SIMULATION AIDS IN THE AUTOMATION OF INDUSTRIAL PROCESSES

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ABSTRACT

The use of simulation aids in the automation of industrial processes is not a new idea. Simulation facilitates the realization of engineering activities related with the installation and the optimization of those control systems in real plants. Nowadays the use of simulation aids is a simpler issue because of the characteristics of current process control systems and current commercial process simulation tools. It will be easier in a near future, when the majority of the control systems will be more based on the use of software controllers. This paper has two main objectives: first a study of the state of the art of simulation for process control and second a research on the use of simulators for automation testing due to the fact that this issue is one of the main objectives of the Sim-Serv community.

KEYWORDS

Control system simulation, Process simulation, Mixed simulation, Stimulation, Simulators

1 INTRODUCTION

This white paper is intended to be a reference paper for non simulation experts, in the area of continuous process simulation. Furthermore, this paper focuses on plant-wide dynamic simulation, which is the most significant breed of simulation from the automation point of view.

Simulation facilitates the realization of engineering activities related with the installation and the optimization of control systems in real plants. Nowadays the use of simulation aids is a simpler issue due to the characteristics of current process control systems and current commercial process simulation tools. This paper has two main objectives: first a study of the state of the art of simulation for process control and second a research on the use of simulators for automation testing.

The paper begins with the presentation of basic simulation concepts, because the majority of simulation users in the automation area are not simulation experts. It continues with a brief reference of the most important standards used in the majority of the automation simulators, and a description of the most commonly used approaches in the development of automation simulators. The production/management simulators are not analyzed.

There is an important section that deals with the use of simulators for automation testing. The paper also presents some comments about the current and the future use of simulators in automation.

The paper concludes with the Sim-serv idea regarding the main activities which will be addressed by the future research and development in this area.

2 INTRODUCTION TO PROCESS SIMULATION

2.1 Uses of simulation

Simulation systems can be classified in the following way according to their use:

- **Demonstration**. Demonstration simulators are normally used for the description of industrial installations. The accuracy of the models is not important, and simple balance of mass based models are normally enough. The display of the simulators is very important and the use of multimedia aids in these simulators is being constantly increased.
- **Engineering**. Engineering simulators are usually focused on the development of detailed studies of industrial processes. The aim of engineering simulators is to evaluate and compare alternative process and control solutions. The mathematical models are the most important part of the simulator and they are usually very accurate. The human machine interface is of less importance than in other simulators
- **Testing.** Simulation is often used for testing the design and implementation of process and automation. The accuracy requirements vary depending on the test case. In automation tuning, the process model needs to give a realistic dynamic response. In testing the automation implementation, qualitative behaviour is often enough.
- **Training**. Training simulators are normally focused in the initial training of the operation personnel of an industrial installation (although installations may need continuous training). The human machine interface is crucial while the accuracy of the mathematical models can be lower. When the simulator is focused on other types of personnel (e.g. maintenance) the accuracy can be even lower.
- **Operation support**. Simulators are used in supporting operative tasks. By using predictive simulators, operators can estimate consequences of alternative actions, and production management can test and optimize production plans. As the simulation speed must be faster than real time, the accuracy requirements cannot be very strict. It is sufficient if the simulation model can predict potential problems and estimate production measures.

2.2 Simulation features

A good second step in a simulation introduction is to mention the main functionality characteristics that all the simulators usually comply with. The ANSI 3.5 1998 guide (related with nuclear plant simulators [1]) provides a very clear definition of these characteristics. These characteristics are also defined in the ISA standard for specifying Fossil Plant simulators [2].

These functionality characteristics are:.

- **Initial Condition**. A set of data that represents the status of the reference unit from which real-time simulation can begin. It is useful to have the possibility of adding new sets of initial data during a simulation session. This possibility is usually known as the “Save of Initial Conditions” option. Some simulators also allow to make a snapshot of the main simulation variables When a series of consecutive snapshots is available, we can talk about the “replay” option.
- **Backtrack**. The ability to reset the simulation to some prior time in operation. Some simulators provide the possibility of returning to a previous moment of the current session without the need to save and restore an initial condition.
- **Freeze**. The controlled cessation of the simulation facility. When Freeze command is executed, the simulation scenario is stopped.
- **Run**. Transition to a live simulation scenario. This transition is usually made from freeze status. Every simulator usually has commands for making possible a run/freeze transition.

