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REPLACEMENT OF THE CONTROL & INSTRUMENTATION SYSTEM WITH THE MICROPROCESSOR BASED SYSTEM IN JAPANESE PWR PLANTS

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Abstract

In Ohi Units 3 and 4, Ikata Unit 3, and Genkai Units 3 and 4, the latest of PWR plants now under operation in Japan, the reactor control system and turbine control system employ the microprocessor base digital control systems with a view to improving reliability, operability and maintainability. In the next stage plants, another application of such digital system is also planned for the instrumentation rack for the reactor protection system for further improvement. On the other hand, in Mihama Unit 1, the first of domestic PWR plants, and later plants except for the latest 5 plants, analog control systems are employed for the instrumentation racks. For the analog control systems of these plants, FOXBORO H-Line instruments, equivalent domestic box type instruments or WH7300 Series card type instruments were initially employed, and later replaced with domestic card type control systems after 10–15 year operation. However, 8–12 years have passed since these replacements, so the 15th year generally quoted as an interval for replacing C&I systems is near at hand. This is the time to consider next replacement. This replacement will be based on the latest digital technology. However, it is not practical way for the existing plants to apply the same integrated digital C&I system configuration for the next stage plants, because it requires the drastic change of the C&I system configuration and significant cost-up. Therefore, we must investigate the optimum digital C&I system configuration for the existing system.

1. Introduction

As domestic PWR plants, 23 plants are currently under operation from the first Mihama Unit 1 starting in 1970, till the latest Genkai Unit 4 starting in 1996. In 18 plants excluding the latest 5 units, analog control systems are employed for the C&I systems.

Concerning the hardware for their C&I systems, domestic card type systems were initially applied to Takahama Unit 3 and later plants. Replacement also took place respectively at previous plants after 10–15 year operation. Currently, 18 plants have domestic card type analog control systems.

However, early models of such domestic card type analog control systems have already been used for 13 years. The interval of 15 years commonly quoted for standard replacement is near at hand, therefore, any problem including failure due to secular deterioration or suspension of parts production could come to surface. The spare space available in the current systems is very scarce because instruments have been added in the course of system improvements made to date, and still more, no space for the additional instrument racks is available too. Also considering the following needs by the customers, now is the time for system replacement.

- Further improvement of reliability
- Reduction of maintenance/repair costs
- Reduction of periodical inspection processes
- Maintaining spare space for the future improvement and modification

These needs for improvement should be reflected in the replacement method, and the general movement in the world from analog to digital technology should also be taken into account, and then, the operational experience of the digital control systems used in the reactor control and turbine control system at the latest 5 plants should be considered. Naturally, such considerations will end in digital systems. Our evaluation includes the following particulars in replacement work:

- As in the next stage plant, the reactor protection system is included in the replacement.

- In the existing plants, the reactor protection system and turbine control system are realized by analog and relay (partially solid state method), and systems are distributed. Therefore, it is not practical to replace all of the systems at once. For the time being, only the analog systems to be improved urgently should be replaced. This means it is difficult to directly apply the digital control system integrating the analog and relay system now under consideration for the next term plant.

- In the future, other systems including the main control board will possibly be replaced with the same method as used in the next stage plant. Therefore, it is necessary to provide a system configuration of compatible interface with such method.

Considering the above arguments, this paper will show the situations concerning the replacement to digital system, which is now under evaluation by considering the current status of C&I systems in Japanese PWR plants and their needs for improvement.

2. Current Status of C&I Systems in Domestic PWR Plants

2.1 Current Status of Domestic PWR Plants

23 PWR plants are classified into the following 4 generations according to their ages:

- 1st Generation (1970–1979)
  Mihama Units 1, 2 and 3 (Kansai Electric Power Co., Ltd.)
  Takahama Units 1 and 2 (Kansai Electric Power Co., Ltd.)
  Ohi Units 1 and 2 (Kansai Electric Power Co., Ltd.)
  Ikata Units 1 and 2 (Shikoku Electric Power Co., Ltd.)
  Genkai Units 1 and 2 (Kyushu Electric Power Co., Ltd.)

