PROTOTYPE OF AN EXPERT SYSTEM BASED NUCLEAR POWER PLANT INFORMATION SYSTEM

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ABSTRACT

The components and functioning of the GPCS information system applicable for intelligent process monitoring and alarm generation in a VVER-440 type nuclear power plant are described. The prototype system has been developed by using the G2 expert system, plant measurements were simulated by a VVER-440 compact simulator and by archive replay sessions performed by the VERONA-u core monitoring system. The GPCS contains an object oriented description of the basic subsystems of the plant and concentrates on the fast evaluation/displaying of measurements and alarms. The high-level information reflecting actual plant safety status is synthesized from primary measured data, by forming global alarms and by evaluating logical diagrams.

1. INTRODUCTION

This paper outlines the results of a joint development performed by the KFKI AERI and MTA SZTAKI in the period between 1991 and 1993. The project has been supported by the Hungarian Government Fund OMFB (National Commission for Technical Development) under contract No. 91-97-42-0344. The basic aim of our efforts was to utilize a modern, powerful expert system shell for the construction of an information system, which meets the following specifications:

- collects a large number (at least 1000) of technological input signals on-line, and processes them with a short cycle time (1-2 sec);
- maintains on-line, bidirectional communication links with several external data collection systems simultaneously;
- consistently integrates the information originating from the different data sources and displays it to the operator in an easy-to-comprehend manner;
- utilizes procedural and rule-based knowledge concurrently;
- performs intelligent process monitoring, event handling and state identification;
- uses convenient MMI for information retrieval and system control.

Based on international experiences and on our preliminary studies the G2 expert system shell by Gensym [1] has been chosen as the framework of the system, and the correctness of our choice has been justified by the performance of the final product.

The development work resulted a prototype information system, which contains an object oriented representation of the technological components belonging to the main subsystems of a

VVER-440 type NPP. The abbreviated name of the system is GPCS (G2 Based Plant Computer Subsystem), referring to the fact, that in a real NPP installation the majority of the input signals handled by the system originates from the plant computer.

During development and tests, measurements from the technology were substituted by simulated input signals produced by the ELVIS VVER-440 compact simulator [2] and by the archive replay of the VERONA-u core-monitorig system [3].

2. APPLICATIBILITY OF G2 IN NPP INFORMATION SYSTEMS

The rapid development we have witnessed in computer hardware and software technology during the last ten years has opened new perspectives in the development of on-line information systems, as well. Powerful hardware platforms and novel software ideas (e.g. the evolution of object oriented programming, OOP) gradually made the application of expert systems for on-line, real-time process monitoring feasible. Early, LISP based expert systems were too slow to be applied in on-line process monitoring and they could handle only rule-based knowledge. The release of the G2 expert system shell in 1988 has changed this situation, since G2 emphasized object oriented knowledge representation, real-time response, simultaneous application of procedural and rule-based knowledge. In addition, G2 offered a flexible and reliable network data interface and a user-friendly application development environment.

The applicability of G2 to build non-conventional on-line information systems was realized soon, its first nuclear related application is probably connected to the OECD Halden Reactor Project (HRP). Their largest G2 application is the ISACS [4] system, which is the prototype of an integrated NPP control room. The SAS-II [5], [6] system in the Swedish Forsmark NPP is intended to present information to the operators after reactor scrams about scram initiating events and about the actual safety status of the plant.

Another promising field for expert system's applications in NPPs is the area of on-line procedure selection, presentation and guidance, the so-called procedure-management systems. An example is the system outlined in [7], which presents the symptom-based emergency operation procedures within the G2 for a Westinghouse PWR.

Considering the above listed developments we concluded, that expert systems (and especially G2) are mature enough to be applied in an NPP environment, where the reliability of the presented information, its fast access and intelligent presentation is a must, since the quality of the displayed information may have direct or indirect influence on the safe operation of the plant.

When designing and creating Computerized Operator Support Systems (COSS) one of the most important tasks is to define clearly and unambiguously the scope and functions of the system during different plant operation conditions. Generally, the tasks to be performed by the plant operators during different plant operation circumstances can be summarized as follows (see [4] for details):

- determination of the actual plant status (status identification);
- selection of appropriate actions, if required (procedure selection);
- performing selected actions (active intervention);
- checking the results of the actions (a new status identification).

