A Phased Migration Strategy to integrate the new Data Acquisition System into the Laguna Verde Nuclear Power Plant

Ramón Montellano-García, Ilse Leal-Aulenbacher, and Héctor Bernal-Maldonado

***Abstract*—**This paper focuses on the strategy applied in the gradual integration of a new data acquisition system with the online Plant Process Computer of the Laguna Verde Nuclear Power Plant. Due to the fact that the data acquisition modules needed to be replaced, the need for a New Acquisition System arose. The issue of whether or not to embark on a complete or modular replacement of its elements required careful consideration. At Laguna Verde, we opted for a phased migration approach, considering two main aspects: that the plant monitoring must remain online during the whole process, because it is required for plant operation and that human machine interfaces and computations design basis must be maintained, in order to minimize regulatory impact. The core of a phased migration strategy hinges on a flexible modular system capable of accepting data streams from multiple data acquisition systems and computers and consolidating this data for their presentation in control room displays and in the power plant historical archive. This paper describes the methodology that was applied to integrate the new data acquisition system into the legacy system, which is based on a real-time mechanism and historical data stream transfer.

***Keywords*—**Data acquisition system, gradual migration strategy, historical archive synchronization, obsolete Plant Process Computer elements, real-time external variables.

I. Introduction

Over the last two decades the Laguna Verde (LV) Plant Process Computer (PPC) plant monitoring has led to increased plant availability, efficiency and productivity while maintaining the assurance of safe operation. However, technology has moved on, and the quest for ever faster, smaller and cheaper components has caused PPC hardware systems to become gradually obsolete. In Laguna Verde, PPC system hardware has not been the exception, and the consequences of failure, aging and obsolescence have become evident. In particular, the rate of failure in DAQ modules has increased in the last years.

When considering a PPC System replacement, it was important to determine whether a complete or modular replacement of its elements was the best option. A gradual migration approach was chosen for several reasons:

- While hardware components will eventually wear out, fall apart, burn up or simply stand in the way, PPC software applications remain of significant value to reactor operators.
- A gradual migration approach offers a flexible, potentially lower cost and lower risk solution than total replacement, which is generally associated with cost overruns and outage extensions.
- Some legacy hardware components remain in use in both reactors (units) and are still operational. A gradual replacement avoids elevated initial expenses.

A gradual, modular migration strategy for critical plant computer systems is based on planned replacements of the most critical technology pieces driven by need and budget considerations.

The core of a phased migration strategy depends on a flexible modular system that supports data from multiple data sources, with the capacity to consolidate the information for presentation in control room displays and in the power plant historical archive. To satisfy this requirement, a New Data Acquisition System (NDAS) based on RTP DAQ modules has been developed. This system features a real-time mechanism and a selected data stream transfer, based on external variables coming from other sources which internally are adapted and embedded as part of the legacy system, thus keeping its human machine interface (HMI) and calculations basis design unaltered. This has been used to integrate the NDAS with legacy real-time and historical applications, such as the Safety Parameter Display System (SPDS), Balance Of Plant (BOP), 3D Monicore, Point Log and Alarm (PLA) and Transient Recording and Analysis (TRA).

This paper presents an overview of the legacy system software and hardware architecture and describes the migration criteria and guidelines, the New Data Acquisition System (NDAS), the real-time mechanism based on external variables for real-time applications as well as the historical data integration for transient recording and analysis applications.

In the next section, the Laguna Verde PCC Systems are described, in order to provide an overview of the GEPAC-Plus legacy system.

II. Laguna Verde PPC System

The Laguna Verde PPC System is a complex, redundant system engineered by General Electric Nuclear Energy (GENE) in the early 1980s [1]. The system is installed in each of the two Laguna Verde reactor units.

A. LV PPC architecture

The system resides in two host computers which are connected to more than 3500 plant instruments and devices through Analogic Data Acquisition System (DAS) components. Identical hardware allows each host to receive and process the same data, providing a redundant view of plant processes.

DEC VAX host computers running the VMS operating system are used for the GEPAC-Plus system. The system processes, validates and computes around 3000 additional points, which are recorded to a disk historical archive. Host computers transmit selected data to sixteen workstations with a HMI, which presents critical information to reactor operators with color graphic displays in order to assist them during normal or transient operation.

