represent a Structure-Operation scheme. The difference with a structural scheme should be the identification of a Structure-Operation from:

- Structure-Operation identifier,
- Domain in which the structure is operating such as chemical, thermal, hydraulic...
- Values of the characteristics of the structure such as valve open, pump on... and of the operation such as temperature, pressure... allowing and identification of the state of the Structure-Operation),
- Upstream and down stream conditions, for example a feed-water system should be able to feed the steam generator if the source output pressure is greater than the sink pressure within the steam generator (in this example the pressure is analog to the torque on figure 6),
- With a different representation on the scheme, for example a different color,
- With a different semiotic, for example on a structure scheme the pieces of equipment should be identified by names (exchanger, boiler...), on an activated Structure-Operation scheme they should be identified by activities (cooling water, boiling water...) representing the Structure-Operations in progress.

A Structure scheme is "time independent" but a Structure-Operation scheme is "time dependent". To complete the interpretation of P. Delattre work, we have to introduce the behavior of the process.

A process should evolve continuously. It is possible to master the evolution of a process through process states.

P. Delattre [2] proposed to defined the states with characteristics. As a process is an ordered network of Structure-Operations, we should have the characteristics of the Structure-Operations and of the process.

Through the evolution of the characteristics of a Structure-Operation, it is possible to identify that a Structure-Operation / process is in a given state when the values of the characteristics are corresponding to the values of a reference state of the Structure-Operation / process.

For each Structure-Operation, we should have intrinsic characteristics (internal properties); we also should have extrinsic characteristics imposed by the process to the Structure-Operation (safety, availability, mode of operation, upstream and downstream interlocks).

A characteristic is a qualitative identifier. A unique alphanumerical identifier is dedicated to a unique and unambiguous property of a Structure-Operation. It can be completed with a quantitative value (a data and its measurement reference).

These Quantitative values should be analog within a range of values (pressure, temperature...) or logical (valve open, intermediate position or closed, valve available or not...).

The characteristics should also be used to characterize and to identify the process states. For each process state, the characteristics of the Structure-Operations should be valued (a value or undetermined).

For each state of the process, each Structure-Operation is determined by valued characteristics related to:

- The structure (for example, valve open, pump on, exchanger unavailable, Structure-Operation in operation ...),
- The operation (for example, pressure, temperature, level threshold...).

Different types of re-presentation of the states of a process can be defined. For example, the easiest re-presentation should be a matrix for each process state, with on the rows, the Structure-Operations, on the columns their valued characteristics (intrinsic for the structure and the operations, extrinsic for upstream and downstream interlocks).

Another way to represent the states of a process should be to value the characteristics on the Structure-Operation schemes; this should be a better suggestive representation, figure 8.

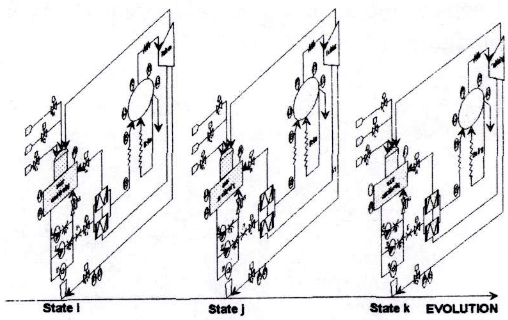

Figure 8: States of a process.

For normal operating, in a predefined state the process is in a steady state. The activated Structure-Operations are synchronic together and in a steady state. It means we have steady-state relationships between the characteristics of the Structure-Operations.

For normal operating, we have a transient when the process is moved from one state to another one. The Structure-Operations are diachronic some should move to "in operation" some others to "out of operation". It means we have relationships between the characteristics and the states of the process.

Abnormal operation is when a failure occurs on a piece of the structure or when an operation is not correctly executed.

An incident is a failure occurring on a piece of a structure or on an operation but the integrity of the process is maintained. In general an incident can be recovered by acting on the structure or to move towards a safe lower energetic state, without impact on the environment.

An accident is a failure occurring on a piece of a structure or on an operation but the integrity of the process is not maintained. We can recover accidents, which have been studied by acting on the structure, to move the process towards a safe lower energetic state and minimizing the impact on the environment.

For a complete representation of process operation, we need to describe two parts: the main process part and the auxiliary part.

The main process part is the process operating on raw material and energy up to the end product and wastes. The auxiliary part is the process (for example power supply, air supply, ventilation) allowing the normal operation of the overall unit.

We point out that the partition between the main process part and the auxiliary part can be also considered as a partition in different domains.

For complex processes, it may be difficult to manage the complexity of a process on a single scheme. To cope with this complexity, we should propose to aggregate structure-operations.

On a Structure-Operation scheme each Structure-Operation is detailed with structure-operations. Each Structure-Operation could be aggregated as a Structure-Operation block, as suggested on figure 9.

