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REAL-TIME POWER PLANT MONITORING AND VERIFICATION AND VALIDATION ISSUES

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REAL-TIME POWER PLANT MONITORING AND VERIFICATION & VALIDATION ISSUES

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ABSTRACT

There is growing interest in the utilization of computer and information processing technology for monitoring of complex plant and/or process systems. In particular, by means of on-line applications of advanced surveillance, early fault detection and diagnosis techniques, the system's reliability can be improved beyond the existing standards. The paper describes the real-time monitoring system of a nuclear power plant and highlights the associated verification and validation issues involved.

INTRODUCTION

Due to some serious accidents with complex systems such as aviation, nuclear industry and others in the last decades, there is growing interest in the utilization of computer and information processing technology for monitoring of complex plant and/or process systems. Specifically, by means of on-line applications introducing advanced surveillance, early fault detection and diagnosis techniques, the system's reliability can be improved beyond the existing standards. In this context, the computer-based surveillance and diagnostic system for on-line monitoring and diagnostics of Borssele nuclear power plant (NPP) in the Netherlands was installed in 1983 and it has been operating successfully since then. The system is located at the Netherlands Energy Research Foundation (ECN) which is about 200 km in distance from the power plant. The system is designed in the form of multi-level and multi-tasking modes of operation using a sophisticated hardware structure which performs the implementation of advanced signal processing techniques in real-time.

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REAL-TIME POWER PLANT MONITORING

The data acquisition and the real-time monitoring system associated with the NPP Borssele is schematically shown in Fig.1. The signals obtained from the plant are introduced to a patch panel which can accept up to 90 sensory signals from various locations of the plant and convey them to micro-computer based signal conditioning unit to make suitable for transmission by telephone lines. The signal conditioning unit can handle up to 32 signals at a time in dc and ac signal mode where any 32 out of 90 signals can be selected as input. The instrumental settings in the reactor for sensors are done by remote control by the supervision of the main computer. The main computer is a VAX 4000/200 equipped with an array processor (Floating Point System FPS 5105). Several workstations are connected to the main processor through an universal communication net Ethernet.

The data processing by the real-time monitoring system is schematically shown in Fig. 2. The data are received from the plant sensors on separate channels and are introduced to the array processor where the data reside as a block for FFT processing for a predetermined number of channels and cross combinations. The power spectra are computed in real-time using exponential averaging so that the dynamic behavior of the signal is identified continuously. The array processor carries out the essential task of computation and provides the other system units with the necessary information for further analyses. After the block length, channel selection, required cross-combinations between the selected channels, spectral window and exponential weighing factor parameters information having been given to the running program in the array processor (FAST), all resulting functions in time and frequency domain are stored in a particular area of the main computer's RAM which was defined as common for common use in real-time. The array processor can handle 32 channels signals with above 40 cross-combinations using a data block of 128 or 256 samples. The size of the memory necessary to store total digital information, i.e., discrete time data, histograms for a given number of points and calculated statistical information such as moments up to order five, auto-cross correlations and the related power spectra with real and imaginary components is 250 kwords of 32 bits. The duration of each cycle of computation being dependent on the block size and the sample rate, it extends from 4s to 16s. The actual computation in the array processor are accomplished in the range of a fraction of a second.

In the monitoring of the power plant a certain period of the latest incoming data sequence is logged for emergency use. The duration of this period may extend up to some days. This feature is accomplished by means of a special software device named "circular file". The size of this data file can be determined selectively to accommodate the data corresponding to desired time duration for storing the latest retrospective information. The circular data file resides in the main storage disk facility of the main computer and accessed by means of a special reading module which can read the file while the circular file is being written. For example, the data read from the file can be used in any desired way as the data can be copied onto a tape for storage. For visual inspection, another special display module is available performing display and plottings.
From the above brief description of the signal processing in the array processor and the formation of the circular file, the hardware and software tasks performed during the data acquisition can be seen in two basic steps, as follows:

