Requirements and experiences on a sustainable digital twin platform for dependable studies of thermal processes dynamics

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Abstract: Digitalization for dynamic simulation studies of thermal processes may focus on just a separate process component, on an energy storage, on a single power plant, or on multiple consumers and producers connected with electric, district heating, district cooling, or natural gas networks. Typical boundary conditions needed for such studies are estimated curves for power consumption, weather and wind. With access to a carefully updated dynamic digital twin of your thermal process in consideration, then at any time, you can test how the processes, the automation and the electrical systems work together. The functionality provided by the simulation platform of the digital twin shall make it possible for process, automation and electrical engineers to update the simulation model making use of its graphical interface, just by drawing process, automation and electric diagrams and filling in appropriate attribute values for the simulated components. Accordingly, it should neither be necessary to hire any experts on Inter-Connected Tests (ICT), programming, nor on the solution of differential equations, to keep the digital twin up to date. The simulation platform of the digital twin shall provide for a library of credibly verified and validated component models required for your application. The platform shall contain a database for the storage of component parameters and connections. To be sustainable, the database shall be easily transported from one computer generation to the following. The platform must cope with dynamic simulation in real time. Then, if you connect the platform to a copy of the real control room equipment you also have access to a training simulator. If you replace the automation system models of the simulator with the actual configured automation system, then it can be tested in advance, already at the suppliers site. It is expected, that the commissioning work at the real plant could be speeded up considerably. Examples of a suitable simulation platform and successful pre-studies of integral process and automation system dynamics are presented in the paper. Digital twins may reduce the need for written paper documents and procedure protocols. Specification of digital twins may be further speeded up and the risk of typing errors reduced whence updating the parameters, if the required attribute values in future would be made available in standardized format for instance over Internet by the relevant component suppliers.

Keyword: digitalization; digital twin; integral check; dynamics; sustainable specifications

1 The dynamic digital twin

To specify the requirements for a reliable, sustainable and still affordable simulation platform for the digital twin, we need to choose from various modelling paradigms, to consider suitable computer implementations, to ensure that continuous maintenance is available of the platform, to check that stringent enough procedures are applied for verification and validation of the model components, and to ensure that the application specific model parameters and connections can easily be transported to new computer generations. The digital twin should be available for engineering applications in different phases in the life-cycle of a plant, such as in the initial design of the integrated process, automation and electrical systems, in the planning for commissioning work, in the testing of operational procedures, in the checking of postulated malfunction situations, in the testing of real automation equipment, in the training of operators, and in the examination of planned plant and automation system revisions. A detailed study on the present status of different dynamic simulation platforms for thermal power plants available has been made, see [1]. Considering the study, it seems that for instance the APROS software could be a suitable platform for maintaining dynamic digital twins of many kinds of thermal processes. Simulation software on the market are usually developed for specific purposes. Different modelling paradigms are applied. Different computer implementations are available. Regarding the digital

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twin platform, we need to recognize proven technology for dependable and sustainable digitalization. We have considered the capabilities of APROS as a modelling and simulation platform for a such a digital twin. Successful engineering applications of making use of APROS during different phases of an energy system life cycle are referred to. It is also considered that the development in computer technology nowadays allows for quite strict requirements on the level of detail of physical mechanisms included, even in a real-time simulator.

2 Modelling paradigms for the digital twin

2.1 Steady state or dynamic models

Steady state fluid flow process models are very useful in the early design phase, for instance when optimizing the process flow structure of a plant regarding energy efficiency. In that early development stage, the detailed control system has usually not yet been designed. Next step is to introduce the tank dynamics but still use a steady state solver for the pipes. A dynamic twin model should, however, also include the dynamics of the pipe interconnects of the flow process to be suited for tuning of the final real control system concept.

For optimization of different stationary conditions of electrical networks so called steady-state load-flow programs are used. However, for checking of the network during fast changes in loads or line connections, then transient stability software, capable to calculate in real time the mechanic frequency oscillations between connected generators in the network and the resulting dynamic load flows, needs to be used. There are also available specific software products for detailed calculation of travelling waves and for harmonic distortion analysis in electrical lines. They might not be capable to calculate in real time and are accordingly not useful for the digital twin.

Control system models should be as dynamic as the real control systems. The control system components are often described by reAlevant transfer functions.