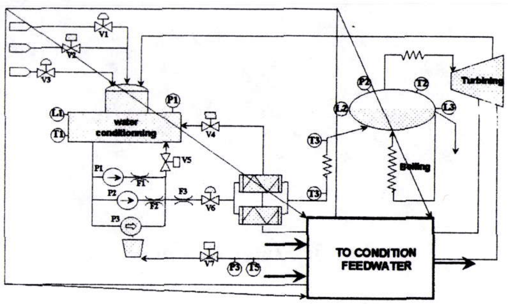

Figure 9: From Structure-Operation description to Structure-Operation block.

Structure-Operation block called “feed-water conditioning”. If we compare this Structure-Operation block with the figure 7 which is “water conditioning” we can notice that the structure used by these two Structure-Operations are different, even if the conditioning seems the same.

In fact, in figure 7, the Structure-Operation is aiming at conditioning, in stand-alone, water contained in the feed-water tank. In figure 9 the Structure-Operation is aiming at conditioning water contained in the feed-water tank in order to feed the steam-generator in producing steam. In the two cases, the water is conditioned but we are in two different states of the process.

Figure 10 should be a Structure-Operation block scheme of a steam generator.

A Structure-Operation block should be represented by a graphical symbol (a suggestive icon of the aggregated structure-operations). The links between the Structure-Operation blocks should represent the exchanges of material and energy, the arrows the flow of material and energy.

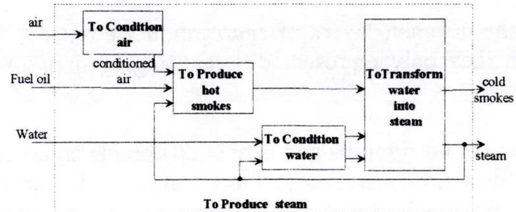

Figure 10: Structure-Operation block scheme of a steam generator.

Note: Currently there is no rigorous and unanimous academic-based theory or method to optimize aggregation of Structure-Operations, such as the macroscopic properties of any Structure-Operation should be issued from the best conjunction of the properties of the structure-operations and of the properties of the network interconnecting the structure-operations.

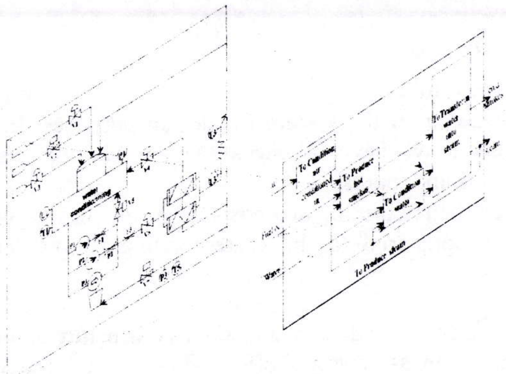

Figure 11: bottom-up aggregation of structure-operation into Structure-Operation block.

On a Structure-Operation block scheme, it should be easier to master a complex process as an ordered network of Structure-Operation blocks.

We point pout that the Structure-Operation blocks are not networked anyhow. The Structure-Operation blocks are ordered taking into account laws of physics and industrial feasibility constraints.

Within the aggregations, it is possible that some properties of structure-operations are not properties of Structure-Operation because they are too weak. In opposite we can have new properties for an Structure-Operation due to the interactions of structure-operations. The aggregations of Structure-Operations can have additive, over-additive and under-additive properties of the structure-operations.

For complex processes we could have different layers of aggregation between the lowest Structure-Operation schemes up to the highest Structure-Operation block scheme of a process.

We point out that the different layers of aggregation are not representing a structural hierarchical system, they only represent different aggregations of a single an unique process.

Note: Currently, there is no rigorous and unanimous graphical languages to describe in consistent way the Structure-Operation schemes and the different layers of aggregation of Structure-Operation block schemes (to improve the understanding it should be possible to use suggestive icons instead of rectangles).

On Structure-Operation schemes, process-engineers should be able to identify easily the Structure-Operation and how to monitor (indicators and transmitters) and to control (actuators) these Structure-Operations and the process.

The operation of the process is depending on the evolution of the Structure-Operations. It is possible to anticipate the evolution of a process through simulation.

Process Simulation

The aim of models is two folds:

- Anticipate the behavior of the system for design purposes. In that case, from the open loop prevision, we have to check the closed loop response for different predefined situations and inputs,
- Explain the system behaviors for diagnosis purposes. In that case, the behavior of the subsystems is compared to the corresponding sub-models submitted to the current inputs.

A good model should, on one hand, have a qualitative structure compliant with the basic physics (equilibrium of mass, energy, effort, flux,...), on the other hand, have a quantitative behavior closed to the current system, which is easier to achieve tuning parameters on state models.