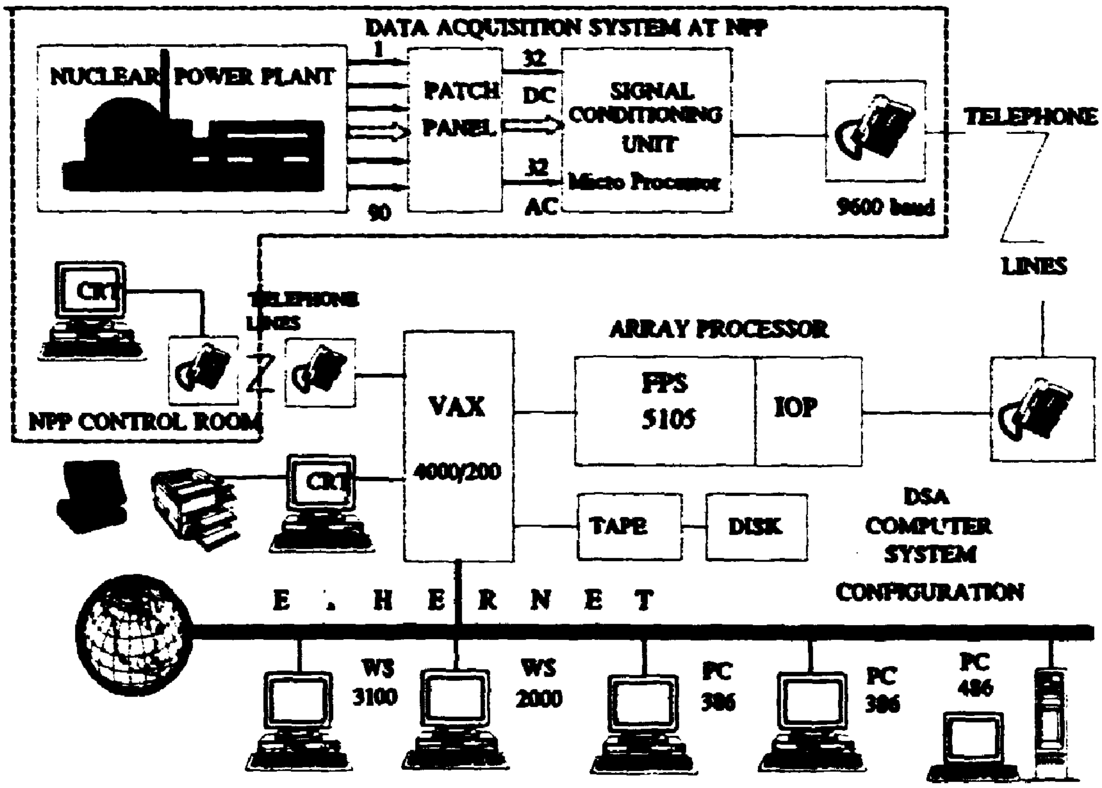

Fig. 1: Real-Time NPP monitoring system overview

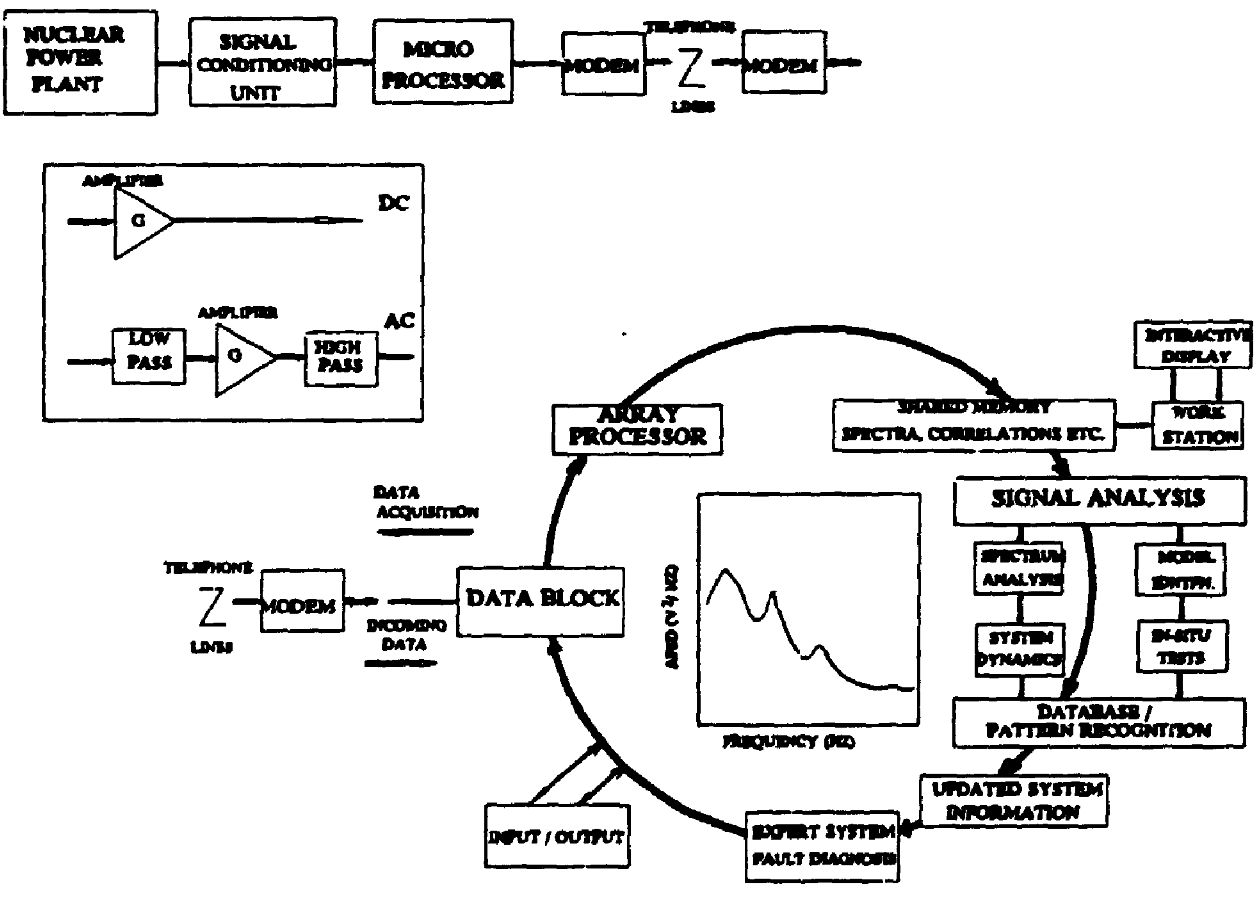

Fig. 2: Data acquisition and on-line signal analysis system

a. Computer-based instrumentation set up in the power plant environment by means of remote control and following signal conditioning and signal transmission.

b. Pre-processing for monitoring using the signals obtained directly from the signal conditioning unit in dc and ac form.

The on-line signal analysis system shown in Fig.2 is designed in the form of multilevel mode operation, as described below.

In the first level, the plant's status is monitored by means of 32-channel dc and ac signal information.

In the second level, the plant's operational status is identified using the dynamic model of the plant and the results of the on-line multivariate time and frequency domain analyses are reported.

In the third level, the results obtained in the preceding signal analyses are stored to form a data base for future reference and use in the further analyses of interest such as pattern recognition, signal modelling and so on. As a special implementation, the information present in the common block can be periodically logged in a circular file for inspection of changes in periodic time intervals.

In the fourth level, the plant's operational status is identified by means of special advanced techniques such as neural networks using the information (spectral, parametric or both) gained in the previous steps.

The detailed description of the monitoring system is reported by Türkcan et al. (1991).

From the above-described real-time data processing, in particular, the software tasks performed can be seen in two basic steps, as follows:

a. Multi-channel signal processing in both time and frequency domain in real-time, such as multivariate signal analysis, exponential averaging of frequency spectra, further extraction of quantities from the spectra for subsequent use, and so on.

b. Using the available processed data in the common block performing further analyses in distributed systems environment. That is, part of the computations is performed by the main processor as the other part is accomplished by means of work-stations connected to the main processor and the large block of shared memory (common block) through the ethernet communication.