- **Override**. The ability to interrupt or modify the I/O data transfer between the simulator mathematical models and the instrumentation which is contained in the panel.
- **Speed up and slow down** . In many uses of simulation, it is desirable to be able to change the execution speed.

It is to be noted that all parts of the simulation system must implement the features in order to be able to work together.

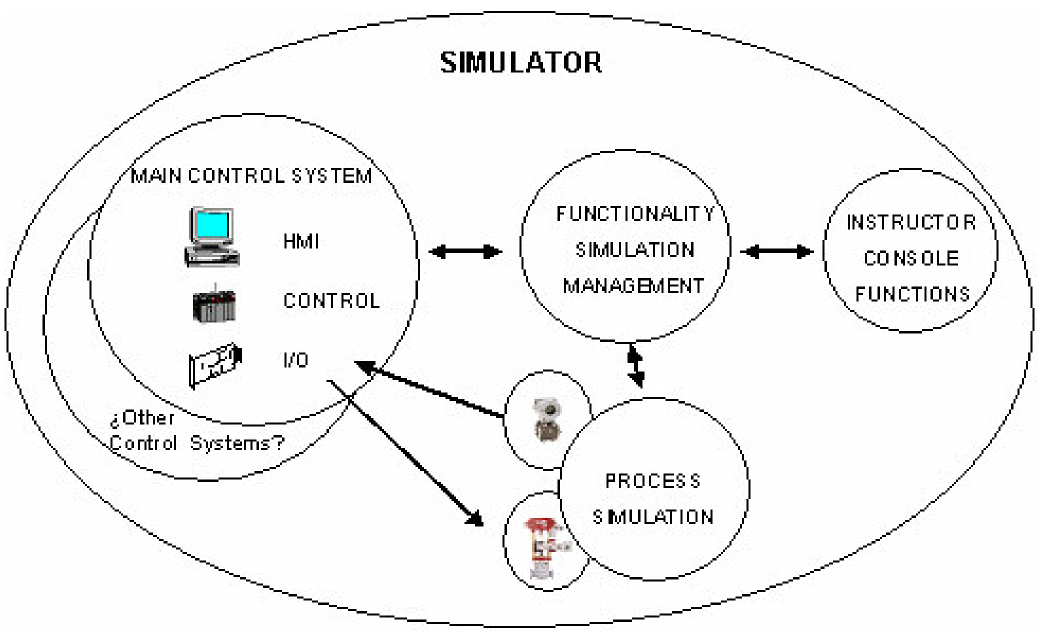
2.3 Functional decomposition of a simulator

This introduction concludes with the description of the main parts that usually compose a simulator of an industrial process.

These parts are:

- **Models of the process**. Simulation models of the installation .
- **Models of the control** system which are controlling the installation. These models of the control should represent all the layers that appear in the real control system: MMI's, process automation, safety systems, communication, field devices.
- **Simulation management functionality**. In addition to the models there is necessary management of the main simulation functionality previously defined.
- **Instructor oriented functions**. When training is included in the purposes of the simulator, it is necessary to include functions for helping the work of the instructors.

The following figure summarizes the main parts of a process simulator.



3 SIMULATOR APPROACHES USING CONTROL SYSTEMS

There are different approaches for developing simulators using control systems. A definition of the main possible approaches is defined in Appendix-A of the ISA standard for specifying Fossil Plant simulators [2].This standard refers to:

- **Simulation**, which uses alternate hardware and software programmed to emulate the instrumentation system including the man machine interface, without necessarily replicating all its functions
- **Partial Simulation**, which uses the actual system hardware and software to replicate the man machine interface. However, actual functions (e.g., control loops, efficiency calculations) are emulated in the simulation computer.
- **Stimulation**, which uses the actual system hardware and software, modified to function properly in the simulator environment. Typically, the interface of the automation and process is defined in a manner that the field devices and hard-wired automation are included in the simulation model .