This leads to a compromise, which means a good choice and identification of characteristics depending on the point of interest.

We point out that the characteristics must be understandable in the worlds of mechanics, control engineering and control operators (for example resistance, storage and inertia).

These characteristics are chosen to be, on one hand, explicitly related to the physical characteristics of the structure and of the Structure-Operations of the process, and on the other hand to be easily identified in the process control activities (see next section) as suggested on figure 12.

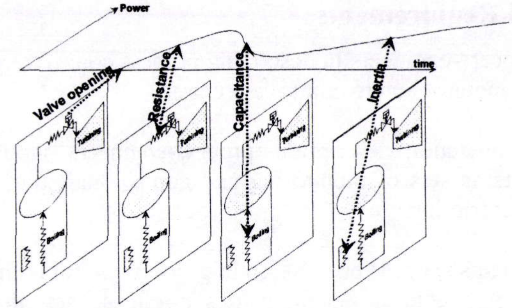

Figure 12: Contribution of the Structure-Operations to the behavior of the process.

Another feature is related to the aggregation of the characteristics. Let us consider a reference production system (figure 6) composed with three Structure-Operations. The open loop response of the production system to a step input load demand is linear in less tan 30 seconds speed limitation. This minimum response is at least required to avoid, in case of large disturbance, frequency drop under protection limits.

If we aggregate two thermal or hydro Structure-Operations (a minimum phase response and non-minimum phase response in less than 30 seconds) in equal proportion, the open loop behavior of the aggregated system should answer to the reference production system. Nevertheless, the closed loop response is unstable.

We conclude of this apparent paradox that a specification on open loop dynamic response (behavior) of a Structure-Operation is not sufficient to guaranty closed loop or interconnected operation.

The problem occurs from linearity. In our example, we are not allowed to assimilate the sum of linear characteristics to a non-linear (speed limitation) one.

In general, for modeling we have to take into account the fact that the parameters of the models depend on the states (displacement, and impulse).

In fact, in our example the speed limitation is due to the actuators. We have to explicit in a standard way the different limitations of the actuators within the units (limitation of speed, limitation of amplitude, limitation of insensitivity).

The Structure-Operation model should be completed by a dual model we should call "Structure-Operation/evolution" model describing, from the user point of view the different states and the transients, the production system has to meet.

An other general question arises from this example. For the grid user point of view, what minimum specification do we need, to avoid interference with the design of the units?

Process Control Requirements

The intention of process-engineers in describing process control requirements should be to represent how to monitor and to control a process.

From the process operation description, process-engineers should describe process control requirements as sets of monitoring and control activities, compliant with the process operation description.

When process-engineers start the description of process control requirements, they don't mind if operators or a control system carries out these activities. Currently, these monitoring and control activities are set up from the implicit process operation feedback, the know-how of the companies and of the process-engineers.

As the process is an organized and ordered network of Structure-Operations, process control requirements should be a structured (compliant with process operation organization) description of the monitoring and control activities of the individual Structure-Operations and of the process, explicating:

- How to organize the monitoring and the control of the Structure-Operations and of the process within the states,
- How to order the monitoring and the control of the Structure-Operations to move the process from one state to another one.

To achieve explicit, complete and validated process control requirements, with reference to Walliser [7], we need to define two types of process control requirements:

- Diachronic process control requirements: to change the state of the process,
- Synchronic process control requirements: to maintain the process in a steady state.

The diachronic process control requirements is a complete set of ordered monitoring and control activities allowing to move the process from one state to another state. The states are defined in the process operation description.

The synchronic process control requirements is a complete set of monitoring and control activities to maintain a process in the steady states. The steady states are described in the process operation description.

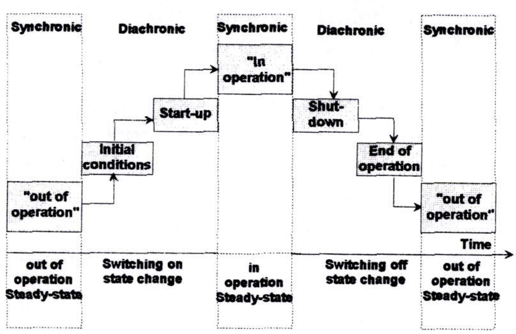

Figure 13: process control requirements as synchronic and diachronic control requirements.

Note: Currently there is not a rigorous and unanimous academic-based theory, nor a method, nor a graphic language, nor a formal language to define process control requirements.

Currently, only pragmatic and heterogeneous methods are used in the different area of process industry, standing on the company know-how, the skill of engineers and the return of experience.

We should try to pave the way in explicating how to represent the monitoring and control requirements.