VERIFICATION AND VALIDATION ISSUES

Verification and validation (V&V) is an important concept in complex system operation. It concerns a broad field of engineering disciplines and in the case of complex integrated human-machine systems, such as NPP it concerns also "soft sciences". The basic objective of V&V is to evaluate the test or monitoring tools and to obtain a high quantifiable reliability. In a general sense verification is to ensure that all specified requirements have been satisfied. On the other hand validation is to provide evidence that the implementation of the design requirements satisfy the mission of the system.

From the real-time monitoring viewpoint, there are three outstanding V&V issues which are signal V&V, sensor V&V and software V&V as described below. From early fault detection and diagnostics viewpoint some aspects of Nuclear Power Plant Verification and Validation are addressed through maintenance procedures. From the complex human-machine systems design viewpoint V&V includes also the human factor considerations as these will be discussed afterwards.

In relation to the safe operation of a power plant, the presence of the signals which provide the static and/or dynamic information about the system should be verified and the relevant quality of the sensory information should be validated. Therefore, in the verification process, identification of failures takes an important place. Failures related to signals may indicate system failures. Advanced computer based techniques are implemented today in real-time so that system and sensor failures can in most cases be identified and diagnosed in the incipient stage. These advanced techniques generally can be categorized as static and dynamic. Static methods are referred to when the system or sensor performance is not correlated with system dynamics. Therefore, static methods use static nominal operational values which are called dc signals. On the other hand, dynamic methods employ mean-removed signals which are called ac signals. The basic signal and sensor V&V considerations in plant monitoring are described below. The general considerations for complex and integrated human-machine systems are described in the literature, (Ciftcioglu and Türkcan, 1992).

Monitoring both ac and dc signals, the verification of the signals and sensors are performed, determining that the signals comply with the first principles of their design. Additionally, using both ac and dc signals, the deterministic and dynamic comprehensive model of the system is verified, validated and based on this model. Further the signal and sensor validation are performed through monitoring and recursive real-time estimation of signals (Ciftcioglu and Türkcan, 1991a, 1991b). The signal verification concerns the identification of the signal with its source and the nominal range. The validation concerns qualification of the data which generally refers to validating for the stability of signals including their statistical properties and anomalies which may be in form of saturation, drift, modulation and so on. The sensor verification concerns the recognition of sensor outputs to isolate sensor failure from system dependent operational changes.

The sensor validation concerns the qualification of the sensor performance in relation to system's performance. For real-time monitoring, the software development methodology should provide a correct, sequential, traceable development of the software with documentation so that the potential errors are discovered early in the software development process.

