Reactor Control Systems of Qinshan Phase III CANDU Nuclear Plant

by

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Abstract

The QCNP CANDU overall plant control system is implemented by dual redundant digital computers to automatically perform all major control, monitoring, operator information management and diagnostics functions. Multivariable digital control algorithms regulate the reactor, steam generator level/pressure, heat transport system inventory/pressure, moderator temperature, turbine load/speed and generator power output. This ensures that the plant can be maneuvered inside a safe and economic operating envelope and will remain inside the envelope under a wide range of failure modes in the control system or the plant equipment.   To ensure that the plant operators are effective as components in the overall integrated control, a comprehensive information system provides an adaptive alarm annunciation system, graphical display navigation, historical data acquisition and processing, records generation and plant wide communications.

Overall Plant Control -Summary

The normal load control system is of the reactor-follows-turbine type; that is, the turbine load is adjusted to the desired value and the reactor supplies this load by simply maintaining steam pressure. This mode of control makes the plant inherently responsive to significant grid frequency changes. A frequency drop opens the governor valves, causing a drop in steam pressure, resulting in an increase of reactor power.

Figure 1 shows the main elements of the overall plant control loop. The plant loads are:

The turbine generator, normally controlled by the unit power regulator. Under normal conditions the turbine load can also be controlled by the steam pressure control program or manually by a hand-switch in the control room.

The condenser steam discharge valves (CSDVs), normally controlled by the steam pressure control program, and can also be positioned under manual control. There is also a set of atmospheric steam discharge valves of limited capacity. These are

normally kept closed, but are available as a controllable heat sink when steam discharge to the condenser is not available.

The main control programs and their functions are:

a) Unit Power Regulator (UPR) - This is the turbine load control program, which changes turbine load as demanded by the operator and maintains generator output at the desired setpoint.

b) Boiler Pressure Controller (BPC) - The BPC program controls steam pressure to a constant setpoint by either changing the reactor power setpoint, or by adjusting the plant loads if it is not possible for the reactor to follow power demands. The SPC also controls the HTS warm-up and cool-down.

c) Reactor Regulating System (RRS) - The reactor flux control program monitors various power demands to determine the reactor neutron power setpoint, and adjusts the reactor's reactivity devices to maintain power at that setpoint.

Turbine and Relief Valve Auto/manual Control

Steam flow to the turbine, and therefore turbine power is determined by the governor valves whose opening depends on turbine load setpoint and turbine speed. The governor droop, i.e. frequency error to stroke governor valves fully, is typically 4%, but may be increased during synchronization. The turbine load setpoint can be raised or lowered at several rates. The slower rates are used for normal load maneuvers; the fast rates unload the set quickly during upset conditions such as reactor trips.

An automatic/manual selector switch determines whether the turbine control commands originate from the computer, or from the turbine control panels.

In the automatic mode, the commands can originate from one of three control programs:

a) Turbine Run-Up - runs the turbine up to speed and block loads it after synchronization.

b) Unit Power Regulator - controls the loading and unloading of the turbine in the normal mode.

The primary function of the condenser steam discharge valve (CSDV) is to bypass steam to the condenser under turbine load rejection conditions. The CSDVs are normally controlled by the steam pressure control program on the basis of steam pressure error and reactor-turbine power mismatch. They may also be positioned, on operator request, through keyboard inputs to the computers.

Condenser steam discharge valve operation may be subject to a number of constraints (low condenser vacuum, turbine exhaust spray, high steam generator level) to avoid damage to the condenser or turbine.

The valves have a stroking speed, typically one second, which is sufficient to avoid lifting the steam generator safety valves on a turbine trip from full power.

The primary function of the atmospheric steam discharge valve is to provide a controllable heat sink when discharge to the condenser is not available. They are normally controlled by the steam pressure control program on the basis of steam pressure error, but with an offset.

The operator can override computer control of the ASDVs and either open or close these valves by a manual hand-switch.