- 2nd Generation (1980 –1989)
  Takahama Units 3 and 4 (Kansai Electric Power Co., Ltd.)
  Tsuruga Unit 2 (Japan Atomic Power Co.)
  Sendai Units 1 and 2 (Kyushu Electric Power Co., Ltd.)
  Tomari Units 1 and 2 (Hokkaido Electric Power Co., Inc.)

- 3rd Generation (1990–1997)
  Ohi Units 3 and 4 (Kansai Electric Power Co., Ltd.)
  Ikata Unit 3 (Shikoku Electric Power Co., Ltd.)
  Genkai Units 3 and 4 (Kyushu Electric Power Co., Ltd.)

- 4th Generation (Future)
  Tsuruga Units 3 and 4 (Japan Atomic Power Co.: planned)

For the C&I system in each generation, the technology then common was employed, the details of which will be shown in Fig. 1.

(1) 1st Generation
The reactor control & protection system and turbine control system are both configured in the analog and relay logic.

(2) 2nd Generation
The reactor control & protection system and turbine control system are both configured in the analog and relay logic. In some plants, however, the reactor protection system employs the solid state logic, and auxiliary system employs the digital control technology.

(3) 3rd Generation
As the digital control technology is developed, the reactor control system and turbine control system employ the digital control system in order to improve reliability, operability and maintainability, while the reactor protection system employs the analog and solid state logic.

(4) 4th Generation
For further improvement, digital systems are applied to the reactor protection system. In addition, concerning the operations on the main control board, conventional hard switches are replaced with the touch operation by CRT. This realizes the integrated digital C&I system.

2.2 Experience of Replacing C&I Systems in Japan

(1) In all the plants of the 1st generation and some plants of the 2nd generation, FOXBORO H-Line instruments, equivalent domestic box type instruments or WH7300 Series card type instruments were introduced for analog protection and control system. Due to the problems including increased product failure and product supply, the domestic card type analog control system replaced the older models having 10–15 years of operation records. 10 years have already passed since earlier replacement. Some plants not replaced since start of operation operate original systems for 13 years.

(2) In order to improve the availability of the Feed water control system, some plants began to employ the digital control system having fault diagnosis function for the backup of the analog control system since 1990.

Fig. 2 shows the actual replacements carried out domestically on the instrumentation racks of the reactor control & protection systems.

Fig.1 Digital application to operating PWRs in JAPAN

	1-st Generation		2-nd Generation		3-rd Generation		APWR
	Mihama-1	Takahama-1	Ikata-1	Ohi-1	Tsuruga-2	Ohi-3 / Genkai-3	Tsuruga-3
Man Machine Interface	Bench Board Hard S/W operation monitor by indicator	Bench Board Hard S/W operation monitor by indicator	Bench Board Hard S/W operation monitor by indicator	Bench Board Hard S/W operation monitor by indicator	Main: Console Aux.: Bench Board Hard S/W operation monitor by indicator	Main: Console Aux.: Bench Board Hard S/W operation monitor by CRT	Console + Large Display Panel CRT touch operation & monitoring
Reactor Protection	Analog & Relay logic (3 ch. & 2 train)	Analog & Relay logic (3 ch. & 2 train)	Analog & Relay logic (3 ch. & 2 train)	Analog & Relay logic (3 ch. & 2 train)	Analog, Solid-state trip logic & Relay ESF logic (3 ch. & 2 train)	Analog & Solid-state logic (4ch, 4train trip & 2train ESF logic)	All Digital (4ch, 4train trip & 2train ESF logic)
Reactor Control	Analog circuit Relay sequence (Simplex) Digital backup for Feedwater control installed at 1995	Analog circuit Relay sequence (Simplex) Digital backup for Feedwater control installed at 1994	Analog circuit Relay sequence (Simplex) Digital backup for Feedwater control installed at 1990	Analog circuit Relay sequence (Simplex) Digital backup for Feedwater control installed at 1994	Analog circuit Relay sequence (Simplex)	All Digital control & sequence (Duplex)	All Digital control & sequence (Duplex)
Turbine Control	Analog circuit Relay sequence (Simplex)	Analog circuit Relay sequence (Simplex) EH replaced by Digital at 1993	Analog circuit Relay sequence (Simplex) Control sys. replaced by Digital at 1991	Analog circuit Relay sequence (Simplex) EH replaced by Digital at 1994	Analog circuit Relay sequence (Simplex)	All Digital control & sequence except Turbine protection (Duplex)	All Digital control & sequence (Duplex)
Auxiliary System	Local analog control & relay sequence Digital replacement planned at 1996	Local analog control & relay sequence Digital replacement planned at 1996	Local analog control & relay sequence Digital replacement planned at 1997	Local analog control & relay sequence	All Digital control & sequence (Duplex)	All Digital control & sequence (Duplex)	All Digital control & sequence (Duplex)

