4.5 SCORPIO-VVER CORE MONITORING AND SURVEILLANCE SYSTEM FOR VVER-440 REACTORS

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ABSTRACT

The SCORPIO-VVER core monitoring system has proved since the first installation at Dukovany NPP in 1999 to be a valuable tool for the reactor operators and reactor physicists. It is now installed on four units of Dukovany NPP (EDU, Czech Republic) and two units of Bohunice NPP (EBO, Slovak Republic) replacing the original Russian VK3 system. By both Czech and Slovak nuclear regulatory bodies it was licensed as a Technical Specification Surveillance tool.

The monitoring system operates in two modes: in core follow mode and in predictive mode. In the core follow mode, the present core state is evaluated by a method combining the instrumentation signals and the theoretical calculation of the power distribution done by the core simulator. This procedure is followed by an automatic limit checking, where characteristics of the current state are compared to the Technical Specifications. The operator obtains relevant information on core status through the dedicated Man-Machine Interfaces.
In the predictive mode, the operator can visualize the core characteristics during the transients forecasted for coming hours or days. Quick forecasts realized by the strategy generator are deeply analyzed by the predictive simulator. Similarly as in the core follow mode, characteristics of the evaluated states can be compared against Technical Specifications.

Since it's first installation, the development of SCORPIO-VVER system continues along with the changes in VVER reactors operation. The system is being adapted according the utility needs and several notable improvements in physical modules of the system were introduced. The latest most significant changes were done in connection with implementation of a new digital I&C system, loading of the optimized Gd2 fuel assemblies, improvements in the area of core design (neutron physics, core thermal hydraulics and fuel thermal mechanics) and improvements in the predictive part of the system (Strategy Generator).

The currently finished upgrades (Upgrade 2 at EBO 06/2009, Upgrade 5 at EDU 12/2009) includes the adaptation of the system to up-rated unit conditions as well as further improvements of methods applied in physical modules, especially as are the improvements of 3D power reconstruction methods by using the SPND detectors in fuel assemblies, as are the changes in design and methodology of the limit checking and as is the implementation of the on-line shutdown margin calculation to the system.

1. INTRODUCTION

The SCORPIO-VVER core surveillance and operation support system [1][2][3], as it is operated at Dukovany NPP in Czech Republic and Bohunice V-2 NPP in Slovakia, has been developed from the original SCORPIO system framework in cooperation among Norwegian IFE and Czech organizations Nuclear Research Institute Rež plc., Škoda JS, a.s., Chemcomex Praha, a.s. and the Slovak VUJE a.s. (participated on later system upgrade in 2001). This system has a remarkable operating record from its first introduction to Dukovany Unit 1 in 1998. It has been installed in other 5 VVER-440/V213 units and it was licensed by national nuclear regulatory bodies in Czech Republic in 1999 and in Slovakia in 2002 as a Technical Specification Surveillance system.

New development in VVER operation is continually challenging the flexibility of system framework, which is demonstrated by almost uninterrupted work on system improvements and tailoring to customer/utility needs. Between the latest most significant changes, which were introduced belongs the implementation of a new digital I&C system, supporting new optimized design of Gadolinium bearing fuel assemblies (Gd2+, Gd2M, etc.), improvements in 3D power reconstruction methods by using the SPND detectors in fuel assemblies, changes in design and methodology of the limit checking and improvements in the predictive part of the system.

This article describes the current status of the system and the latest modifications implemented during the upgrades at Dukovany and Bohunice NPPs.

2. SYSTEM IMPLEMENTATION

The SCORPIO-VVER core monitoring system consists of autonomous modules, which communicate through the communication package Software Bus [4]. The main modules in SCORPIO-VVER are identified in the block diagram shown in Fig. 1. The Man-Machine Interface is developed using the ProcSee GUI Management System [5]. The system is running in full redundancy configuration on powerful HP PA-RISC workstations.
The system support different user logins with different levels of rights and information details. The SCORPIO-VVER operates in two modes: in core follow mode and in predictive mode.