From power plant operation feedback, we should identify different steps to move any Structure-Operation and a process from one state to another one. We should focus on Structure-Operations control requirements before process control requirements.

For normal operation, most of Structure-Operations should have two steady states: "out of operation" and "in operation". Some others Structure-Operations should have more than two; the principle we describe should be the same.

For normal operation, most of Structure-Operations should evolve in four steps, to move from "out of operation" steady-state to "in operation" steady state and vice versa, as suggested on figure 14.

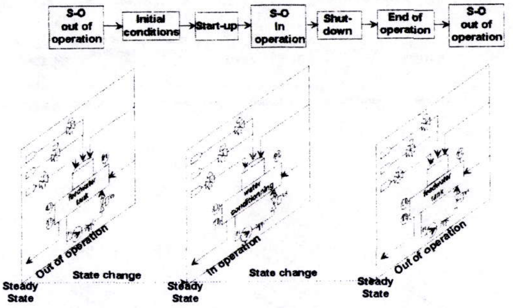

Figure 14: Structure-Operation control requirements.

In the first step, "out of operation" steady state, we should have monitoring activities to check the integrity and the availability of the structure-operations (including the auxiliary structure-operations).

In the second step, we should have monitoring and control activities to configure the structure (for example the circuit alignment to prepare the introduction of material and energy) and to check the upstream and downstream pre-conditions and interlocks allowing to start the Structure-Operation.

In the third step, we should have monitoring and control activities to launch the operation on material and energy and to achieve the nominal operation of the "in operation" steady state.

In the fourth step, "in operation" steady-state, we should have monitoring and control activities to maintain the Structure-Operation in a steady state, as far as some incident can be recovered within the structure, and preventing the environment against Structure-Operation accident.

In the fifth step, we should have monitoring and control activities to shutdown the operation on material and energy.

In the sixth step, we should have monitoring and control activities to remove residual material and energy to clean the Structure.

In the seventh step, we should have monitoring and control activities to restore the Structure-Operation in the "out of operation" steady state.

The monitoring and controlling activities are described in a textual way. For each monitoring activity, we should have a verb describing the activity (verify...), a characteristic identifier (the temperature of...) and the aim of the monitoring (is lower than...). For each control activity, we should have a verb describing the control activity (open, fill in...), a characteristic identifier on which the control is applied (the valve... the tank...). These activities should take profit of the return of experience, from unit operation.

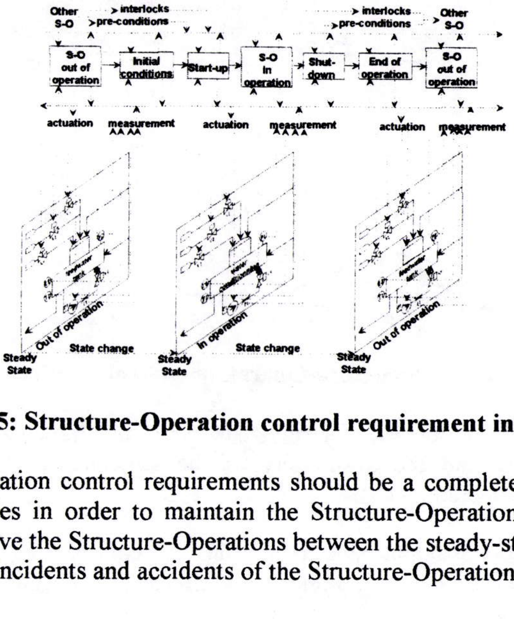

Figure 15: Structure-Operation control requirement interfaces.

The Structure-Operation control requirements should be a complete set of monitoring and control activities in order to maintain the Structure-Operation in the predefined steady-states, to move the Structure-Operations between the steady-states and to recover a predefined set of incidents and accidents of the Structure-Operations.

Structure-Operation control requirements should also include requirements for the measurements and actuations (accuracy, performance, availability, and safety) requested to carry out the monitoring and control activities.

Structure-Operation control requirements should also include requirements for the up-stream and down-stream pre-conditions and interlocks to network the Structure-Operation as part of the process control requirements

Structure-Operation requirements should be standardized. For example each step should be a standardized requirement blocks (out of operation, initial condition, start-up, in operation, shutdown, in operation).

Each block should have inputs, measurements from the process, pre-conditions and interlocks from internal blocks and from other Structure-Operation requirement blocks. The outputs should be actuations to the process, pre-conditions and interlocks to internal blocks and to other Structure-Operation requirement blocks.

The requirement blocks should contain a graph of serial/parallel monitoring and control activities. The requirement blocks should be ordered for a Structure-Operation. Each block should be activated (for example start, stop, idle).

As a process is an ordered network of Structure-Operations, process control requirements should be an ordered network of Structure-Operation control requirement blocks, as suggested on figure 16.