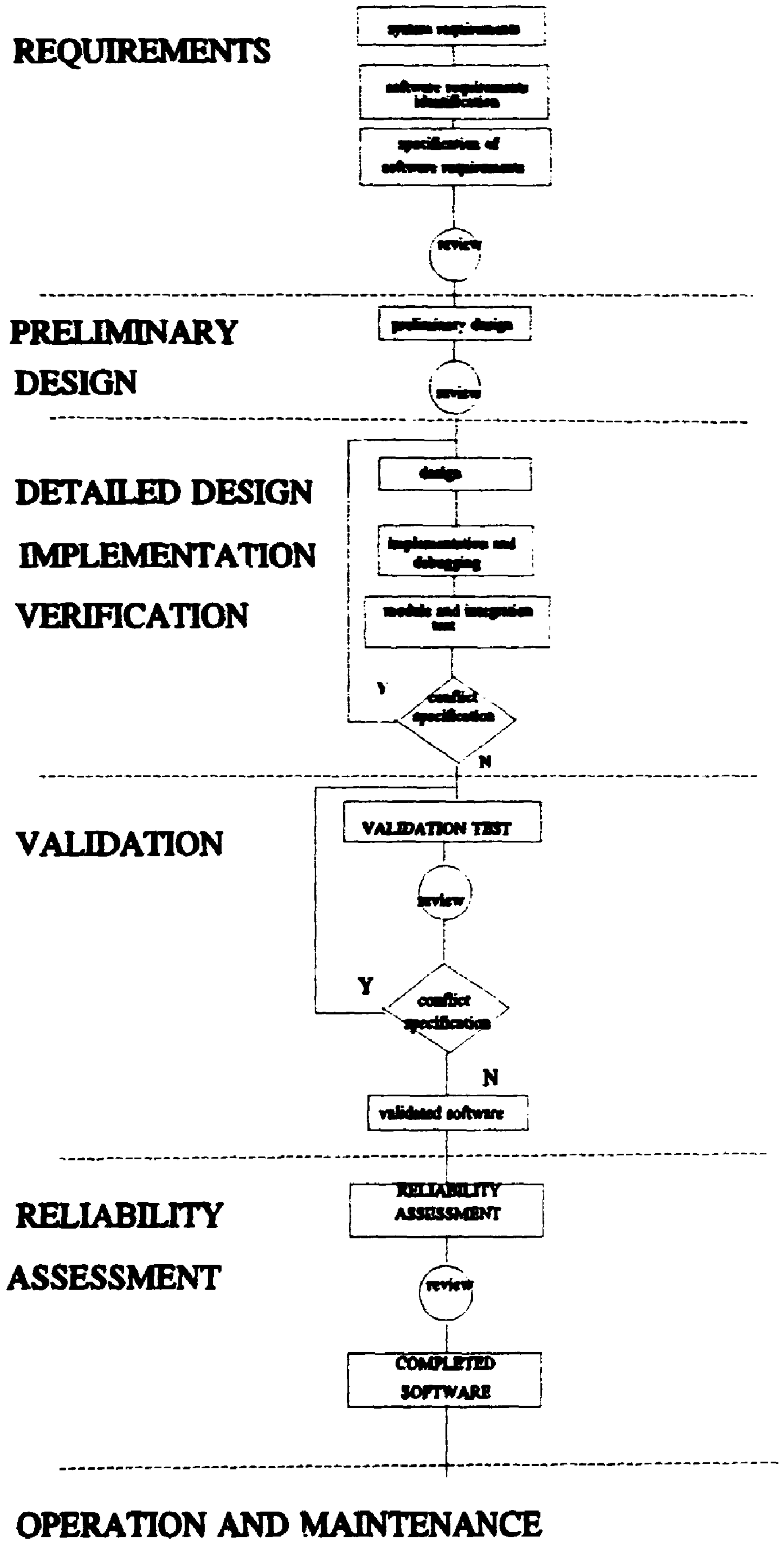

Fig. 3 : Overview of the software development methodology

The requirements or software specifications provide the foundation on which the software is to be built. Verification of the software is to ensure that all specified requirements have been satisfied. Validation is to provide evidence that the software design requirements satisfy the mission of the software. Since the programs are developed based on the software requirements, it is important that the requirements be correct, complete, consistent, understandable and testable. An overview of the software development methodology is provided in Fig. 3, where the objective of the requirements stage is to produce a document that would be unambiguous, complete and correct. Additional objective is the plan to allow early design decisions. The objective of the preliminary design is to start with the design which is consistent with the requirements. The objectives of the detailed design are to produce a program which satisfies the design and which is portable, structured, easy to read, self documenting and traceable to the other supporting documents. The objective of the reliability analysis is to obtain a quantitative estimate of the reliability of the resulting computer program.

Some aspects of NPP verification and validation are addressed through maintenance procedures, where the system as a whole has a required mean time between failures and/or minimum down time influenced by its design for which evidence has to be gathered to demonstrate its reliability as a whole. In this respect, in the last decade, in the nuclear industry reliability centered maintenance (RCM) gained substantial importance as the traditional maintenance methods proved to be rather costly and even not efficiently addressing the NPP requirements. Additionally, traditional maintenance programs do not adequately address new issues, like safety and system functional inspections. Considering economical enhancement through RCM as well as reliability and safety, the RCM can formally be defined as a systematic approach for developing a maintenance strategy like equipment, interval, etc., which takes into account system safety, its ability to function as desired, and the economics, so that the design reliability of the system is satisfied or even improved. Also, system and/or subsystem reliability and mean-time between failures can be quantified. Having its systematic and approach by common-sense features the RCM has proved to be effective in nuclear industry (Gaertner 1989; IAEA, 1990; Zwingelstein, 1992; Ciftcioglu et al. 1992). The role of real-time power plant monitoring as surveillance, early fault detection and diagnostics in the plant's maintenance is illustrated in Fig. 4.