The host computer also performs any requested analyses of real-time or historical data and sends the results over the network to the requesting workstation or terminal. The main PPC functions are the Safety Parameter Display System (SPDS), Balance of Plant (BOP), Point Log an Alarm (PLA), Transient Recording and Analysis (TRA), Rod Worth Minimizer (RWM) and 3D Monicore to evaluate core and fuel performance.

B. Analogic DAQ hardware

The DAQ modules provide real-time data collection, but no data recording or storage. The DAS is composed of 4800 and 5500 Analogic modules.

Fig. 1 presents a typical DAS configuration. The modules are based on either the Analogic 4800 or 5500 series equipment. The 4800 module consists of analog, digital, and multiplexer modules in a brick-style form. This series also provides a Class 1E isolation for safety related plant instrumentation [2].

The Analogic 5500 series equipment is a 19" rack mountable unit which operates a variety of input and outputs via 16 channels of input cards. It is a non-safety related input device.

The 4850 module is a Data Formatter which collects data from input modules and multiplexers. The Formatter is programmable, and selectively formats data for direct memory access (DMA) transfer to the host computer. Each Formatter is capable of processing approximately 150,000 samples per second, which makes the system excellent for recording plant transients at very high speed sample rates.

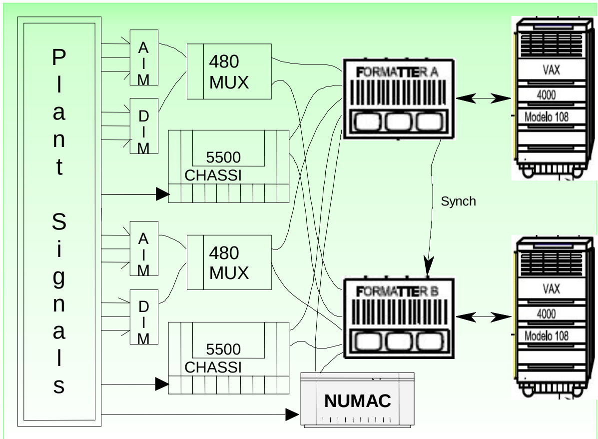

Fig. 1 Analogic DAQ hardware configuration

The Formatters also interface with GENE's NUMAC Rod Worth Minimizer (RWM), NUMAC AutoTip (ATIP), Power Range Neutron Monitoring (PRNM), Leak Detection Monitor (LDM), Startup Range Neutron Monitor (SRNM), Log Count Rate Monitor (LCRM) and Log Radiation Monitor (LRM).

III. Gradual Migration Strategy

A gradual, modular migration strategy for critical plant computer systems is based on planned replacements of the most critical technology pieces driven by need and budget considerations [3].

Failure, aging and obsolescence in Analogic DAQ modules were the main triggers in the search for a solution. Due to the fact that Analogic DAQ modules are not off-the-shelf equipment which could allow a one-by-one replacement approach, a new data acquisition system was developed together with some mechanisms that could allow the integration of an open system into a proprietary one.

The strategy for the integration between the New Data Acquisition (NDAS) and the GEPAC-Plus legacy system, as well as the development of the NDAS, took into consideration the following migration criteria and guidelines.

Availability. It is important to keep the power plant operating with a 99% availability rate as required by nuclear regulatory guides.

Budget considerations. In this regard, the identified factors include: Reducing maintenance cost and periodicity, minimizing outage time and cost overruns and maintaining the present investment by maximizing the usage of still operable legacy hardware modules.

Long-term compatibility and operation. The system must be able to operate long-term. In consequence, support for software and hardware spare parts must be guaranteed for at least the following 20 years. In addition, computer capacity must be improved by taking advantage of new technology. Flexibility for various DAS types is required in order to support future operation scenarios.

Feasibility. In order to have a proper reference and to adequately support the migration strategy, an assessment study was conducted. With this study, stakeholders were able to verify the feasibility of the project. In addition, experience gained in similar projects could help in that sense [4].

Backward compatibility. It is important to preserve safety levels in order to minimize regulatory impact. By designing the NDAS to be compatible with the GEPAC-Plus legacy system, reactor operators will be able to continue using the system without any additional training.

Special attention was devoted to migration issues; the main one identified was related with mixing open versus proprietary systems, such as data integrity and synchronization, as well as historical data retention.

