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CONTROL AND DATA PROCESSING SYSTEMS IN UK NUCLEAR POWER PLANT AND NUCLEAR FACILITIES

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Abstract

This note identifies some of the data processing and control systems in UK nuclear power plant, with emphasis on direct digital control systems and sequence control. A brief indication is also given of some of the associated research activities on control systems and software.

The plant in the UK use an extensive array of control systems; some functions are still performed manually e.g. power control at Calder Hall, others are supervised by quite complex analogue controllers. The latest Advanced Gas cooled Reactors, AGR, make extensive use of direct digital control, while the Sizewell B PWR has one of the most advanced control rooms and control systems in the world.

The first reactors at Calder Hall and Chapelcross were relatively simple plants. Although they used a number of open and closed loop controllers, the reactor power and thus the coolant gas outlet temperature was under manual control. The gas temperature was measured and, on the basis of the value, the operator moved the bank of four control rods to trim the power and maintain the temperature at the desired value. Automatic power control was introduced on the Chapelcross reactors in the early 70's in order to reduce the number of operating staff. The system was a fail-safe dynamic system implemented using Diode Transistor Logic. This system is now approaching the end of life. It is proposed to replace the equipment with a modern digital controller. The same upgrade exercise is to be performed at Calder Hall which still retains the original manual control. The plant have been subject to a number of other upgrades the most obvious of which is the appearance of Cathode Ray Tube, CRT, displays in the main control room. These appeared when a computerized data collection and display system was introduced for the plant activity monitors.

As the series of Magnox reactors were developed so the sophistication of the control, data collection and data display systems increased. One aspect that appeared was the use of direct digital control and CRT displays. These aspects were slow to be introduced however a major step forward came with the AGR reactors. This was due in part to the effective use made of the Ferranti ARGOS computer hardware. Initially the systems were installed on an individual basis with early use of the computers for alarm recording, alarm handling and display. This was followed by direct digital control of the heating and ventilation plant. When Hartlepool and Heysham I were completed, the whole of the start up sequence of the plant was performed under direct digital control. This trend was continued in the design and construction of the latest AGR's at Torness in Scotland and Heysham II in England.

The control systems at Torness and Heysham II contain over 1000 control variables and cover four main reactor plant areas. These are as follows:

- Control of core power generation by motion of the gray absorber rods assigned for automatic control.
- Control of the coolant gas flow rate by regulation of the speed/guide vane position on the gas circulators.
- Control of the feedwater flow. This is performed on a total flow and an individual boiler basis. The latter is to correct for asymmetries in the coolant gas temperature distribution.

- Control of the turbine speed via regulation of the steam pressure and flow.

There are a number of other control systems on the plant e.g. sequence control for the refuelling machine, control of feedwater temperature, start up and load sequencing for emergency power supplies, heating and ventilation system control.

There are a number of options for control of the AGR as base load units. The core heat generation rate is under closed-loop control which is achieved by dividing the core into a number of zones, each associated with a control rod. The heat generation control parameter is the coolant gas temperature measured at the exit of the fuel channels in the zone. There are two further key control loops. The first control loop is for heat removal from the core and steam production. The second control loop is for steam pressure and turbine control. The steam production can be controlled by either forcing the flow rate of the coolant gas or forcing the flow rate of the feedwater. In either case, the other parameter is under closed loop control.

There is more difficulty with the second control loop as it is very sensitive as the once through steam generators contain little effective inertia. There are two effective strategies. First the setpoint of the turbine speed governor can be controlled control the steam pressure. The unit load is then determined by forcing the rate of steam generation as load variations from the governor are eliminated. The second option is to determine the steam pressure by controlling the feedwater pressure. The unit load is then determined by the setpoint of the speed governor.

The difficult of controlling the turbine boiler loop posses a major problem for the control system and for maintaining the plant in the event of a control system or a plant failure. The direct digital control systems have allowed the latest AGR's to survive major transient including rod drop, loss of feedwater flow that normally result in loss of generation and plant trip.

The development of the control systems by the two companies, Nuclear Electric and Scottish Nuclear, that operates the latest AGRs differ significantly, although both had identified the problems associated with generating and interpreting the specifications. Nuclear Electric, formerly the Central Electricity Generating Board have long used a specially developed language CUTLASS for the development of control systems. In contrast, the systems for Torness were developed using close control of the Quality Assurance and software development arrangements with an implementation in the CORAL language.

It is interesting to comment on the operational performance of the automated control systems it is understood that it had at times been the practice of the operators to try to outperform the automatic systems by anticipating transients. The plant performance has been found to have improved since this practice stopped.

The data display systems have been developed with the evolution of the technology and kept pace with the control systems. The design of the systems has required careful planning to ensure that the response time of the system is sufficient. This has led to the need to look carefully at processor load and distribution of functions around the processors and displays. The production of the displays and agreement of the displays with the plant operators form an important part of the system development and system acceptance. Considerable care is required with the human factors and logic of the layout of the displays.

The older plants have been backfitted with digital control systems and more are being introduced. The turbine control of the Hinkley Point AGR is to be replaced with a digital system to improve plant performance. While the improvement is expected to be small it is still sufficient to make the investment worthwhile.

The direct digital control systems at Hartlepool and Heysham I have been improved with a digital controller installed for power raising. The controller raises the power to 30% handling grid connection and synchronization before control is passed to the direct digital control system. This system is now used on a regular basis to take the reactors to power.

The most significant digital backfit on an AGR is probably the installation of a computer based protection system on the Dungeness B plant. The single channel trip system enables plant output to be increased from just over 400 to over 600 MWe per unit. Part of the upgrade was the installation of a computer based monitor of the equipment performance that could also be used to monitor the thermocouple signals and to capture all the thermocouple data in the event of a plant trip.