All these operator actions can be effectively supported by an appropriate COSS, but plant status identification and procedure selection are such activities, where appropriate expert systems can particularly contribute to the safe operation of the plant by supplying fast and realiable diagnosis and advice. The correct status identification requires the execution of a certain amount of algorithms and calculations (e.g. evaluation of measurements, core neutronic and thermohydraulic analysis, etc.), but the appropriate synthesis of the information requires mainly rule-based (declarative) programming. Rule-based diagnosis can be best performed by expert systems, provided, that the system is able to receive on-line measured data and results from the procedural calculations.

During the development of GPCS we concentrated on intelligent process monitoring, plant and subsystem status identification with intelligent alarm presentation, the procedure management and guidance was not considered at the present stage.

Recently most of the on-line COSSs are designed and programmed to function as the sources of consistently integrated and hierarchically arranged plant information. This tendency can be explained by the following main reasons:

- increasing user need to synthesize information originating from various plant subsystems, in order to assess global plant safety status more accurately;
- the need for constructing hierarchical data presentation and retrieval systems, which monitor global plant status and give convenient access to subsystem data;
- the rapid development in graphic workstation technology, which made it possible, that robust, expensive mainframe computers were replaced by networked, task-oriented workstations or PCs;
- the increasing need to standardize man-machine interfaces.

The GPCS system has been designed to function as an integrated information system, at present it integrates information from two subsystems: the compact simulator (which corresponds to the plant computer) and the VERONA-u core monitoring system. The GPCS can be modified easily to incorporate on-line information from four plant units (i.e. 8 subsystems), thus acting as an integrated on-line plant information center.

3. DESCRIPTION OF THE GPCS SYSTEM

The prototype integrated information system has been built up from computers connected to each other via an Ethernet based network, the standard communication protocol was DECnet. The G2 computer is a VAXstation-3100 SPX with 24 MByte RAM, running G2 On-line Version V3.0 Rev.1, GFI, GSI and Telewindows under the VAX/VMS operation system. IBM-PC/AT 486 compatible personal computers are used as Telewindows terminals, the compact simulator is running on a MicroVAX-II, while the VERONA-u system runs on a MicroVAX-3500.

3.1 Simulating measurements for test purposes

In order to provide realistic plant data for the GPCS we utilized the ELVIS [2], which is a VVER-440 compact simulator and uses only a simplified control pult for operator actions. Some of the plant subsystems are not in the scope of simulation (e.g. containment), some use very simplified models, but generally the ELVIS can reproduce plant transients in a realistic manner. Predefined malfunctions can be activated by the instructor, this feature has been utilized frequently in order to test the GPCS response times and the consistency of the presented information during large transients. All main simulated plant subsystems were constructed in the framework of GPCS, except automatics and controllers (e.g. automatic power controller and turbine controller). Simulated data corresponding to the different plant measurements were transferred to the GPCS through the network by the ELVGSI GSI data interface (bridge) program. The simulator runs with 1 second cycle time, but the ELVGSI sends data to G2 in a change sensitive manner, in order to reduce network traffic.

The other system which has been connected to GPCS was the VERONA-u VVER-440 core monitoring system [3]. The VERONA-u processes the fuel assembly outlet TC measurements and the in-core SPND signals in order to provide on-line information about the important reactor and core parameters (e.g. 2D and 3D power distributions, location and parameters of the most-loaded fuel assemblies, etc.). The VERONA-u system was run in archive replay mode, which means that data previously recorded at the NPP were cyclically loaded into the database and then the detailed core analysis was performed. Data were transferred to the GPCS by the VERGSI GSI data interface (bridge) program, which sends data to the G2 in change sensitive way.

Integrating information from the core monitoring system and from the plant computer facilitates fast and reliable plant status identification and diagnosis since on the screen of a single GPCS workstation all the necessary information can be presented consistently: core maps showing actual core safety status, mnemoschemes showing plant subsystem and component characteristics, logic diagrams corresponding to the different Reactor Protection System (RPS) channels, combined with annunciators, event lists and alarms.

