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Automatic Model Generation for Virtual Commissioning based on Plant Engineering Data

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Abstract: The complexity of modern process plants is steadily increasing – and thus the demands placed on automation systems. Today, the validation and testing of an automation system is a demanding task, usually executed under very tight schedules. Therefore, the use of simulations to check-out the automation system earlier in the engineering phase can be very beneficial. This paper investigates the possibility of automatically generating simulation models based on plant engineering data, usable for virtual commissioning. The proposed mechanism is usable without any specific additional application and can be realized with the plant engineering and simulation tool alone. The concept and workflow will be described in detail, and the paper concludes with a case study based on a prototypical implementation. Based on the proposed concept, the reuse of engineering data to generate simulation models, and thus the broader use of simulation throughout the lifecycle, becomes easier and therefore more feasible.

Keywords: Automation, Dynamic Models, Modeling, Plants, Process Automation, Simulation, Tests, Virtual Commissioning

1 INTRODUCTION

Modern process and manufacturing plants are steadily increasing in complexity. Therefore, the demands placed on the automation systems are growing as well. The usual requirements for an automation system for a new or migrated plant operation – high quality, delivery within a short time, and minimal costs – are becoming more and more intensive. It is essential that the automation system function properly to ensure productive and safe plant operation. Thus, the testing of the engineered automation solution becomes critical.

Today, the testing usually takes place during the on-site commissioning within the actual plant. To meet the start-up schedule, these tests must be executed within a very short timeframe. Furthermore, testing based on the actual equipment sets some limitations on the executable test cases.

Using simulation technology to test the engineered automation system functionality earlier in the lifecycle can help in meeting schedules and quality requirements. The target is for the design and testing questions to be answered for the automation engineer without the availability of the actual plant. Even though this so-called virtual commissioning sounds very promising, it is not being used today as a standard within automation engineering.

The reasons for this are the modeling effort as well as the necessary know-how to develop usable simulation models and use-simulation methods in general (Drath et al. (2008)).

To support more widespread use of virtual commissioning, this publication introduces an approach that can reduce the complexity in using simulation throughout the engineering process of an automation system. It investigates whether sufficient models can be automatically derived from plant engineering data and do not have to be built from scratch. The proposed mechanism is designed for minimal complexity and thus avoids the use of additional mapping tools (Barth (2011), Barth, et al. (2013), Bergert et al. (2010), Hoffmann et al. (2010), Hoyer et al. (2008)). Only the programs that are already in use anyway, such as plant engineering and simulation tools are required. One basic assumption made is that the same data is entered and maintained only once. This ensures maximum consistency and error-free engineering. Simulation-relevant attributes are added to the planning object and linked to existing planning data. Thus, the planning data can be used to parameterize simulation models. For a separation of concerns, the simulation behavior is directly modeled within the simulation tool, using simulation components. Through mapping between the planning object and the simulation component, the attribute and connection information of the planning objects can be preserved and reused to create a simulation model.

Section 2 provides a more detailed introduction to the role of simulation within the plant's lifecycle and virtual commissioning, as well as a presentation of the basic principles needed to use the proposed model-generation mechanism. Section 3 focuses on the details of the plant data-based modeling approach and includes a literature study of similar work. The workflow is explained step by step. Section 4 presents a short case study of the proposed mechanism, which is already implemented within a prototype. This is followed by an evaluation of the potential and outlook.

2 SIMULATION AND AUTOMATION ENGINEERING

Simulation is a very broad topic and it has many different interpretations. Because the term simulation is always context sensitive, a brief explanation of how it is used in this publication is provided. This is followed by a more detailed look at virtual commissioning, its purpose, benefits, and hurdles. This section closes with an introduction to the possible data sources and the basic principles needed to use the automatic modeling concept introduced in Section 3.

2.1 Simulation along the engineering life cycle

The term simulation is used in this publication to mean mimicking the behavior of devices, machines, and processes used within a plant or manufacturing operation. Simulation must be distinguished from emulation, which is used here to mean mimicking the behavior of a specific hardware device, such as a programmable logic controller (PLC). The term simulation is used when the behavior of a system that is controlled by an automation system is imitated. The automation system can be emulated in addition (Barth et al. (2013)). Fig. 1 depicts the difference between simulation and emulation.

