

AN AUTOMATIC MAINTENANCE SYSTEM FOR NUCLEAR POWER PLANTS INSTRUMENTATION

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Abstract Maintenance and testing of reactor protection systems is an important cause of unplanned reactor trips due to be commonly carried out in manual mode. The execution of surveillance procedures in this mode entails a great number of manual operations. Automated testing is the answer because it minimises test times and reduces the risk of human errors. GAMA-I is an automatic system for testing the reactor protection instrumentation which is based on VXI instrumentation cards. This system has important advantages over previous ones in terms of easiness to carry out software modifications related to configuration changes in the protection system. The system uses visual programming and the modifications can be implemented by ordinary instrumentation specialists without programming experience.

Keywords: Instrumentation, measurement systems, VXI, control, real-time systems.

1. Introduction

In nuclear power plants, the Reactor Protection System (RPS) plays a key role in the safety of the plant. The RPS is in charge of controlling different signals from the plant and alerting if normal operation conditions are not kept. The RPS is based on instrumentation cards, as Westinghouse 7300TM cards[1], that perform basic operations as amplifiers, signal adding and other more complex operations.

The surveillance conditions are performed by several of these cards composing a loop. Safety rules force to multiply two or three times the same loop to ensure that errors or wrong operation of a loop do not mask an alert condition.

Test operations are normally carried out in a manual mode and the possibility of human errors exists. Therefore, the time needed to perform the procedures is significant. GAMA-I is a new automatic maintenance system which reduces drastically this time and the risk of human errors.

2. Preliminary study.

Periodic testing of the reactor protection instrumentation is commonly carried out in manual mode. The execution of surveillance procedures in this mode entails a great number of manual operations which can be summarised as follows:

- ◆ *Revision of the written documentation related to the procedure to be executed.* In many cases, this stage is obviated because the staff who execute the test are very familiar with the procedure.
- ◆ *Verification of the intervention conditions.* The instrumentation technician verifies the plant conditions, which must be adequate to perform the surveillance procedures.
- ◆ *Placing the loop in test mode.* The channel to be tested is set in test mode by a manual operation and the field instrumentation is isolated. At this point the protection channel logic acknowledges that the channel mode test is in trip condition and, for the duration of the test, if a trip signal is received (real or spurious) on another channel, the protective function will be activated. Because of this reason, it is very desirable to minimise the test time.
- ◆ *Test procedure execution.* A simple description of this stage is depicted in Figure 1. Once the inputs and outputs of the loop have been isolated, and the channel is in test, it is necessary to perform several manual operations on the boards to be tested [2], such as removing cards from the racks, arranging configuration jumpers, replacing cards, connecting test leads to several test points on the board, injecting test signals, and recording and analysing the obtained results.
- ◆ *Putting the loop back in service.* Once the loop has been tested, it is necessary to return the channel to

normal operation. This process includes disconnecting test instruments, removing cards, reconfiguring jumpers, replacing cards, etc.

In many of these operations the possibility of human errors (wrong connections, card damage due to hands-on testing, acting on erroneous switches, etc.) exists, and the time needed to perform the procedures is significant.

Because of the above reasons, the unpredicted trips caused by equipment failure of the reactor protection system are 22% of all the unpredicted trips in nuclear power plants, with an average of 0.25 trips for each 1000 reactor critical hours [3]. Human errors are the main cause of these unpredicted trips originated in the reactor protection system. It is possible to improve the plant safety conditions working in two directions: minimising the time to carry out the tests and reducing the risk of human errors. Both these improvements can be achieved by test automation.

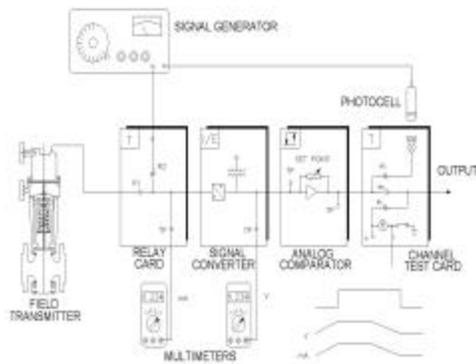


Figure 1: Test procedure on a 7300 reactor protection system.

Several commercial available system have been developed by companies, as Westinghouse, GEC Alstom, Siemens or Gamma-Metrics, to attend this industrial need. GAMA-I is a new automatic maintenance system that incorporates a graphical user interface that makes easier to execute the procedures, to analyse data and even to adjust the cards which response is out of bounds.

