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Construction of Operator Training Simulator for Process Industry

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Construction of Operator Training Simulator for Process Industry

Operator training simulators (OTS) are software tools for training process operators in large-scale industrial applications. The purpose of this thesis was to create onboarding material by documenting the steps involved in constructing NAPCON operator training simulators. NAPCON is a business unit of Neste Engineering Solutions Oy. Originally abbreviation NAPCON comes from Neste Advanced Process Control which was the APC product of NAPCON and is nowadays called NAPCON Controller. The theory part discusses operator training simulator structure and dynamic process simulation. This thesis is based on personal work experience on this topic, end user interviews, relevant literature references and NAPCON specific information. The expertise of Neste simulator trainers was utilized in the interviews conducted during the writing of this thesis focusing on the benefits, requirements, and trainings of a Neste simulator. The resulting whole gives an overview of the subject and serves as a basis for onboarding.

Keywords:

operator training simulator, dynamic process simulation, process model, automation model, simulator environment, testing

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Koulutussimulaattorin rakentaminen prosessiteollisuuteen

Koulutussimulaattorit ovat ohjelmistotyökaluja prosessitoimijoiden kouluttamiseen laajamittaisissa teollisissa sovelluksissa. Tämän opinnäytetyön tarkoituksena oli luoda materiaali koulutussimulaattorin rakentamiseen liittyvistä vaiheista, jota voitaisiin myöhemmin käyttää perehdytyksessä NAPCONilla. NAPCON on Neste Engineering Solutions Oy:n liiketoimintayksikkö. Alun perin lyhenne NAPCON tuli sanoista Neste Advanced Process Control, joka oli NAPCONin tuote ja jota nykyään kutsutaan NAPCON Controlleriksi. Työn teoriaosa käsittelee operaattorin koulutussimulaattoriin liittyviä osia sekä dynaamista prosessisimulaatiota. Tämä opinnäytetyö perustuu henkilökohtaiseen työkokemukseen aiheesta, loppukäyttäjien haastatteluihin, kirjallisiin viittauksiin sekä NAPCONin omiin dokumentteihin. Haastatteluissa hyödynnettiin Nesteen simulaattorikouluttajien asiantuntemusta ja niissä keskityttiin simulaattorin hyötyihin, vaatimuksiin sekä koulutuksiin Nesteellä. Tuloksena on kokonaisuus, joka antaa yleiskuvan aiheesta ja toimii perehdytyksen pohjana.

Asiasanat:

koulutussimulaattori, dynaaminen prosessisimulaatio, prosessimalli, automaatiomalli, simulaattoriympäristö, testaus

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List of abbreviations (or) symbols

DCS	Distributed Control System
FAT	Factory Acceptance Test
HMI	Human Machine Interface
MAT	Model Acceptance Test
NAPCON	Neste Advanced Process Control
OPC	OLE for Process Control
OTS	Operator Training Simulator
P&ID	Piping and Instrumentation Diagram
PFD	Process Flow Diagram
SAT	Site Acceptance Test
SIS	Safety Instrumented System
UA	Unified Architecture
UI	User Interface
VM	Virtual machine

1 INTRODUCTION

Operator training simulators (OTS) are software tools for the training of operation procedures, troubleshooting, imparting information that is fundamental to the process understanding, and maintaining and improving operational skills. A variety of OTS applications are found in airplane and sea pilot navigation, chemical manufacturing, and nuclear power production, as well as for military and surgery training.

This thesis project was commissioned for the NAPCON Simulator Engineering team, and it was intended to serve as part of the improvement of onboarding. The thesis goes through the basics of OTS, dynamic process simulation and the structure of the NAPCON Simulator. Training simulator construction includes many specific and detailed steps, and this material will give an overview of all these steps at a general level.

The end user perspective forms a central part in this work and two of Neste’s simulator trainers were interviewed on its importance. Understanding the end user's perspective is important in the work of the simulator modeller, as they play the role of the client and set the requirements for the simulator. The interviews give an overview to the investment process of an operator training simulator as well as a description of the common training that are organized at Neste.

2 OPERATOR TRAINING SIMULATOR

Operator Training Simulators (OTS) are advanced computer-based training tools which include control system and process simulation. Virtualized or emulated displays are combined with a dynamic process model. In industry, P&ID style graphics, front plates and tabular formats can be considered the standard for the control system interface. (Abel, 2018.)