Fig.2 Summary of C&I rack replacement

■ Sufficient Experiences

No.	Plant	Year	Notes
1	Mihama #1 (Kansai)	1995	
2	Mihama #2 (Kansai)	1994	
3	Mihama #3 (Kansai)	1992/1993	92: Protection, 93: Control
4	Takahama #1 (Kansai)	1988	
5	Takahama #2 (Kansai)	1987	
6	Ohi #1 (Kansai)	1988	
7	Ohi #2 (Kansai)	1987	
8	Ikata #1 (Shikoku)	1989/1990	89: Protection, 90: Control
9	Ikata #2 (Shikoku)	1996/1997	96: Protection, 97: Control
10	Genkai #1 (Kyushu)	1990/1991	90: Protection, 91: Control
11	Genkai #2 (Kyushu)	1994/1995	94: Protection, 95: Control

In case of No.6 and 7, WH7300 series were replaced to Japanese card racks. In case of all other cases, BOX type racks were replaced to Japanese card racks.

3. Needs for Improvement of Current Systems and Replacement to Digital Control Systems

In the domestic PWR plants, as shown in Fig. 3, operation records are stable. This is not only due to higher reliability of the system itself but also, more essentially, to the more substantiated maintenance of system by the users.

- By the more strict system check, defects are detected swiftly, and corrective actions are taken.
- Systems are updated according to the plan drawn by considering operation records.
- Improvements taken for non-conformance occurred are also reflected in other plants.

This plant maintenance should be continues from now on. However, improvements are requested for improvement of reliability according to longer fuel cycles, short annual inspection outage, reduction of the maintenance cost and improvement of operability. The needs for system improvement as described above are presented for the analog instrumentation systems currently used in the reactor protection & control system directly related to the plant availability, and in the turbine control system. In realizing these needs, the current analog technology is not enough, and therefore, replacement is planned by assuming some digital control system to be applied.

