NPP I&C Architecture Design and Its Traffic Load Analysis

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Abstracts - An integrated I&C architecture for nuclear power plants is designed by the systems and devices being developed in a project. Its design reference is the APR1400 that was design certified in Korea. Digital equipment and several kinds of data communication networks (DCN) are used. To confirm the validity of DCN based architecture design, the traffic loads for each network were calculated assuming the anticipated maximum traffic condition. The analysis showed that the utilizations of all networks satisfied the design requirements.

Key Words : Data Communication Network, Nuclear Power Plant, I&C Architecture, Network Load Analysis

1. Introduction

A project, Korea Nuclear Instrumentation and Control System (KNICS), has been underway for three years to develop instrumentation and control (I&C) equipments to apply to the nuclear power plants (NPP)[1]. The KNICS is developed in accordance with the design requirement of APR1400 that was design certified by the Korean regulatory body several years ago. A few requirements are modified to incorporate the advances in I&C technology. In the project we designed an integrated I&C system architecture with the developed equipments - PLC (Programmable Logic Controller) and DCS (Distributed Control System). The PLC is developed as a class-1E equipment to use in the safety systems and now embedded in the plant protection system cabinet. The DCS, non-class 1E equipment, is developed as a platform to the non-safety control and monitoring systems. With these equipments the control and protection system cabinets are designed.

In the architecture DCN's are widely used to interface the digital I&C systems. Those are consisted of information networks, protection networks, control networks and others. Therefore the network traffic load is calculated to evaluate the validity of a DCN based system. It is known that this analysis is a method to measure the performance. The analysis refers the commercial technologies on topology, protocol and transmission architecture for each DCN [2, 3].

2. Design Principles

The architecture design should use, as base platforms, the domestic I&C equipment - PLC and DCS, being developed through the project[4]. The third-party equipments are used to specific stand-alone systems considering the economic cost. The architecture should be designed referring the I&C design requirements of APR1400 and be allowed some modifications of design requirements to improve the maintainability and operability of system. For the design of DCN, the concept of diversity and segmentation by the use of different network and the physical distribution should be adopted. These can make the DCN maintain the deterministic and real time processing features. As well we considered the fault tolerant design to minimize the effects of single failure of equipment or system.

3. I&C Architecture

The integrated I&C system is hierarchically structured with 3 layers, and each system on the layer is modularized. The top layer is composed of control rooms, information processing computer systems and display systems. The middle layer is assigned to control systems and protection systems, and the bottom layer is assigned to measuring and monitoring systems. The DCN is used to connect and interface the systems not only on the same layer but also between the layers. The use of hard-wired is minimized to interfacing of sensor and actuator. Each system can have its own internal networks. Figure 1 shows the KNICS architecture. The main features of KNICS are follows;

- Use of digital technology and data communication
- Human-centered control room design
- Improvement of operability
- Security of the safety through design verification and validation (V&V)
- Improvement of reliability by the diverse equipments

- Enhancement of maintainability by the modularization and standardization
- Reduction of the design period through the prior design certification of equipment.

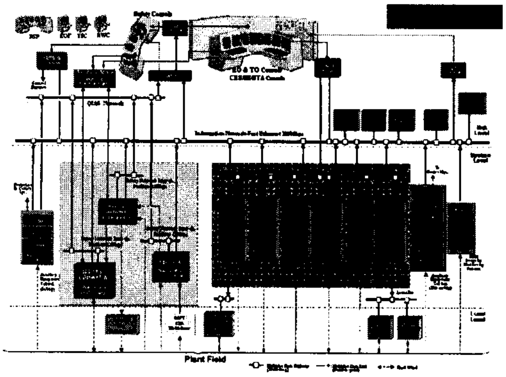

Figure 1. KNICS Architecture

4. Network Traffic Load Analysis

The KNICS DCN, consisting of several types of communication networks, is designed to support the maximum data traffic under all plant operating conditions, and its performance is confirmed by the traffic load analysis. The analysis is performed referring the commercial technologies on topology, protocol and transmission architecture for each network. In addition the design requirements applicable to the nuclear power plant are considered[5]. In this analysis, the serial communication and hardwired are excluded.

1) Classification and functions

The DCN for inter-system consists of as follows;

(1) IPN : provides the interfaces between IPS with displays in the main control room (MCR) and other I&C systems such as protection, control and monitoring systems

(2) QIAN : provides interfaces between qualified indication and alarm system (QIAS) and safety-related systems including the displays for indication and alarm.

(3) CN : provides interfaces among all control systems and between control systems and information systems.

(4) PAIN, PBIN, PCIN, PDIN : provide interfaces among protection systems and between protection systems and information systems including operator modules and soft-controllers.

2) Transmission architecture

The basic transmission architecture of DCN is shown as table 1.