The criteria and guidelines presented in this section were taken as part of the requirements during the development of the NDAS and its integration to the GEPAC-Plus legacy system. The main results of this strategy are presented in the following sections.

IV. New Data Acquisition System

As mentioned in the former sections, a New Data Acquisition System was developed in order to integrate the GEPAC-Plus legacy system with the data coming from the new RTP DAQ hardware.

The NDAS is based on RTP DAQ modules (including 1E-class certified modules). It was developed in C++ for PC servers under Linux, which is a well-supported customizable open-source operating system that provides a low failure rate.

The NDAS is flexible and can adapt to different operation scenarios and it supports the incorporation of new modules over time. The NDAS was designed not only to allow DAQ modules replacement, but to constitute a reliable and robust data acquisition system that will keep evolving and will be able to adapt to different operational circumstances [5,6]. The NDAS key features are described in the following sections.

A. Acquisition Subsystems

The NDAS features support for multiple data sources, giving the system great flexibility and the power to adapt to each customer's requirements. At present, the NDAS is able to acquire around 8000 signals with sample rates that range from 1Hz to 1000Hz from several DAQ modules, including 22 RTP 2300 modules. Fig. 2 shows the RTP acquisition subsystem.

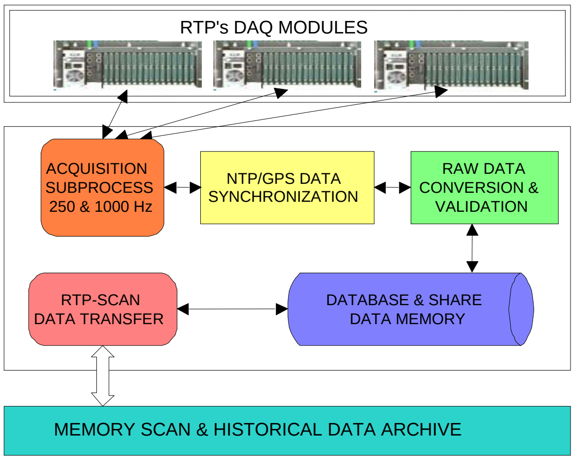

Fig. 2 RTP Acquisition Subsystem

Additionally, the NDAS features a fiber-optic USB communication module (MCUF) which provides NUMAC data to Plant Process Computer (PPC) applications for the GE NUMAC data interface, eliminating outdated Analogic formatter equipment.

The NUMAC interface to the PPC is designed to provide data flow to and from NUMAC systems to support 3D Monicore, plant startup testing and transient monitoring.

The MCUF is an electronic device designed and developed by the Electrical Research Institute of Mexico [7] (patent pending) which also allows bidirectional communication from PPC to NUMAC PRNM, RWM and ATIP devices through NUMAC Server. The MCUF translates NUMAC proprietary protocol data streams into ones that can be accessed by PC computers using a USB port.

The data storage system in the MCUF is based on one memory chip that is logically divided into two different memories that can be accessed by four different clients. One of these memories is used to store previously decoded information set by NUMAC, and then this information can be read via USB on a request basis. The other memory stores data sent via USB by the NUMAC Server; this data is read and encoded in order to be sent to NUMAC [8].

The NUMAC Server was developed in C++ Visual Studio for PC server under Windows XP. Fig. 3 shows the NUMAC interface data flow stream. Periodic real time data are sent from all NUMAC devices to PPC legacy system using external variables through NUMAC server and NDAS.

In addition and upon user request, bidirectional communication is used to send (download) and request (upload) information to and from the NUMAC System. The message transfers use a handshaking protocol.

In Fig. 3 it is observed that bidirectional communication is performed directly between the legacy system and NUMAC devices, via the NUMAC Server. Also, PRNM communication to the legacy system is provided by two Rod Block Monitor (RBM) instruments.