3.1 Improvement of System Reliability

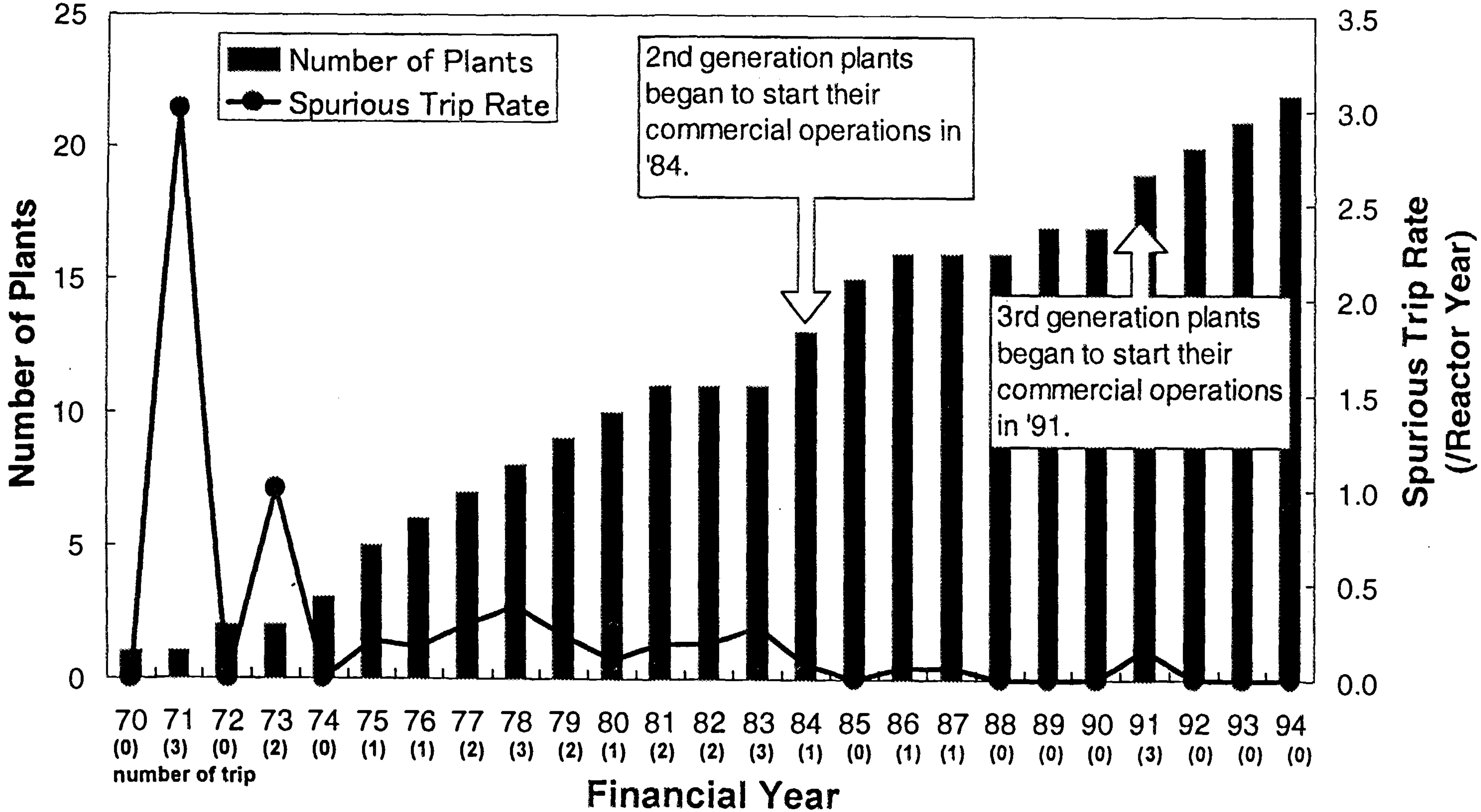
For the analog instrumentation system for the reactor protection & control system and turbine control system, the following two types are currently used. With no plant failure trip as directly caused by the failed system occurring so far, these types boast of a stable operation.

- Mitsubishi Electric Corporation MELNAC Series
  Applied in 10 domestic plants including Takahama Units 1/2 and others.

- Yokogawa Electric Corporation System 1100 Series
  Applied in 13 domestic plants including Mihama Units 1/2 and others.

The parts failed so far in the above-mentioned systems are mainly the mechanical components such as relay, switch, variable resistance and connector. The number of these mechanical components failures are expected to increase as time goes by and as they are used more frequently. Very few semiconductors are detected failed so far, and future occurrence of semiconductor failure is not known. However, these have been used for more than 10 years, and the replacement interval commonly quoted for electrical measurement systems is 10–15 years. This suggests some possibility of a rapid increase of faults. From the above arguments, operations of longer fuel cycles now planned should be considered, and systems should be updated as a preventive maintenance even before entering the period of wearing failure. In implementing the digital technology, a self diagnosis technology should be introduced along with the digital control system, while at the same time, such systems should have redundant architecture.