3.2 Object oriented representation of the NPP technology

3.2.1 The EQUIPMENT class

The EQUIPMENT class contains all the components and equipments (valves, tanks, pumps, etc.) which are placed on the mnemoschemes describing plant subsystems. Objects belonging to the EQUIPMENT class have a DSTAT attribute , referring to the actual disturbance status of the specific component. The abnormal DSTAT status may indicate the component malfunction or the fact, that a measurement connected to the equipment is invalid or violates its safety/warning limit The equipment DSTAT attributes receive values by using logical expressions or alarms.The most important items in the EQUIPMENT class are the valves and pumps, for these objects the status is indicated by dynamic color-coding, as well. The VSTAT valve attribute indicates the valve-opening, the icon of a valve changes color according to the value and status of VSTAT. Similarly, the PSTAT pump attribute indicates the run status of a pump. These attributes receive values through GSISENS sensors from the simulator.

3.2.2 The GSISENS (sensor) class

One of the most important and attractive service of the G2 shell is the flexible and reliable GSI network data interface, which maintains bidirectional data links with external data collection systems. The actual values corresponding to the measurement points in the ELVIS and VERONA-u systems are represented in the GPCS by objects belonging to the GSISENS class, which is a class below the standard G2 "sensor" class. Objects belonging to the GSISENS class receive value through the GSI data server, the status of the corresponding external measurement is used to change the color of the icon belonging to the particular GSISENS object.

3.2.3 The ALARM class

The GPCS uses two different objects for alarm/event handling: the ALARM and the annunciator window. The function of an ANNUN-WIN is similar to the annunciator tiles in the plant control room, which indicate the abnormal status of a component with text, blinking light and sound signals. The two most important attributes of an ALARM object is the priority (which can be urgent, warning or notice) and the alarm status, which indicates the acknowledge status of the specific alarm. The alarm acknowledgement can be performed by using the ACKNOWLEDGE pushbuttons placed on the G2 workspaces containing plant subsystem mnemoschemes. The ALARM class contains two subclasses: SIMALARM (simple, primary alarms) and SUPALARM ("super", compound alarms). A simalarm corresponds to a measurement or component status, and it is directly connected to a measurement through its AVALUE attribute, receiving value from a sensor. A supalarm may correspond to a plant subsystem or reflect the global plant status, it can be determined from logical expressions over simalarms and/or other supalarms. Their typical applications in the GPCS are as follows:

- forming variables, which are suitable to give values to the disturbance status attributes of the equipment objects;
- forming group-alarms, which reflect the global disturbance status of a plant subsystem or the plant itself;
- forming filtered alarms from simalarms.

Here alarm filtering means, that for certain important alarms instead of displaying the primary simalarm to the operator directly, the GPCS displays a supalarm, which is formed by the evaluation of a logical diagram containing appropriate alarm-suppression logic. Activated alarms are stored in ALARM-LIST type lists according to their priority. Lists containing selected alarms can be displayed in the form of scrollable windows, the contents of a list can be written to disk upon request. Normally the operator follows the scenario of a reactor transient on the GPCS display by observing annunciator, simalarm and supalarm icon color changes, alarm lists are meant to support detailed off-line event sequence analysis.

3.2.4 The LOGOBJ class

On-line evaluation of plant logic and interlock diagrams is essential in such a system, which intends to supply information to the operator about the actual reactor and plant status in a fast and easy-to-comprehend manner. In order to create and evaluate logical diagrams in the GPCS a class named LOGOBJ was created below the standard G2 "object" class. The LOGOBJ class contains all the necessary gates and other logical elements, which were required in the construction and evaluation of GPCS logic:

- loginp	=	forms a logical variable from an input gsisens or G2-variable;
- timedel	=	time-delay unit;
- setreset	=	S/R bistable unit;
- comparator	=	comparator unit;
- gate	=	logical gates (e.g. inverter, or_gate, and_gate, xor_gate, etc.).