Concerning the V&V process by pattern recognition or rule-based inference procedures such as expert systems in a NPP, human monitoring and control is essential since the operational decisions for the plant may have to be subject to re-consideration any time. Therefore, even a highly automated monitoring system has to include human operator's monitoring and supervision so that any barrier which may appear between the human and the system supervised by the human is avoided. A simplified operator decision-making model in a plant operation is shown in Fig. 5. The modern computer-based advanced technologies applied to plant design will change the operator's task. In this case exhaustive condition-operational status rules and condition-consequence rules based on functional design specifications have to be available in a knowledge-based expert system to support the human operator. In this way any information needed during rule-based procedures can be obtained in any depth, while making decisions in which human cognition and knowledge-based behavior play an essential role.

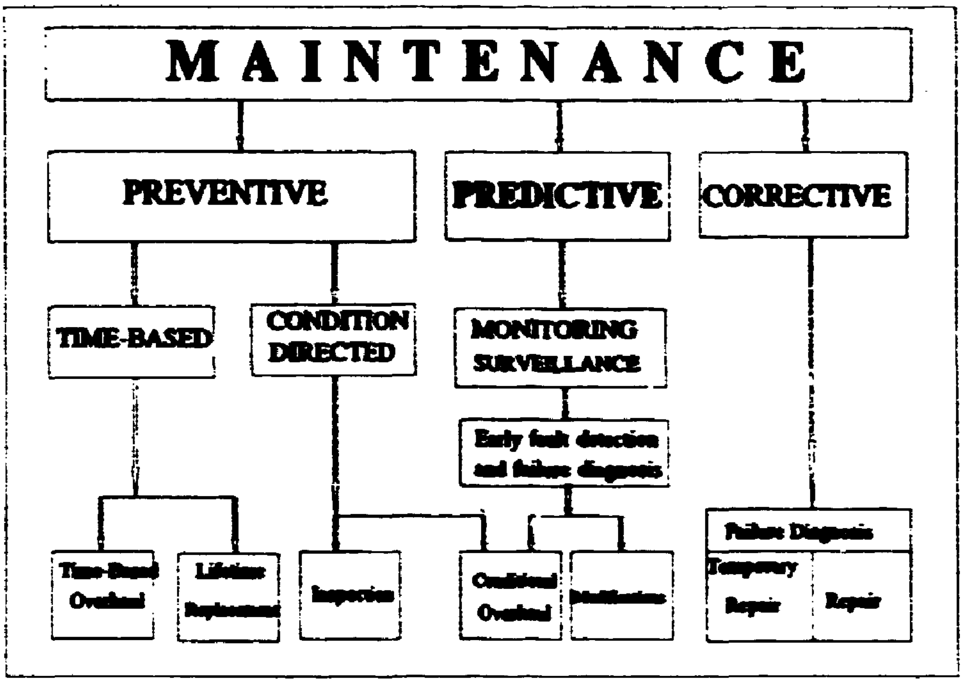

Fig. 4 : Representation of the role of monitoring in NPP maintenance

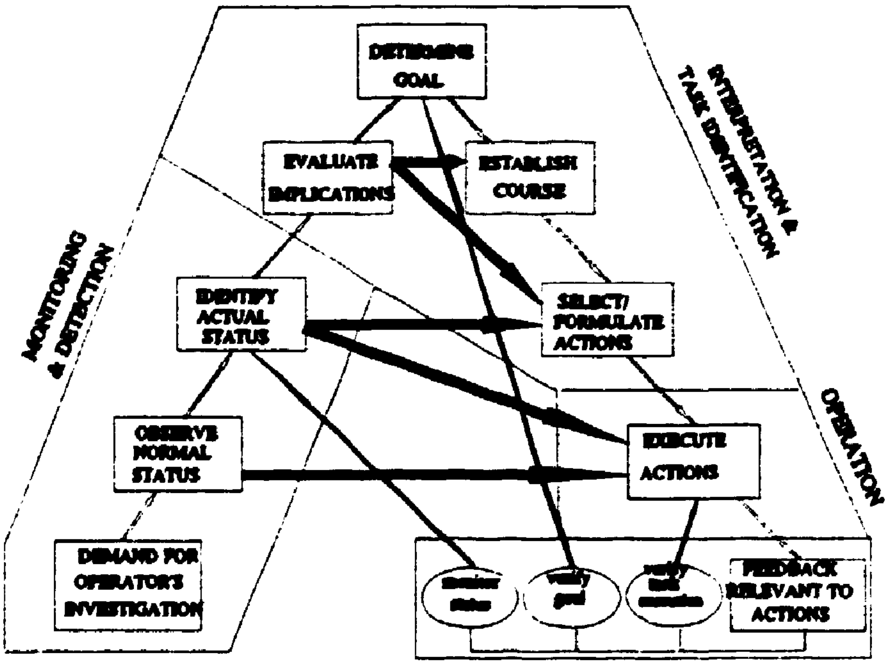

Fig. 5 : Simplified NPP operator decision-making model
The heavy arrows indicate direct transitions

Such knowledge can be qualified as "transparent", in contrast to the "black box" approach used in conventional designs. In this respect, V&V of human-machine systems like NPP requires additional studies taking into consideration also the effect of the human behavior, together with design of the system.

In verification and validation of process (dynamic) systems, redundancy and diversity are important concepts. In system monitoring level, redundancy refers to directly redundant systems performing real-time verification and validation. In the sensor surveillance level, redundancy refers to both sensor redundancy and analytical or functional redundancy. The sensor redundancy refers to directly redundant data when two or more sensors measure the same variable. The analytical redundancy concerns the technique of generating redundant signals from non-redundant sensors and processing them with advanced data processing methods. That is, additional evaluation of a variable is indirectly available from the physical relationships among other directly or indirectly measured variables. The redundancy method, although provides higher reliability in operation, it suffers from the common-mode failures. The diversity refers to a different approach for the end objective so that any eventual systematic or operational erroneous identification, detection or procedure can be avoided by diverse methodologies. In particular, any systematic erroneous procedure behaves as a common-mode failure for the same redundant system components. Also any unforseen operational condition due to lack in design specifications may lead to a systematic error in sensing the operational status of the system so that it may become in the same way a common-mode failure.

