Refurbishing the Reactor Protection Systems of VVER-440/230 and 213 and VVER-1000/320 Nuclear Power Plants with Exclusively Digital I&C Systems

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Abstract

Refurbishment of a nuclear power plant's reactor protection system (RPS) is based on two main sets of requirements.
The first set covers the engineering aspects such as performance, qualification and licensing. Besides these requirements, the interfaces to other instrumentation and control (I&C) functions and systems are also important. Furthermore, maintaining the operating license has to be taken into consideration.
The second set of requirements consists of price-performance relationships (i.e. cost-benefit), ease of service and maintenance as well as installation during scheduled refueling outages as necessary with respect to economic efficiency.

Advanced I&C systems have been developed to meet these requirements as well as the increasing demands being placed on safety and availability.
The main features of these systems are a clear, task-related architecture with adaptable redundancy, consistent application of standards to interfacing and communications, comprehensive tools for ease of design and servicing, and a highly ergonomic screen-based man-machine interface.

A number of VVER nuclear plants, VVER-440s as well as VVER-1000s, have announced their intention to refurbish their RPSs.
The main functions of the new RPS are the following:

- emergency protection
- emergency core cooling
- diesel start and diesel load program initiation.

Siemens' Power Generation Group (KWU) has been in a position to offer highly favorable solutions in this regard which meet all general

requirements as well as plant-specific needs. Since 1994, VVER plants have been placing orders with Siemens to design, supply, install and commission new RPSs, including the ex-core neutron flux monitoring system, utilizing Siemens' advanced I&C system TELEPERM XS.

TELEPERM XS is designed to perform any safety I&C task requiring nuclear-grade qualification. This includes in particular all functions which initiate automatic countermeasures for accident prevention and accident control.
Thus, from an engineering viewpoint as well as with an eye to economic efficiency, Siemens' digital safety I&C system presents an optimum solution for refurbishing reactor protection systems.
The new exclusively digital RPS will fulfill all requirements regarding function, qualification, licensing and cost effectiveness specified by the customer and the regulatory authorities. To achieve optimum economic efficiency, installation and commissioning will take place during the normal scheduled outages. In this way, no additional costs are incurred due to loss of production.

Above and beyond the RPS refurbishment, this digital I&C system provides an excellent foundation for remaining plant service life.

1. Introduction

In recent years the requirements governing the safety and availability of nuclear power plants have changed. Investigations to consider these revisions were conducted in Western nuclear power plants as well as in several VVER plants in Eastern Europe and the former Soviet Union. Depending on the scope of these modifications, analyses investigating the partial or complete modernization of safety I&C systems are economically interesting and indeed necessary with regard to safety.

One of the I&C system concerned here is the reactor protection system (RPS), which serves primarily the functions of emergency protection, emergency core cooling, diesel start and diesel load program initiation.

The existing safety I&C systems in VVER plants are based on analog technology and represent special solutions for safety-related applications. The procurement of spare parts for such systems will become increasingly difficult as time goes by. In some nuclear power plants, the RPS is reaching the end of its service life and in most cases these systems do not match today's high customer expectations with respect to serviceability, maintenance, diagnostics and documentation.

2. Framework for Refurbishment

Refurbishment of the RPS as well as the entire reactor I&C is governed by specified requirements and user-specific needs (see Fig. 2-1).

The main requirements are dictated by the following:
- efficient operation
- qualification to nuclear-grade specifications
- licensing

Requirements dictated by the latter two of the above will vary according to the codes and laws specific to the country in which the nuclear power plant is located.

User-specific needs can be broken down into the following:
- task-related architecture with adaptable redundancy
- consistent application of standards to interfacing and communications
- comprehensive tools for ease of design and service
- long-term supply of spare parts
- aftersales service by the supplier

These needs can be summed up as the demand for an optimum price-performance relationship.

In order to guarantee that the above requirements and needs are met, Siemens proposes a modernization process divided into the following 3 main phases, which are described in greater detail below (see Fig. 2-2):
- preliminary project phase or feasibility study
- concept phase
- realization and implementation phase

This method provides the capability of tailoring special, customer-focused solutions which are both inexpensive and licensable. Furthermore, the customer has the possibility of making decisions during each phase along the way.

2.1 Preliminary Project Phase

The first step of any modernization project is to conduct a preliminary project phase or feasibility study. In cooperation with the customer, the current status of the plant's existing reactor I&C must be clarified and a modernization concept developed.

The main steps in the course of this phase are:
- Record the current status of the existing I&C systems.
- Define the tasks to be performed.
- Develop a proposal for modernization.

The main task within the scope of recording the status of the existing I&C system consists of identifying the I&C functions on the basis of I&C documentation and classifying these functions according to safety goals. This method allows each I&C task to be formalized with respect to the plant process and functions to be compared with the state of the art. In this way, potential improvements of the I&C functions can be shown which go far beyond the simple replacement of the equipment system.

Furthermore, plant-specific features can be pointed out in the course of recording the current status of the I&C systems, such as:
- free space in the switchgear building
- power supply reserves
- cable tracing
- equipment systems implemented in adjacent systems
- interfaces, decoupling.