A simulation of the mechanics, geometry, chemistry, and physics of the manufacturing process can be incorporated into the OTS software. Physical models used in the process can be very accurate, including models for the nucleonics of various nuclear reactors, chemical reactor kinetics, distillation tray, equilibrium and equipment models of pumps, compressors, pipelines, and heat exchangers. Models may include a comprehensive physical characteristic behaviour of liquids and gases, as well as solid mixtures. OTS software defines how control system algorithms and HMI are simulated. Typically, OTS is used for processing, chemicals, pulp and paper, and pharmaceuticals. (Abel, 2018.)

OTS solution providers can be roughly divided into two categories. In the first category are automation vendors, for example, AVEVA, YOKOGAWA and ANDRITZ, which focus more on providing an automation system and related trainings. In the second category are providers with a primary focus on process modelling, which may allow them to provide more comprehensive and accurate training, regarding processes. An example of these providers is NAPCON and INPROCESS.

2.1 Dynamic process simulation

The basic techniques used in dynamic simulation is real-time or accelerated dynamic simulation. These techniques can be used to obtain a true representation of the plant's behavior, including retention times and heat delays. Dynamic simulation enables the study of a stable state with variable throughput, starting, shutdown, input, as well as a change in composition. Dynamic simulators can also be utilized for plant functional troubleshooting, control loop tuning, and real-time optimization. They are harder to set up due to the longer list of requirements in comparison to steady-state simulation. (Edwards, PROCESS SIMULATION, 2013.)

In steady-state simulators, plant behavior is modeled by a continuous time-space-based, steady-state approximation. Technically the determination and calibration of the flow sheet is easier to perform than in dynamic simulation. In dynamic process simulation, execution time as well as step size must be selected so that it is consistent with real-time plant behavior. This involves considering the flow rates, compositions, and thermodynamic conditions of the input stream, as well as performing iterative calculations. In this way, conditions for the flow rates, compositions and thermodynamics of the output current are created. Dynamic simulation can be thought of as a series of simulations in a steady state. (Edwards, PROCESS SIMULATION, 2013.)

2.2 NAPCON OTS

NAPCON Simulator is a highly interactive operator training simulator that provides accurate simulations and dynamic models based on physical properties, reflecting the operation and control responses of the actual plant. The simulator is custom-made based on selected requirements. It includes several operator training applications covering basic processes, process phenomena, and all process devices. (NAPCON Simulator: NAPCON.)

NAPCON Simulator has an extensive chemical component library with built-in kinetics and thermodynamics. Simulation of complex systems as well as disturbance scenario exercises with desired accuracy are made possible by simultaneous use of multiple equations and an easy-to-use graphical user interface. NAPCON Simulator has a database and interface compliant with the OPC Unified Architecture (UA) standard. (NAPCON Simulator: NAPCON.)

2.3 Simulator structure

The basic design of NAPCON Simulator is described in Figure 1. There are three software and four different parts that interact with each other. ProsDS, an in-house dynamic simulation application of NAPCON, runs the process and automation models and enables communication between them. NAPCON Informer is the database that collects and stores real-time process data during simulations, and Display Viewer (DV5) emulates the real plant user interphase and user experience.

The automation model reads the measurement values from the process model and the controllers of the automation model calculate the output values based on these measurements. Calculated control values are then written back to the process model. From there the automation model writes the values of all the tags that are defined to the database, which can then be read from there to the operator and trainer user interfaces. If the value is modified in the user interface, database will read it from there and send the changed value to both the automation and the process model.

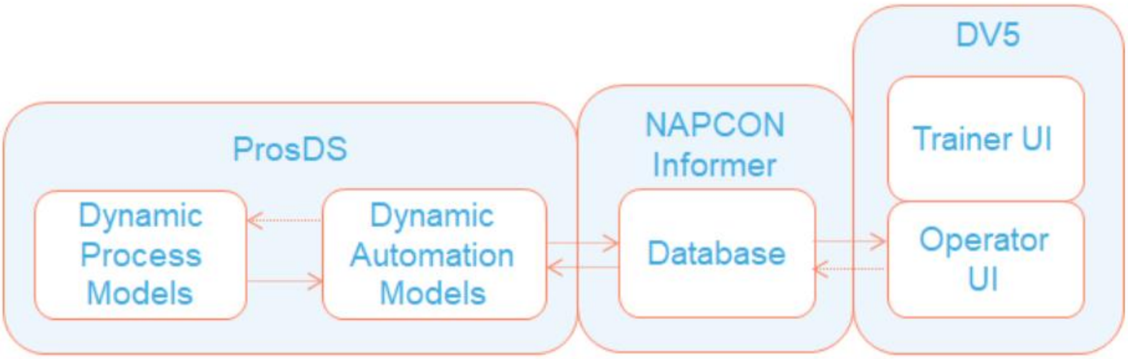

Figure 1. NAPCON Simulator structure. (NAPCON Simulator: NAPCON)