In the construction and evaluation of logic diagrams the logcon object is essential. The logcon is applied to connect the different gates and other logical elements to each other. The color of a logcon connection changes to red, if the status of the logcon is TRUE. The input/output connections belonging to the logic objects are defined by using such logcons. These connections define the topology of the diagram in the G2, therefore generic, connection-based rules can be applied for the evaluation of the gates. Working with rules based on logcon connections makes it possible, that arbitrary logical diagrams can be constructed and evaluated without changing the generic rules. The firing of the rules is change sensitive in most cases, whenever type forward-trace rules are applied in the GPCS extensively. The resulting system response is event-driven: if no change is detected in the input signals, no action will be performed by the software.

Testing and validation of the logic evaluation has been performed by using selected diagrams from the simulator [2] and from Ref. [8]. Mainly RPS logic charts were prepared, these diagrams are not fully conform to the actual plant logic, some modifications and simplifications had to be carried out, in order to comply with the simulation scope.

3.3 On-line functioning of GPCS

At present the GPCS receives cca. 800 input signals from the simulator and cca. 100 signals from the VERONA-u system. The system contains 3200 G2 objects, the total KB is about 25000 lines. Altogether 60 G2 workspaces and 25 plant subsystems are available, the evaluation is performed by 275 rules and by 200 procedures.

The operator may use the GPCS overview panel (see Figure 1.) to select different plant subsystems, dedicated supalarms show the actual disturbance status of all subsystems and the global status of the plant. In case an abnormal situation arises in the technology, the operator will receive a warning indication about the event immediately, the color-code of the alarm indicates the severity of the disturbance. The ANNUNCIATORS button activates a workspace containing annunciator windows, while the LOGICS pushbutton helps the navigation between different logic diagrams. Different types of alarm lists can be initiated by the ALARM LISTS button, Figure 2. shows the MMI objects and an urgent/warning plant alarms example list.

The composition of the G2 workspaces containing subsystem mnemoschemes is uniform: the pictures show the piping network, technological components (valves, pumps, tanks), measurements and on the top of the workspace a supalarm, indicating the global alarm state of the subsystem (see Figure 3. for the feedwater system's picture).

The ALARMS pushbutton displays an associated G2 workspace, where subsystem simalarms are shown together with their alarm texts. Simalarms indicate their activated status and priority by changing icon color. The TRENDS pushbutton displays another workspace, where predefined trend curves are placed, showing the most important measurements of the subsystem.

Information presentation and retrieval in the GPCS is hierarchical: important global events can be best observed on the overview panel, special details are available on the subsystem mnemoschemes and on the associated alarm and trend workspaces. In some cases important components have activatable subworkspaces, which show further details.

The VERONA-u core and loop parameters are displayed in the form of trends and supalarms. With the help of a pushbutton on the VERONA workspace the operator can display on the screen of the GPCS workstation the standard VERONA-u operator display. The VERONA-u display is updated on-line, the MMI works in the same way as in the control room, i.e. printed logs, event lists can be requested, core maps can be selected, and cca. 2000 VERONA-u parameters can be monitored on-line.

4. TESTING AND VALIDATION OF GPCS

The GPCS has been extensively tested by initiating different malfunctions (transients) in the simulator (see Ref. [9]). During these transients GPCS stability, response times and the accuracy/consistency of the presented information has been checked thoroughly. Time sequences of selected alarms and events recorded by the GPCS were compared with the sequences recorded by the simulator and the VERONA-u. The tests confirmed that the GPCS supplies correct information about the status of the reactor and plant subsystems on the primary/secondary sides, the alarm-scenarios are registered properly, even during large transienst. Using the displayed information (i.e. the annunciator picture and the different logic diagrams) the user can unambiguously determine scram initiating events (see Figure 4.) and the scope and characteristics of a specific emergency. Subsystem alarm states and parameter trends can be continuously observed by referring to the appropriate display formats and mnemoschemes.