Based on this information, a unique replacement concept can be developed in cooperation with the customer which considers the following conditions:
- possibility of replacing I&C cabinets
- possibility of replacing I&C functions
- interfaces
- customer-specific needs with regard to operation & monitoring
- licensing conditions
- replacement timeframe during scheduled refueling outage.

A preliminary project phase such as described above has already been carried out for Paks Nuclear Power Plant in Hungary.

2.2 Concept Phase

In the case of a positive customer decision for replacement and modernization based on the results of the above initial phase, elaboration of preliminary concepts can begin. These concepts at the same time form the foundation for plant-specific licensing procedures. Documentation is subdivided into 3 main complexes:

- overall description
- process requirements for I&C
- I&C concepts

The overall description presents the reasons for and a general overview of the modernization project and refers to the detailed concepts. In addition, individual modernization packages are defined and an overall time schedule set. In order to ensure licensability of replacements and modernizations, a detailed verification and validation (V&V) concept for all phases of the project is essential.

If within the preliminary project phase all existing I&C functions of the reactor I&C system have been identified and classified, the safety tasks of the I&C modernization can be defined taking into account the scope of functions to be replaced and the functional modifications to be made. The description of the I&C tasks contains only those functions to be replaced. In addition to safety classification of the I&C functions and definition of the failure-inducing events to be accommodated, it is necessary to specify the time behavior required of the I&C functions. This is a topic of particular importance to digital sequential operating I&C systems, as it must be proven that the total signal response time of the I&C system fulfills the process time behavior requirements.

The main part of the licensing documentation comprises the I&C concept descriptions. Based on the safety tasks of the I&C system, the system architecture must be defined and the I&C functions distributed over the various subsystems. This allows evaluation of the anticipated time behavior. Furthermore, I&C cabinet allocation and module disposition can be derived as well as the power supply demands of the system hardware (power supply concept).

The man-machine-interface of the I&C system is described within the scope of an operation & monitoring concept and an annunciation concept. The test concept and the service concept play a special role in this respect in view of the high customer expectations with regard to testing, maintenance and servicing of the I&C system.

Preparation of the licensing documentation for upgrades being performed at Bohunice V1 and Rovno 4 Nuclear Power Stations is almost complete.

2.3 Realization and Implementation Phase

Realization and implementation of system upgrading begins subsequent to completion of the licensing documentation, and is subdivided into 4 stages:

- manufacture of I&C system
- installation and commissioning
- trial operation
- training and support.

The process of preparing the function diagrams and hardware topology diagrams is called "specification of the I&C system" and can begin within the second phase, "licensing documentation", as this process is not connected to ordering and manufacture of the system hardware. In particular the automatic code generation and subsequent V&V of the I&C functions by means of simulation testbed and load calculations provide a higher degree of certainty for the implementation phase.

Subsequent to ordering and manufacture of the system hardware, in particular the wiring and factory testing of the I&C cabinets, full-scale integration testing is conducted in a test rig. The test specifications applied for simulation must be proven on the target hardware. Furthermore, I&C software is tested using plant simulation software. Goal of the integration test is a full-size test scope in order to ensure compliance within the specified timeframe for installation and commissioning during the scheduled refueling outage.

Erection of the system at the plant is limited to the installation and commissioning of the pre-tested I&C cabinets and connection of the input and output signals.

The implementation phase concludes with extensive instruction and training of the customer's personnel as well as support for system maintenance and inservice inspections.

This modernization concept procedure is currently being applied within the framework of the following I&C upgrade projects:

- Bohunice V1, a VVER-440 Model 230 plant, for refurbishment of the entire reactor I&C.
- Paks, a VVER-440 Model 213 plant, for refurbishment of the RPS and ex-core neutron flux monitoring system
- Rovno Unit 4, a VVER-1000 Model 320 plant, for refurbishment of the reactor trip system and the ex-core neutron flux monitoring system
- Khmelnitzki, Unit 1, a VVER-1000 Model 320 plant, where Siemens will soon begin with refurbishment of nearly the entire reactor I&C system.

All of these orders are based on Siemens digital safety I&C system TELEPERM XS, which is capable of meeting all requirements and customer-specific needs in the field of reactor I&C refurbishment.

3. Refurbishment of Reactor Protection System

In the aforementioned plants, the RPS will be modernized on the basis of the three-phase concept outlined above using the TELEPERM XS I&C system.

Siemens works closely together with its customers as well as with the original suppliers if needed or requested. This practice ensures that maximum know-how is implemented in refurbishment projects, i.e.:

- customer's practical experience in the field of operating and maintenance
- original supplier's theoretical knowledge in the fields of analysis and design
- Siemens' experience in the field of I&C, upgrading of operating nuclear power plants and service activities in every VVER design type.

This guarantees optimum benefit to the customers with regard to:

- safety
- availability
- cost-effectiveness.

Some brief information on the aforementioned projects is presented below.

3.1 VVER-440 Model 230 Plant (Bohunice V1 Nuclear Power Station)

Bohunice V1 Nuclear Power Station is currently carrying out a reconstruction of the plant for the purpose of increasing safety. The reactor I&C will be renewed within the scope of this work.
One part of the reactor I&C is the RPS, which covers the trip system together with the ex-core neutron flux monitoring system and the safety control system.

Another part of the reactor I&C is the limitation system, called ROM. The limitation system serves the function of reactor power reduction in the event that main components such as the main feed pumps become unavailable. At Bohunice V1, the limitation system will be implemented using the same I&C equipment serving the trip system.

