SARIE UPGRADE: NUCLEAR REACTOR AND WATER SYSTEMS "ENGINEERING AND TRAINING" SIMULATOR

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0 - Abstract

Confronted as of its origins with the on-board layout constraints of the French Navy ships, TECHNICATOME integrates, as of the design, the ergonomics and the risks control related to the human factors.
During more than 30 years, TECHNICATOME demonstrated a one of a kind know-how from the design to the execution of powerful, flexible and highly available nuclear compact reactors. A total control which includes up to the supervision and monitoring systems, the acoustic discreetly of the systems and its components, implemented on on-board reactors, testing reactors as well as experimental reactors.

The functionalities of simulation were right from the start used by TECHNICATOME during the design phase of these installations to carry out operation engineering analyses on the thermal hydraulic and neutron aspects, to validate the principles of operation of the supervision systems like by the use of digital models in 3D CAD to validate the kinematics of operation or the interactions between systems.

More recently, and starting from the end of the Nineties, a thought needs was launched to determine the interests related to the development of a training simulator associated with these installations with objectives, among others, to ensure the phase of initial training of the new operators, to widen the field of the training to the accidental situations, the management of crisis and crews behaviour supervision, the possibilities of replay which support the consolidation of the acquired knowledge(debriefing) with situation resume, and to increase the overall training capacity.

An upgrade and modernisation project of these various simulation means was thus launched since 2001 with the objective to optimize the whole of the tasks supported by these means.

1. Preliminary study – needs determination

A simulator is first of all the combination of a model and supervision and monitoring interface of which the representations are one and the other more or less comprehensive and faithful compared to existing or future reality. The choice of the couple (completeness - fidelity) is done according to the objective of the final end-user by taking his budget into account. The full-scope replica simulator (100% - 100%) has many advantages in the absolute, but has two major disadvantages: its cost and its development period.

In many cases, the optimization of the couple (completeness - fidelity) to reach lower cost for each functionality considered is not carried out.

Thus when the analysis of the real need is imperfectly specified, the major tendency consists in moving initially towards full-scope replica simulation and it is only at the stage of the financial study that a keen interest appears for other solutions.

It is thus largely better to express each functional objective in term of specification element whose analysis of the development cost is compared with its “weight” compared to the total objective, which makes it possible to seek the adequacy of the simulation means with the targeted needs and to optimize the development load to each design topic.

The end-user carries out at the beginning an analysis of the various desired functionalities utility and expresses them in the technical specification. On the basis of these elements, it is important to link with a simulator vendor who will specify part of the elements and will identify those which have a strong influence on the final cost of the simulator.

This work in synergy then makes it possible to evaluate the value and to finalise the requirements of it: the user evaluates their utility (or impact of their degradation) on one hand, the simulator vendor situates these elements on a scale of costs and proposes simplifications allowing to reduce them.

This approach thus makes it possible to carry out the initial project specification which formalizes a set of functionalities having to be provided within the simulator. Their choices follow on from the first prioritization of their utility. These functionalities must then be specified in terms of HMI and modeling: it is then a question of judiciously determining their levels of fidelity and completeness (or more generally their level of complexity) and of specifying the whole of their characteristics.

TECHNICATOME thus associated Corys TESS Company in its process to establish a general panorama of the available simulation means, illustrated with examples resulting from an experiment of several years of project development. An inventory of the useful functionalities in each phase of the project life cycle was proposed and the quality criteria to be covered by the simulation software workshop were described in their generic principles.

2. Project outline

On the basis of the preliminary study, but also pushed by prohibitive maintenance costs and facing impossibility of simply configuring these simulators for new engineering analyses, TECHNICATOME made in 2002 the decision to carry out a complete upgrade and modernisation of its simulation configurations corresponding to a set of 6 nuclear-powered propulsion simulators (submarine and aircraft carrier) gathered under the SARIE label.

The specification specified the fields of application in which these means were to be able to be used, according to the project development phase of the concerned system:

- **Design:** engineering analyses of the reactor overall operation, optimization of the I&C system various regulations and automatisms, components dimensioning, support to the choices of the system architecture and assistance to the drafting of procedures corresponding to the plant general operation.
- **Execution:** Test preparation and performance analyses, functional validation of I&C system (emulator coupled to SARIE), validation of the incidental and accidental instructions procedure.
- **Operation:** engineering analyses and validation of modifications (either on hardware or procedures) in order to minimize the costs and the unavailability of the nuclear-powered installation and incidents analyses (interpretation, checking of the margins, proposal for evolutions…).
- **Training:** training of the new operators on the reactor operation, behaviour and safety, training of operators (Navy, Testing reactor) to the normal, incidental and accidental situations, refreshing training course following an important modification of an existing installation

