ALPES, A DEMONSTRATOR FOR ON-LINE CORE TEMPERATURE VISUALISING AND PROCESSING

A. Lebrun, J-P. Trapp
Commissariat à l'Energie Atomique
Centre d'Etudes de CADARACHE

S. Sala
Electricité de France
CNPE de CREYS MALVILLE

Abstract

On the French fast reactor Superphenix, core temperature signals are involved in reactor protection. A study showed that improvements could be implemented for Control Rod Withdrawal (CRW) detection. The new methods of detection required an industrial qualification only achievable with on-line operating. Therefore, an experimental on-line demonstrator, known as ALPES, has been put in place in order to enhance protection performance, especially in the field of CRW detection.

The ALPES demonstrator has been connected to the surveillance plant computer for about a year. It continuously processes several hundreds of temperature signals from the Superphenix core. Over the course of the year, we proved the industrial feasibility of the new methods of protection.

At the same time, ALPES displays to the plant physicists, through a user-friendly man-machine interface, the results of on-line calculations concerning fluctuations and data usually achievable only with off-line calculations. New visualisation instruments, useful for daily surveillance or monitoring of special experimentation, were proposed and tested during this first year of operation.

ALPES demonstrator aims

Three years ago, a R&D program was undertaken in the CEA to improve protection methods of the fast reactors using the core thermocouples. It is supported by EDF, NOVATOME and the experimental device is installed in the NERSA fast reactor Superphenix.

The studies began with a review of Total Instantaneous Blockage (TIB) protection methods; for the moment, however, Control Rod Withdrawal (CRW) protection is our main concern. At the same time it appeared that numerical processing of the temperature signals could provide improvements in plugging detection. The result of these feasibility studies was a set of protection methods based on temperature signal processing. In order to prove their interest and to prepare the system for industrialisation, the best method was to perform a real-time demonstration with an on-line device connected to a real reactor. It was decided to develop the ALPES demonstrator and to install a connection with the Superphenix reactor computers.

Since the demonstration required a real-time transmission of the temperature data, the surveillance aspect of temperature signal processing could also be improved. Two topics were therefore selected. The first was to provide a visualisation device for on-line surveillance of the reactor, able to display any signal using an up-to-date man-machine interface (MMI). The second was to enable the calculation (and display) of several average tendency indicators usually calculated off-line with recorded data.

The surveillance features of the ALPES demonstrator are directed toward the plant physicists with the purpose of helping them use the huge amount of reactor data transmitted by instrumentation both easily and rapidly. This is done to help them focus on unexpected events and to decide whether complementary off-line calculations are necessary or not.

Description of the demonstrator

The different goals of the demonstrator lead us to separate the application into several independent processes. To achieve this, a multi-task operating system was required and UNIX was chosen. The computer is a commercial work-station (HP). Because the ALPES machine is only a demonstration device and because acquisition frequency is low (1 Hz), it is not necessary to use a real-time operating system (OS). The conventional time-shared OS is used but we developed a special routine[1] to allow hierarchisation of the different processes.

The application is separated into four independent processes for acquisition, protection, surveillance and visualisation tasks. Acquisition and protection processes have the highest priority order obtained with the real-time HP-UX command[2]. The surveillance process runs managed by the time-sharing OS. The visualisation process (human-machine interface) is also an independent process whose refreshment speed depends on the machine availability because its priority level is the lowest.

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[1] This routine is based on the command *select(0,0,0,time out)* that gives the machine free for a selected time.

[2] This command is *rtprio*. Notice that it requires superuser privilege.

The interest of such an organisation is to make sure that use of elaborated visualisation features (3D maps for instance) will never lead to a loss of data. The users can really freely use the HMI, calculation and data storing are always primordially performed.

The separation of the processes enhances the reliability of the demonstrator, but this requires a specific manner of communication between them. We chose the shared-memories to perform the data inter-process transmission.

Sequencing of the processes is performed as follows. First the acquisition process is waiting the data block from the data server (reading blocked mode). It immediately puts them into the shared memory and waits again for fresh data. During this time, the protection and the surveillance processes are asleep and the machine is free for visualisation tasks. They periodically wake up and look for fresh data; if new data are available they are immediately processed. The application is sequenced by data arrival. One interest of such an organisation is that a data transmission problem does not cause troubles in the demonstrator. Another is that open processes (surveillance for instance) can be enriched with new features, without any interaction with the protection experimentation. The last advantage – but not the least – is that the visualisation process never conflicts with calculations. The visualisation process always utilises the remaining power of the machine after calculations are done.