In power plant operation, the system V&V procedures using modern technologies are broadly based on two distinct methodologies. These are, pattern recognition and rule-based artificial intelligence.

In pattern recognition methodology for V&V the features of the normal system are extracted and these are compared with the features extracted during operation. However, the methodology has limitation in extracting the normal system's features because the complete knowledge about the system's features are limited to the operational experience and/or the expected operational conditions in automated learning procedures.

The V&V based on the artificial intelligence utilizes rule-based inference procedures. The rules for normal and abnormal operation have to be prepared in advance, based on experienced human experts and/or physical and functional design specifications. However, acquiring all operational status knowledge is also difficult. Acknowledge-based systems do not reason independently and adaptively based on the basics of design and functionality principles which are called first principles. Both pattern recognition and artificial intelligence methodologies for power plant monitoring and V&V can employ artificial neural networks (Ciftcioglu and Türkcan 1992) to alleviate the above-stated difficulties.

CONCLUSION

By means of the advances in the computer technology, the implementation of a real-time power plant monitoring and dynamic signal analysis system is described. As hardware and software, the system has several essential components to perform the task. Among these, mention may be made of a remote-controlled data acquisition system, a fast data processing system and a dynamic signal analysis system. For a complex system like a NPP, the system verification and validation is an important issue as the plant operation involves many engineering disciplines and also the "soft sciences". Additionally, the real-time requirements impose substantial time limitation for the implementation of tasks. The system V&V is accomplished partly by means of V&V of the system components which are monitored by the help of sensory signals. Therefore, an essential part of the V&V task involves the real-time analyses of the data provided by these signals. In this respect the NPP real-time monitoring system described possesses the required design features to carry out this task which provides enhanced reliability and availability in plant operation.

Software V&V is an important issue in real-time monitoring of NPP and it concerns to obtain high quantifiable software reliability through the evaluation of the software test tools and techniques and application of systematic software test methods. For complex and integrated human-machine systems like NPP, modern computer-based conceptual designs require V&V of the software before the conventional designs are superseded by new designs.

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