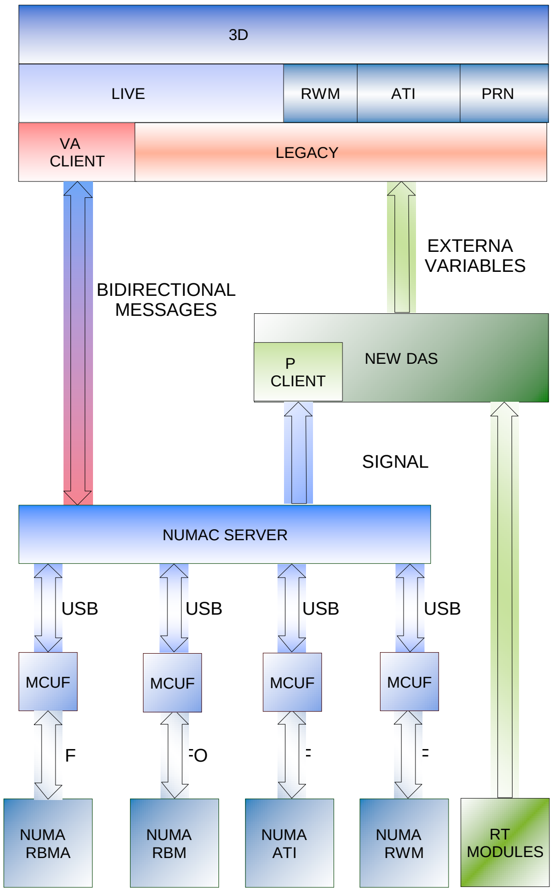

Fig. 3 NUMAC interface data flow stream

This configuration retains the same NUMAC services actions and reports, minimizing user retraining.

B. Advanced historical data archives

Application migration provides opportunity for functional improvements. In that sense, the NDAS provides a reliable and customizable historical archive. The system supports the Scan data archive, which records every signal at the acquired frequency rate for 12 hours or more.

The Scan archive is the Master Historical Archive of the NDAS because it is accessed by several processes to read data. With that in mind, the SCAN Master Historical Archive resides in a shared memory area since it is the fastest method of inter-process communication [9].

One of the reasons high-speed historical data access is crucial for the NDAS is that it is necessary for creating alternative historical archives. In addition to the shared memory SCAN archive, the NDAS supports other types of historical archives that are stored on disc and feature different compression methods and structure. The master SCAN archive serves as the source of data for the processes that create these alternative archives. It is important to note that the NDAS supports several historical archives at the same time and hence the importance of fast and reliable inter-process communication.

The process that generates the Master SCAN Archive is referred to as the Scan Process. The Scan Process is synchronized with the Central Acquisition Process and thus with the Acquisition Subsystems to seamlessly integrate all data in one single shared-memory archive, just as if all samples came from one single data source.

Fig. 4 is a simplified block-diagram that shows the overall synchronization relationship between the Acquisition Subsystems, the Central Acquisition Process, the Scan Process and the related shared memory areas.

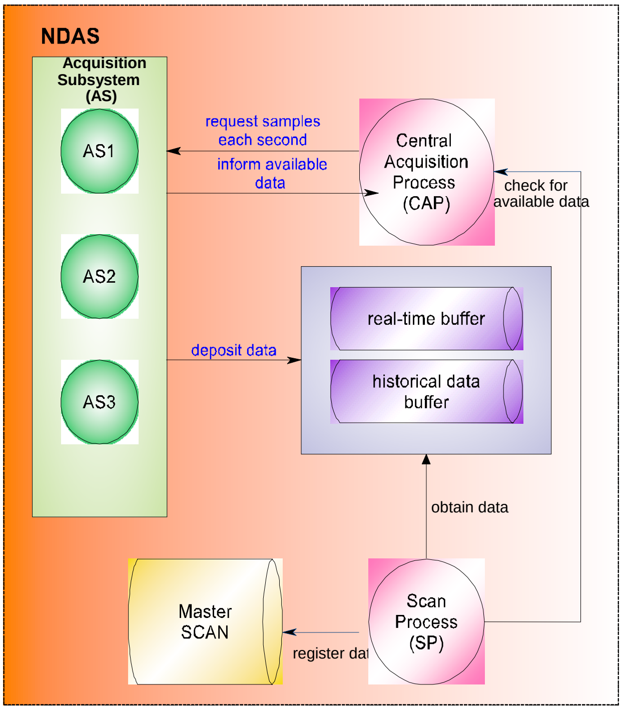

Fig. 4 The Scan data archive generation process

The above figure shows how the Central Acquisition Process requests data each second to each Acquisition Subsystem, which in turn inform whether they have available data. If they do, after all Acquisition Subsystems finish depositing data, the Scan Process records the information in the Master Scan Archive.

