NPP CONTROL COMMAND: CONSIDERATIONS FOR THE FUTURE

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Abstract

Recent years have seen considerable improvements in the performance available from instrumentation, computerized data acquisition and processing systems, signal processing and related display processing systems. This progress implies the need for a complete rethink of the approach to future surveillance, control and protection systems for use with nuclear reactors, especially regarding new reactor systems. These new systems will in the future need to ensure full compatibility between safety improvements and the enhanced economic competitively of nuclear power. This paper presents an exercise covering the main functions that can as of now be considered for future applications in this field.

1. INTRODUCTION

For all reactors, thermal, fast (breeder or not) or other types, the Instrumentation and Control (IC) system has two main functions:

- ***Control and surveillance,***
- ***Protection.***

These two functions must be strictly separated as usual, as regards the materials used in the measurement channels; this separation can lead to the use of a doubling material (based on the diversity principle): applying to sensors and associated electronics which are used to elaborate the signal and diagnosis.

In the past, the surveillance function was assumed to indicate only very simple results (values or trends) and display it to the reactor staff; now, and especially in the future, this function will include and combine:

- The state of the measurement channel,
- The state of the measurement value,
- A diagnosis of the reactor state.

In the past and even today, the protection function is performed by very simple systems based on making a comparison between the measured signal level and fixed values considered as thresholds; generally this type of operation uses analog systems.

In the future, and already in some current applications, the protection function will be performed by computerized systems with thresholds that vary according to the reactor state (power level, etc.).

In this paper, we present some considerations on these two functions, taking in account the considerable progress made in the electronics and computer fields.

It should be noted that this exercise, which appears dedicated to fast reactors can in the most part be transposed to other types of reactor, as in most cases the data processing systems are completely independent of the rest of the operation.

2. RECALL: PRESENT SURVEILLANCE SYSTEMS IN LFMBRs

It should be remembered that the measurement acquisition and processing systems that are used on LFMBRs (French reactors) were designed at a time when computer systems were in their infancy (1970 for Phenix and 1980 for SPX). This also applies to a large part of the PWRs built over the last decade.

The equipment that was available at the time offered only limited performance, requiring in general the use of large scale general purpose computers, i.e. the opposite to the current trend towards 'dedicated' systems.

The result was the concentration in a small number of large (or medium) sized machines of all of the very large amount of data acquired from the reactor, and necessary for its control and for the surveillance of essential operating parameters.

This large scale data acquisition is in contradiction with the quality of the related processing, and this is due to the limited performance available from these computers.

For example, all of the neutronic, thermal, hydraulic and clad rupture data for the SPX system is acquired and processed by a single computer.

The notion of the Man-Machine Interface (MMI), although implied in people's minds, could not truly be applied.

These circumstances lead to 'closed' systems where the analysis of results could not, except for rare exceptions, be performed in real-time meaning that the data was read back from various magnetic media; the loss of time resulting from this design has always been considerable, when it has not actually caused a loss of data.

In addition, the independence of each data acquisition and processing system, at least in relation to storing results, leads to a dispersion of results that makes it difficult to summarize the results obtained.

The acquisition and the storage of measurements is, in general, inadequate especially in relation to fast changing events (reactivity, clad ruptures, various incidents, etc.).

The storage of results on the media used (in general on magnetic tape) causes, in addition to the problems of long term storage, obliges the operator to perform long, complex and costly operations (tape copies) in order to fulfill storage requirements.

3. CONSIDERATIONS ON THE SURVEILLANCE SYSTEMS

3.1. General

First of all, we will list some of the general principles that form the basis of the surveillance systems:

a/ independence relative to the protection system,
b/ 'dedicated' acquisition systems, i.e. dedicated to a specific field (neutronics, thermal, etc.),
c/ implementing 'predictive' systems,
d/ connecting these systems via a computer network,
e/ continuous high speed measurement acquisition,
f/ appropriate storage (slow or fast, depending on requirements),
g/ on-line analysis of measurements,
h/ diagnostics on the correct operation of measurement channels,
i/ optimized data presentation (MMI) combined with pre-diagnostics,
j/ connecting acquisition systems to a general data bank,
k/ analyzing results off-line by semi-automatic processing of stored measurements,
l/ implementing a supervisor.

These few principles will lead to considerable development of signal processing and to considering as a whole, ***all of the surveillance systems: from the sensor to diagnostics via the Man Machine Interface***.