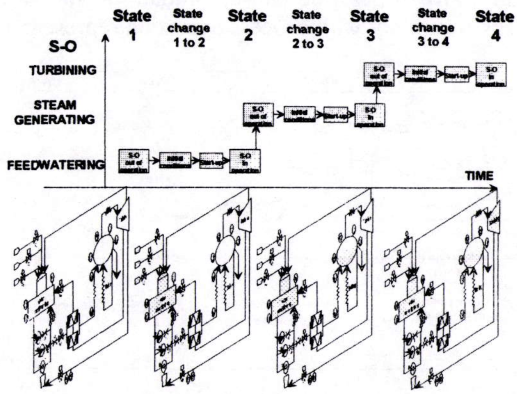

Figure 16: Process control requirements of a steam production process.

On figure 16 are suggested the steam generator control requirements. We point out that the requirements are in fact an ordered graph of Structure-Operation requirement blocks. Each block is a sub-ordered-graph of monitoring and control activities. Each Structure-Operation block is network with the related up-stream and down-stream blocks.

We point out that the structure of the requirements is not a hierarchy of power, it is a hierarchy of organization where the information must flow between each block to achieve and autonomous system. We can refer to Laborit [3] "*each cell, each organ, each system control nothing, but each cell, each organ, each system, receive information to know what it has to do, to co-operate to the operation of the overall system. Each cell, each organ, each system send information to the rest of the overall system to request needs to be satisfied to continue to operate in good conditions... This double circulation of information is fundamental to understand...to achieve an autonomous overall system*".

We should paraphrase as each requirement block receive information to know what it has to do, to co-operate to the operation of the overall process. Each block send information to the rest of the overall requirements to request needs to satisfy to continue to operate in good conditions.

It appears that the characteristics defined within the process operation description are used within the requirement blocks.

We also point out that only the states of the process are defined in the process operation description. The added value of the process control requirements is to explicit how to maintain the steady states and to propose how to move from one state to another one.

To improve the quality and to reduce the costs, the process control requirements should be written with a process control requirement function block language. This language should allow to build blocks and to reuse standardized blocks available in a library.

This language should allow to describe and to validate by simulation the definition of the requirement blocks compliant with process operation representation and feedback.

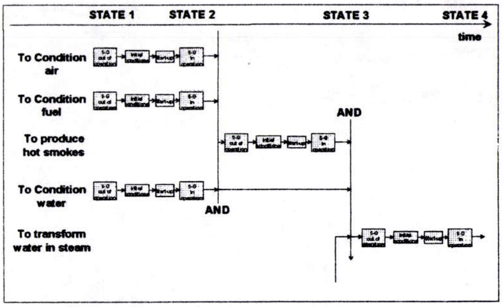

Figure 17 process control requirements.

It should be also interesting for process-engineers to optimize the ordering, the coordination, the pre-conditions and the interlocks between the requirement blocks, to reduce time of start-up and shut-down of the process.

Last but not the least, plant management should be interested to prepare the start-up, the shut-down and the non scheduled activity in order to optimize the monitoring and control activities to save time.

Once the process control requirements should be defined and validated, control activities should be shared between control operators and a control system.

Here is a difficulty to share monitoring and control activity processing between operators and a control system.

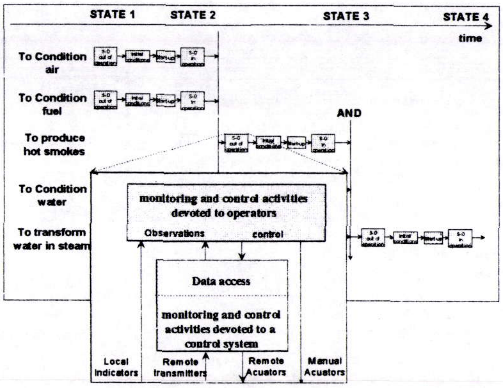

Figure 18: share of monitoring and control activity processing between control operator and system.

Note: Currently, there is not a rigorous and unanimous academic-based theory, method or language to share and to optimize the activity processing, between control operators and a control system, taking into account control operator and control system performances, such as activity duration, serial and parallel activity management capacity, activity planning, availability, safety, cost.

Currently, only pragmatic and heterogeneous methods are used in the different area of process industry. The share of control activity processing between control operators and control systems is implicit standing on the company know-how, the skill of engineers and the return of experience.

Monitoring and control activities should be devoted to control operators when the monitoring activities need to access to local indicators and the control activities to manual actuators.

The allocation of monitoring and control activities to control operators should also take into account the desired level of automation and the related definition of the control team and the distribution of the activities between the operators (unit chief operator, process part operators, shift operators…).