This project is currently in the realization phase, based on the concept phase carried out in 1995 and early 1996.

In accordance with the process engineering tasks, the trip and limitation system and the safety control system will be configured in a two-train redundancy (see Fig. 3-2) and each of the two trains will be designed with three channels. This means that each physical variable in the process will be measured six times. Each of the two redundant trains will acquire, monitor and logically gate three of these measured data and process them into output signals. These functions are performed by data acquisition computers and signal processing computers. An additional computer is provided for each redundancy to allow evaluation of the ex-core neutron flux signals.

In order to rule out any software common cause fault, the various actuation signals are conditioned on different computers within the data acquisition and control computer. This means that the computers run different programs. Following limit value generation, the signals are evaluated in each computer using a 2-out-of-3 configuration and then logically gated further. At the control level, the output signals are logically gated to actuation signals using relays in a six-contact system in a 2-out-of-3 configuration. The actuation signals then initiate scram.

3.2 VVER-440 Model 213 Plant (Paks Nuclear Power Station)

The order for Paks Nuclear Power Station covers refurbishment of the trip and limitation system, the ex-core neutron flux monitoring system and the safety control system.

The concept being applied for this project differs from the one above in the following points. The I&C functions of the neutron flux monitoring computer, the data acquisition computer and the signal processing computer are summarized in one system. The configuration consists of a three-train redundancy with two channels in each of train. The safety control actuators will be initiated via voter systems. Apart from this configuration, the scram will also be initiated via the six-contact system (see Fig. 3-3).

3.3 VVER-1000 Model 320 Plant (Rovno 4 and Khmelnitzki 1 Nuclear Power Stations)

At Unit 4 of Rovno Nuclear Power Station the trip and limitation system and the ex-core neutron flux monitoring system will be modernized.

As mentioned above, Siemens is working together very closely with the plant personnel on this project. Rovno staff are thus involved in the engineering process for the purpose of cooperation in the concept phase and supply in the realization phase.

Similar to the refurbishment at Bohunice V1, the trip and limitation system will be configured in a two-train redundancy (see Fig. 3-4) and each of the two trains designed with three channels. In contrast to Bohunice V1, however, the functions of data acquisition and signal processing will be performed by one computer for each channel. The concept for evaluation of the ex-core neutron flux signals is the same as described above.

This structure will be implemented at Khmelnitzki Nuclear Power Station in a similar way. The limitation system ROM is separated from the trip system, and the reactor power control system ARM is added to one of the trains.

4. TELEPERM XS

As noted above, these projects are based on the digital safety I&C system TELEPERM XS.

4.1 System Elements

The main system elements of TELEPERM XS are the following(see Fig. 4-1):

- standard hardware
- specific system software
- engineering system

Given the experience gained from conventional I&C systems and digital computer-based systems for non-safety-related applications, no hardware components have been specially developed for the TELEPERM XS systems. Rather, selected components of Siemens' standard equipment families have been type-tested and qualified to international nuclear codes and standards.

The second system element of the TELEPERM XS system is the specific system software, which was developed in accordance with the DIN IEC 880 and DIN ISO 900x standards. The system software consists of:

- the small static operating system MICROS
- the runtime environment, which connects the application software with the operating system, and
- libraries of function blocks for I&C functions.

The system software has been developed to a large extent independently of the target hardware in order to allow portability of the software in case of changes in hardware generation.

The third and most interesting element of the TELEPERM XS system consists of the SPACE engineering tool for specification, automatic code generation, verification and documentation of the I&C functions during the engineering process as well as for testing, diagnostics and possible modifications of the I&C functions during operation.

TELEPERM XS permits the automation structure to be adapted flexibly to given plant requirements. System design allows all requirements to be met cost-effectively (see Fig. 4-2).

4.2 The SPACE Engineering Tool

The full-size engineering tool of the TELEPERM XS system is called SPACE (**SP**ecification **A**nd **C**oding **E**nvironment).

The main idea of software development and verification with the SPACE tool consists of automatic code generation from data-based formal graphical specification of the I&C functions.

In the past, I&C system tasks were conventionally described by process engineers and physicists in the form of verbal descriptions, diagrams and equations.

The I&C engineer has a set of well defined, tested and qualified function blocks in order to convert the task description into function diagrams. The same method and tools are used for specification of the system hardware. Thus, the database is the single source for code generation and completely describes the designed I&C system. Furthermore, this engineering technique, termed forward documentation, ensures that the designed function diagrams and the I&C function running on the target system are always consistent.

This method of automatic code generation from formal specifications with the SPACE tool provides several advantages:
- generation of parameter lists and order lists from the database
- capability of performing load calculations at engineering stages
- capability of testing and simulating functions without target hardware.

4.3 System Qualification

Qualification and licensing procedures for an I&C system based on TELEPERM XS is divided into:
- type-testing of the components independently of any specific application, and
- licensing procedures for specific applications.

One of the main goals in developing TELEPERM XS was to shift the major portion of qualification to the non-plant-specific part. Type-testing in accordance with valid national and international codes and standards (see Fig. 4-3) covers:

- the hardware modules, and
- the on-line software (operating system, runtime environment, libraries of function blocks).

