CAPRICORE, A NEW ON-LINE CORE MONITORING SYSTEM

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ABSTRACT

CAPRICORE is an advanced on-line core monitoring system applicable to both PWR and BWR reactors and it can be used as a core supervision system. CAPRICORE was born in 1993 as a project sponsored and managed by IBERDROLA Nuclear Fuel Group for the specification, development and installation of a vendor independent on-line monitoring system to be installed in COFRENTES BWR NPP and ALMARAZ PWR NPP. It uses a new version of the Studsvik's SIMULATE-3 core analysis code, to evaluate core and fuel performance, periodically and upon demand. This system generates information of the actual state, reading current live data, as well as of the past states, allowing the calculations and predictions over the possible future states of the reactor core. This information is presented to the user through an interactive graphic interface.

CAPRICORE facilitates the surveillance of the Technical Specifications, the control of the Xenon oscillations and the neutronic axial flux difference as well as the comparison of results between the incore detector measurements and the Core Design predictions. The predictor capability allows reactor engineers to accurately estimate margin and reactor performance during operational planned manoeuvres, such as cycle initial start-up, power ramp after a reactor trip, load follow, coast-down or low the power in a programmed manner.

CAPRICORE has been installed at the COFRENTES NPP unit at the end of 1997 and at the both ALMARAZ NPP units in mid-1998. Now, it is in the final testing and demo phase.

1. INTRODUCTION

To give answer to some strategic objectives of IBERDROLA regarding the fuel diversification, the Nuclear Fuel Group of IBERDROLA began in 1992 a long-term project to establish complete and independent capabilities to perform reload design and transient analysis, named the GIRALDA* Project. IBERDROLA is aware that to reach

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* GIRALDA "Gestión Independiente de Recarga: Análisis y Licenciamiento de Diseños Avanzados" (Independent Reload Management: Analysis and Licensing of Advanced Designs).

and maintain a complete independence it is necessary to have a vendor-independent core supervision system. CAPRICORE is the on-line core monitoring sponsored and managed by IBERDROLA applicable to both BWR and PWR NPP´s. IBERDROLA has designated IBERINCO as the technical responsible for the project and STUDSVIK to develop a version of SIMULATE-3[1] with a new adaptive module, hereafter referred to as S3ADAP module. IBERDROLA is currently in the process of providing advanced SIMULATE-3 adaptive methods[2,3] to improve the accuracy.

The main capabilities of the system, which has many features not presently available in other monitoring system, are improving the operator's ability to monitor Technical Specification compliance, detecting and alarming for abnormal plant operating conditions. CAPRICORE provides operators with accurate predictions of future plant conditions, as well as with accurate and timely evaluation of their proposed operating strategies, assuring compatibility with the off-line and core-design models. It also provides an efficient, easy-to-use, advanced graphic user interface. The complete system has been developed to make used of the existing hardware.

2. CAPRICORE SYSTEM DESCRIPTION

There are four major components (modules or subsystems) in the CAPRICORE system:

- **PRETIR:** plant data interface.

  This subsystem includes two separated functions: GPLA gets automatic and periodically, every 15-60 seconds, plant measurements (RT, Real Time data) from the Data Acquisition System of the different plants. These measurements are transferred to the CONTROL subsystem to be used in monitoring cases and to be stored in the system database. GDET gets, upon user demand, the in-core measurements that are checked and transferred them to the CONTROL subsystem.

- **CONTROL:** monitoring process control.

  This module uses the RT data and the in-core measurements provided by the PRETIR subsystem (under the automatic monitor option) or by the user (under the manual monitor option) to update the shared memory and the data base contents. It writes these data in the simulator input file and starts the S3ADAP module in order to monitor the core performance. Two different monitors can be started by CONTROL:

  INCORE processing monitor.

    It is executed when new in-core measurements are available. These data are provided to S3ADAP together with the corresponding core state conditions. For BWR, S3ADAP determines the LPRM calibration factors to be used in subsequent manual or automatic monitors.

  LPRM processing (BWR) or normal (PWR) monitor

It is started upon user demand or periodically (continuously or according to a user provided triggering logic). The core state conditions and LPRM measurements are provided to S3ADAP.

After each simulator execution, CONTROL reads the monitoring results, prepares the monitoring periodic summary to be stored, with the rest of the simulator related files, in the CAPRICORE data base and update the monitoring status information in the shared memory.