Monitoring and control activity processing should be devoted to a control system when the monitoring and control activity performances (accuracy, availability, safety) are too high or repetitive. In general the synchronic activity processing is allocated to a control system (activity processing related to protection, controlling characteristics in steady states and surveillance).

A process control requirement function block language should be an interesting tool for process-engineers. They could analyze and optimize meaningful and rational share of activity processing between control operators and a control system, taking into account estimated activities duration (from return of experience of unit operation), response time of the process and performances of control operators and control systems. Activity processing should not be restricted to control but should also include periodic tests, maintenance and technical management activities.

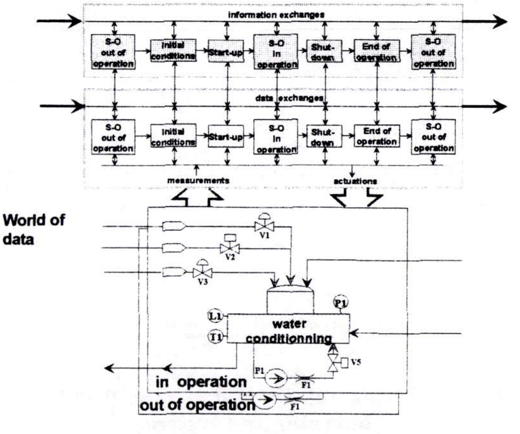

Figure 19: share of activity processing between operators and a control system.

Process control requirements should also include requirements for Human machine interface (safety, availability and performances), in particular the presentation of monitoring measurements, the presentation and the control of actuation and Structure-Operations, last but not the least, the alarm presentation.

From the process control requirement point of view, we should define an element as the set of monitoring and control activities dedicated to a Structure-operation. The interactions between the elements should be the exchanges of information between activities dedicated to the control operators and the exchanges of data between activity processing dedicated to control system, figure 19.

Monitoring And Control Function Requirements

Let us make the assumption that the process control requirements are available and the share of activity processing between operators and a control system is completed and validated.

Standing on the activity processing devoted to a control system, the intention of process-engineers is to translate the activity processing into monitoring and control function requirements with a semi formal language.

The monitoring and control function requirements should consist in identifying each monitoring and control function and describing the inputs, the outputs, the processing, the control operator and the control function access needs and the performances.

For synchronic and diachronic process control, we can distinguished four types of monitoring and control functions:

- Measurement monitoring functions: elaboration of a measurement from one or several transmitters (for synchronic and diachronic purposes),
- Open loop control functions: controlling on/off actuators with respect to one or several measurements and/or with respect to an order from an operator or a sequence (mainly for synchronic purpose),

- Closed loop control functions: controlling modulated actuators with respect to one or several measurements and a set-point (mainly for synchronic purpose),
- Sequence control functions: controlling on/off actuators, sequencing open and closed loop control functions and other sequences (mainly for diachronic purpose).

Process engineers should translate the monitoring and control activity processing into monitoring and control functions, for each Structure-Operation and for the process, with a special care for measurements and actuations.

Measurements are used to monitor characteristics of Structure-Operations. Measurements should be used by operators, for monitoring and control activities, and by monitoring and control functions.

For each measurement process-engineers should describe the requirements as performances (such as engineering unit, accuracy, update, safety, availability, failure reporting). Process-engineers should also describe the control operators, monitoring and control function access needs. These requirements should be a set of attributes encapsulated into a measurement requirement block.

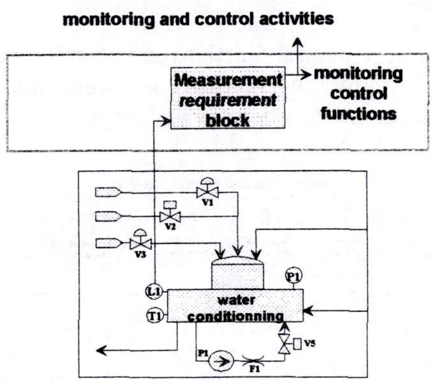

Figure 20: measurement requirement block.

Actuations are used to control directly or not characteristics of Structure-Operations. Actuations should be used by operators for control activities, and by control functions.

For each actuation process-engineers should describe the requirements as performances (such as type of actuator, power supply, type of power interface, instrumentation, response time, safety, availability, failure reporting). Process-engineers should also describe the control operators and control function access needs. These requirements should be a set of attributes encapsulated into an actuation requirement block.

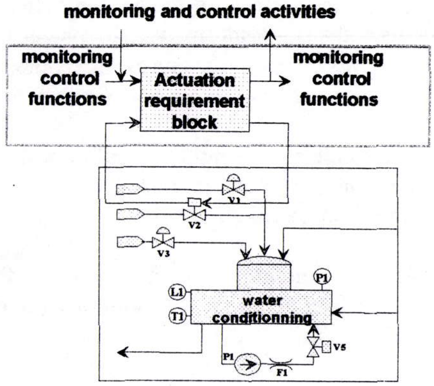

Figure 21: actuation requirement block.