5. Conclusion

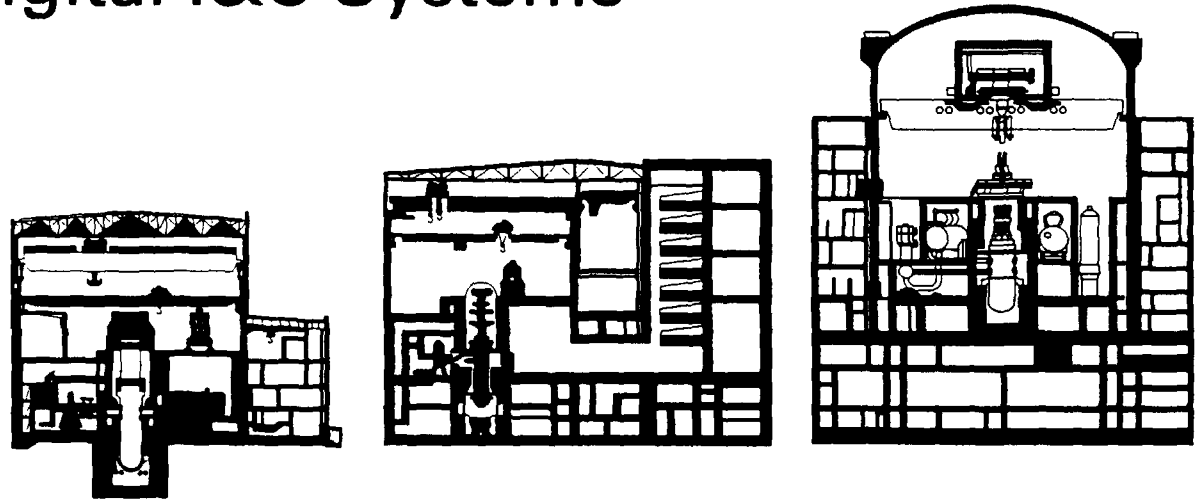
The area of application for the TELEPERM XS system in VVER nuclear power plants will be found in the field of replacement and modernization of existing I&C systems. TELEPERM XS fulfills the requirements specific to nuclear plants and is adaptable to any user-specific needs.
To date, customers operating plants representing all the various design types of VVER nuclear power plants have awarded Siemens contracts to design, supply, install and commission trip and limitation systems.

This cooperative work, joining together customer personnel know-how in operating and maintenance and Siemens' long-term experience in the field of I&C systems and I&C upgrading, will prove exceptionally beneficial to VVER nuclear power plants.

Subject

Refurbishing the Reactor Protection System on VVER 440-230 / 213 and 1000-320 NPPs

with Digital I&C Systems



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Frame of Refurbishment
Requirements and User-Specific Needs

Requirements

- efficient operation
- qualification to nuclear-grade specifications
- licensing

User-Specific Needs

- task related architecture with adaptable redundancy
- consistent application of standards to interfacing and communications
- comprehensive tools for ease of design and service
- long-term supply of spare parts
- aftersales service by the supplier

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Frame of Refurbishment
Project Phases

Refurbishment

Preliminary Project Phase

- record the current status of the existing I&C systems
- definethe tasks to be performed
- develop a proposal for modernization

Concept Phase

- overall description
- process requirements for I&C
- I&C concepts

Realization and Implementation Phase

- manufacture of I&C system
- installation and commissioning
- trial operation
- training and support