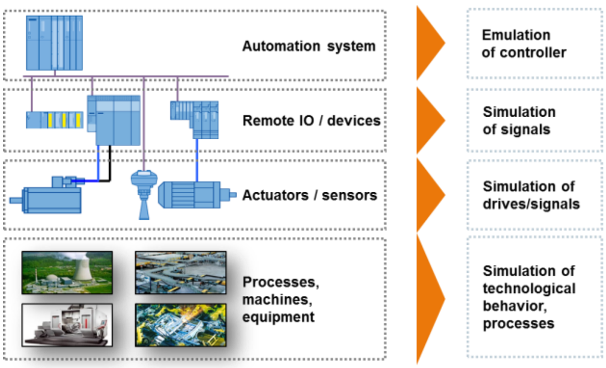

Fig. 1. Different simulation and emulation levels

Further differentiation can be made within the simulation scope. The interface between an automation system (also if emulated) and a plant behavior simulation is based on a signal simulation layer (all signals going in and out of the automation system). Within a plant configuration, the signals are wired into devices, which can be simulated by the device layer. The plant-specific behavior and process is simulated and modeled on a third layer, the process layer. Fig. 1 shows the three different simulation levels. The level of detail, especially within the process layer, can vary enormously. This starts with very simple logical models based on mathematical blocks and ranges all the way to first-principle models for a chemical process, for example (Bayer et al. (2003)), or 3D finite-elements models for the dynamic behavior of a production machine, for example. Even though the methods described in this paper are general, the examples are chosen from a process industry perspective unless otherwise stated.

The level of detail for an adequate simulation model is heavily dependent on the questions the user wants to answer through the use of the simulation model. Across the standard engineering processes (Urbas (2012)), the starting point for simulation occurs already during the design phase, with the use case of static and dynamic process simulations to size and design the plant (Bayer et al. (2003)). Later in the lifecycle, when the automation engineering starts, virtual commissioning is used by the automation engineers. Starting with the end of the engineering phase and throughout the operation phase, operator training simulators can be used (Cox et al. (2006)). During the operation phase, simulation plays multiple roles in the area of plant optimization (Bohlmann et al. (2013)).

The idea of reusing models throughout the lifecycle and use cases is valid but very challenging (Bausa et al. (2006), Nagl et al. (2008), Schopfer et al. (2004)). Models must be interpretable by various simulation tools or different simulators must be able to simulate in parallel and communicate with each other for data exchange and synchronization. The first option requires a common modeling and simulation language. This might not be possible to realize for the broad scope of simulations across the lifecycle as the requirements are too difficult to satisfy with one standard. For a narrower scope, such as for virtual commissioning, some effort is made to extend standards like AutomationML with simulation-relevant information (Bergert et al. (2010), Moritz et al. (2011)). The second option involves co-simulation. For co-simulation between various applications, multiple investigations have already been carried out and are presented in the literature (Oppelt et al. (2013), Schopfer et al. (2004), Nagl et al. (2008), Lüder et al. (2013), Barbieri et al. (2013), Bastian et al. (2011)). A common dominating standard for co-simulation used across the lifecycle might develop in the future but does not yet exist.

The simulation-related use case that might be used more commonly in the future by automation engineering is virtual commissioning followed by operator training. Therefore, this paper focuses on lowering the entry barriers for virtual commissioning but also proposes methods usable across the lifecycle to foster the idea of a lifecycle simulation as well.

2.2 Virtual commissioning

The target of virtual commissioning is the early validation and check-out of the automation project for a specific plant operation. Therefore, this task should be executable by the automation engineer in parallel with the normal automation design. Furthermore, it should be possible to use the original automation project as it would be deployed in actual production. Thus, the simulation must be connectable either to a real hardware controller or to an emulated one.

A simulation model is sufficient for this scenario if the automation system believes it is talking with the real production system (Bergert et al. (2008)). It is not necessary to model every plant and process aspect in detail. Sometimes a simple logical model or a model able to simulate water-runs is sufficient. The testing scope varies from alarm limit-, interlock-, logic-, loop- and sequence-check-out and thus the needed modeling depth. The model-generation mechanism, introduced later, focuses on the generation of simple models suitable to simulate water-runs (system level due to the Lasa et al. (1999) classification).

The benefits of virtual commissioning are mainly that the tests can be performed without the dependence on real plant equipment and also prior to real commissioning, with less time pressure. This enables error detection earlier in the design phase, when correction is usually more time- and thus cost-efficient (Wünsch (2007)).