The NDAS also provides support for other types of historical archives such as Delta (stores significative changes), Average (stores averages at 1Hz) and FFT (stores high-frequency averages suitable for frequency analysis).

Fig. 5 shows the integration between different elements in the NDAS for alternate historical archives generation.

The Central Acquisition Process and the Master SCAN processes are considered central processes since they are the main data processing programs within the NDAS architecture. Through these two processes, acquired data are organized and made available for the rest of the NDAS processes.

Memory management is another important part of alternative historical archive generation. Because the NDAS is a soft real-time system, the adequate use of buffers in crucial. Both the Central Acquisition Process and Scan processes use internal buffers so they can adapt to different operation scenarios.

To generate alternate historical archives, other processes take data from the Master SCAN shared memory area, process the information and store it on disk.

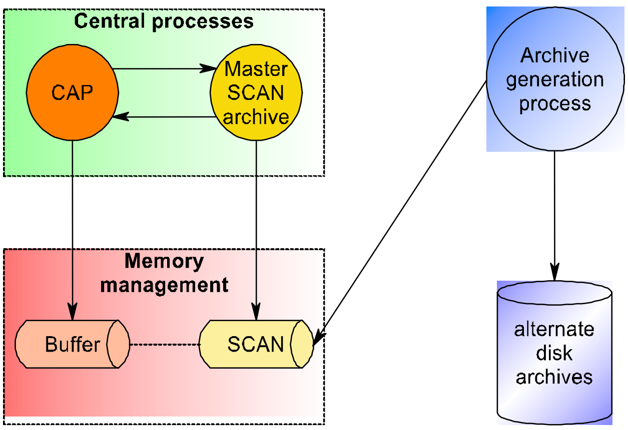

Fig. 5 Alternate historical archive generation

One of the advantages of the NDAS regarding historical archive management is that there can be several active historical archives at the same time. By default, the system automatically writes to disc a 12-hour version of the memory-residing Master SCAN archive. However, operators can launch multiple customized archives as well. In this type of customized archives, operators can choose which signals to include in the archive, the sampling rate for each signal and the archive duration.

V. Key integration elements

Having described both the NDAS and the GEPAC-Plus legacy system, the next section describes key integration elements and how those were implemented according to the Laguna Verde migration strategy.

It is very important to mention that the GEPAC-Plus legacy system, complies with a good modular design which allows us to identify the key software elements to modify in order to integrate the new data acquisition system while keeping the design basis and the same application functionality. Moreover, experience gained at integrating the PPC system in the Laguna Verde Simulator as a stimulated system [10], confirmed this approach.

Fig. 4 LVPPC integrated into the LV Simulator

The main difference in this case is the fact that NDAS must work together with the former system. In addition, the Simulator acting as a data provider is limited to a low-speed data transfer, with a 1Hz resolution for each variable.

In order to minimize regulatory impact, the integration was focused in one of the main regulatory functions: the Safety Parameter Display System (SPDS). SPDS gives control room operators the information they need during plant emergencies. Specialists at U.S. nuclear power plants developed safety parameter display systems after the 1979 nuclear accident at Three Mile Island, which underscored the need for information to be better displayed in control rooms [11]. SPDS collects and displays critical safety information at a workstation in the control room and other locations in the plant. Information on the status of key conditions, such as reactor core coolant, is displayed in a clear format on a computer screen.

Data integrity, redundancy, synchronization and data scheduling are key elements in order to accomplish the SPDS objectives. In order to achieve the former, the system is structured as follows:

Each sensor connected to a DAS input module is represented by a unique point definition which specifies the input module the sensor is connected to, what type of data is supplied by the sensor (analog, digital, control rod drive position, integrated or pulse), how the data is to be converted, and what delta change is to be used for the sensor by the formatter delta check programs. These points are called “measured points”.

In addition, composed points are combinations of measured points, constants and other composed points. A composed point is defined by a composition instruction list with point identification, constants and operators which follow reverse polish notation logic. Some operator instructions use information associated with hardware information such as sensor precision.

Along with each point value, measured or composed, a point status is also defined or calculated. This is known as “the point quality status” which marks one of the main characteristics of nuclear power computer programs. The point status is contained in two 32-bit status words, whose bits have meanings related with acquisition and processing calculations. A point collection database contains groups of points which are processed (recalculated or updated in their values and statuses) at regular intervals, and for which a certain number of past values are to be kept.