In addition, the control of a powerful and original simulator software workshop was regarded as an essential vector of success of the project. This workshop was expected on one hand to meet the various functional needs and to structure on the other hand the organization of the tasks of the development team.
The specification thus described also the qualities awaited at the workshop level as well as in terms of generic functionalities:

- **Architecture and Modularity:** modular workshop of independent tools whose products are assembled in a common structure of data, management of the libraries “of modeling and HMI dynamic reusable objects”, segmentation in several modules of work aimed at the simulator software production and allowing a parallel management of the development tasks.
- **Generics and configurability:** each work module comprises a fixed base, targeted on its generic character. This results for example in a generalization of the integrated “objects” approach using graphic modeling editors. Configurable elements recorded in objects libraries are then associated to this fixed base. These qualities ensure in particular the reusability of work throughout the development of the project…
- **Opening towards the standard:** to allow to integrate external modules, in particular “standard” tools of the market for work not being specific to simulation and to ensure the communication with external products (for example, connection with the real control room replica).

- **User-friendliness and ergonomics:** by their design and their ergonomics, the whole of the tools must be mastered in a few training weeks by engineers and suitably qualified technicians. The user must be able to make the initial product evolved without requiring support from a software specialist not easily available.

3. Project execution and specific constraints

Two years of work were then necessary to completely renovate the SARIE workshop environment and to bring all the selected functionalities awaited by the teams of TECHNICATOME. The recovery of the existing engineering configurations was carried out by a semi-automatic importation of the calculation data thus avoiding the heavy and complex revalidations and acceptance test.

Through the use of the new open and evolutionary simulation workshop both on software and hardware architecture, this operation allowed:

- To reduce considerably the cost of software (and hardware) maintenance,
- To preserve the crucial functionalities using encapsulation of the "company" thermal hydraulic code CEDRIC with its field of qualification (10 years of R & D) and to preserve the investment in the existing engineering configuration,
- To have an open workshop and to benefit from a mutualisation of the functionalities,
- To have an ergonomic and teaching aids man/machine interface (HMI),
- To extend the SARIE workshop application through a better representativeness (field of modeling) while remaining on its initial missions and to guarantee the software non-regression.

Corys TESS developed innovating and effective solutions to be able as well as possible to control the costs and the times of this project, having made it possible to optimize the project execution stages:

- The evolutions of the data package (topology of the model) being very frequent, a very dynamic solution of communication between "commons" FORTRAN and the ALICES variables space had been implemented,
- The whole of the I&C simulation models is ported from the ESOPE language (derivative of FORTRAN) into C++ language. These codes are reprogrammed via the ALICES graphic interfaces,
- The porting operations (development of the elementary objects, object instantiation in simulation model documents,…) were mainly based on the capacity of ALICES to import data described in XML format.

The validations of the porting is based on ALICES workshop qualification as an engineering tool together with the non-regression of the engineering configurations porting.

The ALICES workshop qualification is marked following the functional tests, by taking again the old functionalities but especially by validating the development of new functionalities.

The non regression of the engineering configurations porting is validated on a whole of transients tested jointly in the old one and the new environment:

- The scenarios, extracted from the old workshop are coded via the ALICE exercise feature,
- The events of the alarm and log books are compared,

- The curves are compared using via reference curves ALICES superposition feature.

Currently 100% operational, these configurations are used in support of the control of work of the naval propulsion on-board nuclear reactor. In particular TECHNICATOME engineers make the most of the configurations as a support to operation engineering analyses, for the training of the operators and the functional validation of the operation procedures.

4. Conclusion

The functionalities of the SARIE simulators, ported to the ALICES technology, the CORYS TESS universal simulation platform, that offers unequalled flexibility with an entirely open design, now offer a whole of added values among which one can quote:

- The man-machine interfaces developed during the porting project meet an aim of mutualisation between the needs for engineering and training. For this reason, the compatibility of these interfaces, with the needs for training, was a project constant concern.
- Dedicated dialogs allow the simulator execution in engineering mode (development of forced control loop overcoming the original system I&C automatisms).
- a flexible graphic environment, quick modification possibilities and unitary tests,
- the possibility of developing models based on the standard libraries: optimization of the system modeling by giving the choice between CEDRIC thermal hydraulic code or ALICES object libraries according to the simulation fidelity requirements and by using the already existing libraries on ALICES (machinery components, electrical gears, …),
- the possibility of coupling these new models with already existing developments (the possibility of re-usability of the former investments is a very appreciated characteristic of the workshop), the possibility to encapsulate nuclear propulsion specific engineering codes (ex: CEDRIC), of connection with other model/code (black boxes) allowing to extend the field of simulation,
- The pluridisplinarity of the Windows platform and the post-processing tools integrated in ALICES bring a great flexibility during the drafting of engineering reports while the simulator can be used either in a single machine configuration at the time of engineering phases, or in a multi-machines configurations during training courses.