For checking of integrated plant dynamics, the digital twin should accordingly include suitable dynamic fluid flow process models, transient stability electrical grid models, and control system models. The solvers of these models should be readily integrated in the simulation platform of the digital twin.

2.2 Identified or mechanistic models

Black box and grey box transfer function models are usually identified by making step response tests to the real components. Making this kind of tests with real processes might in many cases not be advisable. Grey box models include several transfer functions and some structure of the real process.

Mechanistic models based on main physical principles and process structure can be designed even before the construction of the real component or energy system.

Dynamic mechanistic fluid flow models arise from the conservation equations of mass, momentum and energy. The structure of a one-dimensional fluid flow process is suitably discretized for the mathematical calculations to a limited grid of control volumes. Adjacent heat structures of the processes are also discretized for one-dimensional mechanistic calculation of the heat diffusion through the structures. Empirical correlations are used for calculation of heat transfer between the flow and the structures. Data-bases are available for looking up required material property data for included fluids and structures.

2.3 Discretization of flow and diffusion structures

Because of the real-time simulation requirement of the dynamic digital twin, we must focus on one-dimensional flow and diffusion studies. The one-dimensional discretization to control volumes is *e.g.* well suited for pipes and vertical tanks. There is a simple restriction, as described in [2], for the length of such a control volume: The phenomenon under study should not proceed further than the distance between two control volumes during one time-step, to guarantee dynamic correctness. The solver should anyway be implicit for stability. For example, if you study the proceeding of a temperature gradient in a pipe with maximum of 10 **m/s** water flow speed, and choose a control volume pipe length of 1**m**, then the time-step should not be more than 100 **ms**, which is suitable for real-time simulation. Further, if the heat diffusion speed in the pipe wall is not more than 10 **mm/s** and the control volume pipe section wall is discretized to 1 mm layers, it is safe to use the 100 **ms** time-step. On the other hand, if you want to study the detailed pressure transient in a water filled pipe proceeding with 1 km/s and use the same 1 m control volume length, then the time-step should be at most 1 **ms**.

The outcome from these dynamic one-dimensional studies with the dynamic digital twin may be recorded and used as flow boundary conditions for off-line detailed CFD studies of some specific volume of interest, or as temperature boundary conditions for specific software developed for material integrity and ageing studies of plant mechanical structures.

2.4 Homogeneous, separate phase and non-equilibrium flows

The dynamic digital twin should be capable to consider several kinds of flows, such as single phase, homogeneous, separate phase and non-equilibrium flows. In a typical homogeneous flow model, the included phases are mixed in the pipes having the same temperature and proceeding with the same velocity, but in the tanks, they may be separated, still having the same temperature. In the separate phase flow model, the included phases may be separated also in the pipes and they may have different velocity or even different direction. In the non-equilibrium case, the different phases may even have different temperatures in the same control volume.

Of course, when there is only liquid water in a pipe, then a single-phase model could be used to save calculation time. On the other hand, for instance in a CFB boiler plant, the flue gasses and the circulating bed material certainly have different temperatures and velocities whence passing the control volumes.

3 Software and hardware for the digital twin

3.1 Procedural model programming and execution

High level languages have been developed such as Algol, FORTRAN, Pascal, Ada, Java and C to enhance programming with processor specific assembler code. These languages have from time to time been used for procedural programming of simulation models. Subroutine libraries supplied *e.g.* for solving of differential equations made these general-purpose languages more suited for modelling of dynamic processes.

In parallel, specific languages for modelling and dynamic simulation purposes such as the Advanced Continuous System Language (ACSL) were taken into use, see **[3]**. Whence developing large models in the past, the model programming effort was shared by several programmers.

To speed up the programming, libraries of pre-programmed model component subroutine procedures were developed for instance by EPRI in the Modular Modeling System (MMS), see **[4]**. Typically, the compiling and linking process of the procedural models to get the executive program, could take much time. This procedure was needed to repeat after each change in the source code of the modelled system.

3.2 Table-driven model specification and execution

Table-driven simulation tools were developed, as well. In these tools, the integral model specifications and variables are stored in in-core data-base tables of the tool. Accordingly, no programming, compiling and linking is needed after any change in the application model configuration. The APROS simulation server is a table-driven modelling and simulation tool like most nuclear system analysis condes. It was originally programmed in FORTRAN 77 language and running on a 32-bit VAX-8650 computer and operated from alphanumeric terminals with the APROS command language, see **[5]**.