3 A CUSTOMER’S PERSPECTIVE

The most common reasons for the use of training simulators are that operators can learn the skills they need to run a plant safely, efficiently, and profitably through repeated practice. Two simulator trainers at Neste were interviewed to collect more detailed reasons and determinants for this reasoning.

3.1 Benefits of a training simulator

Simulators were taken to use at Neste primarily to have a safe way to experiment and learn how to operate processes and to minimize errors. New production line was being built at Neste, which was known to be challenging to operate and with high risks and this may have underlined the need for a simulator. This simulator has now been in service since 2006, which can be seen as the company’s commitment to enabling the best possible training for each operator. (Liljemark & Sinisaari, 2021.)

The main focus during training is to increase and maintain the professional skills of operators. This includes understanding about the effects of basic operations, the causal relationships resulting from them, as well as understanding the links between processes and identifying phenomena occurring in the processes. It is aimed to create a learning environment as realistic as possible and to give the opportunity to practice potential disturbances or operations that are less likely to be carried out, in a safe environment. The current simulators allow trainings that focus on exercises that are related to the work of operators, but another possibility is, for example, to test new controllers with the simulator in a faster and safer way before implementing those to a real plant. (Liljemark & Sinisaari, 2021.)

One way to measure the benefits of the training simulators is based on feedback. This is shown as positive feedback from the operators themselves, as well as from the line managers on the effects from training, as noticed through an improvement in daily plant operations. There have also been special cases, for example, in which a disturbance situation that was recently practiced, occurred in the plant, and through the practice, allowed operators to resolve the disturbance in an excellent way. However, no direct correlation is evident that this kind of training decreases the frequency in the occurrence of disturbances, due to the multitude of possible external influences acting directly on the occurrences of any disturbances. (Liljemark & Sinisaari, 2021.)

Working in a high-risk plant can be stressful. With the help of the simulator, the certainty and the trust for the basic operation of processes can lower that stress load so that 100% of the work contribution of the operators does not go towards the basic operations but resources are saved for a potential disruption. Consequently, even in case of disturbance, it would also be possible to perform at full energy and therefore this could be also taken as one of the benefits. (Liljemark & Sinisaari, 2021.)

3.2 Investment process

Investing in the training simulator requires, in addition to the simulator itself, a clear training plan specifying trainees, necessary repetitions and exercises. Unit-specific training needs are thought through on a risk basis in terms of safety and productivity. The authors of the training plan must therefore have solid knowledge of the economic impact and the impact of the process unit on other units. (Liljemark & Sinisaari, 2021.)

There is a separate authorized organization for the simulator training at Neste. The organization includes persons responsible for planning the trainings, approving those and communicating with the simulator team. The simulator team prepares and tests the simulator's functionality in the training and maintains the training readiness of the simulators. They are also responsible for the training of new operators and preparing staff for more special faults and malfunctions. Shift trainers normally work as operators in the shifts but have a second role in the simulator training. They provide the most up-to-date information on what training is needed, as well as information on qualifications attainment and maintenance. The training organization also includes a simulator steering group responsible for the approval of large change needs, as well as the prioritization of maintenance changes. A separate authorized organization plays an important role in the consistency and continuity of simulator training. (Liljemark & Sinisaari, 2021.)

Predefined requirements are set for the training simulators based on the training needs. The basic condition for all the training is to be able to simulate the process accurately enough to create an illusion of operating the real plant. Situations practiced on the simulator must therefore be fair in time and closely reflect the scale that they would be in the real plant. Creating this illusion is very important to make the educational situation reliable. The trainers also play an important role in how they create disturbances with the simulators so that the situations would result from another and correspond to real plant behaviour. (Liljemark & Sinisaari, 2021.)

In the past, there have been attempts to build simulators that would be able to perform almost anything, which of course has been slower and more expensive, but today there are more specific requirements for the simulators. These include unit-specific operations and disturbance exercises which can be fixed and supplemented if necessary. (Liljemark & Sinisaari, 2021.)