5. SUMMARY

The principles and functioning of the GPCS prototype information system have been outlined in this document. The system contains an object oriented description of the basic subsystems of a VVER-440 NPP, emphasizes fast evaluation/displaying of measurements and alarms. The high-level information reflecting the actual plant safety status is constructed from primary measured data, by forming global alarms and by the evaluation of logical expressions and diagrams.

Plans for further developments consider the on-line plant application of GPCS and the modification of the system to function as a Safety Parameter Display System (SPDS, see [10]). In the planned SPD system the occurrence of specific process symptoms will be diagnosed by the G2, using rule-based and procedural knowledge simultaneously. Selection of the possible success paths, procedure presentation and guidance, checking the correctness of the operator's actions during procedure execution, etc. will also be implemented by using G2.

6. REFERENCES

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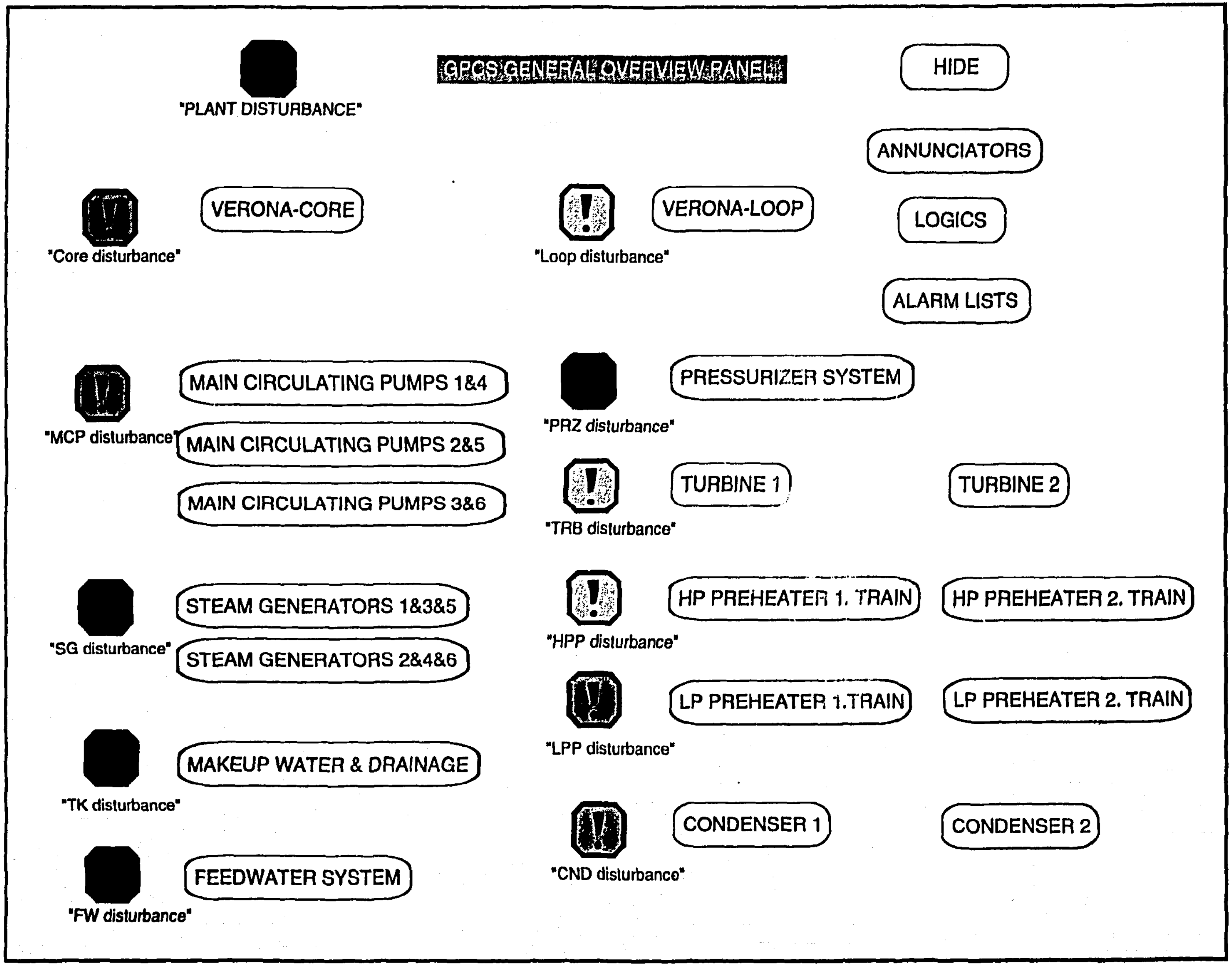