Before the advent of graphical user interfaces, all application model specific variables, parameters and connection data were specified and stored in tables, either by editing specific text files or by applying simple line editor commands to update model object parameters and connections directly in the real-time database of the simulation server.

In the table-driven server, the functionality of each model type was pre-programmed into the platform. For instance, whence simulating a pipe network, only one instance of the pipe section equations of required accuracy level was needed in the source code even if there were 1000 pipe sections in the application model.

The source code of the table-driven platform does not depend on the application model. For making changes in the application model no changes were needed in the software platform, and of course no compiling and linking efforts. The changes in the application model could be done process, electrical and automation experts. No programmers or mathematicians were needed. In many cases the source code was not even available of table-driven platforms. The platform supplier was responsible for the verification and validation of the functionality of the platform.

3.3 Modern user interfaces and interfaces to design data

Modern CAD-like user interfaces have been developed both for procedural models and table-driven models for placing and connecting of available model objects on the application model diagram on the screen. Also, graphical specification of higher level models may be possible by combining several lower level model objects to a new sub-process with an own new symbol. Object-oriented software is well suited for the development of graphics clients for simulation servers. Standardized connections with various design data-bases reduce the need to manually re-type model parameters. Standardized on-line interfaces enable connection to real control systems and operator interfaces. The first graphics client connected to APROS simulation server was running on VAX/VMS workstations, the next on UNIX workstations and the present graphics client software runs on Windows 10 computers. Figure 1 shows how the user specifies the models at component level with a hierarchical graphic user interphase of the APROS Digital Twin platform. APROS automatically generates the structures at the calculation level.

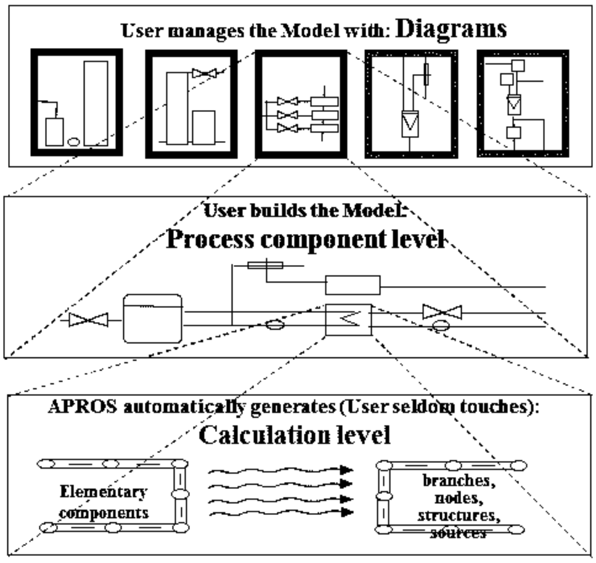


Fig.1 Specification of the Digital Twin model with the hierarchical user interphase.

Engineering software interoperability improves considerably the efficiency in engineering workflows. Required manual work is reduced, enabling faster and more robust design to be conducted. In process industry and power generation, the ISO 15926 standard is being adopted as a neutral engineering data classification. In a recent study, see [6], the work conducted in integrating model specifications into an engineering data workflow, is reported. Standard engineering data could be automatically transferred to simulation model specifications for APROS. A case study was conducted to demonstrate the implemented features. Process engineering data in the Proteus XML format was used as the source data for simulation model data generation. The case study shows that the implemented features could reduce manual work considerably, lowering the threshold for utilizing simulation.

3.4 Shared and distributed memory computing

It is interesting that FORTRAN still is in the front line of number crushing scientific computing platforms. Computer vendors have faithfully optimized their FORTRAN compilers for newest hardware. Automatic vectorization and threading for both multicore and manycore computing nodes is included. Additional directives *e.g.* in accordance with OpenMP standards are available for the programmer of the source code of the platform to further assist the compiler. Each core has threads available for storage and execution of code, they can vectorize the computing in each thread in accordance with SIMD principles making use of long processing words, *e.g.* containing eight double precision variables each. The cores have large local cache memories for fast access to processing data. An iterative solution can be made very fast if there is no frequent need to access next level memory outside the processing chip during the calculation, *e.g.* to shared external memories or to separate computing nodes.