Overall Plant Control
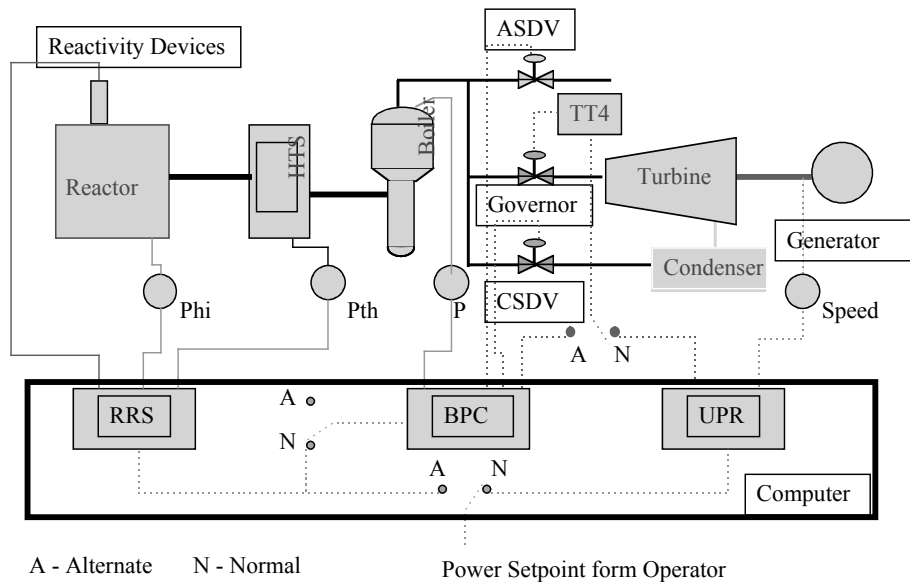
Figure 1
Overall plant Control Diagram

Reactor Power Measuring Devices

Three ion chambers mounted on the side of the reactor measure neutron flux over seven decades, 10^{-7} full power to 1.5 full power. Solid-state amplifiers convert the ion chamber current into three sets of triplicated signals for use by the control computers:

a) Log Neutron Power, 10^{-7} to 1.5 full power
b) Linear Neutron Power, 0 to 1.5 full power
c) Rate of Change of Log Power, -15% to +15% of present power per second

The log neutron power signal response time is typically a few milliseconds in the higher decades, increasing to approximately 20 seconds in the lowest decade. In the event of extremely low power levels, such as those encountered in the initial criticality of the reactor during commissioning, a separate set of startup instrumentation is used.

Twenty-eight platinum clad straight individually replaceable (SIR) in-core flux detectors measure reactor power over two decades, 10^{-2} full power to 1.5 full power, in the fourteen power zones associated with liquid zone controllers. At each location there are two detectors for redundancy. Solid-state amplifiers convert the detector current to a suitable computer input signal. The control system transforms this computer input into a signal that closely matches corresponding changes in reactor power. The platinum-clad Inconel detectors have a relatively slow rate of burn-up (loss of sensitivity due to accumulated exposure to neutron flux).

The detectors are characterized with a response approximately 90% prompt, 10% delayed, to changes in neutron flux. Thirty percent of the signal results from reactor gamma rays, one-third of which are delayed. This accounts for a major portion of the delayed signal generated by the detector. The overall response is a good representation of the power-to-fuel dynamic characteristics of a CANDU reactor.

Vanadium SIR in-core detectors measure neutron flux at 102 selected points throughout the core to determine reactor flux shape and local power levels. Amplifiers, similar to those for the platinum-clad detectors convert the vanadium detector current signals to corresponding computer input signals.

Vanadium detectors are characterized by very slow burn-up in a high neutron flux and essentially 100% neutron response, but have a relatively slow response (5.4 minute time constant).

At high power, total reactor thermal power is measured on the secondary side of the steam generators. It is based on redundant measurements of steam flow, steam pressure, feedwater flow and feedwater temperature. The measurement lags the actual reactor power to coolant by approximately twenty seconds due to transport delays and thermal time constants.

At low power, the total reactor thermal power is calculated from temperature rise measurements across the reactor. The regulating system controls total reactor flux level and flux tilt, the latter by equalizing measured power in 14 regions associated with 14 liquid zone controllers. Spatial flux control is required only at relatively high reactor power (above 20% full power) where the possibility of xenon-induced instabilities exists.

Total reactor power is determined by a combination of ion chamber signals (at low power) and platinum-clad in-core detector signals (at high power). The cross over occurs around 10% full power. Because neither measurement is absolute, the flux signals are continuously calibrated against reactor power measurements based on thermal signals.

The 14 zone power measurements are based on the platinum-clad flux detectors. Absolute measurements are less important here because the spatial control system simply equalizes measurements. However, a single flux measurement may not be entirely representative of the average power in a region of the core due to local flux disturbances caused by refuelling. Therefore, the platinum-clad detector signals are also calibrated continuously against vanadium detector measurements of average zone power.