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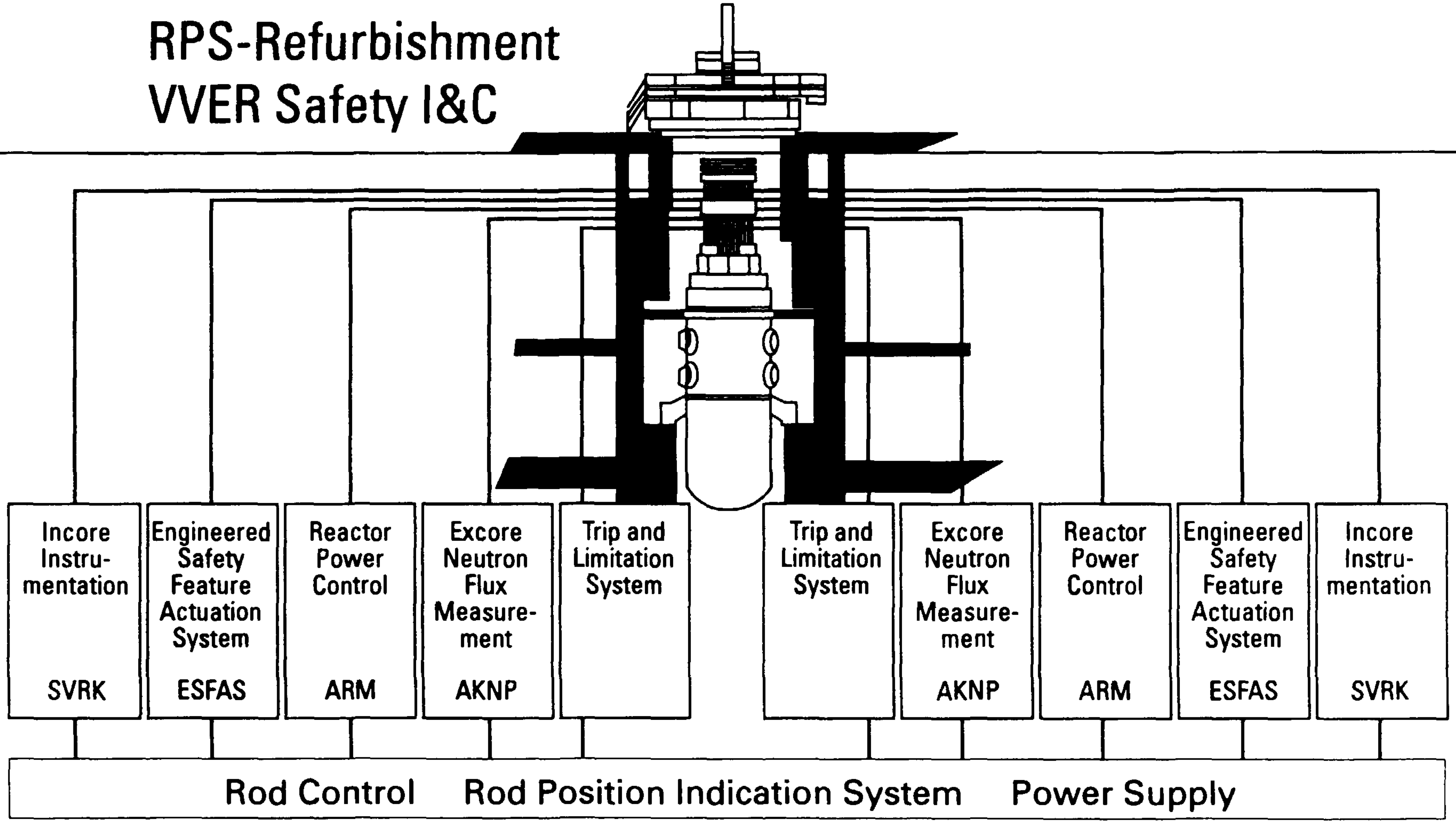
RPS-Refurbishment
VVER Safety I&C



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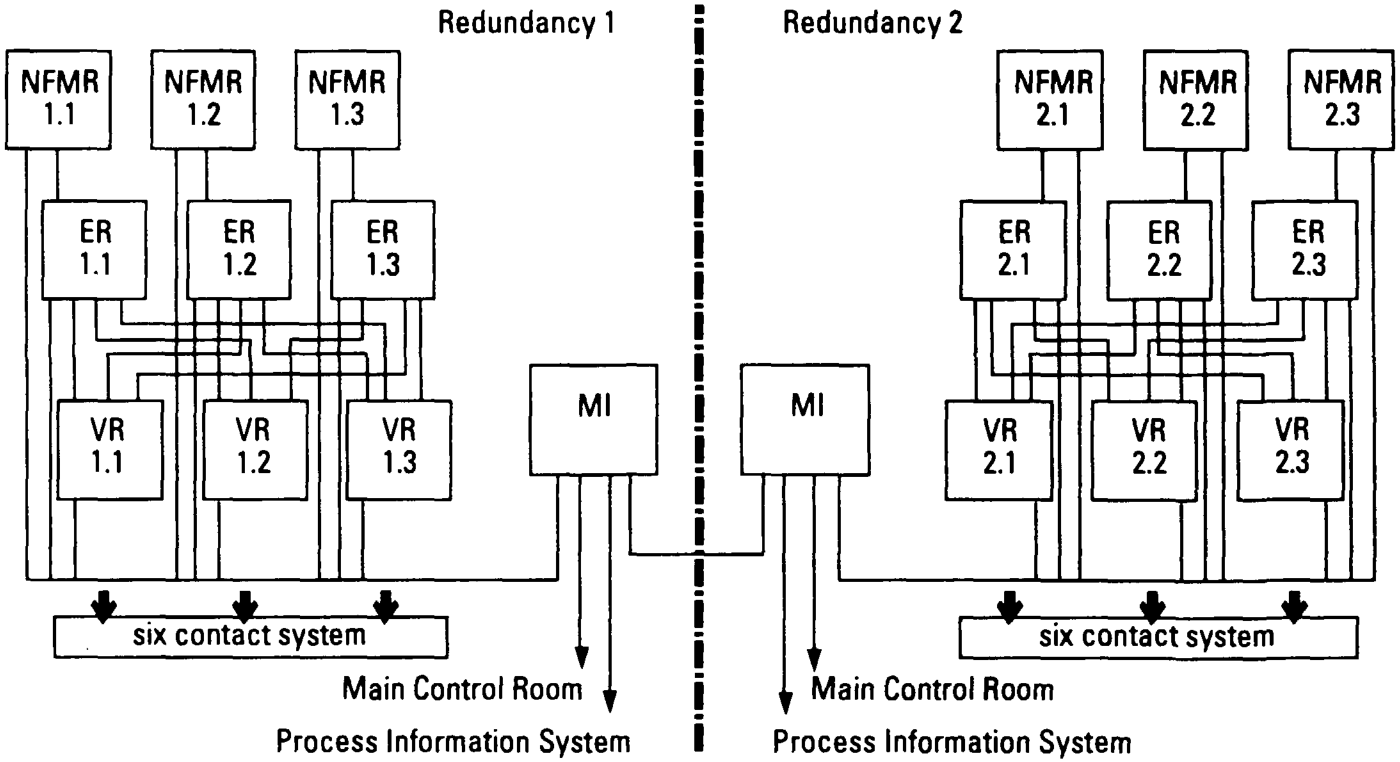
RPS-Refurbishment VVER 440-230