Fig.3 History of Japanese PWR trip rate caused by C&I failure & related human error



3.2 Reduction of Periodical Inspection/Reduction of Maintenance Cost

(1) Reduction of Maintenance Items and workload

Currently, the analog instrumentation system is checked for the following items in each annual inspection:

- Calibration test of all cards (static test)
- Dynamic test of PID, LEAD/LAG cards
- Confirmation test of bistable set points
- Check of A/M station
- Others; check of power unit, etc.

Since these checks are carried out with all the component cards of the plant's control protection system, the time and workload required for those checks dominates a fairly large portion of the checks done on the C&I systems in each annual inspection. In a short annual inspection of 40 through 49 days, such portion may be critical in the annual inspection processes, and should also be improved to reduce maintenance cost.

By digitalizing the control system, it is possible to confirm its integrity by a self-diagnosis function which is unique to digital systems. Therefore, it is also possible to reduce the following checking scope/checking items substantially.

- Calibration test of all cards (static test)
  The control block that used to be realized by analog cards conventionally will be configured by software. ROM/RAM storing these software are continuously checked by its self diagnosis. They need no additional checks. Analog input unit that is left as hardware can be calibrated on-line by intelligent I/O cards. This does not need additional checks, either. This means only the analog output card should be calibrated in the static test of cards.

- Dynamic test
  No checks are required, because the self diagnosis of the ROM/RAM storing software continuously carries out such checks.

- Confirmation test of vise table settings
  Same as above.

If the number of current check processes is specified as 100%, the method described above will reduce it down to about 35%. This means a reduction of 65%.

(3) Actions to Take for Product Availability

The card type analog instruments now under operation have been used for about 15 years since first installation, and some of the parts used in it are no longer produced. The card type analog instrumentation rack consists of about 40 types of cards in realizing a control protection function at a plant. However, about 50% of the cards experienced the problems of parts availability.

To deal with the parts which are no longer produced, the manufacturer of the instrumentation rack is requested to switch them to the second sources, or keep them in stock so that steady supply may be maintained. However, in consideration of the tendency found in the industrial world in general by which digital technologies take place of the conventional analog technologies, product availability is feared to deteriorate. This means it is difficult to provide solution by such minor modifications as have been done so far.

Circuit patterns or circuits themselves will have to be changed. Then, new cards will have to be made, and development verification test will contribute to increase costs incurred by the cards.

To reduce the costs of plant maintenance/repair, it is necessary to supply products stable. In this regard, too, analog control systems must be replaced with digital control systems.

3.3 Improvement of Operability

Not only to establish a stable controllability throughout the plant power level, which is robust to external disturbance, but also to configure a plant gentle to human being, further improvements and automation will have to be made.

- Automation of plant's heating/cooling operations
- Automation of low-power operations (automatic control rod control system at 15% power or lower)
- Automation of turbine startup operations
- Others

In adding these automatic logic, the following things must be reflected as the features of digital technology (It is difficult to provide analog system because it requires a huge scale system.):

- Complicated operations can be processed with higher accuracy.
- A number of operations can be processed by one unit.
- Functions can be changed or expanded easily, because it is done in the software.

3.4 Maintaining Space for Expansion

In some plants of long operations, the space for installing digital instrumentation system may be scarce, because improvement works have been repeated so far. In such a case, cables may be deployed with no room for expansion, hindering the system improvement work planned for maintaining/improving the plant. To deal with these problems, the following things must be reflected as the features of digital technology to provide solutions for system's expandability.

4. Basic Designing Policy for Digital C&I System

To realize the needs for system improvement, the latest digital technologies must be applied.

Since it is not practical to provide the same system configuration as in the latest plant because a large scale of addition and modification will be necessary, only the improvement needs related to the analog instrumentation system in the existing plant should be dealt with by digitalizing the system. The designing in such a case should be carried out in a way that good interface can be maintained even if totally digitalizing C&I system involving the main control board in the future.