This will have the following consequences:

a/ The ***acquisition computers*** connected to this system, that are independent of the protection system, ***are not failsafe qualified***; despite this, the quality of the implementation and the qualification tests must be especially well executed.

The processing software must be able to evolve over time, to support requirements that where not taken into account during design, or to match technical changes.

b/ Each surveillance domain will be processed by a specific computer that will perform all of the functions required for surveillance.

c/ Anticipated fault detection (core, components, etc.).

d/ All of these computers will be connected by network, which will allow transmission by each one to the other of any data that might be necessary for its own processing.

e/ Current computers enable high acquisition speeds. Acquisition will be performed at a speed that will not exceed a second and may, as appropriate, be far faster (0.1 sec, or even be a little as a few msec).

f/ High speed storage (t<<1sec) is of interest only in the case of a specific event; under normal circumstances storage will be performed at a rate closer to every second (or more); the decision will be taken automatically after analyzing the measurement and the performing a diagnostic of normal operation.

g/ On-line analysis (1st. level) of signals used to determine the characteristics of the type of operation: normal or 'degraded'; this analysis is connected to e/.

h/ A signal analysis process will be located in the acquisition systems in order to provide continuous or periodical diagnostics on the correct operation of the channels used for measurement acquisition.

i/ The Man-Machine Interface should be especially 'elaborate' in order to present the operators and duty staff with information that is as concise as possible on the state of the control systems and on the reactor: pre-diagnostics can also be considered.

j/ The acquisition systems will be linked, via the computer network, to a data bank that can acquire, in real-time or not, all of the data collected by the various computers. This data bank will be connected by the computer network to the workstations of the various users (analysis of operation, equipment maintenance, etc.) whether they are located on-site or away from it (crisis team or expert consultants, for example).

k/ Automated processing of data retrieved from the data bank will allow a fast analysis (2nd. level) of the results; the finer (3rd. level) analysis being performed by specialists in the domain.

l/ A supervisor will ensure the surveillance of the entire system: measurement channels and acquisition computers and will indicate any malfunctions.

3.2. Description by Domain

The headings below will cover the general specifications of each of the surveillance domains. A surveillance domain refers to a set of measurements performed on a given physical domain and possibly any additional or correlated measurements.

3.2.1 - Neutronic Domain (all reactor types).

This is the domain covered by all of the neutronic sensors (in the pressure vessel or below it). The surveillance system must:

- Continually monitor any change to the neutronic population, regardless of the state of the reactor (shutdown, during the divergence, rising in power and rated power),
- Monitor the evolution of reactivity via on-line monitoring (using a digital reactimeter),
- Monitor the position of the control rods,
- Provide a diagnostic on the neutronic situation of the reactor (reactivity comparator),
- Provide a diagnostic (continual or periodical) on the state of the measurement systems.
- Provide the neutronic elements required for on-line monitoring, using 3D calculations,
- Store all of the data required, at the necessary rate and send them to the data bank, either continually or periodically after a preliminary examination (quality, coherence, amount).

3.2.2 - Core Thermal Domain (LFMBR, RBMK etc.).

This is the domain covered by all of the thermal sensors that ensure temperature surveillance of the output from the core (Cr-Al thermocouples and Na-Stainless Steel, if necessary); the surveillance system must:

- Continually monitor the evolution of core output temperatures,
- Calculate all of the parameters required for this monitoring,
- Continually evaluate the margins around the thresholds,
- Ensure, on demand, any settings that may be required,
- Provide core temperature maps (and/or any other parameters) as well as diagrams that illustrate the current situation,
- Provide, on demand, elements for comparison with comparable previous situations, via the related data bank,
- Provide the data necessary for on-line 3D monitoring (preferable in the future),

- Storing data and sending it to the data bank after prior examination.

3.2.3 - Clad Failure Domain (Mainly LFMBR).

This domain is covered by the system for detecting clad failures (whether built-in or not), the localization system and the system for cover gas surveillance.

Note that this surveillance domain does not cover protection against local fusion accidents (slow or fast blockages, random command rod movements, etc.) that will be ensured by a specific surveillance system.

Note that this system will need to receive information relating to the neutronic power (domain 3.2.1) and hydraulic data (domain 3.2.2).