The standard is dated in 1993, after which control system suppliers have started to provide emulation tools for their systems. These tools are also known by many suppliers as virtual automation systems, and their use is referred to as virtual stimulation (e.g. in [Thayer]).

The main benefit of virtual automation systems is that they can produce the same behaviour using the automation configuration of the real installation.

The terms used for describing simulation approaches are not widely accepted so there can be small differences in the names assigned to each possible solution by the main simulator suppliers.

The advantages and disadvantages of each method that are presented in this standard are presented in the following lines.

3.1 Simulation

The following are advantages of the simulation method:

- Ease of accommodating simulator modes of operation and malfunctíons.
- Cost effectiveness, especially if emulation software is available “off the shelf” and simulation computer resources can be shared.
- Hardware maintenance, training, and spare parts costs are lower than in other methods.
- The simulator can be built in a relatively short time.
- The scope and extent of the simulation is not conditioned by the tools.
- The schedule for the simulation system is independent from the schedule of the control system, which enables the use of simulation in the evaluation and optimisation of the control system before commissioning.

The following are disadvantages of the simulation method:

- The simulation model of the control application may differ from the reference system
- Relatively high software maintenance costs as the simulation model of the automation system including the MMI's must be maintained separately from the reference system.

A simulation model of the control application requires naturally time and manpower, which is naturally a drawback. However, in case the simulation model is built early enough and efficiently utilised throughout the life span of the plant, it is surely worthwhile.

3.2 Partial Stimulation

Advantages of the partial stimulation method are as follows:

- It is easy to accommodate simulator modes of operation and malfunctions.
- Partial stimulation provides high visual fidelity.
- The lowest combined software/hardware maintenance costs are associated with partial stimulation. It is obvious that the cost of less equipment should result in a smaller maintenance cost although this assumption can be affected by the strength position of the control system supplier.

- The control system displays can be tested in the simulation system before installing them on the plant.

Disadvantages of the partial stimulation method include the following:
- Possible discrepancies between simulated and actual system functions
- Possible interface throughput: limitations for large screens.
- As basically every function displayed on the screen needs to be implemented in the simulator, the simulation model scope and extent cannot be freely chosen.

3.3 Stimulation

The following are advantages of the stimulation method:
- Stimulated software and configurations are easier to keep up to date with the plant
- Plant spare hardware can be used for the simulator.
- Stimulation is potentially more cost effective, since systems are getting more and more complex and, therefore, more costly to emulate.
- The entire automation system can be tested in the simulation system before it is installed on the plant.

The following are disadvantages of the stimulation method:
- Possible limitations in the communication throughput between the stimulated system and the simulator may limit update rates to the point that the simulated processes are difficult or impossible to control (distributed control systems). Communication delays can cause potential problems especially in pulse control and in fast control loops.
- Modification to the stimulated required to accommodate the stimulator modes of operation are strongly dependent on the system internal architecture and can be extensive.

The following figure shows the aspect of the Tecnatom BWR simulator where the Honeywell DCS has been stimulated.

The selection of any of these three methods requires a careful analysis of the complete life-cycle costs associated with each item for a specific application, including:
1) Hardware equipment;
2) Software design, development, and testing activities including user involvement (e.g., design reviews, data collection);
3) Hardware and software maintenance and updates;

4) Training; and
5) Documentation.

Other cost-related factors should be considered, where applicable, such as
1) Availability of in-house spare equipment;
2) Importance of visual fidelity versus functionality; and
3) Acceptability of a limited functionality during certain modes of operation (e.g., backtrack/replay).