Currently, the major hurdles to a more common use of virtual commissioning are the demanding modeling effort and the know-how required to develop such simulation models (Drath et al. (2008)). An automatic modeling mechanism with minimum complexity, usable by non-simulation experts, lowers the hurdle for more intensive use of virtual commissioning throughout the automation engineering lifecycle.

2.3 Data sources

An automatic modeling approach depends on the availability of the necessary information to develop a simulation model. For virtual commissioning models, there are two possible sources of data: (1) the automation system engineering and (2) the plant engineering. The information about the signal and device level (Fig. 1) can generally be provided by either source. Information about the plant topology, needed for the process level simulation (Fig. 1), is generally only available within the plant engineering system (Barth (2011)). In the future, an integrated engineering approach, where parts of the automation system are also generated from the planning data, may become more common (Tauchnitz (2013)). The planning data can thus be regarded as the master source of information and will be used in the approach described below.

2.4 Basic principles

To utilize the model generation process described in Section 3, the simulation and planning tool must provide some basic functions. First, both tools must provide a mechanism to create and maintain object libraries (types). The objects must be clearly identifiable. Based on these objects, a user-specific configuration consisting of object instances can be generated. In addition, the possibility to parameterize a simulation model automatically via an imported file must be provided as well as the option to import a description of a model provided in a generic format, for example XML. Based on the XML description, the simulation system must be able to build the instances of the objects and connect them appropriately.

3 AUTOMATIC MODEL GENERATION BASED ON PLANT ENGINEERING DATA

Although there are several approaches available in the literature (Barth (2011), Barth et al. (2013), Hoyer et al. (2008), Bergert et al. (2010), Hoffmann et al. (2010)), most of these solutions are not commonly used in industry. The reasons for this are the complexity, the high level of manual work required, or the usage of proprietary mapping tools that have to be configured. In terms of these approaches, the solution presented will overcome these limitations. The user should be able to stay in his or her domain and focus on the task of automation engineering, supported by simulation for fast and easy testing.

The conceptual idea is to create a system where the planning tool is the single source of information, also including the simulation-relevant knowledge. The target is for the end user to not have to set up the automatic model generation but to be able to use and work with it.

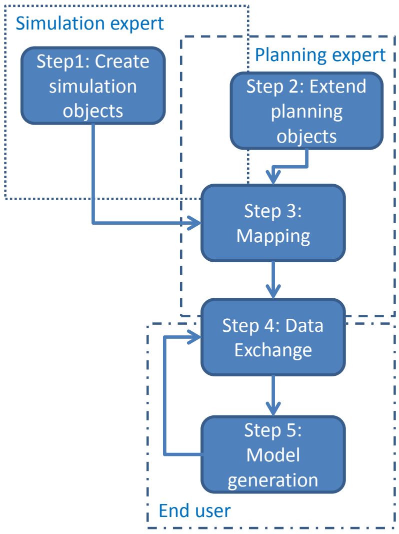

Fig. 2. Workflow and user roles for automatic model generation mechanism

Fig. 2 illustrates the workflow for the automatic model generation based on plant engineering data. The five work steps are split into two main phases. The first phase (steps 1-3) must be done once to set up the system. For this, different user roles are involved. The second phase (steps 4-5) describes the automatic model generation executable by the user designing the automation system.

3.1 Workflow: step 1 – create simulation objects

The basis for this step is the simulation tool and its library with defined components. These components can be maintained and created within the simulation tool itself, if not already available within a simulation component library. This creation process is a one-time task. It does not have to be performed by the end user alone but can be done together with a simulation specialist who is an expert in the tool. Cooperation at this step is critical to have sufficient simulation components that fulfill the needs of the end user later on.

Furthermore, a placeholder simulation component should be available for cases where the simulation functionality of certain components is to be defined later on. The placeholder component does not contain any specific simulation behavior, but highlights that some work might be needed to establish a proper simulation model for the full plant configuration.

3.2 *Workflow: step 2 – extend planning object*

The second step, which is also a one-time task, can be carried out by the planning tool expert. This can also be done in cooperation with the simulation expert and the end user. During this step, the planning objects are extended by simulation-relevant attributes (e.g. the parameters for a pump might be nominal mass flow, nominal pressure, nominal speed, input component, output component, x and y coordinate on P&ID,…) that correspond to the equivalent simulation object of step 1. The simulation-relevant attributes are then linked with the appropriate planning data (if available) in a subsequent step.