Once the requirements of measurements and actuations are completed, process-engineers should identify the monitoring and control functions, as:

- function Identifier,
- Inputs (from measurement, control functions and control operators),
- Outputs (to actuation, control functions and control operators)
- Performances (such as accuracy, safety, availability).

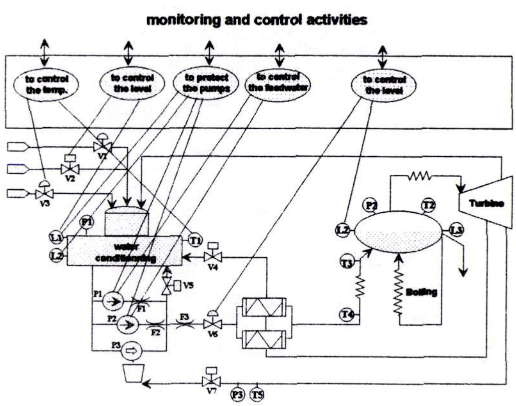

Figure 22: identification of the monitoring and control functions.

Process-engineers should also detailed the requirements of the monitoring and control function with a function block language.

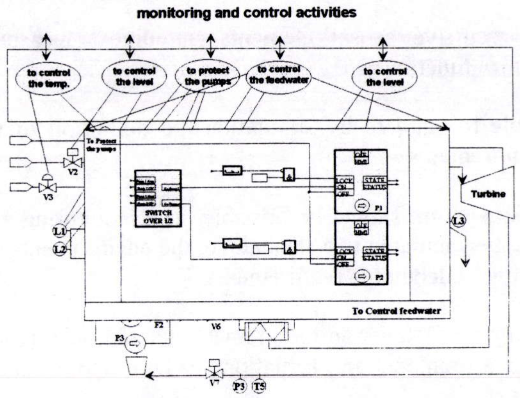

Figure 23: Control function requirement diagram of the control function "to control feed-water".

Each monitoring and control function requirements should be detailed as networks of Elementary Function Blocks (EFB) and Application Function Block (AFB), in particular measurement and actuation requirement Blocks.

Figure 23 is an example of a control function requirement diagram for the control function "to control the pumps". The processing of the control function is a detailed network of elementary and application function blocks.

Process engineers defines also constraints, attached to the elementary and application function blocks such as safety, availability and time constraints, for example function blocks processing order, constraints of implementation of blocks (in the same I&C device, or not).

The monitoring and control requirement diagrams should be considered as perennial requirements implementable into any I&C devices.

Note: Currently there is not a rigorous and unanimous academic-based theory, nor a method, nor a formal graphic function block language, to describe monitoring and control function requirements.

Currently, I&C suppliers deliver only specific programming function block languages. Fortunately the International Electrotechnical Commission is working on the standardization of elementary function blocks and should also propose standardized rules to build application function blocks.

Process engineers should defined the monitoring and control requirement diagrams for the Structure-Operations. These monitoring and control functions should be activated (initialization, set, idle, reset) in conformance with the planning of activities to maintain the Structure-Operations in steady States, to change the state, for normal and abnormal process operation.

An element should be a monitoring or a control function requirement. Such element should be either linear causal elements (measurement), feedback causal elements (control loop) or recursive causal elements (intelligent measurements, actuations monitoring and control function).

It should be possible to validate by simulation the definition of the monitoring and control function requirements.

Different types of simulation should be possible. The monitoring and control function requirements should be simulated in a standalone, the environment of the function block language should allow to debug the requirements.

The monitoring and control function requirements should be simulated connected to a simulation of the measurements and actuations to take into account a predefined and realistic set of failures.

The monitoring and control function requirements should be simulated connected to a simulation of the measurements and actuations and of the process. The quality of the simulation is depending on the quality of the model. We point out that for new processes it should be difficult to anticipate the behavior of this process. But for well-known process it should be possible to set up a simulation of the process.

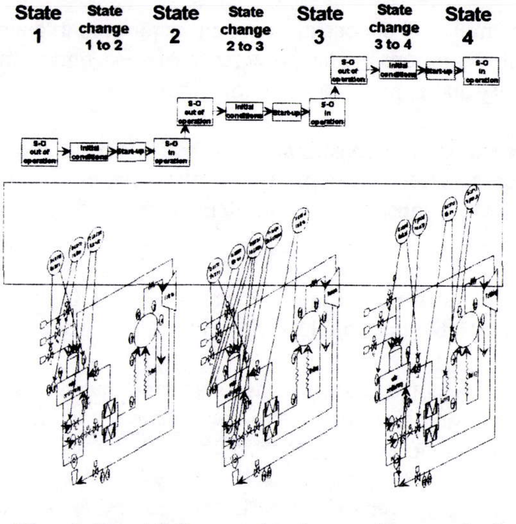

Figure 24: Simulation of the monitoring and control of a process.