On the other hand, the surveillance conditions vary during life cycle of the plant due to different reasons as modifications of operation conditions or even in the plant structure appearing new signal to be monitored and disappearing others. These modifications mean surveillance procedure modifications, new procedures and elimination of obsolete ones. The great majority of the commercially available systems have failed due to this fact. When the need to make a change to the system has arisen, no matter how small this may be, they had to resort to an expert programmer in order to modify the application. GAMA-I includes an application that allows the user to create and modify their own procedures by himself in a very simple and intuitive way.

Therefore, the work described here presents the GAMA-I system (figure 2) that resolves the above problems and allows the automatic generation and execution of surveillance procedures related to the Westinghouse 7300TM Reactor Protection System (RPS), although it can be easily migrated to other platforms.



Figure 2: GAMA-I system.

3. System description.

The automatic test equipment can be sketched in two main blocks: the signal conditioning/data acquisition block and the instrumentation controller/processing block (see figure 3). The two blocks have been implemented using commercial modules based in standards. The first block is based on industry standard VXI for instrumentation cards (relays matrix, multiplexers, signals generators, multimeters and digital I/O modules) and the second one is based on the HP-745i workstation, supporting the hardware and software necessary to control the VXI instrumentation and the GAMA-I software.

During the execution of test procedures, the input signals to the RPS must be maintained. The matrix of 16x32 two wired-channels or 8x16 four wired-channels routes the different signals (current, voltage and resistance ramps/steps) involved to the appropriate pins on the RPS instrumentation cards. This section is used to minimise the number of signal generator instruments and to provide a more flexible connection. The measurement block (128 single-ended multiplexed input channels and 6 digits 1/2 multimeter) is capable of acquiring signals with a maximum sampling rate of 750 samples/s. By means of the digital I/O module, 64 digital input channels (0-24V.) and 32 digital output channels can be provided,

for the user's convenience, in order to allow for loop configurations and status monitoring.

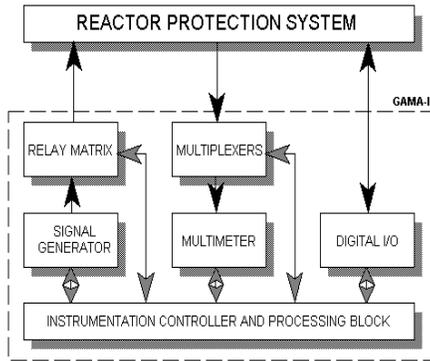


Figure 3: GAMA-I testing equipment.

4. Working modes.

From the point of view functional, the system GAMA-I works in two different modes:

- *Generation mode.*

This mode is used for developing new test procedures or to update existing ones procedures which can be done by personnel without programming experience. For this, the system provide a visual programming environment [4] that allows the user to perform this task in a simple and intuitive way, without requiring programming experience. The operator reproduces, on the generation mode window, the wiring diagram of the loop to be tested, by combining conceptual entities, that represent plant instrumentation cards, field transmitters or panel indicators (the possible components of a loop).

These generic modules are particularised to the loop by means of the TAG or name assigned by the user to the component. The compiler interprets the visual components and translates them into easy-to-use information for the execution mode.

The sequence of card testing is determined automatically, based on the component order established on the graphical representation. Figure 3 shows seven components integrating a loop. Each component represents a type of W7300 card or field transmitter.

- *Execution mode.*

This mode allows to perform the surveillance procedures removing all manual operations and reducing dramatically the time consumed by the traditional test procedures.

The numerous connections between instrumentation cards and test instruments (measurement instruments,

signal generators, registers) are limited to an only connection between the GAMA-I system and the instrumentation cabinet that contains the loop to be tested. Further more, the software verifies that this connection is right.

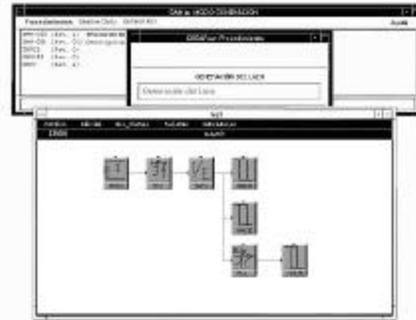


Figure 4: User interface to define new test procedures.

The system automatically performs all the operations involved in the test (instrumentation alignment, signals generation and measurement, data recording, analysis of results and diagnosis of problems). An Advanced Graphical User Interface guides the operator through the test, providing him with an on-line help in every step of the procedure. The man-machine interfaces of the Generation and Execution Modules have been designed according to human factor criteria [5].