4 PROCESS AND AUTOMATION MODELING

Process and automation modeling is initiated by determining the scope of the model. This, in turn, is affected by the planned model capabilities and forms an essential part of the scope determination work. To comprehend the effects of key objectives holistically, the scale of the model must be sufficiently large. In the design and development of the simulation model, the model builder must identify key elements of the process, as well as their interrelationships and behaviors, to incorporate these into the model. The focus should be on aspects of the process which are particularly important to the purpose of the model, and which are believed to affect the resulting variables. (Kellner, Madachy & Raymond, 1998.)

4.1 Initial data

Piping and instrumentation diagrams (P&ID) are used as initial data for process modelling. P&IDs include all the piping of the process flow, along with the installed equipment and instrumentation. The customer delivers the plant’s P&IDs and the scoping for the process model is done by marking every piece of equipment, pipe and instrumentation that is included in the simulator on the diagrams. Heat and material balance, equipment data sheets and process descriptions are also important initial data that are required for the process model definition.

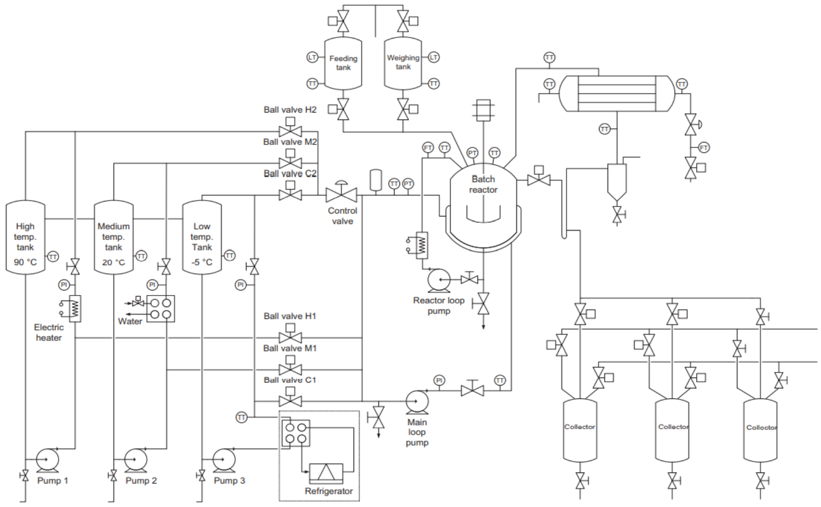

Figure 2. Piping and Instrumentation diagram (P&ID). (Balaton, Nagy & Szeifert, 2012)

For the automation model, distributed control system (DCS) and safety instrumented system (SIS) diagrams work as a narrative. In the diagram's functionalities and connections of every control loop, measurements etc. are expressed visually, see Figure 3. The initial data set of these diagrams can consist of several thousand sheets, depending on the scope. The scoping can be done in a similar way to the P&IDs. In the narratives the initial data is in written form.

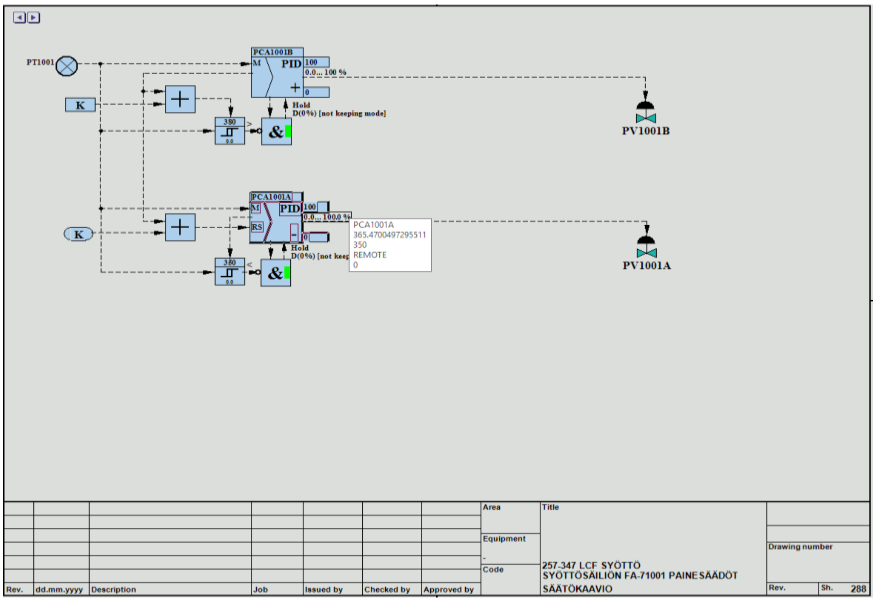

Figure 3. DCS sheet. (NAPCON Simulator: NAPCON)