ER	data aquisition computer
VR	signal processing computer
NFMR	neutron flux monitoring computer
MI	meassage interface



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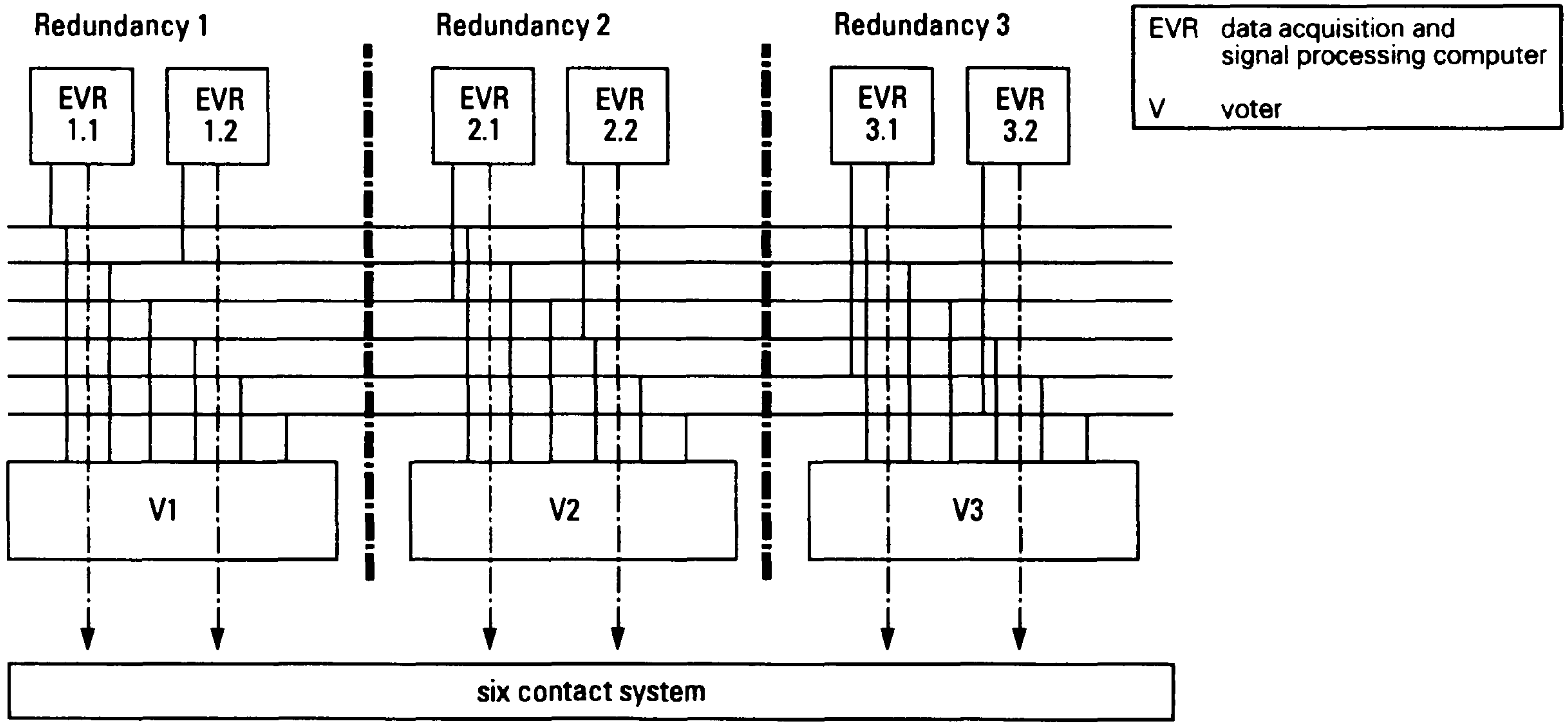
RPS-Refurbishment
VVER 440-213