3.3 *Workflow: step 3 – mapping*

This step is also carried out by the planning tool expert. After extending planning objects by adding simulation-relevant attributes, the existing planning information must be mapped to the values of these attributes. This is also done only once and ensures that the simulation component being used can be configured with the right parameters, which are set by the design engineer. Through this step, the planning tool becomes the single source of information and automatic reuse of the information for the simulation model generation is possible.

The mapping mechanism is directly integrated into the planning tool, which means that all information defined within the plant engineering phases is available for the mapping process. For the simulation model generation approach, information from various lifecycle phases is needed (e.g., specifics of the designed process like mass flows from the front-end-engineering-and-design phase or tank properties – such as volume – from detailed design phases (Urbas (2012)). Through the direct mapping between the source information and the simulation attribute, changes – for instance, those made by the design engineer – can be passed along to the simulation objects and used immediately when the changes are released. This will ensure data consistency and error-free engineering, and at the same time minimum complexity.

3.4 *Workflow: step 4 – data exchange*

Data exchange involves two steps. The first step, which is done once, implements a mechanism within the planning tool to acquire the simulation-relevant information and transform it into an exchangeable format. This format is designed to satisfy the import format of the simulation tool. The import format can be derived from a certain standard (e.g. AutomationML), or it could be a proprietary scheme (e.g. XML) for a specific simulation tool.

The second step is performed by the end user every time a new simulation model is created due to design changes. This step is very efficient because the above-described data collection mechanism is triggered and the exchange information is created automatically.

3.5 *Workflow: step 5 – model generation*

The final step of the concept is the import and generation of the model within the simulation tool. For this, the exported information from the planning tool provides the basis to automatically generate a foundation of a simulation model. Some manual work is needed to make the model executable (e.g., setting initial values, defining boundary conditions and sources or sinks). Furthermore, if placeholder components are included in the simulation model, the simulation behavior must be defined. Finally, the model is ready and can be used for virtual commissioning.

4 CASE STUDY AND PROTOTYPE IMPLEMENTATION

The concept was checked by a prototype implementation using the simulation tool Simit (www.siemens.com/simit) and the planning tool Comos (www.siemens.com/comos). A simulation model was generated automatically from planning information, suitable to simulate a water-run (see Fig. 3). All engineering-relevant information is stored within Comos, forming a single source of information.

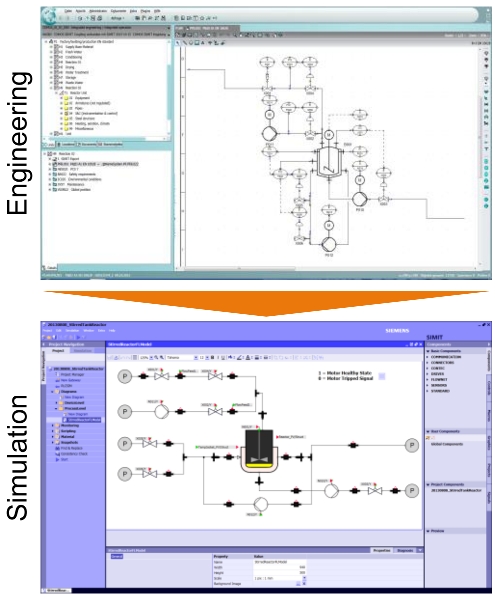

Fig. 3. Automatic model generation prototype

4.1 *Workflow: step 1 – create simulation objects*

For each simulation-relevant process object in Comos, a corresponding Simit library component is realized with a suitable simulation component. Input and output connectors of the simulation component are created. Additionally, simulation parameters are defined to adjust the simulation component behavior. This simulation library is created once and can be reused.

4.2 Workflow: step 2 – extend planning object

A Comos P&ID (Piping and Instrumentation Diagram) is built with instances based on a type (Base Object) library. Simulation objects are assigned to each base object so that every instance used in engineering has this additional knowledge.

4.3 Workflow: step 3 – mapping

Simulation objects are assigned to all engineering objects that are located on a P&ID (see Fig. 4). Each simulation object contains a link to its simulation component inside the simulation library (see Fig. 5) and all parameters (see Fig. 6) that are relevant for its configuration.