Figure 1. The GPCS overview panel

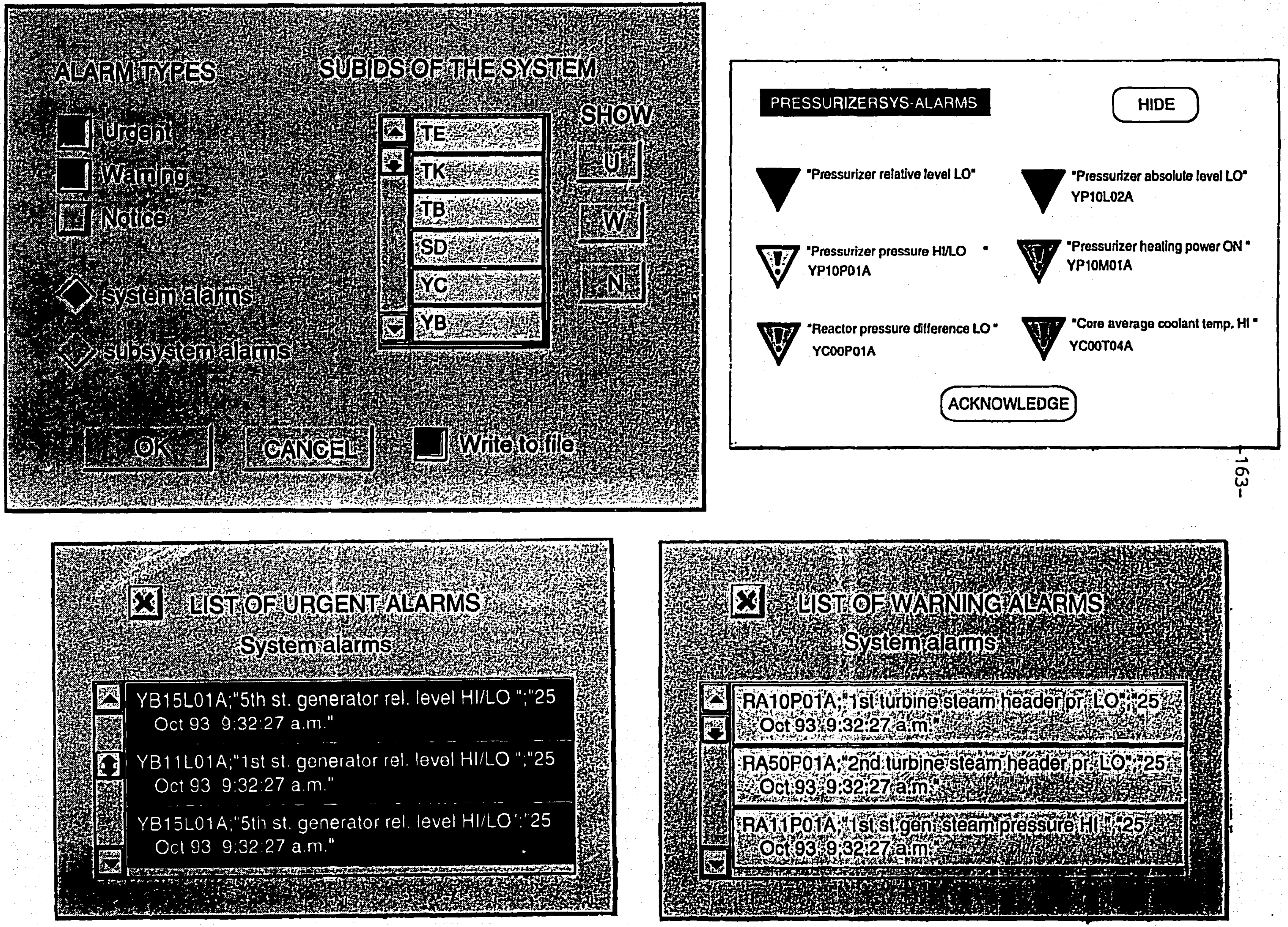

Figure 2. Urgent