We point out the state of the monitoring and control functions id depending on the state of the process control. For example a control loop should in manual, when a Structure-Operation is out of operation, it should be in automatic when a Structure-Operation is in operation.

A complete simulation of the overall monitoring and control of the process should be interesting to validate completely:

- The monitoring and the control activities of control operators (optimization of the ordered graph of activities),
- The inputs, the outputs and the processing of the monitoring and control functions,
- The data requested for control operators.

Control Documentation Requirements

Let us make the assumption that the process control requirements are available, the share of activity processing between operators and a control system is completed and validated, and the data control operators need.

The intention of process-engineers should be to define the control documentation requirements. This control documentation should support data exchanged between control operators and the control system; it should be user friendly.

The definition of requirements for a control documentation is not trivial; it is the ergonomic area. A control documentation should be a set of documents easy to understand and to use.

To monitor and to control a process, control operators need different types of documents:

- To start and to shut-down the process for normal operation,
- To maintain the process in the different steady-states for normal operation,
- To move the process towards normal operation when characteristics are out of range,
- To move the process towards a safe energetic state in case of abnormal operation (incidents, accidents), requiring specific monitoring and control activities.

For the normal operation, to start and to shutdown a process, control operators should use the ordered graphs of serial/parallel instructions to monitor and to control the changes of states from cold shutdown up to nominal operation.

These graphs of serial/parallel instructions should be issued from the graphs of, validated during the commissioning and adapted to the real life process monitoring and control.

The process-engineers should propose monitoring and control activities, they will be commissioned (validated, upgraded and adapted) by contractors and control operators in the site.

The documents for the start-up and the shutdown of a process should be graphical representation of graphs of serial/parallel instructions. There are a large variety of possible graphical representations.

In addition, to the graphs of instructions, control operators should need two complementary representations of the Structure-Operation schemes, one with the remote transmitters and actuators, another one with the indicators and remote transmitters, the manual and remote actuators. These two schemes should be consistent and updated in the same time; the access should be direct.

For the normal operation, during the start-up and the shutdown of a process, control operators should need documents representing the different steady states of the process. Within the steady states, we should distinguish the monitoring, the control and the alarm handling documents.

For process monitoring purpose, control operators should need an overview of the process operation. This overview representation should be a graphical representation of the aggregated Structure-Operations, summarizing the main balances of material and energy of the process. In addition control operators should access directly to the Structure-Operation schemes for more details.

For process control purpose, control operators should need to interact directly on the process (individual actuators, switch on/off redundant actuators or files). In this case through Structure-Operation schemes control operators should interact directly on the process.

Control operators should also need to interact with the monitoring and control functions (adjust controller parameters, change limit parameters of measurements…). In these cases, control operators should access to dedicated menus.

When disturbances occur, control operators should need alarm handling, listing activities control operators should carry out to recover the predefined disturbances.

For abnormal operating, incident or accident, to move the process towards a safe low energetic state, control operators should use specialized accidental instruction list to monitor and to control the process down to a safe state.

In addition to the previous monitoring and control documents control operators should access to real time description of the programming schemes, to understand the activities the control system is carrying out. We should also have logbooks, technical sheets…

Note: Currently, control documentation is a forum depending on the industrial area (with their own graphical symbols, display, command, alarm…) and of people carrying out the definition of the monitoring and control documents.

However, it should be interested to try to find some rational scientific basis for the monitoring and control documents to improve quality and to reduce costs.

For example, one should check the interest to achieve a common representation between the Structure-Operation schemes (set-up for process operation representation) and the representation of control documents for steady states.

Conclusion

We tried to introduce system analysis within process control. We focussed on some aspects of engineering; we should investigate the full process control life cycle and further on, for maintenance and management.

However, it seems system analysis should be one way to rationalize process control and to stand it on strong definitions, concepts and theories, able to take into account:

- the complexity of process and of process control with different and consistent levels of knowledge and point of views, without limitation for knowledge improvement,
- the organization as a consistent ordered network of Structure-Operations for the process, a complex graph of monitoring and control activities, carried out by

operators, a complex graph of monitoring and control processing supported by a control system, without limitation for future integration of maintenance and management,

- The behavior of an autonomous system as a process, activities of control operators, processing of a control system and their interactions.

One difficulty should be to set up a multi-use language and a common data base able to support the different types of representations needed for the different points of view (such as mechanics, control requirements, design and implementation of programming schemes, control documents). This should need cross-fertilization and co-operation between different worlds, which is not usually a natural attitude.

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