For connection of several computing nodes in parallel with own computing tasks there are standardized MPI subroutine libraries available. Here the software configurator may have the possibility to divide the complete model into suitable tasks running on separate distributed memory nodes with localized memory tables. A table-driven once finalized computing platform needs only to be optimized once for new computer hardware configuration to get a new platform software version, whereas procedural models need to be re-programmed, optimized, compiled and linked to new tasks each time there is a change in the application model. The serial processing speed of the processors has in fact not increased much during the last years.

A study described by Intel [7] regarding their Xeon processors shows that their E5-2699 V4 Broadwell-EP family 22 core processors released in 2016 may run 187 times more efficient if optimally vectorized and threaded, than just in serial mode. It may have up to 55 Mb upper level fast cache memory shared by the cores. One of the challenges in the computing platform development is to design such an extensible table structure for the model variables and parameters that it minimizes the need for occasional updates of single distributed memory locations, which may result in page faults and delays. Most frequently updated variables, *e.g.* calculated during iterations should be in continuous vectors in low level core specific cashes for fast access.

4 Verification and validation of the digital twin

It is generally assumed that a carefully certified version of the table-driven simulation platform also calculates correctly in new model configurations, in new plant designs and in new transients of interest, even if no measurements are yet available. Presently there are 189 validation test cases available to certify the correct operation of the APROS system code. The following 10 separate tests and 17 integral power plant validation cases are used regularly at each APROS version change:

- Separate tests: Edwards pipe, Battelle top blowdown experiment, Becker’s experiments, Ersec reflooding test, Marviken critical flow tests, liquid blowdown to containment, blowdown experiment mx-ii at Marviken containment facility, spray experiment (isp-35) at Nupec containment facility, steam condensation experiment (isp-47) at Mistra containment facility, and water level rise transient in Pactel pressurizer.
- Integral tests: Stopping of main recirculation pump, reactor scram, small break LOCA, large break LOCA and ice condenser model, and stopping of three main recirculation pumps for 3d-neutronics test with the Loviisa NPP model. Stopping of main recirculation pump, and reactor scram with another VVER-440 model. Steam line break, and reactor scram with the Olkiluoto 1 model. Electric load rejection, turbine trip where turbine bypass fails, loss of condenser vacuum, trip of all recirculation pumps, feed water line break at ATWS, and a steam line break test with the Forsmark 3 model. Change of set-point transient at a CCGT power plant connected to district heating network.

5 Applications of the dynamic digital twin

5.1 Various needs for a dynamic digital twin

If a dynamic Digital Twin is available for a plant, it can be used for many purposes and in different phases of the whole lifetime of a plant as shown in Fig.2.

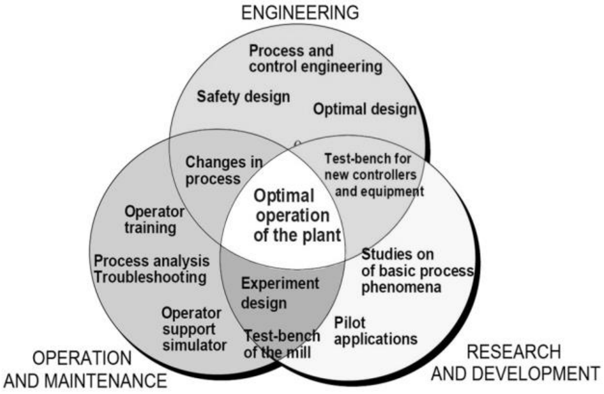


Fig.2 Application areas of a suitable Digital Twin of a plant.

The digital Twin may be used both for initial research and development, for engineering planning of the plant, and to support operation and maintenance of the plant. The research applications may include studies of basic phenomena and novel design principles. The engineering applications safety design, process and control engineering, as well as factory testing of control equipment. The operation and maintenance applications may include process analysis and troubleshooting, operator training and planning of upgrades.

5.2 A sustainable simulation model of Olkiluoto-3 EPR plant

The simulation model contains a detailed description of the primary and secondary circuits, emergency systems, protection systems, main and some auxiliary control systems, see [8]. The simulation model has been validated in steady state, transient and accident situations. The EPR simulation model has been used in the analyses of some transients such as a spurious closure of low pressure steam admission valves and reverse flow of the low-pressure turbine extraction lines. The developed simulation model has been utilized also in the safety analyses *e.g.* in the analysis of the cold leg large break loss-of-coolant accident (LBLOCA).