4.2 Process modeling

The goal is to construct a process model which has very similar dynamic behaviour as the real plant. This is done by modelling the physical and chemical phenomena of the process and the process dynamics with the process model. The process models also consist of different kind of equipment, e.g., distillation columns, pumps, reactors, vessels, furnaces, and heat-exchangers. Illustrated below is an example of a process model in a simulator.

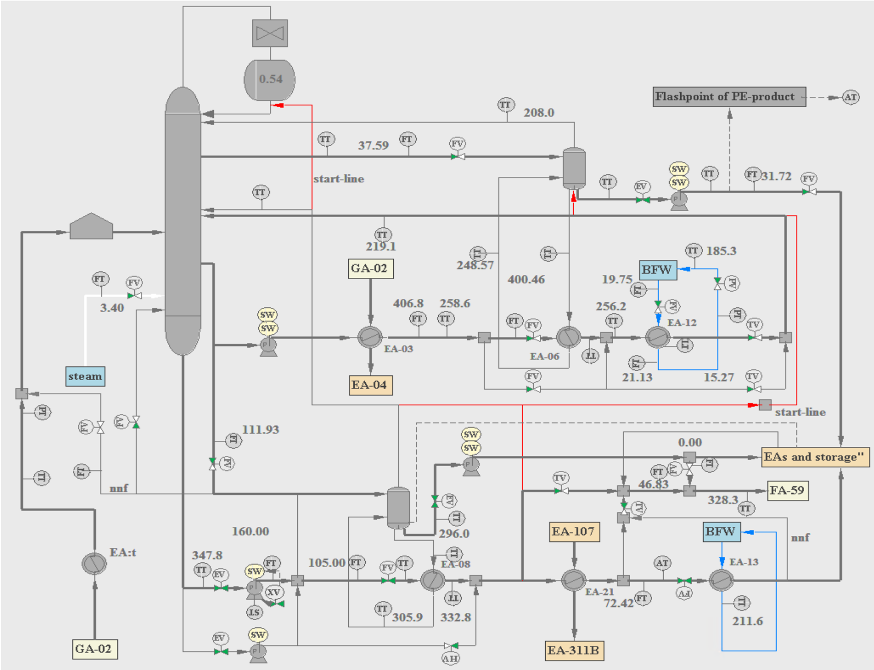

Figure 4. The process model in a simulator. (NAPCON Simulator: NAPCON)

4.2.1 Automation model structure

The automation model of the simulator consists of a distributed control system (DCS) and a safety instrumented system (SIS) which are modelled as dynamic automation models in the simulator. DCS as the control system is responsible for all the operation actions, measurements, and alarms. The SIS consists of logics and safety-critical measurements which then cause the emergency shutdown (ESD) if the interlock limits are exceeded.

DCS and SIS are modeled in the automation models as they are implemented in the real plant. In the diagram approach, the look and functionality remain the same and therefore, models are, more or less, representative of the real plant automation's functionality. Below is an example of a control loop in the automation, shown to represent the similarity of the simulator model and initial data of DCS sheets in Figure 3.

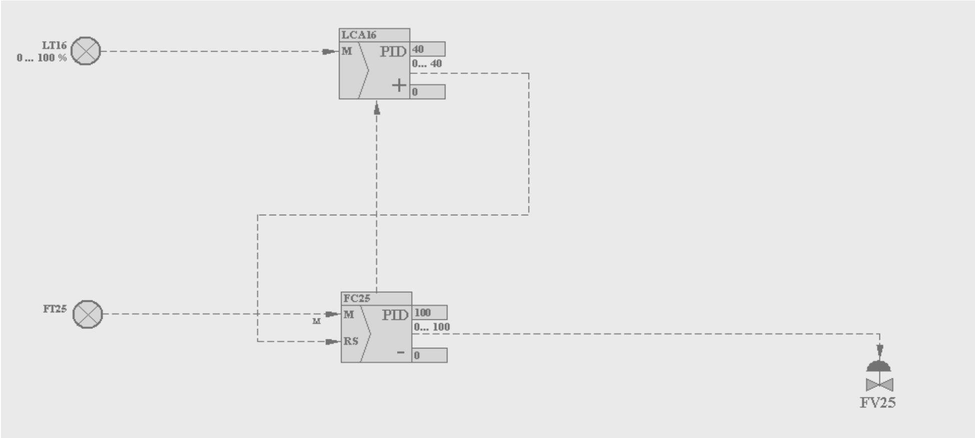

Figure 5. Automation model in the simulator. (NAPCON Simulator: NAPCON)