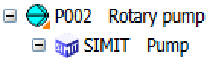

Fig. 4. Linking simulation and planning object

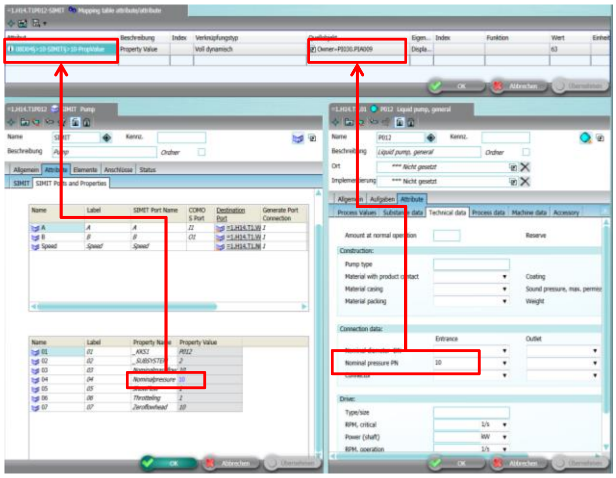

Fig. 5. Mapping of information

Name	Label	Property Name	Property Value
01	01	_KKS1	P010
02	02	_SUBSYSTEM	2
03	03	Nominalmassflow	10
04	04	Nominalpressure	8
05	05	ShowFlow	1
06	06	Throtteling	1
07	07	Zeroflowhead	10

Fig. 6. Simulation parameters of a pump object

4.4 Workflow: step 4 – data exchange

Using an integrated query technology, all simulation-relevant components and information are collected and exported into an XML file. During data collection, the connections between the simulation components are analyzed. The XML file contains the complete structure and parameters of the simulation model (see Fig. 7).


```
- <GENERIC VERSION="7.1">
  - <FOLDER NAME="H9">
    - <DIAGRAM NAME="H9.PFB.001" WIDTH="9504" HEIGHT="13456">
      - <COMP UID="f_01b31n_37l6jxmm" NAME="P012" REF="A3ASG2Q9OZ">
          <TRANSFORM SCALEX="1" SCALEY="1" ROTATION="0" />
          <POS X="1410" Y="2703" />
          <PROP NAME="_KKS1" VALUE="P012" />
          <PROP NAME="_SUBSYSTEM" VALUE="2" />
          <PROP NAME="Nominalmassflow" VALUE="10" />
          <PROP NAME="Nominalpressure" VALUE="8" />
          <PROP NAME="ShowFlow" VALUE="1" />
          <PROP NAME="Throtteling" VALUE="1" />
          <PROP NAME="Zeroflowhead" VALUE="10" />
        </COMP>
      </DIAGRAM>
    </FOLDER>
  </GENERIC>
```


Fig. 7. Excerpt XML export for a pump object

4.5 Workflow: step 5 – model generation

Whereas the XML file is imported, the plant simulation model is assembled by creating instances of simulation library components. After the model is generated, some additional simulation aspects must be considered. For example, the boundary condition of an open pipe end are added and adjusted, as this information is not necessarily available in Comos. The simulation can be executed thereafter.

The process engineering data usually changes during the plant lifecycle due to optimization. Thus, the simulation model must be updated. The update process can be handled efficiently, using the described simulation model generation.

5 POTENTIAL AND OUTLOOK

Automatic generation of a simulation model from plant engineering data, without any additional mapping tool, is possible and was successfully implemented within a prototype.

The presented mechanism can clearly reduce the effort in creating simulation models for virtual commissioning. Furthermore, the concept of entering information only once is extended to simulation. The fact that the mechanism is designed to integrate into the normal tool landscape and processes with minimal complexity leads to a high likelihood of acceptance by the user. This will result in more common use of virtual commissioning for the early testing of automation projects.

To decrease the complexity and the hurdle for integrated simulation-based engineering even further, the collaboration between the planning and simulation tool must be as close as possible. This requires the development of concepts for tighter bi-directional couplings between the relevant tools. This will support faster engineering, especially when changes are made, and also enable backpropagation toward the design department of changes made within the simulation. Some effort is also needed to create and maintain the libraries. Improvements in this area can deliver additional benefits, for instance by working on model exchange standards.

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