4 USEFUL STANDARDS FOR AUTOMATION SIMULATION WORKS

The cost-effective build-up, maintenance and use of simulation systems consisting of software and hardware by multiple vendors is possible only based on the use of standards and other vendor-independent specifications. The specifications must address the data contents and interfaces in both configuring and using the simulation system and each part of it. At present there are a number of automation and cross-domain standards that can have relevant roles in the integration of different simulation solutions.

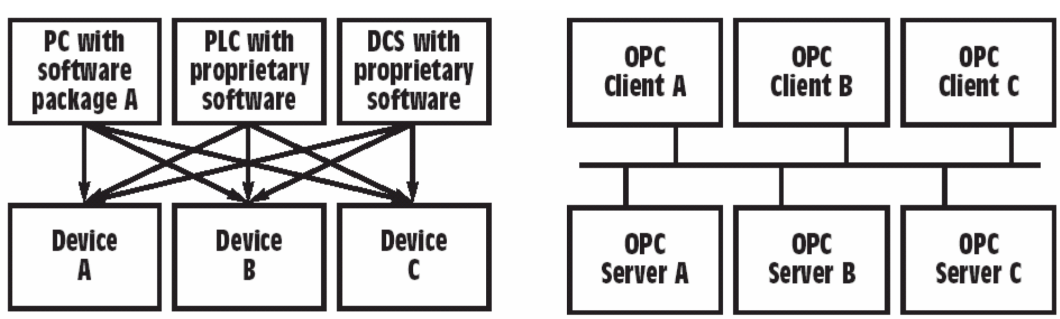
This section presents brief summaries of a few standardisation efforts: their aims and current states. The relevancies of different standards in simulation are also discussed e.g. in [8].

4.1 OPC

OPC [12] is the acronym for OLE for Process Control and it is the most widely used vendor-independent specification for communicating control system products, normally drivers between field equipment and control or human interface devices. The specifications are maintained by the non-profit OPC Foundation, which is an industrial consortium rather than a standardisation body. However, as the specifications have been implemented in practically every automation and simulation product, they have become de facto standards. As the acronym OLE in the name suggests, the standardisation work by OPC Foundation was originally based on the use of the Microsoft component technologies. Later on, Web Services and XML technologies have become increasingly important.

The next sentence in the OPC Foundation presentation material sums up the initial objectives of the OPC Foundation: “OPC will bring the same benefits to industrial hardware and software that standard printer drivers brought to word-processing.”

The following figure, obtained from the OPC Foundation website, shows on the left hand side, an example with a high number of specific drivers connecting many different devices with different Human machine interfaces, while on the right hand side the simplification that produces the use of the OPC standard is presented.



The Foundation has released a number of specifications in order to provide a suited solution for any communication necessity needed in the work with control systems: Data Access, Alarm

& Events, Historical Data Access, Batch, Data Exchange, Security, Complex Data and XML Data Access. The specifications for Commands and Common I/O are under construction.

The most commonly used interface specification is the OPC Data Access, which is currently supported in all major commercial control systems. Typically the control system provides an OPC server interface, however some control systems can be used as OPC clients, which simplifies the architecture in case the system is used in connection to an OPC server, e.g. a simulation engine. There are also products available for cross-connecting data between OPC Data Access servers.

When OPC is used in simulation an interface for controlling the simulation features is needed. There are basically three ways to design the interface: as a non-standard extension interface, as data items that are toggled or given different string values to correspond the operations, or as OPC commands in accordance with the upcoming specification. [11]

It is to be noted that the OPC standards are merely interface specifications, which specify how to find the data, how to read it, write it and subscribe to it. In the task of integrating a simulation system this is a good start, but also the data semantics and contents have to be agreed upon in order to make a fully functional system.

4.2 CAPE-OPEN

The vision of CAPE-OPEN standardisation, in which CAPE stands for Computer Aided Process Engineering, is plug and play compatibility between simulation tools. The CAPE-OPEN specifications address the functionality within a simulation engine, e.g. the solution of material properties and chemical reactions. The effort started out as a European project involving a number of simulation software providers, end users and research, and the work continues within the CO-LaN network [4].