4.2.2 Model testing

Ensuring model quality is the goal of the testing phase along with reducing fine-tuning during acceptance tests (MAT, FAT and SAT) for both the process and the automation model. It is necessary to ensure that predefined conditions are met before starting testing, (e.g., calculation parameters). The process model is tested for the desired level of robustness and capability, including technical robustness outside the desired operation regime. Testing can be roughly divided into two parts, namely technical testing and response testing.

Testing the responses of the model is typically required within the intended operating regime and it includes testing with realistic operations. In technical testing, the model is pushed significantly harder to identify any major issues that might occur. This is a time-efficient way to get quick feedback on the robustness and performance of the model. Model response testing and technical testing do not replace one another, and therefore, both must be performed separately. The model testing requirements and the acceptable, passable simulation result vary, depending on the goal of the model's operation regime.

Testing of automation models can be done sheet by sheet after each sheet is configured, or when the bigger entities are complete. Template loops can be used as a reference for early testing of loops and can then be utilized as much as is practically possible. Finally, all the testing phases and results should be recorded and documented accordingly.

5 DATABASE AND USER INTERFACE

5.1 Database

The database is a part of the DCS in a real plant, but in a simulator, it is configured as a separate system. The purpose of the database is to provide trends and alarm lists to an operator, showing the history of the values of the process.

All the components are configured to the database as tags, a tag being a code combination of letters and numbers, containing the needed parameters e.g., description, unit, low and high limit values, for each component.

Figure 6. Simulator database. (NAPCON Simulator: NAPCON)

5.2 UI Configuration

A simulator's user interface (UI) emulates the real plant DCS UI, and it is the system where all the control room operations are done. The user interface is divided to an operator UI and a trainer UI. An operator can for example navigate between process displays, change set points, or follow the alarms. The trainer UI is similar but with extra trainer features, allowing the creation of different training scenarios e.g., stop pumps or causing a furnace shutdown. The trainers are also able to act as a field operator and control manual valves and field switches from the user interface.

The UI configuration is an important part in the simulator's design, since it is linked directly to the level of realism presented to the trainees and is the only part of the simulator that trainees actually see and use. The UI is configured for several process and interlock displays, which include static and dynamic elements, alarm lists, trends, loop windows and control room switch displays.