CONTROL includes auxiliary functions for the thermal energy, gross energy and cycle exposure accumulation, as well as for the daily and monthly summary preparation.

- **S3ADAP:** SIMULATE-3 adaptive version.

  For PWR, S3ADAP is the standard SIMULATE-3 code. For BWR, S3ADAP includes different modules to:

  - Provide detector data validation, rejection and normalisation.
  - Carry out the LPRM to TIP calibration.
  - Accumulate LPRM depletion to allow correlation of LPRM sensitivity loss/gain calibrations.
  - Provide comparisons between calculation and LPRM/TIP measurements.
  - Estimate uncertainties in measured in power distributions and margins to limits.
  - Provide trend analysis both failed/failing detectors and biases in calculation model.

- **PROCESO:** user interface.

  PROCESO includes a graphic user interface that runs in any compatible personal computer connected to the CAPRICORE main computer and a non-graphic (menu-driven) user interface that is executed in the computer where CONTROL and S3ADAP resides. The PROCESO subsystem also includes two server programs that are executed in the CAPRICORE main computer. Both programs communicate with the associated client (graphic or non-graphic) using the TCP/IP protocol.

  The first server, SUSR, receives a connection request when a user logs into the CAPRICORE system and creates a sub-server process that periodically sends to the associated user-client the actual plant data, the main monitoring results and the system status information.

  The second server, SREQ, receives a connection request each time a user demands a system function and creates a sub-server process to execute this function. Each sub-server process access to the CAPRICORE data base to collect the user-demanded data and returns these data to the associated user-client, or communicates to CONTROL the user request together with the additional user-provided data (through the shared memory).

PROCESO allows the user to:

- Demand information about the system status.
- Demand the edition of reports with actual or historical plant data.
- Demand the edition of reports with actual or historical monitoring results.
- Provide “measurements” to be used in manual monitoring cases.
- Demand the S3ADAP execution for monitoring and predictive calculations.
- Modify the system configurations.

The graphic interface is a friendly and powerful tool to show core and plant status information. It is a windowed interface that can display, via a compatible personal computer, the live and historical plant data, and the monitoring and predictive results, including axial, 2D and 3D distribution.

These four modules are interconnected through the Shared Memory and the CAPRICORE Data Base.

At Cofrentes NPP, the CAPRICORE main computer is a DEC Alpha Station with Open VMS operating system, which communicates via Ethernet -using the DECNET protocol- with the DAS computer (DIGITAL VAX 4000 model 300).

At Almaraz NPP, the main computer is a SUN workstation with UNIX operating system and the DAS resides also in a DIGITAL VAX computer with Open VMS operating system. Both computers are connected via Ethernet, using the TCP/IP protocol.

The CAPRICORE system is written in C++, FORTRAN and Microsoft Visual Basic languages and it is portable to other similar platforms with a minimum effort.

3. ADAPTIVE MODEL EVALUATION

3.1. TIP ADAPTIVE MODEL DESCRIPTION

The SIMULATE-3 adaptive model includes different options to translate the ratio between the measured and calculated detector response to the nodal power distribution, and therefore to the thermal limits calculations. When TIP measurements are available, this translation is carried out in the following four steps:

1. Unmeasured or rejected TIP data can be optionally substituted with the calculated values. If this **substitution** is carried out, the TIP ratios are set to 1.0 for the given detector.

2. TIP ratios are assigned to the four bundles surrounding each detector and they are optionally **reflected** from each real detector location to the three other symmetric locations (pseudo-detectors).

3. TIP ratios are radially expanded to bundles not adjacent to a real detector (or pseudo-detector if reflection has been applied) according to a user-provided weighting **matrix**.

The size of this matrix determines how far a detector affect to the surrounding bundles or, in other words, it determines what detectors are affecting to a given bundle.

4. The expanded TIP ratios are then applied to the calculated power distribution to obtain the adapted power distribution. In this step, it is possible to carry out a full 3D (**total**) adaption or simply an **axial**-only adaption of each bundle.

Once the adapted power distribution has been obtained by SIMULATE-3, it can be used to determine the **predicted detector response**. This is simply done by averaging the expanded TIP ratios of the four nodes surrounding a given detector and applying this average value to the computed TIP response. As will be shown bellow, when the predicted detector response is computed with total adaption and with a weighting matrix small enough to avoid interaction between bundles surrounding two adjacent detectors or pseudo-detectors (3x3 without reflection or 1x1 with reflection), the predicted TIP response agree with the measured one.