4.3 HLA

The High Level Architecture HLA [5] is a general purpose architecture for simulation reuse and interoperability. The architecture has its origins in distributed defense simulations, in addition to which it has been used on different domains. The HLA spefications have been adopted as the IEEE standard 1516.

The HLA standard specifies rules for joining a software component in the distributed simulation system (federation): how the accessible data and supported events are expressed and published on the interface of each component (federate). Furthermore the standard specifies how the simulation system is executed in a run time infrastructure (RTI).

The implementation of a HLA federation is dependent on the RTI product used, and there are several public domain and commercial RTI products available. These are in turn based on different communication technologies, e.g. CORBA products, and full compliance between different RTI products cannot be guaranteed.

4.4 Product and process data standards

Typically a simulation model sophisticated and accurate enough for automation system checkout and operator training can be built entirely based on process design data: the interconnections of process components, their dimensions and basic correlations e.g. pump curves. Measurement data from the actual plant is required for fine-tuning only.

Therefore, the idea is tempting to automatically import data to simulation from process component suppliers' repositories and engineering consultants' databases. Such arrangements would greatly save the manpower and costs in the simulation system build-up and maintenance.

ISO TC184/SC4, i.e. ISO’s sub-committee 4 (Industrial Data) of technical committee 184 (Industrial Automation Systems and Integration) maintains the following standards concerning the process and automation data life cycle management [15]:

- Standard for the exchange of product data (STEP) - ISO 10303 is the most extensive family of standards maintained by SC4. In addition to the exchange of data the standard provides information models on data representation. STEP comes in dozens of parts specifically targeted for representation of e.g. geometries or materials. STEP is successfully employed in e.g. aerospace, defence, automotive and shipbuilding industries.
- Parts library (PLIB) - ISO 13584 is targeted for part library data exchange between suppliers and users in a computer-interpretable format. [13]
- Industrial manufacturing management data (MANDATE) - ISO 15531 is a relatively new standard whose scope covers data related to e.g. the use of resources and material flow.
- Life-cycle data for process plants including oil and gas production facilities - ISO 15926 is maintained and enhanced by the Norwegian POSC/CAESAR project [POSC_reference]. The standard has been developed based on the data warehousing needs of large multi-supplier projects in the process industry.
- Process specification language (PSL) - ISO 18269 defines a neutral representation for manufacturing processes.
- Integration of industrial data for exchange, access, and sharing (IIDEAS) - ISO 18876 aims at better interoperability of applications and organizations that implement different standards.

All of these standards attempt to make it easier to carry data between tools and organizations, e.g. from a component supplier to the engineering and from there on to the end-user.

All of the above standards are extensive; implementing any of them in a product is very laborious. Furthermore even implementing a standard in a product does not necessarily connect it seamlessly to the data flow of the process life cycle. The process design data is semantically rather complicated, and the conceptual levels of data are different in different applications.

4.5 IEC 1131-3

IEC 1131-3 is the common name of the software section of the IEC 1103, which is the most important standard into the PLC (Programmable Logic Controller) arena. The software part has become in a “de facto” standard in the control system work because the definitions adopted in this standard have been commonly adopted for the majority of the Control System manufacturers.

This standard defines 5 different program languages. It also specifies how the configuration of the software in PLCs should be implemented in order to make possible the concurrent use of different languages in one PLC. The languages defined in the standard, which can be text based languages or graphical languages, are:

Text languages
- Mnemonic (List of instructions)
- Structured Text

Graphic languages
- Ladder diagrams
- Function Bock diagram
- Sequential function chart

Any automation function can be written in any of the languages but the complexity of the program needed to make the automation can be very different. The reusability of the code is the main advantage obtained from the flexibility provided by the different languages of the standard and it is one of the key aspects pursued by the standard.