Figure 1 displays the organisation of the processes and the inter-process communication shared memories. The implantation of the demonstrator in the NPP devices is also displayed in this figure. The measurements are performed with 469 thermocouples which feed the protection computer (TRTC). The digitised data are sent to the NPP surveillance computer (CORA). In order to avoid any problem with data extraction the connection with the surveillance computer is made via a PC devoted to data service. It picks up the data in a special memory disk of the NPP surveillance computer (CORA), converts them into the UNIX standard (IEEE 745 standard) and finally sends them to the ALPES demonstrator on an ethernet link.

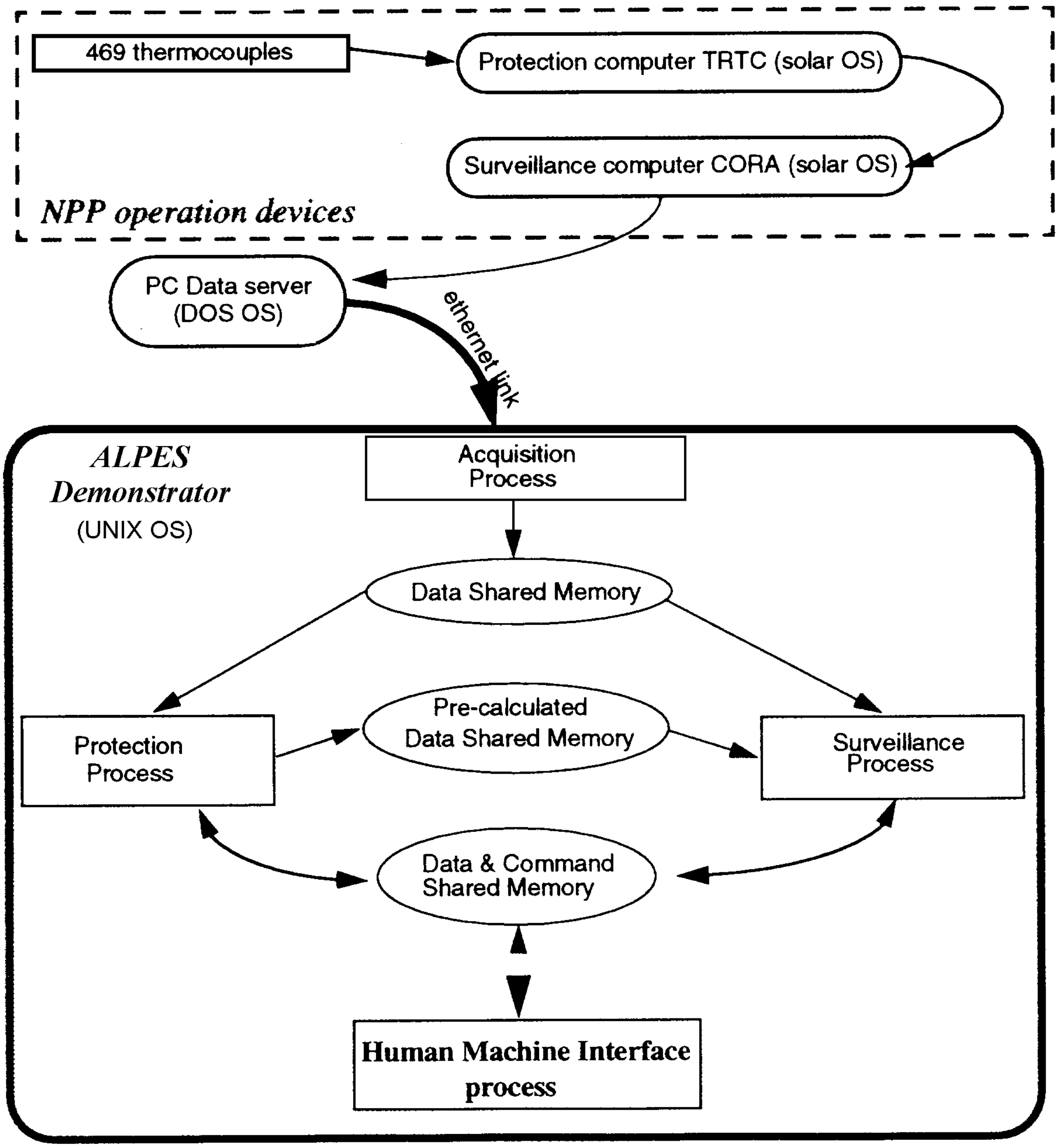
Protection improvements

The demonstrator is an experimental device whose main goal is to test and validate new protection methods. According to this goal, all new methods of protection, specially guaranteed against Control Rod Withdrawal, are tested at the same time.