5.3 First automation renewal at the Loviisa 1 and 2 plants

APROS simulators have been used extensively in Loviisa automation renewal projects. Loviisa is VVER-440 type Nuclear Power Plant with two units, which started to produce electricity on 1977 and 1980. To ensure safe and reliable operation of the plants the automation is renewed from critical parts. As described by Näveri *et al.* (2010) [9] APROS was used extensively already in the first automation renewal in which parts of original automation was replaced with digital I&C provided by Areva and Siemens. A virtual copy of the operational I&C provided by Siemens and the safety I&C system provided by Areva was connected to the APROS model and the automation was tested beforehand with realistic process response.

5.4 Recent re-use of the Olkiluoto 1 and 2 BWR plant model

An extensive engineering analysis model has been developed on the Apros simulation platform for the OL1 and OL2 plants. It has been updated, validated from time to time and re-used in many applications. According to Porkholm *et al.* (2012) [10] the dynamic behavior of the whole power plant can be simulated already in the design phase, when the plant is "on the paper", because the Apros models are based on basic principles physical equations. Possible faults in the design of the process, automation or electrical systems can be observed at a stage when modifications are easy to do. This ensures that the modifications can be realized in the real power plant safely and fast.

5.5 Dynamic analyses of a coal plant evaporator as an engineering simulator use case

According to Lappalainen *et al.* (2012) [11], the simulation study was initiated due to the damages recognized in the evaporator tubes, followed timely by a recent change of control strategy at the plant. The simulation study showed that operation in superheating control mode does not stress these parts of the tube lines substantially more than in level control mode. This was seen both in normal operation and in the transients simulated. In superheating control mode, end of the tube lines heated up more than in level control mode, but the risk for the tube material was still considered low in normal long-term operation conditions. In superheating control mode, however, the end side of the tubing is clearly more sensitive for excessive high temperatures in case of power or flow disturbances. This must be addressed when planning operational practices. The major outcome was a good understanding of the practically meaningful factors in this problem case.

5.6 Model based development of the design and operation philosophy of solar thermal power plants

The solar thermal power plant design and operation process is optimized by having a system level thermal-hydraulics model for the solar receiver to simulate the transient start-up and shut-down events, see Terdalkar *et al.* (2013) [12]. Since all the major components of the system are included in the model, it reflects the transient response of each of the components on each other and on the overall system. This simulation can be used to generate input conditions for component level life usage analysis. The component level life usage analysis is done using the finite-element method. The component level life usage analysis determines the permissible ramp rates. The thermal-hydraulics dynamic simulation outlines the operational philosophy of the system. APROS one-dimensional system code was used for the dynamic simulations providing boundary conditions for the ABAQUS 6.11 finite element code. To optimize plant operating modes, several iterations of simulation and analysis were performed. Each iteration included a system level dynamic simulation followed by finite element analyses for multiple components while considering the plant level effects.

5.7 Simulation model-based studies of a CFB plant with gas turbine repowering

Circulating fluidized bed (CFB) technology is known to have sufficient scale to act as a large grid balancing unit, see **[13]**. Although the load change rate of the CFB unit is known to be moderately high, supplementary repowering solution will be evaluated in this paper for load change maximization. The repowering heat duty is delivered to the CFB feed water preheating section by smaller gas turbine (GT) unit. Based on the performed simulations, considerably good improvements to the CFB process parameters are achieved with repowering. Consequently, the results show possibilities to higher ramp rate values achieved with repowered CFB technology. This enables better plant suitability to the grid balance markets. Both dynamic and steady-state simulations accomplished with APROS simulation tool are used to evaluate repowering effects to the CFB unit operation.

5.8 Analysis of hybrid configurations of concentrated solar power and conventional steam power plants

This study presented by Suojanen *et al.* (2017) [14], focuses on modelling, analysis and comparison of three hybrid configurations of concentrated solar power and conventional steam power plants. The configurations include feedwater preheating, cold reheat line and high-pressure turbine concepts, in which linear Fresnel collector solar field with direct steam generation is applied to generate steam parallel with the steam boiler. The modelling is conducted using dynamic simulation software APROS, which enables investigation of the system operation under varying process conditions.

