THE EXTENDED ON-LINE CORE MONITORING TECHNOLOGY WITH THE LATEST VERONA-u VERSION

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Abstract

The VERONA core monitoring system has been serving the reactor operators of the Paks NPP Hungary since 1984, providing on-line information about the internal status of the core as well as about the most fundamental physical parameters characterising the energy flow from the reactor to the generator. The applied computer technology became obsolete since then, motivating a substantial upgrade. The backfitting activity was initiated in 1990 and the first operational version of the upgraded VERONA-u system went on-line in 1993 at Unit 2 of the NPP. All the other units have been supplied with the new system since then. The new HW/SW platform offered considerably higher resources, making formerly inconceivable services feasible. The paper outlines the services of the VERONA-u V4.0 system, from the high precision and high reliability data acquisition subsystem to the core parameter interpretation. Also some details are given on the preparation work related to the transitions to a new core parameter limitation philosophy and the interpretation challenges posed by the future use of advanced fuel assemblies.

Introduction

The VERONA system is an on-line core surveillance system that is based on the standardly installed in-core instrumentation of the VVER-440/213 type core (210 assembly outlet T/Cs and 36 assemblies furnished with SPND strings with seven detectors in each). Its earliest pilot version started to operate soon after the physical start-up of the first unit of the Paks NPP. Two major upgrading projects have been carried out since: the VERONA and the VERONA-plus versions that were operational for 8-10 years on the four units of the NPP and the VERONA-u version that utilises the resources offered by the computer technology of the mid-90s and it is operational for three years. Though the VERONA-u system represents a substantially higher level of HW/SW technique compared to the previous versions, there are no substantial differences in the core analysis algorithms. Right now two directions of upgrading are under way: some further software improvements to utilise the recently available larger computer storage capacities and substantial core calculation algorithm improvements to adapt the system for using advanced fuel assemblies and a modified core parameter limitation philosophy.

Brief overview of system's history

The general need for such a system had already been formulated before the commissioning of the first unit of the Paks NPP [1] and within less than a year, in 1984, the pilot version of the system was operating at the first unit. The first two units were supplied with the finalised first version of the VERONA system. In parallel to the software development the existing foreign experiences were collected [2] and several methodical studies had been carried out [3]. Units 3 and 4 received a more advanced version, the VERONA-plus [4], that utilised the experiences gained with the two systems in operation and the new advances in computing technology.

Before the mid-90s the software of the original systems became old fashioned and the computer hardware became more and more difficult to maintain, motivating a substantial upgrading project. The result was the fully re-engineered VERONA-u system [5] and the new PDA data collection system [9]. After a one-year parallel operation with the old system at Unit 1, the VERONA-u system has been installed at all four units along with the PDA data collection system, during the subsequent refuelling outages of the units.

General features of VERONA-u

The new system strongly utilises the options provided by current-day computer technology: the large operational memories and the high capacity disk systems [7]. Several new advancements in the field of methodology have also been utilised in the system [6]. The most important general features of the system are the following:

- High-precision and high-reliability data collection system, the PDA [9], to substitute the original HINDUKUS system;

- Redundant, high-capacity hardware for the detailed analysis with automatic take-over in case of a subsystem failure;

- Evaluation of measured parameters with a 2 sec cycle time;
- Full core evaluation with one minute period;
- State-of-the-art software technology with highly organised and highly controlled on-line database providing a high degree of separation of functions and the data;
- New and deeper core assessment methodology: pinwise evaluation of the most important limiting parameters;
- Extensive X-Window based user-friendly operator's interface with a great number of screens and windows [8];
- The system is both an important support tool for operators in the control room and an effective behind-the-scenes support system for experts;
- Utilities and screens to support power transient management;
- Flexible trend curve presentation tools both for on-line parameters and for historical data;
- Utilisation of the LAN technology;
- Dual configuration with automatic take-over on failure;
- Extensive automatic historical data file building and saving;
- Tools for historical data analysis;
- Effective and safe tools to support system management.

Measurement uncertainty re-assessment

The evaluation of the uncertainties of the parameters used and derived by the VERONA core surveillance system has always been a key issue and several studies have been carried out to establish the required figures. However, the introduction of the advanced high-accuracy data collection system PDA and some modifications in the in-core sensors have motivated a re-evaluation project of the uncertainties of the in-core measurements. The available large volume of detailed historical data that has been collected by the VERONA-u systems provided an extremely good database for such an evaluation. We used the recorded historical data from three cycles of two different units that were available with 10s resolution. Most of the analyses were carried out on files that were extracted from the original files and covered the three fuel cycles with 15 min. resolution from two different units. The very extensive data sets offered an ideal basis for large scale statistical analyses. No such possibilities were not available with the earlier systems.