To gradually introduce data from the NDAS, structure, data integrity, scheduling and synchronization must be respected. Next sections describe these considerations in detail.

A. Data Structure

In order properly classify signals regarding the migration process a new classification of signals was introduced: internal and external variables. All measured signals belonging to Analogic modules are known as internal variables and other signals coming from other sources are known as external variables. In order to maintain the same data structure, a single flag was introduced to distinguish between internal and external variables, so that computing information is maintained if necessary.

A real-time mechanism was designed to introduce external variables data accordingly with process collection information. As shown in Fig. 5, once a second, all external data are collected from the NDAS server using client-server TCP/IP protocol where only selected data are updated or processed. In case of a communication error, data are treated as a module failure.

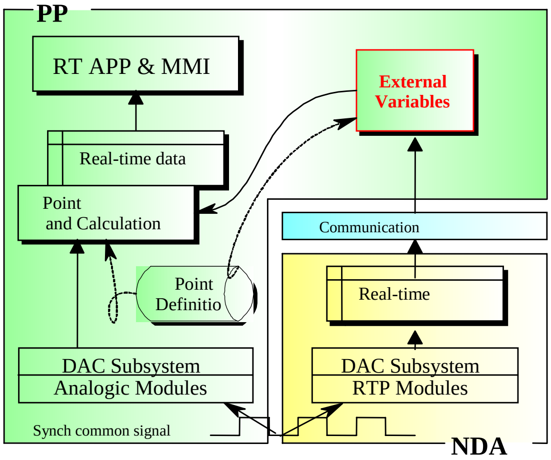

Fig. 5 Real-time data transfer

Along with each external variable, a byte point status related to the acquisition is included. An algorithm has been adapted to translate the byte point acquisition status to the two 32-bit status words. Further processing is treated as an internal variable.

During the real-time mechanism design, we found that floating-point numbers of the NSAD and ICS systems are mismatched. This is because the NSAD uses IEEE-754 format (Table Ia) and the SIIP uses VAX/VMS format (Table Ib). Hence, we developed algorithms to convert from IEEE-754 format to VAX/VMS format and vice versa.

Table Ia IEEE-754 floating-point number representation

	Sign	Exponent	Mantissa
bits	31	30..23	22..0

Table Ib VAX/VMS floating-point number representation

	Mantissa 2nd Part	Sign	Exponent	Mantissa 1st Part
bits	31..16	15	14..7	6..0

B. Historical Data

An important part of the integration between the legacy GEPAC-Plus system and the NDAS are historical data. Historical data must remain available to operators at all times in order to obtain reliable information on the plant state at different time intervals. The communication mechanism [12] uses point-to-point TCP/IP over Ethernet. The PPC is the connection client and the NDAS is the server. Both nodes exchange messages by using socket functions.

The new design relocates and renames two legacy functions: scaninit to scaninitVAX and scan to scanVAX. Furthermore, four additional functions were developed in

FORTRAN, language used by the legacy system, and a data administrator in C programming language to provide the PPC with historical data from the NDAS. Fig. 6 shows the new design.

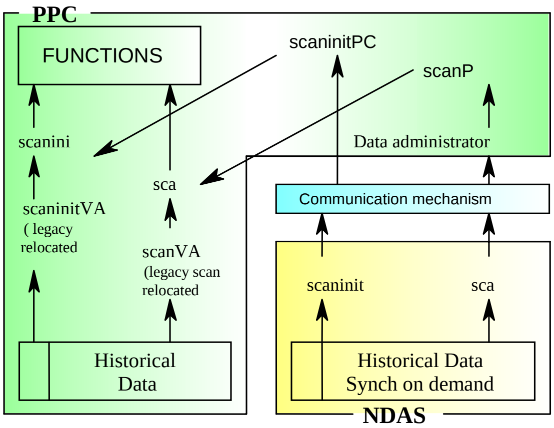

Fig. 6 Historical Data new design

All functions continue handling the same parameters used in the original functions. Scaninit processes external and internal variables separately. In addition, scaninit keeps pointers to the positions where each variable was last accessed by the PPC function. Finally, Scaninit calls the scaninitVAX and/or scaninitPC functions as shown in Fig. 7.