5.9 Dynamic simulation of a large multi-stage flash distillation plant

Multi-stage flash distillation (MSF) is a leading technology within the thermal desalination field. An integral method for one-dimensional modelling and dynamic simulation of thermal desalination processes is applied, according to Lappalainen *et al.* (2016) **[15]**. The APROS-based process model combines the simultaneous mass, momentum, and energy solution, local phase equilibrium by Rachford-Rice equation, and rigorous calculation of the seawater properties as function of temperature, pressure and salinity. A brine recycling MSF plant was modelled as a case study, presenting advanced and unpublished simulated features and transients. The successful results suggest that the method presented is a competent approach for dynamic simulation of thermal desalination processes.

5.10 Second automation renewal at the Loviisa 1 and 2 plants

The second automation renewal project at Loviisa is implemented during the annual maintenance periods in the years 2016, 2017 and 2018. The automation supplier is Rolls- Royce. Also, in this project APROS has several important roles. APROS is the main safety analysis tool of the Loviisa NPP. With the safety analysis it is ensured that functionality of the automation is designed in such a way that that the plant can be brought to safe state without violating the criteria set by the Finnish Nuclear Safety authority. Short term analyses prove that the automatic safety systems will bring the plant to a controlled state without operator actions. Long term analyses prove that the operators using the emergency operating procedures will bring the plant to a safe state. This way the new functional architecture of accident management is validated with over 100 analyses covering transients from anticipated operational occurrences to Large Break LOCA. The APROS model used for the safety analyses is the most accurate thermal hydraulic model of the whole plant but automation is modelled in a simplified way but so that the functionality of the automation is maintained.

These safety analyses cases were then utilized in the test planning of the dynamic tests with the real and emulated automation systems. To connect the real and emulated automation, the plant model must be detailed in way that it comprises all the measurements and operating devices with identical I/O to plant I/O. The automation was also modeled in detail with APROS to attain reference test data to the actual tests. The plant behavior in the tests was evaluated by the operators of the Loviisa NPP.

The automation testing took place in two locations: in the Rolls-Roywse test field, where APROS was connected to real cabinets as well as emulations and in Fortum's development simulator which provided interfaces to 'all' other systems. The experiences from the tests have shown that the dynamic transients allow for 'operational profile' testing which is more realistic and efficient than individual signal tests. These speeds up the testing process. Most errors were found already during the integration to the simulator, which made the modifications even more agile.

5.11 New APROS-based training simulator at Loviisa

Alongside with the automation renewal project also a new training simulator has been introduced with a new state of the art APROS based model. The model is identical to the model which was used in automation testing. The full scope APROS model of Loviisa NPP includes process, automation and electrical power systems as well as a 3D reactor model. To maintain real-time simulation several parallelization options have been used. The operator interfaces have been implemented with touch screen HMI identical to hardwired panels in the real control room. This was again a new important application of the APROS-based Digital Twin model of the Loviisa plant.

Table 1 shows the extent of the full scope training simulator model of the Loviisa plant. The 3D reactor model is on one PC and the rest of the plant, including control and electrical systems run on the other PC.

Table 1 The extent of the dynamic Digital Twin model of the Loviisa plant

Model property	Count
Diagram pages	3800
6-equation thermal-hydraulic nodes	1000
6-equation thermal-hydraulic nodes in 3D reactor model	3500
3-equation thermal-hydraulic nodes	3800
Containment nodes	64
Valves	4200
Pumps	400
Analogue signals	54000
Binary signals	155000
Controllers	300
Electrical nodes	400
Electrical switches	300
In core database size (Mbytes)	53

The model runs readily runs in real time on the two virtual PCs on server platform, equipped with 64-bit Intel® Xeon™ E3-1240 v3 CPU @ 3.40 GHz and RAM 12.00 Gt.

The APROS models used in the Loviisa training simulator have been transported to the newest APROS 6 version equipped with a new graphical user interface. An example specification sheet of one of the turbine plants is shown in Fig.3. Both process equipment, electrical equipment and automation equipment can be specified on the same sheet.