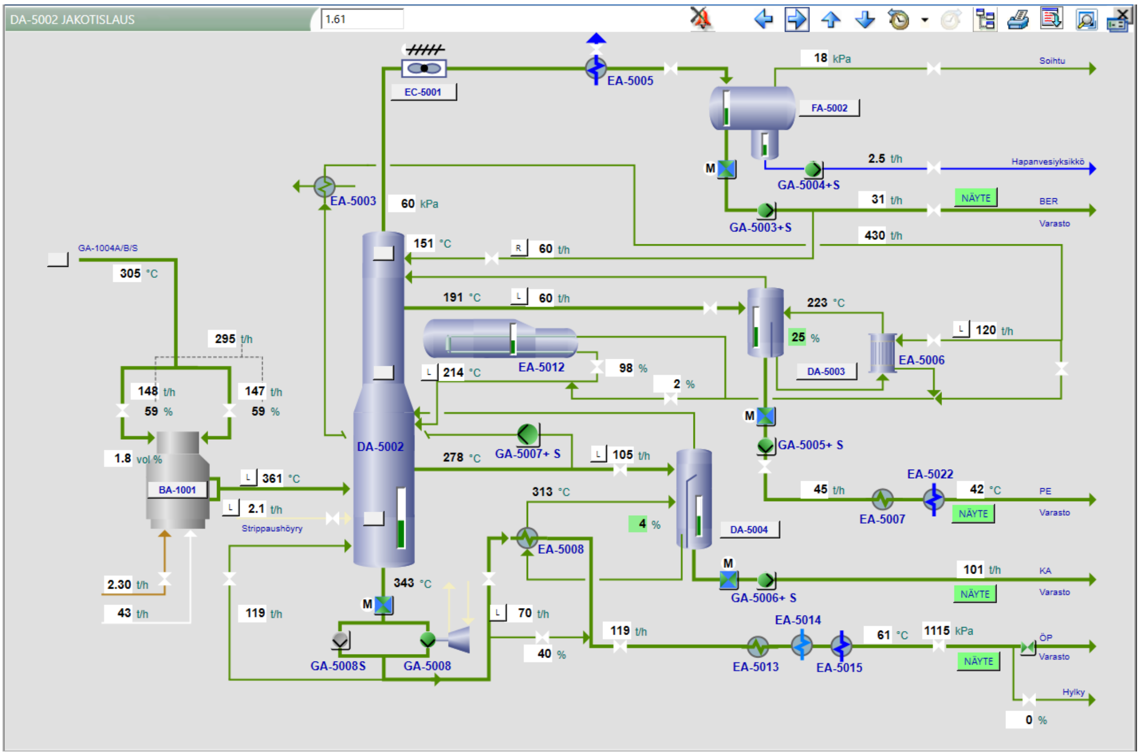

Figure 7. Simulator User Interface. (NAPCON Simulator: NAPCON)

5.3 UI and database testing

UI and database testing is carried out by checking that all the information from the database is going to and from the automation model and the UI accordingly. Practically, this means that all the dynamic boxes are showing values and the right units in the display. It is also critical that the upper and the lower limits values are set correctly to the database for the functionality of the entire simulator model. This can be tested from the interlock displays by changing the values and observing that the colors are changing accordingly, while the static parts of the displays are reviewed here also.

6 SIMULATOR ENVIRONMENT

6.1 Virtual machines

A virtual machine (VM) is a virtualized infrastructure where all the OTS components are combined. This infrastructure includes the software and the hardware, like the physical server and its hardware resources. At NAPCON, all the other OTS components run in this virtual infrastructure besides DV5 and Alarm sounds, which run on a physical trainer and operator station. (NAPCON Simulator: NAPCON)

6.2 Customer’s physical environment

A customer’s physical environment includes the virtualized infrastructure with its hardware. Usually, the training room is equipped with several computers and screens, allowing the operators to open all the relevant displays, alarms list etc. at the same time. See an example of an operator training simulator room in Figure 8.

Figure 8. Operator training simulator room. (Stone, 2018)

7 INTEGRATION AND TESTING

The integration phase combines the process with both automation and UI, as well as the database, to compile an entire simulator. During the integration, the process must stay in a steady state throughout, meaning there are not e.g., any major flow or pressure level swings.

After the integration, final testing is performed which includes MAT, FAT, and SAT testing. All these are performed according to a predefined protocol. In the next chapters, there is a short description of these tests.

7.1 Model acceptance test (MAT)

A model acceptance test (MAT) includes verification of the flow sheets. At this point the flow sheets should meet in terms of the marked scope of P&ID and for the completeness of the simulation model. This includes all streams, equipment, and instruments. The MAT ensures that models include some control loops and alarms to allow for proper analysis and stabilization of the model. Test observations and comments should be recorded, and the necessary corrections carried out. (Sangaran & Haron, 2017.) (Alamo & John, 2009.)

7.2 Factory acceptance test (FAT)

Following the model acceptance test, the controllers, emergency shutdown and the basic control system are tested in the simulator environment on a virtual machine. During the FAT, disturbance tests are also carried out to determine whether the models can enact disturbances as configured and respond accordingly. These tests should always be started from a steady state. During the test, model responses are then compared to those of the expected response. As per the MAT, all observations are recorded and verified. (Sangaran & Haron, 2017.)

7.3 Site acceptance test (SAT)

Post FAT approval, the simulator package will be delivered to the customer and installed in their simulator training environment. The main target of the SAT is to ensure that all the simulator hardware was delivered, remote connections were tested, and overall functionality of the simulator was verified. Introducing the simulator and training scenarios for the customer is also part of the SAT. All findings are recorded and corrected according to customer requirements. Once the site acceptance test (SAT) is done, all documents should still be properly inspected and preserved. (Sangaran & Haron, 2017.)

8 TRAININGS AT NESTE

Neste started making simulators and developing tools for modelling them as early as 1987. However, it was not until 2004 that the training simulators were systematically built for training use and in 2006 the first training version was completed. (Liljemark & Sinisaari, 2021.)