The core outlet thermocouples and the in-core SPNDs were treated separately. Several measurements from around the reactor core, e.g. the ex-core ionisation chambers and the cold-leg, hot-leg thermometers were also included in the analysis [12].

In general, we followed a scheme that the measurement uncertainty can be assumed as a superposition of three components:

- The short term instability;
- The long term instability;
- Individual variability of the sensors.

A specific statistical program has been developed to extract the above information. The basic idea of the method is that a linear regression was evaluated between a selected functional of a group of measurements and an other functional of a different group of measurements. In other words, the method utilised the direct and the indirect redundancies available in the set of measurements. These redundancies range from simple duplicated measurements, through symmetrically located measurements, to those cases where a measured parameter could be derived from some others by applying a physical model (analytical redundancy).

In addition to the required uncertainty figures corresponding to the actually applied measurement evaluation methodology, the analysis also yielded some refined methodologies that could improve the thermocouple uncertainties by 20% in case of the core-outlet measurements (from 0.65°C to 0.53°C) and by 70% in case of the loop-leg temperature measurements (from 0.44°C to 0.13°C).

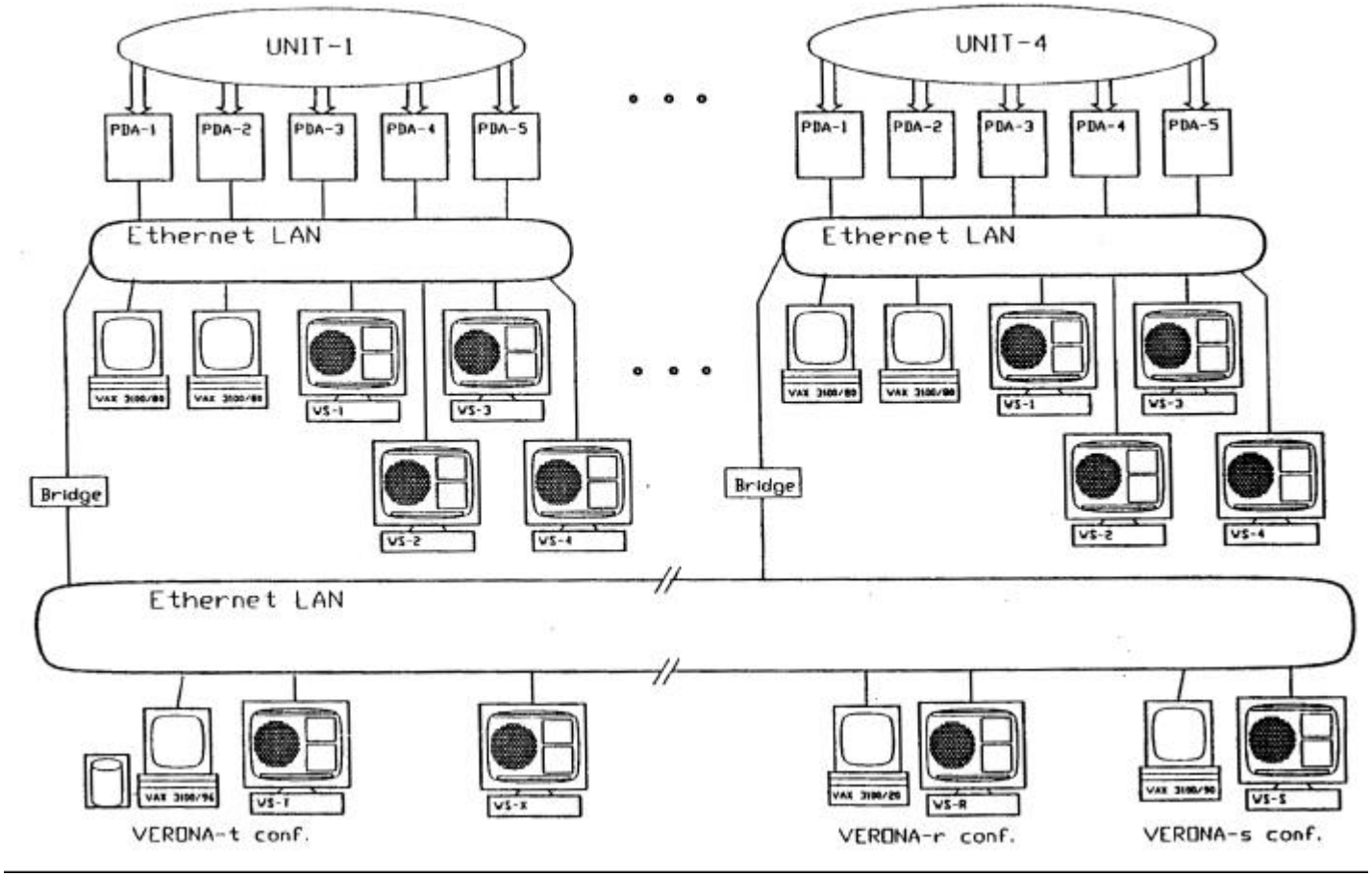
Features of the VERONA-u 4.0 version

The main feature of the latest version of the system is that it integrates the originally unit-wise systems into a plant-wise system. The integration has aimed at three fields:

- Software management and maintenance;
- Database management and maintenance;
- Historical data file (archives) management.

The basic hardware tool of the integration is a central server configuration – similar to the on-line computer configurations at the units but it is supplied with higher storage and computing capacities – that is linked through the local area network to the on-line configurations. In Figure 1 this configuration is marked as the VERONA-t configuration. Specific tools have been developed to support the software version management of each of the unit subsystems, as well as of the actual databases valid for the individual units. This central maintenance configuration also serves as a depository of the actual software resources of each of the on-line configurations, including the actual databases.

Figure 1. Block diagram of the plant-wide configuration



The current-day large capacity and fast disk units make it feasible to build historical data files that cover a whole refuelling cycle. Such files are extremely useful both for post-event analyses and for many kinds of R&D activities (e.g. code validation). The retained data can also be utilised for different diagnostic analyses, e.g. to evaluate long-term ageing effects of some technological components [11]. It is a general experience that since these very detailed and reliable archives (historical data files) are available there is an increasing demand for such data from many different technological departments of the utility.