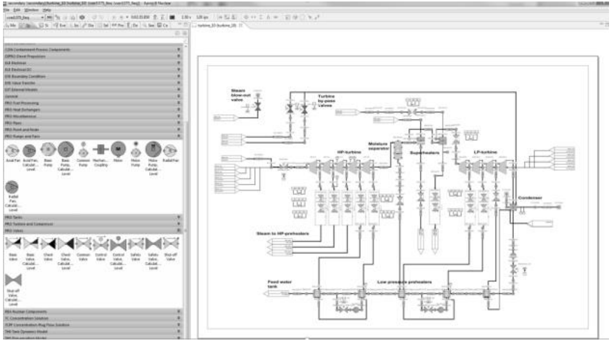
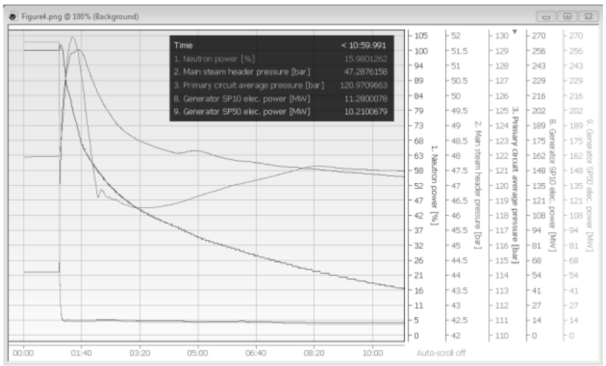


Fig.3 Example diagram of the APROS 6 user interface.

Example curve plot of a simulation experiment is shown in Fig.4. It shows plant behavior after a postulated trip of the external power grid. Here the turbines reduce their power to home use of the plant itself.



Time	< 10:59.991
1. Neutron power [%]	15.9801262
2. Main steam header pressure [bar]	47.2876158
3. Primary circuit average pressure [bar]	120.9709663
8. Generator SP10 elec. power [MW]	11.2800078
9. Generator SP50 elec. power [MW]	10.2100679

Fig.4 Example curve plot with APROS 6 graphics.

Figure 5 shows a picture of the control room of the new full scope simulator at Loviisa. Whence the simulator is equipped with a full scope best estimate analysis model including the electrical and control systems of the plant, new scenarios can easily be implemented.

Fig.5 The control room of the new full scope training simulator of Loviisa.

6 Conclusions and future possibilities

The above use-cases of a dynamic digital twins implemented on the APROS platform represent different instances of the life-cycles of the plants and processes under study. It is obvious that the nuclear application-oriented verification and validation procedures of the thermal hydraulic solvers in APROS also are most beneficiary for the simulation of other processes. Our requirements for such a Digital Twin have been concluded as follows:

- Steady-state or dynamic models: Dynamic
- Identified or mechanistic models: Mechanistic
- Shall the simulation model run in real-time on affordable computer platforms: Yes
- Shall the calculation engine be procedural, or table driven: Table driven
- Shall suitable methods for automated division of the plant equipment into calculational control volumes of flow and heat structures be included: Yes
- Shall the flow calculation provide both for homogeneous flow, and for separate phase flow with different velocities and different temperatures of the phases: Yes
- Shall parallel calculation of process, electrical and automation system models be readily integrated in the platform: Yes
- Shall it be possible to simulate the whole plant in real time on affordable computers: Yes
- Shall model specifications be easily transportable from old computers to new computers, operation systems and new simulation platform versions: Yes
- Shall the model building blocks of the platform be delivered readily verified and validated for every new platform version and update: Yes
- The graphics user interphase shall enable easy modelling and simulation by process, automation and electrical engineers. Computer programming skills shall not be needed: Yes

In future, it seems possibility to convert relevant engineering data, such as piping, electrical and automation diagrams and related parameters, to table driven simulation model specifications. The engineering design work obviously benefits much if the component manufacturers could provide access to their digital component data libraries over Internet, so that the engineer specifying the integral model could choose a suitable component such as a pump, copy its symbol with relevant parameters from the manufacturer’s library, and just place it on the process diagram of the graphical modelling interface.

The dynamic data management features of the table-driven solvers could make it possible to optimize the algorithms to suit the data structures of novel multi-core, multi-thread and multi-vector processing. This makes it possible to consider real mechanistic models, not only simplifications, for faster than real time applications. It could, for instance, be possible to show predicted curves, if no manual operations are made, on the operator’s screens. Such models could also be used for advanced model predictive control implementations.

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