Blockage detection improvements are achieved by thermal noise extraction. Numerical filtering of the signal noise allows to decrease the threshold level especially in the external part of the core in which thermal fluctuations are the most important.

Total Instantaneous Blockage (TIB) detection is based on an original method of concomitant detection on the neighbours subassembly [1]. Since the loss of coolant is total and instantaneous the blocked fuel assembly thermocouple does not provide a significant signal. The thermal radial flux to the neighbours is used to detect TIB. The method consists of removing the continuos component of the signal and following only their fast evolution. Each signal is compared with an absolute threshold that depends on the required sensitivity and on the normal fluctuation of the signal. For given sensitivity

Figure 1. Organisation of the ALPES demonstrator processes



and Alarm Failure Rate (AFR), False Alarm Rate (FAR) varies. No need of industrialisation for this protection method exists up to now. Nevertheless, the result of the experimentation shows that the protection could be performed with a sensitivity near 0.3°C/second at full power.

The Control Rod Withdrawal (CRW) detection improvements are based on the test of four detection methods [2]. they deal with the same idea: look after the fast evolution of signals specifically and sensitively reactive with the CRW. The first method uses no specific signal. Each individual fast component of the temperature measurement is compared to an absolute threshold depending on thermal fluctuation. The second CRW detection method, which is not yet fully developed, is based on the TIB detection mechanism; concomitant threshold overshoots around the control rod are monitored. Individual thresholds are continuously fitted on the signal fluctuations, in order to keep the Alarm Failure Rate (AFR) constant when the signal fluctuations move.

The other two methods use algorithm to build the detection signals.

One is based on the measurement of relative evolution between two groups of signals. both groups are chosen to have the same behaviour during normal operation of the reactor. Groups of signals are used instead of single signal because the average calculations reduce the uncorrelated fluctuations. The signals, called power-tilt indicators, are normalised in order to keep them independent of power level. The second uses individual differential temperature already calculated in the blockage detection [3]. They are considered as the co-ordinates of a vector whose norm rapidly varies when a CRW occurs. The protection of the whole core requires only a single signal called global indicator.

Note that normal operation (an increase in power for instance) of the reactor does not cause any variation of the detection signals.

All these detection methods have been tested over the course of a year between 0 to 50% of nominal power. The False Alarm Rate (FAR) has been measured by on-line calculation and recording of the Probability Distribution Functions. It has already been proved that industrial operation of these methods is possible with a spurious scram probability very low. The estimated sensitivity seems to be adequate enough to avoid any non-reversible consequence of a CRW.

Surveillance improvements

On-line calculation for surveillance goals are performed with the ALPES demonstrator. This kind of calculation is usually done off-line with recorded data. Average values of all the thermal indicators are calculated on user-selected durations. Temperatures, linear power, blockage detection indicator, thermal fluctuation standard deviation are always available. The extreme values reached on plugging detection indicator are calculated and displayed on core map to help understanding thermal fluctuations or drifts. The plugging detection indicators are recorded on two “flip-flop” files and the demonstrator is equipped with a small visual program that allows to scan the data and calculates the first statistics indicators. These tools are provides to permit rapid access to the data without any heavy data transcription from the NPP surveillance computer.

Another feature of the ALPES demonstrator is its ability to record temperature signals. A routine performs data recording with a user-selected periodicity, the whole data (one point per second) can be continuously recorded. An automatic process downloads the recorded data to a DAT magnetic tape. The media and the format of the stored files are compatible with the off-line analysis tools used by NPP physicists. ALPES can playback the recorded data and compare old recorded data to the current thermal status.

An important feature of the surveillance capacity of the demonstrator is that data is displayed in a convenient way. The human-machine interface (HMI) is the emerged part of the surveillance iceberg. Since off-line surveillance calculation tools already exist at the Superphenix NPP, we chose to enhance the visualisation of the signals. There is no production of calculation results in number files, the data are always viewable on graphs or maps and the pictures can be captured to make a library (paper or digital) of results.