The automatically built cycle-long historical data files contain all measured primary data and many characteristic derived data of the on-line systems with 15 min. resolution. User friendly and effective utility programs are available to help any potential user of the files in locating special situations, events in the data files. The cycle-long historical files are available both on the on-line systems and on the VERONA-t configuration. In this respect this latter also serves as a back-up of the on-line files.

Upcoming developments

The actual system evaluates some pinwise parameters, and the actual plant operational procedures prescribe limitations on these parameters. However, the expected introduction of advanced fuel assemblies with radial, axial profilisation, burnable absorbers etc. and with more complicated fuel load patterns suitable for four cycle fuel utilisation, the actual ways of derivation of these parameters would no longer be accurate enough. The latest versions of currently applied core calculation codes [13,14] provide adequate support for designing such cores. The on-line core monitoring algorithms, however, still need to be upgraded to match these requirements. This upgrading project will take place during the year of 1997. As a result of this project a new version of the VERONA-u system will be available that should be suitable for working with advanced fuel assemblies and to support the required new limitation strategies. The new algorithms will rely more closely on calculated results than the current version does, since no measured information is available on the pinwise distributions within the assemblies.

The new limitation strategy aims at removing some redundant limitations and introducing, at the same time, such limiting parameters that characterise the potentially dangerous hot spots in the reactor more adequately than the currently limited parameters. First of all, it requires going into the more detailed continuous (frequent) reconstruction of the best estimate of the reactor power generation distribution down to fuel pin level. The monitored limiting parameters can be thereafter the pinwise temperatures (T_{clad}, $T_{coolant}$, T_{fuel}), power or DNBR values.

The project for elaborating the new methods and the new core parameter limiting strategies has already been started and it is being performed to a great extent by the experts of the power plant utility in a close co-operation with the KFKI Atomic Energy Research Institute.

Before using the new algorithms in the on-line system to directly support the reactor operators it will be necessary to re-evaluate the uncertainties of the evaluated limiting parameters. The uncertainties will be evaluated as function of main reactor state parameters, function of available detectors, etc. As a result of this study the system will be able to provide at any moment the upper limit values for each of the limiting parameters corresponding to the actual amount and quality of information.

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