4.1 Safety/Reliability

The protection system for the next stage plants has the 4-channel configuration of 2-out-of-4 output to enhance plant safety and availability. In the existing plants, however, 1 channel must be added to the detector to meet the above requirements. And the nuclear reactor trip breaker rack is configured in 2-train of 1-out-of-2 output. If these things are to be improved, huge impact will be brought to the plant systems, leading to increased costs. Therefore, the current 2-out-of-3 output configuration should be maintained.

By taking advantage of the digitized system, and by substantiating the self diagnosis function, a failure diagnosis rate of 99% or more is maintained.

To maintain the functional diversity of the reactor protection system, the reactor trip parameters requiring such diversity are processed by independent microcomputer, while from the view point of defense-in-depth, the reactor trip functions and the ESF actuation functions are processed by independent computer.

4.2 Operability

The interface with the main control board or other systems should be via hard wired. The current hard-wired interface should be maintained. However, in consideration of other systems to be digitalized in the future, the system should be configured in a way that interface can be maintained easily by multiplex transmission. The interface with the plant computer should be made by the multiplex transmission through the unit bus. As far as the control system (non-safety) is concerned, the system configuration by considering multiplex transmission should be based on such system configuration as has operating experience at the latest plants. Safety system should be configured by considering separation and independence.

(1) Information Transmission for Safety System (Equipment operation, status signals and PAM)
The signal transmission line of safety system should have a multiplex information transmission line independent of the non-safety systems. This information transmission line should consist of the 2-train configuration maintaining mutual independence.

(2) Information Transmission of Non-safety Systems
The transmission to the non-safety systems should be made by installing the information transmission line to the unit bus. The connection to the unit bus in the non-safety systems should be electrically separated by optical fiber, while at the same time, the data should be transmitted one way from the safety system side to the unit bus, so that no failure in the unit bus side should affect the functions of the safety system.

And if the control system rack is to be replaced, the new system should be able to deal with the expansion of automation and the improvement of controllability.

4.3 Maintainability/Testability

By substantiating the self diagnosis function, any failure of the system should be identified in the level of card or module, and the results of such diagnosis should be able to be displayed on the rack.

System should be configured, if possible, with cards or modules so that any failed parts can be replaced easily.

The maintenance of the software should be facilitated by the maintenance tools so that it may be tested/calibrated easily.

The instrumentation rack for the safety system should have a built-in automatic tester, and the integrity check required during operation should be basically automated .

4.4 Economy

The interface between systems should be established by photo-multiplex transmission, so that the interface with other system in the future can be configured by multiplex transmission. Consequently, such system should be able to deal with the problems encountered in finding the routes for cable deployment at the existing plants.