Human-machine interface

The ALPES human-machine interface was developed on the Dataviews graphical editor (Dvdraw) and adapted to the requirements of the project with the Dataviews graphical library (Dvtools). The result is a graphical application that allows to enter commands to drive the application as well as display any data calculated in the demonstrator. The ALPES HMI is an independent process with low priority that communicates with the other processes of the application through a shared memory.

As is shown in Figure 2, the HMI is basically organised in four windows[3]:

1) An information window that displays the reactor status, with general purpose data (core entrance temperature, primary pump speed and thermal power). All the messages sent from the application appear in this information window (these messages are also recorded).

2) A main window on which special displays can be selected. It can be a three-dimensional core map as well as individual signal graphs. The main window is the entrance point to a set of nine sub-windows. Each of these is devoted to the display of representative signals of a particular protection or surveillance goal.

3) A command window that regroups all the command tools of the application. For instance, it is possible to change cut-off frequencies of the filters or to select data to be displayed on the other windows. Simulation features are available to measure the sensitivity of the detection methods and, for instance, to perform optimisation of the filter cut-off frequencies.

4) A core map that allows to display any subassembly data calculated through the surveillance process. Selection of the data to be displayed is made in the command window that is always available. The colour table can be fitted on user-selected boundaries, so it is possible to enhance small effects. The date and the power level are displayed in order to make the captured pictures reference documents.

Feedback experience of on-line measurements

Concerning protection goals, after one year of operation, the on-line demonstrator ALPES has proved that the new CRW detection methods could be applied on an industrial reactor. The normal behaviour of the signal was analysed (PDF analysis). Spurious scram ratio (FAR) would be, for the most interesting methods, less than $10^{-7}(s^{-1})$. This ratio

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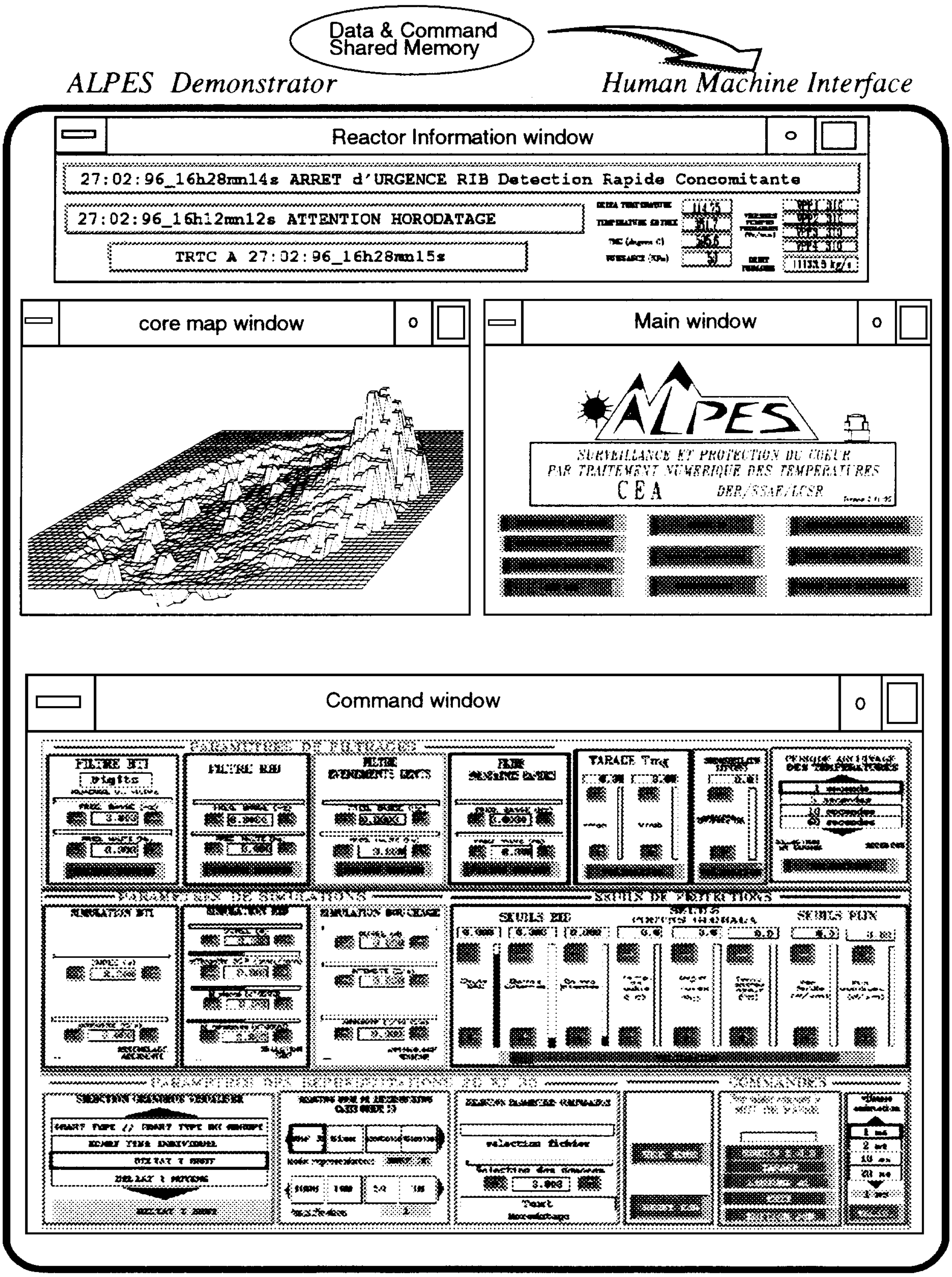
[3] Since no colour reproduction is possible in these proceedings, we choose to avoid displaying screen pictures. Nevertheless, colour pictures are available and can be requested (e-mail: lebrun@planck.cad.cea.fr).