and warning alarm lists

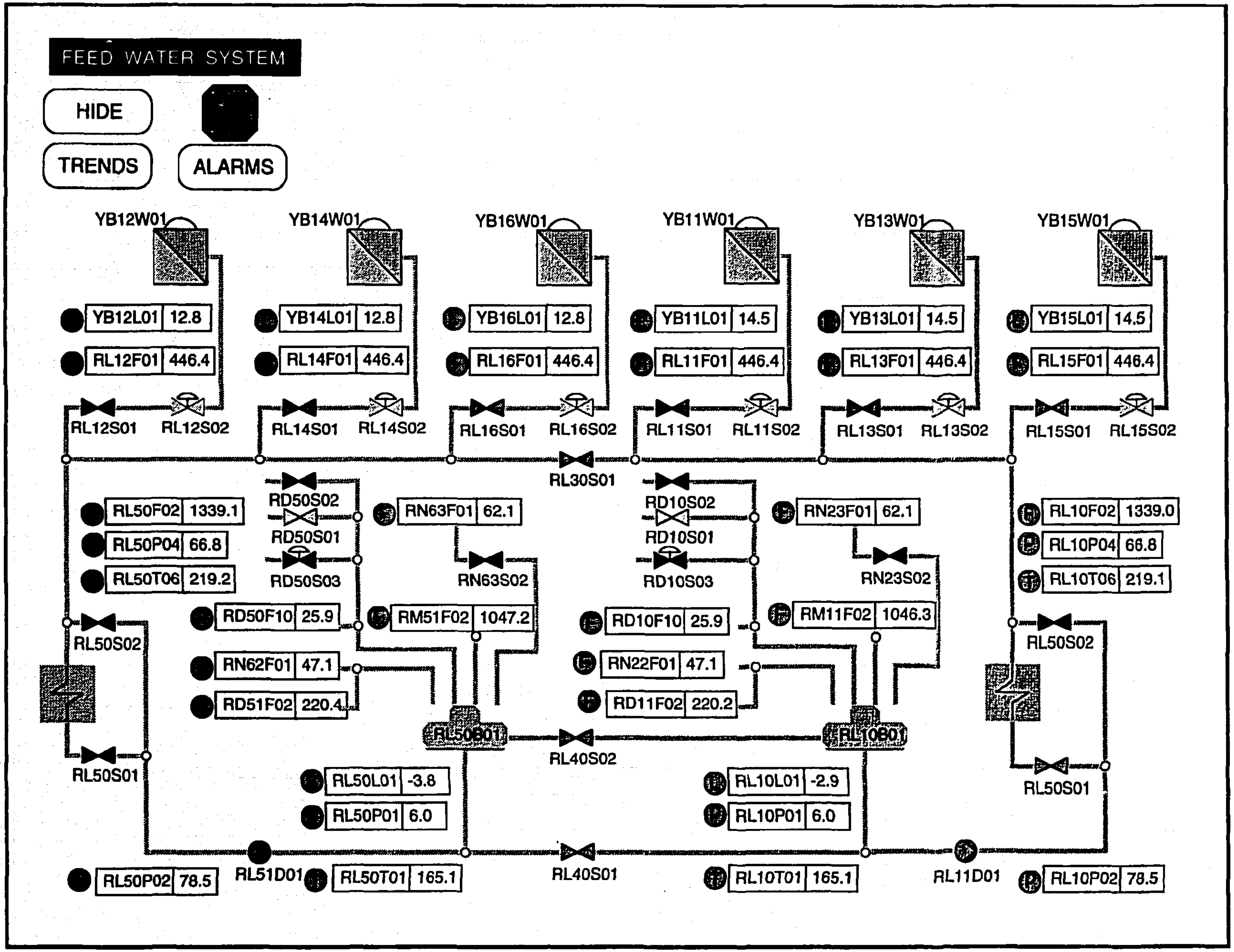

Figure 3. Feedwater system