Reactor Regulating System (RRS)

The reactor regulating system is that part of the overall plant control system that controls reactor power, and maneuvers reactor power in accordance with specified setpoints.   See Figure 2.
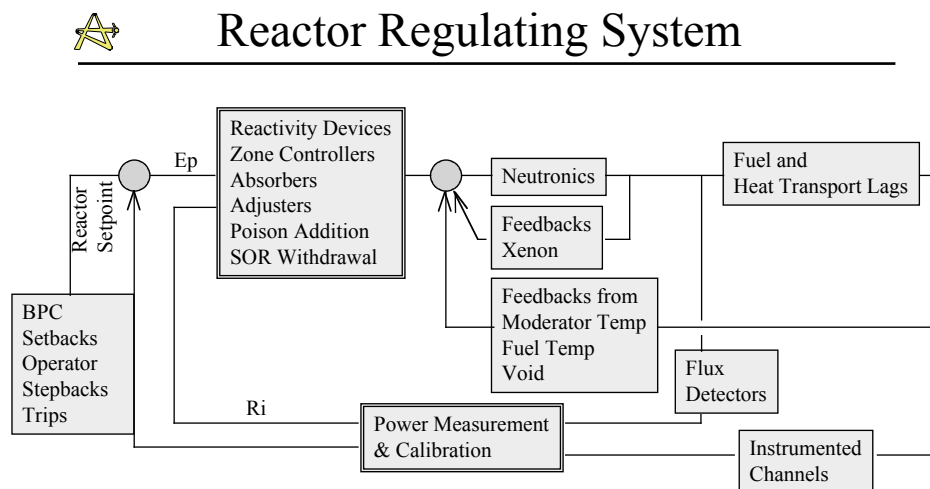
Figure 2: Reactor Regulating System Block Diagram

During normal operation, the setpoint is calculated by the steam generator pressure control system to maintain constant steam pressure in the steam generator. During serious plant upsets, RRS provides controlled or fast power reduction automatically. RRS also responds to operator manual request for reactor power reduction or shutdown.

The reactor regulating system is composed of input sensors (ion chambers, in-core flux detectors and process measurements), reactivity control devices (adjusters, light water zone controllers, mechanical control absorbers), hardware interlocks and display devices. Reactor Regulating System action is generally initiated by digital control computer (DCC) programs which process the inputs and drive the appropriate reactivity control and display devices.

Functional Requirements

a) To provide automatic control of reactor power to a setpoint at any power level between 10^{-6} FP and Full Power as specified by the operator (ALTERNATE mode) or to the power level required to maintain steam pressure in the steam generators (Normal mode).
b) To maneuver reactor power at controlled rates between any two power levels in the automatic control range (above 10^{-6} FP).
c) To insert or to remove reactivity devices at controlled rates to maintain a reactivity balance in the core. These devices compensate for variations in reactivity arising from changes in xenon concentration, fuel burnup, moderator poison concentration, or reactor power.
d) To maintain the neutron flux distribution close to its nominal design shape, so that the reactor can operate at full power without violating bundle or channel power limits.

The demand power routine computes the desired reactor power setpoint and compares it with the measured bulk power to generate a bulk power error signal that is used to operate the reactivity device.

The primary reactivity control devices are the 14 liquid zone control absorbers. The reactivities inserted by the zone control absorbers are varied in unison for bulk power control or differentially for tilt control. If the reactivity required to maintain reactor flux power at its specified setpoint exceeds the capability of the liquid zone control system, the reactor regulating system programs call on the other reactivity devices. Adjusters are removed for positive reactivity shim. Negative reactivity is provided by the mechanical control absorbers or by poison addition to the moderator. The movement of these devices is controlled by average liquid zone controller level and the effective power error.

In addition to controlling reactor power to a specified setpoint, the Reactor Regulating System performs the function of monitoring a number of important plant variables, and reducing the reactor power, when any of these variables exceed specified limits. This

power reduction may be fast (setback), or slow (setback), depending on the possible consequences of the variable lying outside its normal operating range.

The signal processing logic associated with RRS, implemented in the duplicated control computers (DCC-X and -Y), are redundant and fail-safe in the software and hardware.