In the core follow mode, the present core state is evaluated by a method combining the instrumentation signals and the theoretical calculation of the power distribution done by the core simulator, which is based on the universal finite-difference program MOBY-DICK [6]. This procedure, called 3D power reconstruction, is followed by an automatic limit checking, where characteristics of the current state are compared to the Technical Specifications. The operator obtains relevant information on core status through the Man-Machine Interface (MMI) in the form of well arranged screens containing trend curves, core map pictures, diagrams and tables displaying relevant information on the core state including margins to Technical Specifications.

In the predictive mode, the operator can visualize the core characteristics during the transients forecasted for coming hours or days. Quick forecasts realized by the strategy generator are deeply analyzed by the predictive simulator. As no detector signals are available in this case, the accuracy of the predicted core state depends heavily on the quality of the physics model. Similarly as in the core follow mode, characteristics of the evaluated states can be compared against Technical Specifications, and the predicted behaviour of the core can be analyzed through the number of dedicated screens.

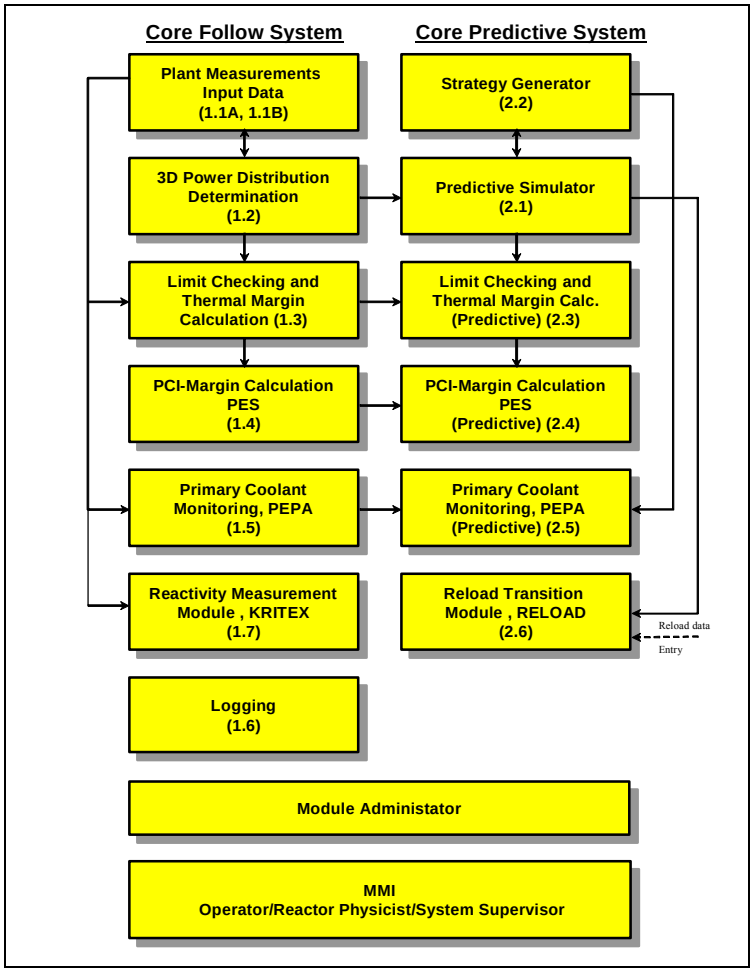

Figure 1. Main modules of the SCORPIO-VVER

The SCORPIO-VVER system includes following main features:

- Maintaining the communication with plant data sources, collection of input data.
- Validation of plant measurements and identification of sensor failures.
- Temperature measurement sensor calibration, evaluation of isothermal state.
- Enhanced with a tuned/weighted combination of measurements and calculations to obtain precise values of important parameters.
- On-line 3D power distribution calculation with pin power reconstruction, based on the validated outlet temperature from thermocouples, SPND measurements and from the results of core simulator.
- On-line core simulation based on two-group 3D coarse mesh calculation code.
- Limit checking and thermal margin calculation allowing for surveillance of VVER core limits such as DNBR, Sub-cooling margin, FdH and other peeking factors, etc.
- SPND monitoring, evaluation, interpretation and transformation to linear power.