8.1 Simulator trainings

Simulator trainings at Neste can be roughly divided into two different types, namely disturbance situation trainings and maintenance trainings. During disturbance trainings, possible disturbances that might occur, or disturbances that have already occurred in a unit are faced while in maintenance trainings, the so-called routine procedures which, due to the shift system, may occur quite rarely for individual operators are presented to the trainees. (Liljemark & Sinisaari, 2021.)

Maintenance trainings also include training situations for the potential risk points of the units. The schedule for the trainings has been agreed upon during each shift individually. (Liljemark & Sinisaari, 2021.)

Simulator trainings are also held when a new operator is completing qualification as well as for each new unit qualification. The role of simulator trainings is quite small in operator training, but it is mandatory. In addition to theory and field training, future operators can familiarize themselves more with the basic automation and control system, how the controllers work and how they are operated in the control room in the simulator trainings. The operator also receives coaching for a future exam and more systematic simulator training will begin after the training period. (Liljemark & Sinisaari, 2021.)

The training situations are usually arranged so that the trainer has one operator at a time to train. Training is also draining for the trainer, so to make the situation as realistic as possible, and thus get the greatest benefit from it, 1-1 situations are preferred. Some of the more massive disturbance situations can be practiced throughout the whole shift, with more than one trainer on the scene. In these cases, monitoring and practicing of communication among operators is done, which is very important due to the interactions of many process units. (Liljemark & Sinisaari, 2021.)

8.1.1 Challenges

The biggest challenge in the simulator trainings is the resources of the shifts. Operators work in shifts and usually there is no opportunity to leave for a longer time to train in the simulator room. The potential solution to this would be seen as separate, pre-defined training dates that have existed in the past but have been left out. (Liljemark & Sinisaari, 2021.)

Simulator training can be considered valuable for Neste, as plant operation following the starting of systematic training has paid dividends already. However, closer involvement of the line organization could possibly improve the consistency of simulator training, as well as provide broader tools for systematic implementation. (Liljemark & Sinisaari, 2021.)

8.1.2 Development

Simulator training development involves the simulator team, NAPCON, as well as the Neste line organization. The simulator team has been growing over the years, allowing for the creation of good new ideas, as well as imaginative training scenarios. The features of the simulator have been growing during this time as well. Operators and line managers also play a large part in the development of simulator trainings, as the need for training comes directly from production lines. Efforts have been made to meet these needs by developing new simulators for process units where they do not yet exist. Also, statistical training has evolved and is being monitored systematically. (Liljemark & Sinisaari, 2021.)

The development of simulator training can be seen in the variety of training scenarios, as well as in their content. Of course, this is also a result of the development of the simulators, so that they can perform more varied trainings. In the early days, the focus of trainings was more on emergency operation, but today there is an increasing emphasis on quality adjustment and optimization in trainings. Time is also spent on the design and continuity between the exercises, and it is seen as an important part of the development of training. (Liljemark & Sinisaari, 2021.)

9 CONCLUSION

This thesis aimed to gather the main topics related to the construction of an operator training simulator and combine them into cohesive onboarding material. With the help of NAPCON's user manuals, other documents, and professional consultants, I was able to implement my own work experience at NAPCON to compile this thesis.

During this thesis project, I went back to my first summer at NAPCON and at least for me this kind of onboarding material which tells you the main topics, how they are related to each other, and what the operator training simulator actually is, would have been helpful since I had no previous experience. Of course, to a person who already has work experience in the field and therefore has the main topics up on it would not need the guidance about OTS itself. Still, the OTS modelling work includes many complex work parts and usually you first focus on just one part at a time. So, in every case it would be beneficial to briefly go through every part and how the parts are connected to each other. I also think that it is important to understand the end user point of view from the very beginning of the OTS modelling work and it is a valuable addition to this thesis.

I see this thesis as a useful onboarding material as intended for the simulator teams but also for other stakeholders, e.g., the Neste simulator training organization. For example, when they do the evaluation of a new simulator it could be useful information to know what steps are required.

This material could also be used as potential information for new customers. For customers who do not have an OTS yet but would be interested in one, this material possibly with some modifications could give a good overview of what it takes to build an OTS on the NAPCON side and what it takes from the customer's perspective. The end-user perspectives would open the idea of what the whole OTS investment means and how to get the most out of it. At the end I believe that I managed to build up valuable material for NAPCON and Neste for the future. The material will serve its purpose as onboarding material.

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