5 USING SIMULATION IN AUTOMATION TESTING

5.1 Benefits of simulation-assisted automation testing

Generally speaking, simulation can be used for the following types of automation testing:

- Validating the overall plant concept and control system requirements before the selection of the automation supplier
- Testing of control strategies before the implementation of the automation application [7]. Every automation tasks/algorithms can be pre-tuned before the commissioning on the site. The use of simulation in the case of complex automation programs is very helpful: performing a test in a complete set of plant scenarios is very difficult during a plant start-up and it is very easy in a simulator.
- Testing of Human Machine Interfaces. Simulation can be used both at design time to develop the HMI concept and for final validation of the implementation. [10]
- Simulation-assisted Factory Acceptance Test of the automation configuration [14]
- Input-output equipment testing
- Other equipment testing (non Input-output equipment)

Many of these uses of simulation are standard practices very well received by the regulatory bodies in the nuclear industry hence they are commonly carried out in the nuclear sector. The transfer of these practices to other industrial domains has already started, as the processes are becoming more complex and even higher requirements are being set for safety, product quality and production efficiency.

Using simulation for the above purposes in an automation commissioning project will reduce risks related to the project schedule and the quality of the project deliverables.

Work otherwise done on the site can be carried out in the office in parallel with other project activities. The commissioning time on the site will be shorter and the plant will be in production in less time. This is a benefit to both the automation supplier and the end-user.

Flaws are detected earlier, which makes it less costly to correct them. The later in the project a design change is requested the higher impact it will have on the project costs.

As the tests can be run without any risk of damaging the plant process, also the extreme and abnormal operating conditions can be extensively studied before the commissioning of the system. A better test coverage can be achieved than with traditional methods.

It is to be noted that simulation does not entirely remove the need for a Site Acceptance Test including installation test, trial runs and automation fine-tuning on the site. However, the time and effort needed for the tests on the site will be significantly lower than if simulation is not used.

5.2 Guidelines for planning and executing the tests

There is basically no standard way to select test runs when using simulation assisted automation testing. As a rule, the benefits of simulation are used best in system-level tests that uncover any problems in the overall behaviour of the system, in the process and control concepts and in the plant performance. A plant-wide model gives a plant-wide response, which includes cross-dependencies of control loops. The fact that a signal goes through the system correctly can be verified without a model-based process response.

The core of these testing activities is many times relegated to the final acceptance tests (Site Acceptance tests), and the use of simulation aids permit the anticipation of more tasks to previous testing stages (unit tests, integration tests and Factory acceptance tests – FAT).

The selected configuration for the simulator will condition the type of tests that could be performed within:

- When the simulation option mentioned previously is selected, the use of the simulator for testing is more limited (although many engineering designs can be tested, even the suitability of control actions).

- In the partial stimulation and full stimulation approaches the human machine interface of the control system can be fully tested.
- In the full stimulation approach and in the approach based on using a simulation tool for the control system the testing options are much wider and easier.

It is very important to remember the possible impact of simulator accuracy in the test planning. This caution will avoid the possibility of obtaining wrong results. In many cases, this limitation can be solved using more than one simulator for the test activities, in order to exploit the benefits that can supply each specific simulator (for example, the use of specific simulators is very useful for the input output equipment related tests).

5.3 Current and Future use of Automation Simulators

The use of simulation for testing will increase in a very near future because all control system suppliers will provide simulation aids and simulation tools. In addition, the availability of a full software version of any control system provides an alternate method of using control systems in simulators [3].

Nowadays, basically three approaches are used in the industry to implement the automation functionality in simulation systems:

- the approach based on using a simulation tool that simulates the whole control system (e.g. DeltaV [6] or metsoDNA [9])
- the approach of using real control systems or parts of them
- the approach based on the use of soft controllers for reproducing in a simulator the behaviour of a control system (e.g. ABB [16]).

The second and third approaches provide advantages for the qualification and testing of safety systems because the control strategies and functions installed in the simulator can be identical to the control strategies and functions installed in the reference plant. In the second approach hardware and firmware considerations could also be simplified.