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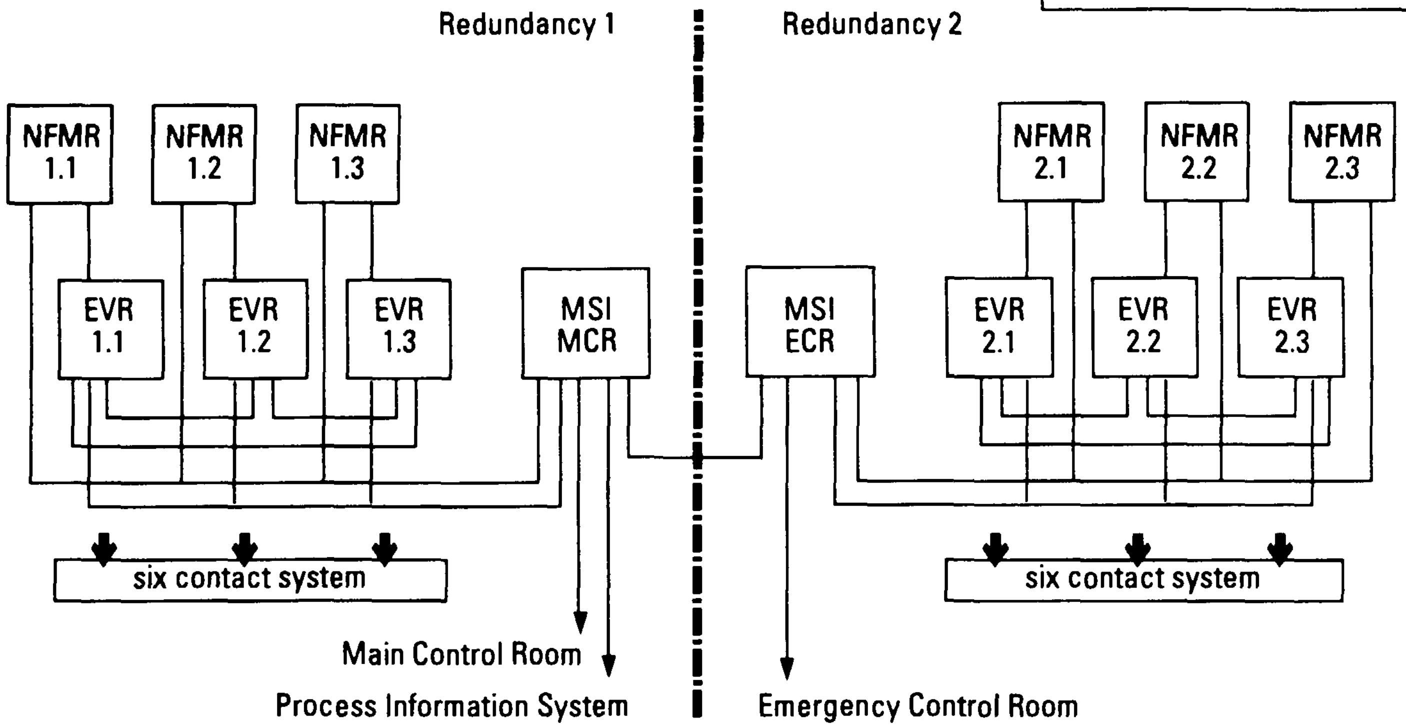
RPS-Refurbishment
VVER 1000-320

EVR	data aquisition and signal processing computer
NFMR	neutron flux monitoring computer
MSI	meassage and service interface
MCR	main control room
ECR	emergency control room



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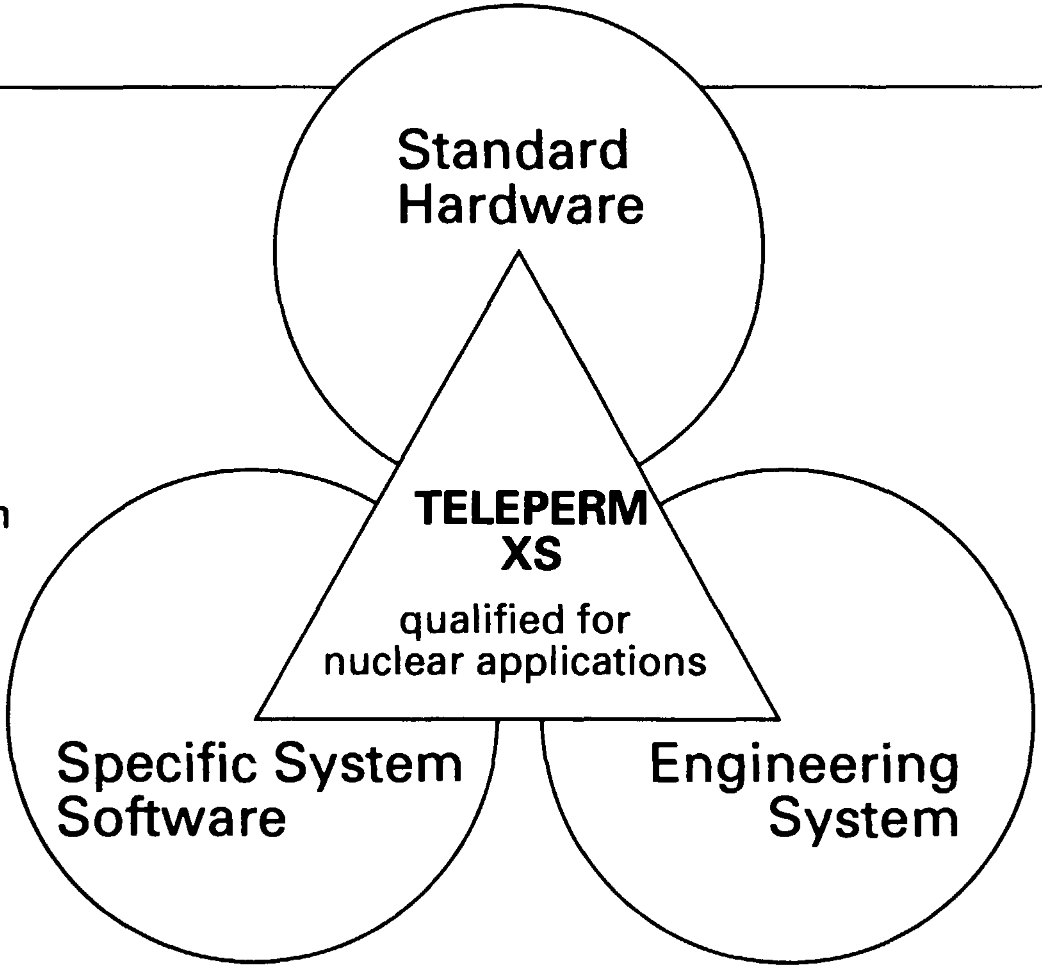
TELEPERM XS – Main System Elements