5. Software design.

The software architecture has been designed with the following considerations in mind:

- *Flexibility.* The system should be designed to allow fast procedures reviews, implemented by non-skilled technician.
- *Adaptability.* The software should be applied to different instrumentation systems of similar technology.
- *System safety.* The system must be robust and reliable, because it could produce a spurious reactor trip in case of software malfunction.
- *User friendly.* The final product will be used by people with little background in computer science. Hence, it must be easy to use and it should be adapted to the skills and common practice in their domain.
- *Time restrictions.* The timing requirements should be accomplished for ensuring that the information the operator receives on the screen reflects the actual state of the instrumentation.
- *Scalability.* The performance of the system must not vary when its sizes increases.

The architecture is shown in the Figure 5. The two main modules (execution and generation) are loosely coupled by one Surveillance Procedure Database (SPD). This fact increases the safety, stability and robustness of the final product .

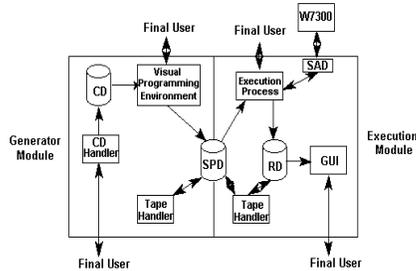


Figure 5: Software architecture.

The SPD includes information about the procedure to be executed (loop topology, scaling information of the W7300 cards taken part into the loop to be tested, administrative conditions to perform the surveillance procedure, etc.). This information is inferred automatically by the Visual Programming Module during the compilation stage and allows the configuration of the Execution Module for a particular procedure.

The Generation Module, provides a visual programming environment with a library of commercial cards and field transmitters. Considering only the card type and from the information provided by the Components Database, the system is capable of modelling the type of test to be carried out, configure the GAMA-I instrumentation involved and even identify the type of report assigned to that type of card. The TAG(card identifier) gives the information needed to assign parameters to each of the different card models from the information of the Components Database which contains all the particular characteristics of each of the cards in a sequence.

The Execution Module allows to perform the particular surveillance procedure from the information provided by the SPD interacting with the GAMA-I instrumentation and with the final user by means of an advanced graphical user interface. The results are storage into the Results Database, which contains information about numeric measurements, as well as test conditions, logbook entries, etc.

Finally, the acquisition of the signals coming from the instrumentation as well as the test signal injection is responsibility of the Data Acquisition System (DAS). Its design is based on the use of software polling, as it

implies the lowest level of custom programming, thus increasing the reusability of software.

Conversion to engineering units is typically required before analogy data are used by other software module. DAS performs this conversion in real-time after each data sample is acquired. Range checking is performed with each data sample. Alarm checking is supported by the comparison of the value of each sample with the alarms limits defined. During the sample data processing, the execution module can actuate concurrently to activate or deactivate a sensor, change the gain or modify the range or alarm limits.

The core of the data acquisition is a sampling plan which contains information related to the interval of time for recording the value of each signal. Its design was based on the structured design paradigm for real-time systems. The number of sensors being processed by the data acquisition system varies when the test procedure changes. In order to obtain a system that admits a large number of sensors to be processed without missing any deadlines, a distributed architecture was selected [6]. In this way, sensors are implemented as independent entities and the implementation of the sampling plan is also distributed.

6. Conclusions.

In this paper, an automatic system (GAMA-I) for testing the Westinghouse 7300TM Reactor Protection System (RPS) has been presented. The proposed system allows the execution (execution mode) of surveillance procedures, reducing dramatically the time consumed (approximately by 80%) and the risk of human errors. As a consequence of this improvements, the number or non-expected reactor trips is reduced by 10%. Furthermore, the system includes a visual programming environment (generation mode), in order to modify existing applications or implement new applications by non-programmer users.

One of the main results of the project is, as it was expected, a drastic reduction of time consuming in the maintenance procedures. Figure 6 shows a comparison of the conventional method and the methodology using GAMA-I. For a typical test, the time consumed by a procedure of 4 hours can be reduced to 45 minutes.

This time reduction is so important that the reference plant in which the system has been implemented is studying the possibility of testing the instrumentation more often due to the easiness and speed obtained by the system.

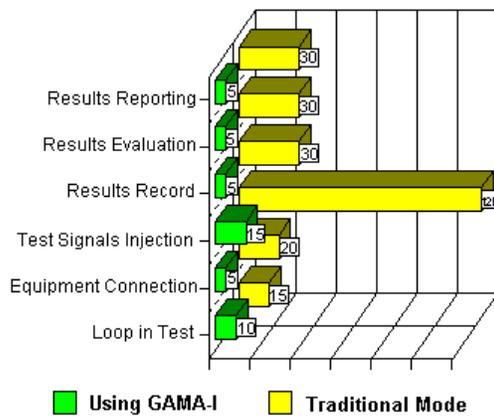


Figure 6: Comparison of conventional method and GAMA.

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