Reactor Power Control Calibration

The reactor regulating system uses estimates of ion chambers and platinum-clad Inconel flux detectors to generate fast, approximate zone and bulk reactor powers. These estimates generate short-term power error signal to drive the zone controllers and stabilize the flux in the core. Over a longer time span, these signals are slowly calibrated to agree with more accurate estimates of reactor and zone powers calculated from thermal measurements and flux mapping respectively.

a)   Bulk Power Calibration

The fast, approximate estimate of reactor power is obtained by either taking the median ion chamber signal (at powers below 5% FP), or the average of 28 in-core platinum-clad Inconel detectors (above 15% FP), or a mixture of both (5 to 15% FP). These signals are filtered and calibrated by comparison with estimates of reactor power based on thermal power measurements from one of the following two sources.

−   Twelve pairs of resistance temperature detectors (RTDs) in total are located on the reactor inlet and outlet headers. The average temperature rise generates an accurate estimate of reactor power, which is used to calibrate the platinum flux detector signals below 50% FP.

−   Above 70% FP, measurements of SG steam flow, feedwater flow, and feedwater temperature are used to estimate reactor thermal power based on average SG power calculation.

−   In the intermediate power range (50 to 70% FP) a linear combination of both estimates is utilized as the calibrating signal.

Bulk calibration of platinum-clad inconel detectors is primarily to correct for the rather complicated dynamic relationship between the platinum-clad Inconel detector signal and the instantaneous fuel power. From the point of view of power generation and fuel integrity, fuel power is of most direct interest and must be closely regulated when the reactor is at or near full power.

b)   Spatial Power Calibration

Short-term spatial control is based upon fast, approximate filtered measurements of zone power obtained by taking the average of the platinum-clad Inconel flux detectors in each zone. Long-term spatial control is achieved by calibrating the fast zone power measurements with accurate estimates of zone flux power obtained by processing the vanadium flux detector signals through the flux mapping routine. In the present design, flux mapping is used to provide an accurate estimate of average zone flux in each of the fourteen zones. These estimates are available once every two minutes (flux mapping sampling interval), and lag the neutron flux by approximately five minutes (vanadium detector time constant). Spatial calibration in a zone is done by matching the average zone flux estimate generated by flux mapping with appropriately filtered zone platinum-clad Inconel flux detector readings. This calibration is relative to the average of all zone fluxes and therefore flux mapping calibration cannot affect bulk reactor power. It does, however, improve spatial control. The flux mapping routine rejects individual detectors whose readings disagree significantly with the rest of the detectors. The net result is a smoothed accurate steady state estimate of relative zone power.

Fail-Safe Operation

The reactor power measurement and calibration are made as tolerant as possible to the sudden loss of various measurements. A number of spread checks ensure that all measurements are in reasonable agreement. Measurements that fail the spread check are rejected.

For some measurement faults such as loss of two or more ion chamber log readings at low power or loss of six or more pairs of platinum detector readings at high power, there is no recourse but to fail the program in the controlling computer. Failure of the program in the controlling computer results in a transfer of control to the standby computer. If the program in the second computer detects the same measurement faults, it will fail too, causing the liquid zone control units to flood, i.e., fail safe.

The regulating program is designed to fail safe on irrational control signals (e.g. if at less than 5% FP the median ion chamber signal is irrational). During a reactor startup, the operator manually raises power to -6 decades at which point the computer automatically takes over control. Special software provisions facilitate a smooth transition between operator and automatic control.

Demand Power Routine

The demand power routine serves three functions:

a) it determines the mode of operation of the plant,

b) it calculates the reactor setpoint, and the effective power error that is used for driving the
c) reactivity control devices,
d) it automatically adds poison to the moderator if required.

The source of the reactor power request depends upon the selected operating mode.

In the Normal mode, where the reactor follows the turbine, the request comes from the steam generator pressure control program. Maneuvering rate limits are built into the demand power routine. The maximum power maneuvering rate requested is 1% FP per second above 25% FP and those below 25% FP are:

%FP	NORMAL Mode	ALTERNATE Mode
10 - 25	4% present power per second	4% present power per second
< 10	1% present power per second	4% present power per second

In the Alternate mode, where the turbine follows the reactor, the requested power is set by the operator who also selects the maneuvering rate. This mode is used on plant upsets or at low power when the steam generator pressure is insensitive to reactor power.

During reactor setback, the demand power routine receives a negative maneuvering rate from the setback routine. Should the reactor be already reducing power at a greater rate, the setback rate is ignored; otherwise the setpoint is ramped down at the setback rate. The plant will be switched to Alternate Mode when the setback clears.