- Operating system
- Runtime environment
- Libraries



Tools for

- Specification
- Code generation
- Verification
- Testing
- Documentation
- Diagnosis

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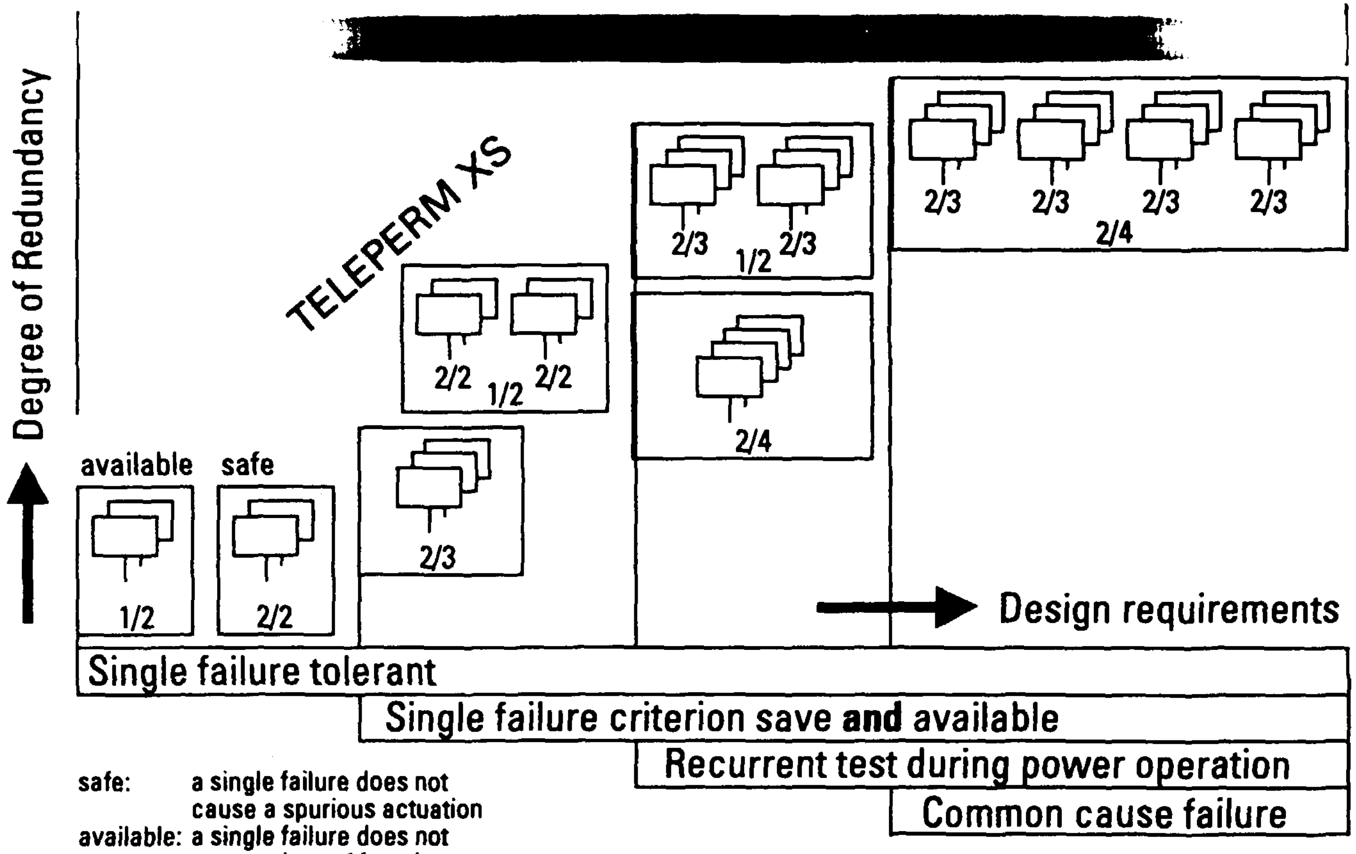
TELEPERM XS
Adaptable to Individual Applications



safe: a single failure does not cause a spurious actuation
available: a single failure does not cause a loss of function

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TELEPERM XS
Qualification

Software | Hardware

Typetesting

Hardware	
Requirements	KTA 3501 IEEE 323 IEC 987
	KTA 3503
	EN 55011 IEC 801
	IEEE 344 IEC 68 IEC 1131

Software	
Requirements	KTA 3501 IEC 880
	ANS-10.4
	IEEE 829 IEEE 1008
	ISO 9000-3

Quality Verification

Tools	
Requirements	ANS-10-4
	IEEE 829 IEEE 1008
	ISO 9000-3