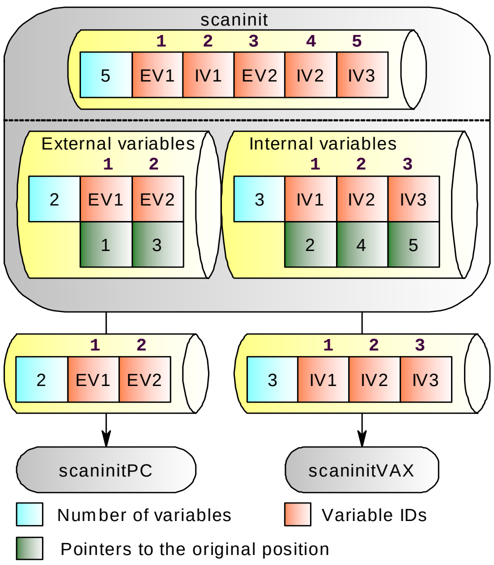

Fig. 7 Variables selection

Summarizing, the historical data flow from NDAS to PPC is merged into the PPC local historical data archive. ScaninitVAX performs the validation of internal variables. ScaninitPC opens communication with the NDAS and performs the necessary validations on external variables. ScanVAX supplies local historical data and scanPC supplies historical data from the NDAS through the communication mechanism shown in Fig. 6.

C. Data Synchronization

For the legacy DAS system, data synchronization is exclusively managed by one master Formatter. Initially Formatter time is provided by the VAX clock and updated hourly. This feature allows all Analogic data to be stamped at the same instant. In the case of the NDAS system, data are synchronized based on a Network Time Protocol (NTP) Global Positioning System (GPS) server.

Real-time data is processed once a second as soon as it is acquired, so that it is automatically synchronized. However, historical data used for transient and sequence of events analysis must be available at a one millisecond frequency for digital data and four millisecond frequency for analog data. Regarding data synchronization, the main challenge was to solve the problem caused by the different time stamp mechanisms used between new and legacy DAS systems.

In order to solve the problem, a common digital signal changing once a minute was introduced in both systems and recorded at a 1 millisecond precision, as shown in Fig. 5. A program in the NDAS validates, verifies and records the digital synchronization signal in a file, both times when it changes [13]. With this information, any historical time stamp is referenced using an interpolation method.

D. Data Monitoring Functions

Another key integration element that helped significantly during the integration of the two systems was the development of auxiliary functions for data monitoring [14,15] at different points in the data flow, as well as auxiliary functions for memory monitoring and a debug mechanism for batch processing. Fig. 8 shows the main data monitoring points in the data flow.

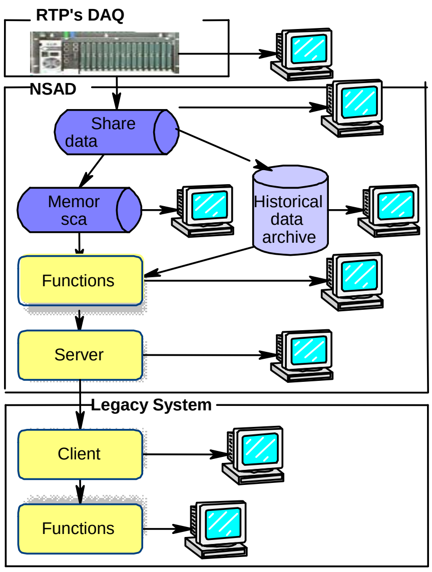

Fig. 8 Data monitoring points in the data flow

With these functions, data loss and errors were identified quickly and concisely, in addition to helping narrow significantly the area of conflict. This allowed finding fast and concise solutions thus saving time and resources.

VI. Final LV PPC hybrid system

Fig. 9 shows the resultant Laguna Verde PPC hybrid data acquisition system architecture. The system acquires data from both Analogic and RTP modules and integrates it into a final user application. Also, it has been adapted to receive periodic data from NUMAC devices and communicate with the legacy system through a message protocol in order to assist the reactor engineer in 3DM applications.

This hybrid configuration allows a gradual replacement platform for obsolete components while reducing maintenance costs and improving system reliability.