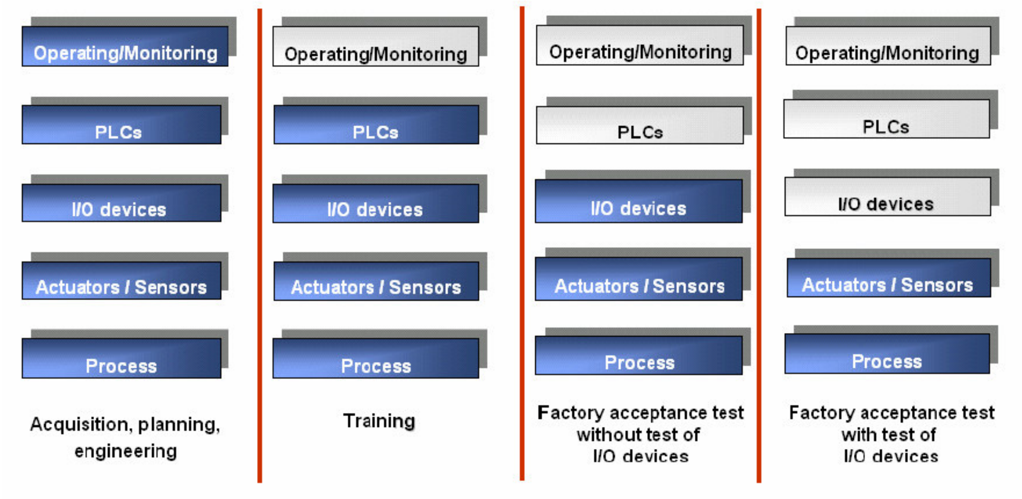
On the other hand the first one can be easier to implement because the simulation tools are specifically designed for simulation environments.

These three approaches can also be merged in the future if some simulation characteristics are added to the normal controllers used in physical installations.

Time will tell which of these approaches will be most successful on the market.

Automation simulators are currently used most in the first stages of the full life-cycle of the control systems. The simulation opportunities mentioned in this paper, show that the use of simulation could be easier in the full life-cycle of the control systems.

The following figure obtained from the PCS control platform brochure by Siemens, summarizes the items which can be tested with the help of a simulation based approach in the first parts of the control system life-cycle.



6 RESEARCH AND DEVELOPMENT NEEDS IN AUTOMATION SIMULATION

This section attempts to conclude, what needs to be done in order to make simulation aided automation testing more popular and rewarding.

- Standardization of automation Simulation terms.
- Standardization of interfaces between automation systems and simulators. Although OPC Data Access interface may be enough for transferring data values between the components, some general guidelines and design patterns for specifying and implementing the interface between a control application and a process model would be valuable. There are efforts in progress [11]
- Easy and fast model generation. An improvement in the model libraries updated and offered by process designers / vendors will always be very useful. Furthermore, the simulation software providers should evaluate together the available standards for plant data exchange across the lifecycle. A common view on how these standards are best utilised to speed up the model build up phase will be very helpful.
- Development of guidelines for practitioners in the area, i.e. automation engineers who do the testing. Guidelines on the selection of test runs for plant-wide simulation tests, Human Machine interface tests, simulation work with virtual automation systems etc. will increase the productivity of many firms. In addition, information regarding possible practices/training could be very well received.
- Specification and dissemination of the development needs inside automation systems to support simulation aided testing. If they are properly addressed, these needs are very small and they can be easily adopted by automation system suppliers.

The most important part of the addressed needs is the need for guidelines. Of course, these guidelines should be submitted to a collective like OPC foundation, ISA community or ISO organization.

Standards in most cases present generic frameworks, interfaces and reference models that can be used for building systems that solve interoperability problems. However, in order to be able to achieve real interoperability on a concrete level, the software tool providers and users must participate and closely follow latest standards. It is important to remark that the successful implementation of standards is usually based on strategic alliances, and for just about every standard there are pressure/interest groups aimed at getting the most out of the respective standard.

In an open discussion, the Sim-serv community is trying to address the different levels of requirements set about the specification of automation tests. There are some conceptual simple activities (if the correct experts are involved) that can be very useful for simulation end-users.

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