Table 1) Basic Transmission Architecture of DCN

	Type	Access Method	Topology	Frame Format
IPN	100Mbps Fast Ethernet	CSMA/CD	Bus	Overhead : 26Bytes Length: 46-1500 Bytes
QIAN, PAIN, PBIN, PCIN, PDIN	Profibus-FMS	Token Passing	Physical :Bus Logical :Ring	Overhead : 9 Bytes Length: 1-246 Bytes
CN	Token -Ethernet	Token Passing	Ring	Overhead : 33Bytes Length (Min): 72 Bytes

3) Performance

The bases for the performance calculation are

(1) The data analysis margin of 20% is assumed except for CN (40%), the maximum propagation delay is 5 μsec (1 km), the overhead for application layer is 40 bytes (based on TCP/IP) except for Profibus-FMS (50% of lower layer), the expansion capability is 30%. The transmission cycle are 100 msec for protection network (PAIN~PDIN) and CN and 500 msec for IPN and QIAN.

(2) The evaluation factors for performance analysis are the transmission delay time and the utilization. The evaluation criteria for the performance of each network considering the transmission delay time and the network type are

[IPN] :

- transmission delay time < 500 msec
- network utilization < 20%.

[QIAN] :

- transmission delay time < 500 msec
- network utilization < 40%.

[PAIN/PBIN/PCIN/PDIN, CN] :

- transmission delay time < 100 msec
- network utilization < 40%.

(3) The factors considered and the procedures for the performance calculation of each network are

[IPN] :

- calculation of raw data load for each link
- addition of analysis margin of 20% and TCP/IP overhead of 40 bytes
- fragmentation of data frame exceeding 1500 bytes
- addition of pad in data frame less than 46 bytes
- addition of 26 bytes for overhead in data frame
- addition of 96 bits for inter-frame gap
- calculation of transmission time for each link
- calculation of total transmission delay time
- calculation of transmission capability considering expansion of 30% and transmission cycle time of 500 msec.
- calculation of network utilization

[QIAN, PAIN/PBIN/PCIN/PDIN] :

- calculation of raw data load for each link
- addition of analysis margin of 20%
- fragmentation of data frame exceeding 256 bytes
- addition of pad in data frame less than 1 bytes

- addition of 9 bytes for overhead in data frame
- calculation of transmission delay time for each frame(frame size*bit time)
- addition of 96 bits time for dead time
- addition of propagation delay time (1km=5μsec)
- addition of 33 bits time for token synch. time
- addition of 3 bits time for token examination
- addition of 24 bits time for frame examination
- addition of propagation delay for token and link
- calculation of FDL transmission delay time
- addition of FMS overhead of 50%
- calculation of total transmission capability (bps)
- addition of expansion of 30%
- calculation of utilization

[CN] :

- calculation of raw data load for each link
- addition of analysis margin of 40%
- addition of 33 bytes for overhead in data frame
- fragmentation of data frame exceeding 72 bytes
- calculation of transmission delay time for each frame
- addition of 96 bits time for dead time
- addition of 29 μsec for data frame generation
- transmission delay time for token(72 bytes)
- addition of 4 μsec for recognition time of token frame
- addition of 5 μsec for token generation
- addition of 5 msec for optic transceiver delay
- addition of propagation delay time (1km=5 μsec)
- addition of TCP/IP overhead (40 bytes)
- addition of expansion of 30%
- calculation of network utilization considering transmission cycle time (100 msec).

4) Results

As shown in table 2, the traffic load analysis for KNICS DCN shows that all of the networks designed in architecture satisfy the performance requirements.

Table 2) Results of the traffic load analysis for KNICS

	IPN	QIAN	CN	PAIN (PBIN)	PCIN (PDIN)
Total Node #	85	25	35	8	6
Total Link #	102	24	252	10	9
Total Raw Data Point Number	305,819	24,924	11,951	2,436	906
Total Raw Data Size (bits)	4,148,553	132,340	40,508	14,320	8,620
Transmission Delay Time (msec)	55.83	22.88	15.19	8.76	6.12
Network Utilization	13.40%	5.95%	19.75%	11.40%	7.96%

5. Conclusion

We designed an integrated I&C architecture with home-made digital equipments and confirmed the validity of architecture through traffic load analysis. Therefore, the integrated I&C architecture developed will be applicable to the next NPP and the upgrading of operating plants. In addition, the design will ensure the international competitiveness in the point of view of cost and technology.

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References

[1] D. H. Kim, et al, The Concept of KNICS, Korea Electrical Engineering Society, 2003.

[2] Normative Parts of Profibus-FMS, -DP, -PA according to the European Standard, EN 50 170, Volume 2

[3] Local Area Network Performance, Gilbert Held

[4] C. K. Lee, et al, Developing Equipments of KNICS, KINS Safety Workshop, 2002.

[5] C. K. Lee, et al, Traffic Load Analysis of DCN for KNICS, KNS Conference, 2004.