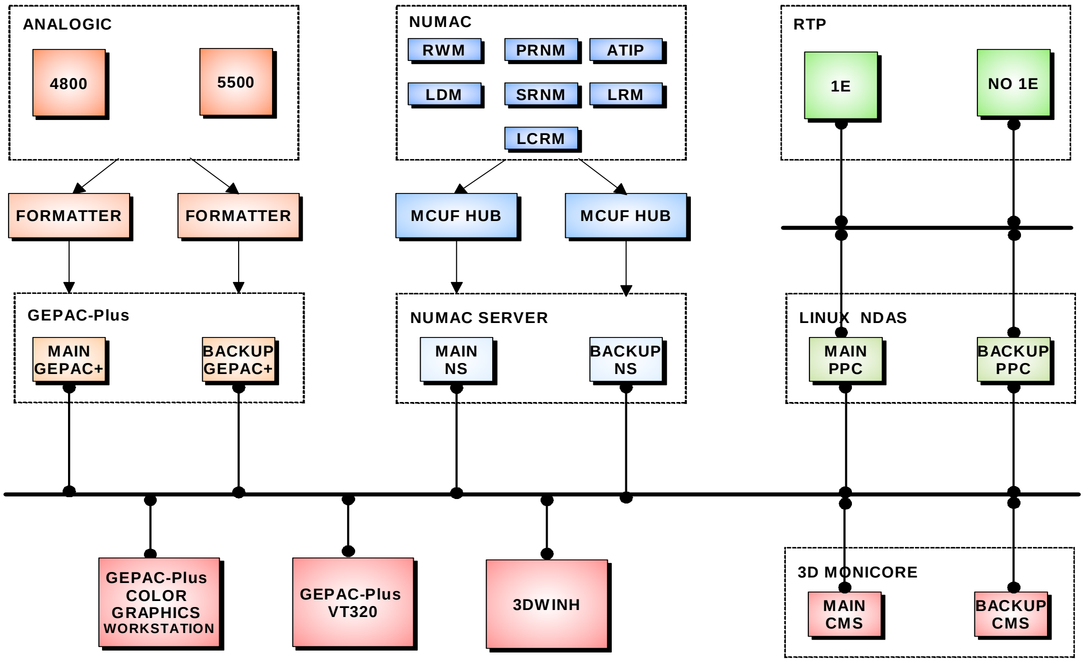

Fig. 9 Laguna Verde PPC hybrid DAC system

VII. Conclusion

A gradual integration of a new data acquisition system to the PPC of the Laguna Verde Nuclear Power Plant has been applied following a planned strategy, driven by migration criteria and guidelines.

The gradual migration strategy allowed the power plant to continue operating with more than 99% availability rate as required by nuclear regulatory guides.

The phased migration approach is flexible; avoiding cost overruns and outage extensions. Present investment has been maintained by maximizing the usage of still operable legacy hardware modules.

For long-term compatibility and operation, a New Data Acquisition System (NDAS) was designed. The NDAS is based on RTP DAQ modules (including 1E-class certified modules). It was developed in C++ for PC servers under Linux, which is a well-supported customizable open-source operating system that provides a low failure rate. Support for software and hardware spare parts is guaranteed for at least the following 20 years and maintenance cost and periodicity has been reduced. Computer capacity has been improved by taking advantage of new technology. Flexibility for various DAS types is supported and the system can adapt to different operation scenarios as well as to the incorporation of new modules over time.

Experience gained at integrating the PPC into the simulator helped verify the feasibility of the integration of an open system into a proprietary system. This allowed a successful project completion in time and cost.

Finally, the original design basis for human machine interfaces and computations has been maintained, in order to minimize regulatory impact. By designing the NDAS to be compatible with the GEPAC-Plus legacy system, reactor operators will be able to continue using the system without any additional training.

At present, the NDAS is running and smoothly integrated to the Laguna Verde PPC legacy system in the Nuclear Power

Plant in Veracruz, Mexico. The system has been online for more than two years, supporting both Analogic and RTP DAQ modules.

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He was involved in two technical projects in General Electric Nuclear Energy (1990) and S3 Technologies (1994), participating in the design of an HMI for the Integrated Computer System for Nuclear Power Plants and in the First Of A Kind Engineering (FOAKE) project of the Department Of Energy (DOE) at USA, developing the HMI prototype system for ABWR Nuclear Reactors.

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