picture in GPCS

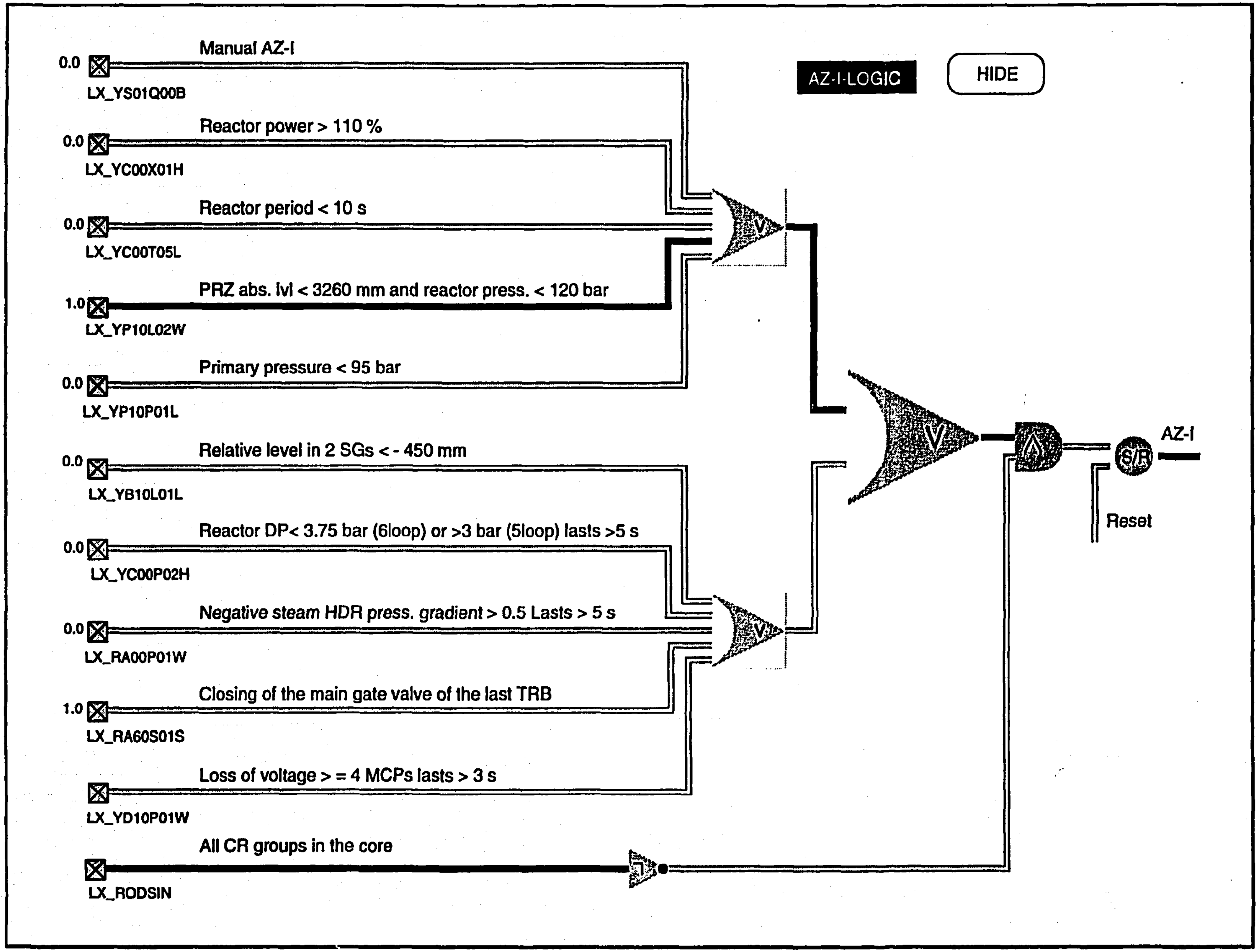

Figure 4. RP level I logic diagram