The monitor system running under DOS operating system was supplemented by a dedicated thermocouple health monitor that was used to investigate thermocouple performance. The success of this system in investigating plant behaviour has resulted in a new health monitor being installed. The new monitor runs under OS/2 operating system and captures and stores all thermocouple data on dual redundant optical discs. The system can perform complex analysis functions e.g. using commercial spreadsheet and statistical packages and also output data to the station network for processing as required by the station SUN computers. Some other plants have connected the power plant data collection system to the station network to allow data to be transferred and be used as input to physics calculations for fuel performance and reactivity.

One area of digital control which was initially unsuccessfully employed was for fuel route control. There were intrinsic problems with the safety case for on load refuelling of the AGR. These arose from excessive vibration of the stringer as it was removed from placed into the channel. There were further issues associated with potential failure of the control system that could result in the refuelling machine becoming stuck on the pile cap with an assemble part inserted into the core. The problems arose in part because of concerns over the quality of the software and difficulty in substantiating the reliability claims. This experience in this case of sequence control indicates that great care must be taken in developing control systems and particularly computer based systems. It is necessary as part of the process of technology selection and system implementation to consider the needs of the operator and the regulatory requirements.

Computer based control systems have been applied extensively in other nuclear facilities in the UK, these include nuclear chemical plant and fuel and transport flask handling facilities. These application have extensive use of commercial Programmable Logic Controllers, PLC's. Although simple to program using application specific programming languages including ladder logic and employing graphical programming interfaces their deployment has not been without difficulty. The systems were implicated in a recent incident at British Nuclear Fuels, BNF, that occurred during non-active commissioning of plant. Problems were also encountered in an incident during the commissioning of PLC controlled cranes in a waste handling plant. Although neither case resulted in harm, the commissioning exercise revealed undesirable behaviour. These examples clearly show the hazards associated with the development and deployment of computer based control systems.

It is anticipated that future developments will see the introduction of more complex systems including:

- tighter digital control to improve plant performance;
- improved displays and support systems for operators including alarm handling and plant fault diagnostics;
- more extensive distribution and use of historical and on-line plant data;
- the use of plant monitoring to track sensor and instrument performance to reduce the amount of calibration and maintenance required. These developments are expected to lead to the introduction of preventive maintenance planned on the basis of the output from the monitoring systems.

Considerable activity has been undertaken on the topics of direct digital control, operator aids and human-machine interaction. Some has been through association with the Halden and Ispra laboratories, other work at simulators in the UK. The latter is possible as the UK has always provided access to plant simulators for training plant operators. This provision includes simulators for prototype reactors such as Prototype Fast Reactor, PFR, and the Steam Generating Heavy Water Reactor, SGHWR, as well as for the Magnox AGR and PWR plant.

Following difficulties with sequence control, a self-checking sequence controller was developed using digital, but not programmable technology. The system works on the basis of pattern recognition looking at the pattern of the current inputs to check them against the reference pattern expected for the demanded state. If the pattern compares correctly, then the controller can pass to the next state on demand. In the event that a change is required the new sequence of controller outputs is established and checked via the pattern recognition logic. If the match is found the commands are issued and the controller moves to the next state. Once the state is reached, an immediate check is done of all inputs to ensure that the required state has been reached. This check is again performed using pattern recognition.

Fuzzy logic control has also been investigated. One concern has been the state of some of the sensors and instrumentation particularly as they age or suffer from calibration drift between outages. The latter is becoming more of an issue as the AGR reactors move to a three year outage cycle and there is less opportunity to perform calibration checks. One of the approaches investigated was to used three value fuzzy logic to represent the state of an instrument as good, uncertain, and bad and assign a time dependent function to the probabilities. These probabilities were reasoned with control algorithm and a weighting of the certainty that the proposed action would be correct. In the case where the uncertainties were large, the possible alternative control action are identified. The confidence in the predicted action and the sensitivity to prediction of an alternative control action due to sensor and instrument state could be used to determine if and what calibration action would be necessary. The system would be appropriate for complex algorithms and would require historic data of sensor and instrument performance i.e. failure and drift if it were to be integrated into plant maintenance procedures.

It was noted during the development work that a number of the complex control algorithms could accommodate the total loss of some inputs without having a significant effect on the control algorithm. While such lack of sensitivity would be known from the control equations, it cannot easily be allowed for in a conventional control algorithm. It was proposed that it could be accommodated within a rule based or a fuzzy logic based controller.

One particular aspect of digital control when applied to safety systems i.e. class A of the IEC-1226 classification is that of software production. The major nuclear control systems have been produced using CUTLASS a bespoke language developed and supported by CEGB (now Nuclear Electric). Other application specific languages e.g. CORAL, have also been used very successfully e.g. at Torness. Should the control systems perform functions that cause the system to be placed in class A then it is expected to be much more difficult to deploy. For example it is expected that the software would have to be subject to static analysis e.g. with MALPAS, source code comparison and extensive dynamic testing.

Nuclear Electric have produced a comprehensive guide for computer based systems as an internal standard. This document was re-issued following a period of trial use within Nuclear Electric, Scottish Nuclear Limited and AEA Technology. This, along with IEC-880, remain the essential references for computer based protection and control systems in the UK although much is expected of IEC-1508 which is currently issued in draft form.

Software research in the UK has been quite extensive. Two nuclear related projects, the DARTS and the PODS experiments, have shown that much of the difficulties arise at the specification stage. These problems would appear difficult to detect and expensive to repair. The DARTS project also showed, on the basis of the four channels produced, that there was no significant difference in the ability of the different methods to identify specification problems and errors made during the development. The use of mathematically formal methods did however appear to result in the detection problems and potential problems earlier than the conventional methods.