5. System Configuration

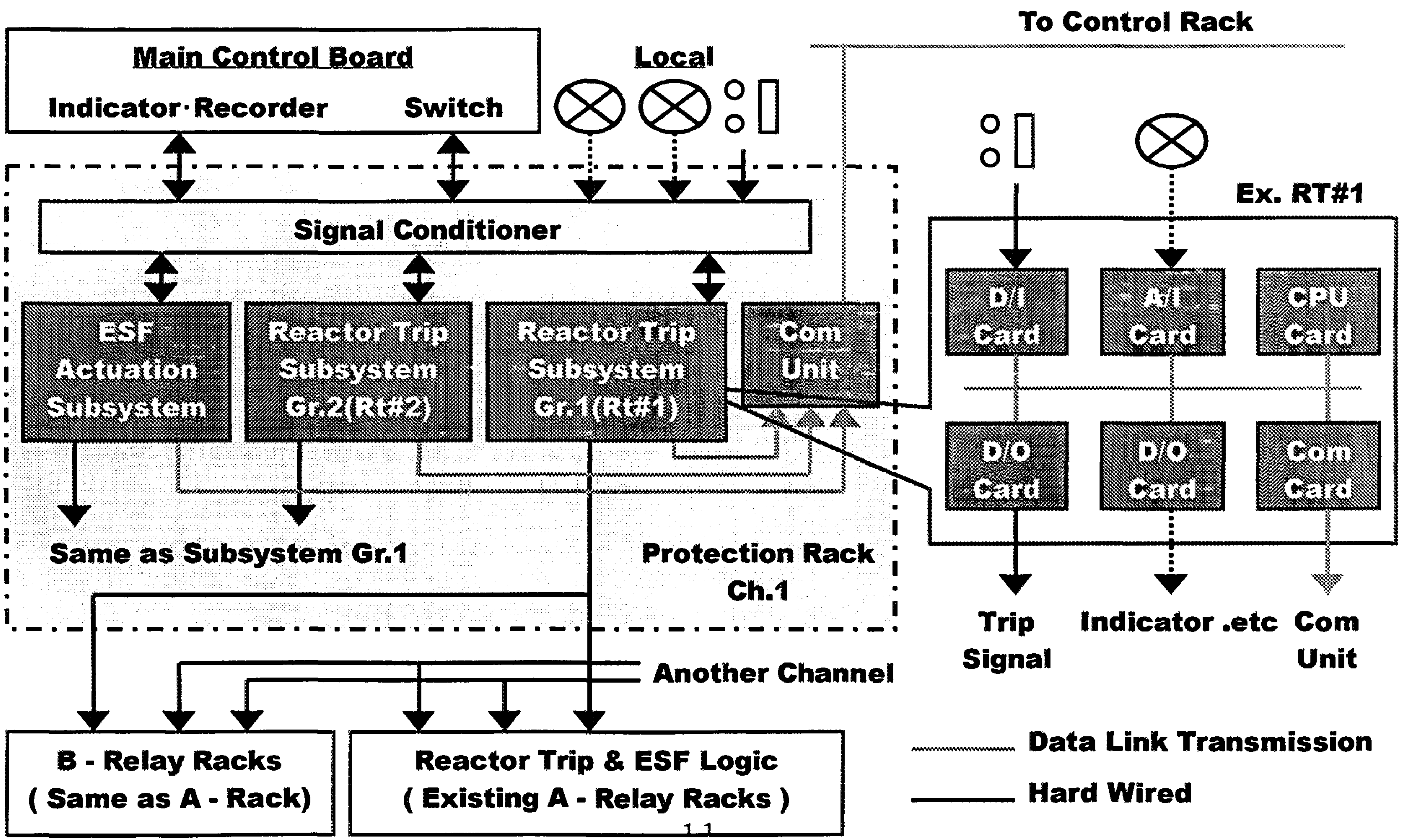
Fig. 4 shows the configuration of the digital system now under consideration for use as the protection system. Such system will be realized by applying partially the digital reactor protection system which has already been qualified in the development and verification tests for the next stage plant.

(1) The protective functions are distributed functionally into 3 CPU groups (RT #1, RT #2, ESF), and the card constituting each CPU group should be the one that has already been implemented in the control system rack at the latest plants with good operating experience.

(2) The interface with other systems including the main control board should be made by the hard wired connection through the signal conditioner card. If other systems are digitalized in such configuration, the signal conditioner card may be removed, and the multiplex transmission should be applied.

(3) The interface with the control system rack to be replaced with digital control system at the same time and with the plant computers already digitalized should be changed from the conventional hard-wired interface to multiplex transmission, so that the cable quantity may be reduced, and the expandability (flexibility for modification) of information interface may be maintained.

Fig.4 System construction of digital reactor protection rack



5. Conclusion

Some Japanese analog card racks in 2nd generation plants have already been used since 10 to 15 years and will come into the general replacement intervals of the C&I system.

Concerning next replacement, digital technology is necessary in order to improve the existing plant capability.

We start the study of the best procedure for digital replacement of the C&I systems. At the final stage of this replacing procedure, all C&I system will be replaced with the digital system. As the result of our rough study, the reactor control and protection racks must be replaced first.