- Integrated modules for monitoring fuel performance, conditional power distribution.
- Integrated modules for monitoring of coolant activity for identification of fuel failures.
- Predictive capabilities and strategy planning, offering the possibility to check the consequences of operational manoeuvres in advance, prediction of critical parameters and end of fuel cycle detection, main steam-header pressure driving, etc.
- Convenient monitoring and prediction of approach to criticality during the reactor start-up.
- Automated transition between cycles (fuel reload).
- Logging functions with archive for all calculated and main measured data.
- User definable printer output for protocols and forms.

3. SYSTEM UPGRADES AND RESPONSES TO THE PLANT OPERATING NEEDS

The SCORPIO-VVER system is subject of regular upgrades, which serve to system improvements and modifications according to utility needs.

Currently two new upgrades – Upgrade 2 for Bohunice NPP [7] and Upgrade 5 for Dukovany NPP [8] – were successfully finished. The main goal of the latest upgrades was the system adaptation to the up-rated parameters of the units, nevertheless notable improvement of several system modules will be implemented as well. The most important modification concerns the 3D power reconstruction module, triggered by the limits in accuracy of the current method of the reconstruction relying heavily on the fuel assembly outlet temperature measurements. Another important improvement touches the limit checking part of the system, where on-line shutdown margin calculation is implemented.

3.1. Implementation and upgrade history in Czech Republic:

First implementation of SCORPIO-VVER at Dukovany NPP in Czech Republic:

- Completed in 1998, migrated to all 4 units.

Dukovany's short upgrade history:

- 2000, Upgrade-1, system maintenance and system tuning.
- 2003, Upgrade-2, adjusting the physical modules to EDU's requirements.
- 2004, Upgrade-3, adaptation to use the Gd2 fuel type, moving to 42 axial layers.
- 2005, Upgarde-4, system adaptation to work with the upgraded I&C system.
- 2007-12/2009, Upgrade-5, improvements in operation support tools, implementation of SPNDs to the 3D Power Reconstruction, support of new GD2+ and Gd2M fuel, support the up-rated reactor thermal power, upgrade of the system HW.

3.2. Implementation and upgrade history in Slovak Republic:

First implementation of SCORPIO-VVER at Bohunice NPP V2 in Slovak Republic:

- Completed in 2001, migrated to 3. and 4. unit.

Bohunice's short upgrade history:

- 2006, Upgrade-1, adaptation to use the Gd2 fuel type, moving to 42 axial layers, improvements in Strategy Generator, implementation of online shape function generation.
- 2008-06/2009, Upgrade-2, adaptation to the newly implemented I&C, improvements in limit checking (online shutdown margin calculation) and 3D Power Reconstruction method, improvements of Strategy Generator, support the up-rated reactor thermal power, upgrade of the system HW.

4. EXPERIENCES AND SUPPORT

Since the first installation the SCORPIO-VVER system has a remarkable operating history and experience. More than 10 years of experiences from 6 unit of VVER-440 type of reactors, from two different NPPs, in two different countries helps to the SCORPIO-VVER developer team put the system to very high level of quality and reliability.

The system was enhanced and adjusted to fulfil all requirements of NPP operators and to fulfil all operating rules and conditions defined by the State Office for Nuclear Safety in each country.

The system developer team is ready to respond to all needs of the NPP's, solve the difficulties and answer all questions in local language of NPP operators. All system documentations and user guides are maintained in 3 different languages: English, Czech and Slovak.

5. CONCLUSION AND FUTURE CHALLENGES

The SCORPIO-VVER core monitoring system with its flexible and modular framework successfully responses to the plant operating needs and advances in nuclear fuel cycle strategies and fuel design. Modular framework allows for easy modifications of the system and implementation of new methods in physical modules. These facts have been confirmed by successful upgrades and more than 10 years of reliable operation of the system.

The development of the system will continue in near future too. Between the planned upgrades belongs the system Upgrade 3 for Bohunice V2 NPP in years 2011-2012 (implementation of new type of fuel, enhancing of limit checking) and one new challenge, which is the adaptation and implementation of the SCORPIO-VVER Core Surveillance and Core Monitoring System to the Reactor Training Simulator for reactor physicist in Slovak Republic.

Even if the system is installed only on VVER-440 reactors, it could be adapted for needs of other VVER type reactors and to needs of training and education facilities too.

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