It ensures:

- Diagnosis on proper measurement channel operation,
- Monitoring the activity of the cover gas and any necessary transmission of an alert and alarm,
- Continual monitoring (at optimized rate) of 'clad failure' signals,
- The generation and transmission of alerts and alarms,
- The surveillance and diagnostics of the hydraulic sampling system (if necessary),
- In the event of a clad failure, time management and the margin before the thresholds,
- Managing the localization system (starting prospection and signal management),
- Presentation of summary diagrams on the situation of the reactor in this domain,
- Temporary storage of data before transmission, after examination, at the data bank.

Note that this system should receive data relating to the neutronic power level (domain 3.2.1) and some data on the hydraulic domain (domain 3.2.4).

3.2.4 - Primary Pressure Vessel Domain (all reactor types)

This covers the primary and secondary flow rates, the temperatures of the main components (vessel, intermediate heat exchangers, inside of the vessel, surface, etc.), the core acoustics:

It will ensure:

- Monitoring changes to all acquired parameters,
- Monitoring their evolution during transitional phases,
- Any transmission of alerts,
- The presentation of summary diagrams covering the situation of the reactor in this domain,
- Transitory storage of data prior to transmission, after examination at the data bank.

3.2.5 - Primary and Secondary Circuit Domain

This domain covers all of the motion, speed and acceleration component sensors (piping, shafts, etc.), the temperatures of the steam generators, pipes and turbine.

Its functions are similar to those of the previous domain.

3.2.6 - Preventive Surveillance Domain (all reactor types)

This is a 'new' system whose purpose is clearly ***anticipated fault detection*** whether this relates to the core or to the pressure vessel or to any of the components of the primary or secondary circuits.

This anticipated detection should contribute to ***improving reactor availability*** (and therefore plant availability) by repairing at a chosen time, any potential faults that if not found by this detection could lead to an unexpected reactor stoppage.

This system combines:
- neutronic data (channels below or in the pressure vessel),
- acoustic data related to the core and to the steam generators (or others),
- mechanical data (motion and vibration sensors),
- thermal data (thermocouples).

It should also comprise the detection of any sodium gas build up caused by argon (in LFMBRs) or level surveillance (water - steam) in PWRs.

The processing of signals and the analysis that will lead to a fault diagnostic will be made on-line (or after a slight delay), by a computer 'dedicated' solely to this function; it may receive, over the network, any additional data from the other surveillance computers.

This surveillance of course includes the detection of foreign objects.

This also contributes the preventive maintenance that will have effects on the competitivity of the installation.

4. ABOUT THE PROTECTION SYSTEMS

This system must be independent of the previous one[(*)], so as to meet the ***principle of independence*** that is so important to the safety authorities. It is intended to:
- Protect the reactor against any excursion outside of the normal operating domain,
- Avoid multiple incidents from degenerating into an accident,

[(*)] Measurement channels and systems for processing and generating the stop signal.

- Reducing or eliminating the possibility of accidents occurring,
- Reducing the consequences of any possible accidents.

In the past, and even most often currently, protection is ensured by analog systems which from a threshold being exceeded, trigger the reactor shut down procedure; in some cases (CANDU, neutronic checks on the French PWRs, monitoring core temperatures such as in LFMBRs) this form of protection is computer initiated.

But this is far from being the rule.

The settings of these thresholds are most often fixed; they are the result of a compromise between ensuring safety and correct reactor operation that can cannot tolerate excessive planned or unplanned stoppages.

This compromise level is often highly conservative and may also illustrate 'designers' willingness to abide by conventional wisdom.

Dynamic protection management leading variable threshold levels depending on the state of the reactor is probably inevitable. This will lead to computerized safety threshold management.

Obviously, the FAILSAFE qualification of these systems and especially the related software is the major problem to be resolved to ensure the acceptability of these systems to the safety regulators in the various countries.

Some of these aspects have already been resolved in whole or in part (e.g. in Canada). These aspects are not impossible technical problems, but rather a question of the general approach to safety as well as the personnel and hardware resources that must be applied.

5. CONCLUSION

The considerable progress achieved over the last few years in the field of instrumentation and systems for computerized data acquisition and processing and for signal processing lead us to ***envisage far reaching changes in the vision of surveillance and protection systems for future nuclear reactors***.

These systems must clearly be designed to:

- Improve safety,
- Improve the availability of the installations,
- Reduce human errors,

while contributing to improving the competitivity of nuclear power generation in relation to other power sources.

At the same time, and this is not the least important factor, the result will most likely be ***better acceptation of nuclear power by public opinion.***

EXAMPLE OF A COMPUTERIZED SURVEILLANCE SYSTEM