Figure 2. Human-Machine Interface of the ALPES demonstrator



depends on the sensitivity of the methods and also on the signal processing parameters. The filter design tools included in the demonstrator were used to perform the filter optimisation and to select the best cut-off frequencies. They were chosen in order to avoid any threshold fitting during the whole fuel cycle. Since CRW is a very unlikely event, the convenient protection methods have the be extremely reliable; false alarm rate must be as low as possible. In addition, they must require as few manipulations as possible in order to avoid any human error.

The recording feature of the demonstrator was used to get the data of experiments performed on the reactor like feedback coefficient measurement or control rod drift experimentation. The analysis of the recorded data was used to estimate the sensitivity of the detection methods. The protection methods tested with ALPES would avoid any fuel-assembly accident in any case of CRW. Nevertheless, this kind of experimentation is only a sequence of steady states. Because dynamic effects probably enhance the thermal variations, and would have a great influence on detection, it was decided that a specific experimental program was needed. This study, called Voluntary Control Rod Insertion, aims at measuring detection performances. The program is planned to begin at the end of this year. The demonstrator will acquire all of the data and provide a real-time interpretation of the experimentation.

Concerning surveillance goals, on-line displaying of the data is used by the NPP physicists, specially for the experimentation they perform on the reactor. For example, they can fit themselves unofficial surveillance thresholds far below NPP official thresholds and get information on the behaviour of the signals before they reach the first alert thresholds. Real time graphs, which did not exist on the NPP surveillance computer, are interesting data displaying devices as well as core maps. Pictures were captured and stored to build a library of the reference status of the reactor.

ALPES can also be used as a fast way to have a glance at the thermal status of the core. The system was used to help understand high level fluctuations on a particular ratio power to primary flow rate. It was interesting to measure the Probability Density Function of the differential temperature to make sure the high level of fluctuation was not the result of a fuel-assembly blockage. On the other hand, the on-line calculated average tendency data are not used enough, the reason being that no qualification was performed with regard to the off-line tools. As a result, off-line tools remain standard and official tools.

Conclusion

The results concerning the protection improvements, especially in the field of Control Rod Withdrawal detection, already make the ALPES R&D program a success. The compatibility with industrial operation is proved and the first estimations allow us to be very confident on the sensitivity topic. After the sensitivity would have been accurately measured, the eventual industrialisation of them could be prepared. For instance, one of the four algorithms developed in ALPES, called global indicator method, could probably be implemented in the existing protection computer of Superphenix reactor.

Concerning the surveillance topic, the main idea is not to provide another off-line analysis tool with many result files and automatic paper graph production. Rather, the aim of the surveillance part of ALPES is to provide, all day long, fresh basic information on the thermal status of the core. Fluctuation level, differential temperature extremum, drifts, etc., can be checked at any moment of the day without any data manipulation. If something unusual occurs, recorded data are available and can be analysed with off-line tools.

References

[1] Numerical processing of the core temperature for FBR core surveillance.
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[2] Anomaly detection of the radial power distribution by temperature signal processing.
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