3.2. EVALUATION METHOD

In order to decide between the different adaptive options available in SIMULATE-3, it is required a method for evaluating the uncertainties in the adapted power distribution. This nodal power uncertainty evaluation will be also required during the adaptive model qualification.

The comparison of the adapted power distribution with the measurements obtained through gamma scan seems to be the only way to determine the nodal power uncertainty. However, Iberdrola is still in the process of decided when a gamma scanning will be carried out at Cofrentes NPP, and there are no public gamma scan data with the fuel bundles actually loaded at Cofrentes (GE-11 and SVEA-96). Additionally, gamma scan data are normally obtained for a single or a reduced number of state points. For these reasons, an alternative method is proposed to evaluate the adaptive model uncertainty.

The proposed evaluation method is based on the predicted detector response calculation. Instead of carry out these calculations with a full set of TIP measurements (33 detectors at Cofrentes NPP), it is assumed that a given TIP is failed and only 32 detector measurements are used in the adaptive process. Then, the predicted response of the 'failed' detector in compared to the measured one. This process is repeated for each TIP string in the core. In that way, the **TIP uncertainty of the adaptive model** for a given state point will be computed.

It is anticipated that, when this method is used with those options leading to a reduced adaption of unmonitored bundles, the TIP uncertainty of the adaptive model will be very close to the TIP uncertainty of the non-adaptive model.

If it is assumed that TIP uncertainties are equal to nodal power uncertainties, the proposed method could replace the gamma scan comparison during the adaptive model qualification. Otherwise, the proposed method can be used to extend the adaptive model qualification to different state points, once the TIP uncertainty is correlated to the nodal power uncertainty obtained through gamma scan comparison.

In any case, the proposed method will be helpful during the choice of the different adaptive model options to be used for on-line monitoring at Cofrentes NPP.

4. PRELIMINARY RESULTS

The evaluation method has been applied, only for demonstration purposes, to single state point (991227) of Cofrentes NPP. It should be noted that the core model and cross section library we are actually using correspond to old CASMO/SIMULATE-3 versions. That is the reason to obtain a TIP RMS of 6.9 %. We expect reduce in the future this non-adaptive uncertainty to the normal SIMULATE-3 values (5 %).

In Table I are shown under the header "One failed TIP" the TIP uncertainties obtained with different adaptive model options. It has been also included, in the right column, the TIP uncertainty obtained when all TIP measurements (33 locations) are provided to the adaptive model.

These preliminary results shown that, when the adaptive model is used, the TIP uncertainty is reduced more than a 30 % (from 6.9 to 4.5).

Table I. TIP uncertainties, RMS (%), with different adaptive model options

Adaptive model options			**One failed TIP**		**Non failed TIP**
Reflection	**Matrix**	**Shape**	**Subst.**	**No subst.**	
Without adaption			---	---	**6.9**
No	3x3 (a)	Total	6.9	6.9	0.0
	4x4 (a)		4.8	**4.5**	3.0
	4x4 (b)		6.9	4.5	0.1
	4x4 (a)	Axial	5.1	4.9	3.8
	4x4 (b)		6.9	4.9	2.6
Yes	2x2 (a)	Total	5.7	5.5	4.1
	2x2 (b)		5.8	5.6	3.9
	3x3 (a)		5.4	5.3	4.6
	3x3 (b)		5.5	5.3	4.2
	1x1 (a)	Axial	6.9	6.9	3.3
	2x2 (a)		5.4	5.3	4.2
	2x2 (b)		5.5	5.3	4.1
	2x2 (c)		5.9	5.3	3.3
	3x3 (a)		5.2	5.2	4.6
	3x3 (b)		5.3	5.1	4.3

(a) all 1.0

(b)

1.000	0.667	0.333	0.001
	0.444	0.222	0.001
		0.111	0.001
			0.001

(c)

1.000	0.001
	0.001

5. CONCLUSIONS

An on-line core operational support system developed by IBERDROLA called CAPRICORE has been installed at COFRENTES and ALMARAZ NPPs. The system makes use of an advanced SIMULATE-3 adaptive model to provide core power distribution and core predictive capabilities to the plant personnel for monitoring and operational support.

The proposed evaluation method shows that the TIP uncertainties can be reduced up to a 30% when the adaptive model is used.

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