The effective power error is calculated as a weighted sum of (a) the difference between the calibrated log power and reactor demanded log power setpoint and (b) the difference between the lograte and demanded maneuvering rate. If the effective power error exceeds 10% for at least two seconds and the rate of power increase is positive, the demand power routine adds gadolinium poison to the moderator at the rate of 0.75 milli-k/minute. This automatic addition of poison prevents loss of regulation due to slow growth of unforeseen reactivity excess in the core and also that resulting from a decreased reactivity load due to the decay of xenon when the plant has been shutdown for extended periods. The operator has the option of overriding this automatic poison addition.

A deviation limiter prevents the power setpoint from exceeding 1.05 times the actual power to prevent power increases at large rates.

Reactivity Control and Flux Shaping

The functions of reactivity control and flux shaping are performed by the light water zone control absorbers, the adjusters and the mechanical control absorbers.

These different kinds of reactivity control devices are provided for diversity such that failure of one set can be overcome by negative reactivity from another set.

The primary method of short term reactivity control is by varying the levels in the 14 liquid zone control absorbers. Normally, adjusters are fully inserted, mechanical control absorbers are fully withdrawn and the average zone level is between 20% and 70% full. The liquid zone control program converts the power errors into lift signals to the liquid zone control valves. The total lift signal to a given liquid zone control valve consists of a signal proportional to the effective power error plus a differential component proportional to the zone power error and zone level error at low power.

A shortage of negative reactivity is indicated by high zone controller water level and/or a large positive power error. In this case the mechanical control absorbers are driven into the core in two banks. In the case of a shortage of positive reactivity, indicated by low zone controller water level or a large negative power error, adjusters are driven out in banks according to a fixed sequence.

Adjusters and mechanical control absorbers are driven out at a speed based on power error. This reduces the shim reactivity rate at low power errors, and enables the zone controllers to offset the inserted reactivity with minimum power disturbances.

CANDU 6 Digital Control Centre

The CANDU 6 Control Centre combines the well-established operations interface and control systems, proven through 70 reactor-years of operation, with advanced features developed and proof-tested at AECL, to deliver a state of the art set of features and benefits.

The CANDU 6 control centre design is founded on proven systems, components and technology and only incorporates improvements with proven features and systems. The control centre design maintains all the elements demonstrated to be successful in operating CANDU units. Additionally, improvements have been made and performance tested as an integrated whole in AECLs mockup at Sheridan Park and in various implemented applications in operating CANDU plants (Gentilly-2, Bruce B, Bruce A, Pickering A, Pickering B). An artists' impression of the latest generation Main Control Room is included in Figure 3.

Figure 3
QCNP CANDU 6 Control Centre
Preliminary Draft

The typical CANDU 6 MCR provides a central location for the control and monitoring activities essential to the safe and reliable operation of a CANDU station. The overall unit controls are CRT based at the operator console using setpoint control through two dual redundant Digital Control Computers (DCCs), while the system and component controls are at the MCR panels. To achieve this, the control room can be thought of as a combination of digital systems and conventional process control systems supervised by human operators using computer displays, and conventional instrumentation and controls from the main control room (MCR). A significant amount of direct control of the process is achieved through computerized control with the DCC providing the operators a window into the process and the capability establish set-points for automated functions or to intervene in the control of the process as required. The use of computerized control and display permits the operation of the plant by a single operator during most normal situations. Operation from the Main Control Room is supported by a series of facilities: The Control Equipment Room, Computer Hardware Room, Shift Supervisors Area, Technical Support Centre, Emergency Response Centre, Work Control Area, Control Computer Equipment Room and Computer Office.

A secondary control area (SCA) is included in the CANDU 6 design as an alternate operational control facility. The SCA is used if the MCR becomes uninhabitable or non-functional for any reason (e.g., fire, toxic gas). Instrumentation and controls necessary for

establishing and maintaining the plant in a safe shutdown state have been provided in the SCA. This contains the controls of Shutdown System 2, Containment System and portions of the Emergency Core Cooling functions, Post Accident Monitoring (PAM) instrumentation and information as required for expected use of the SCA, Emergency Water Supply controls and Emergency Power Supply as provided by the emergency diesel generators.

Digital Systems

Overall, CANDU 6 plant control is highly automated, so that the operator's role is to provide top level commands and to monitor and supervise rather than carry out manual control. This control is augmented by fully automated safety system action which affords a long operator grace period for decision making in the event of any upsets or accidents.

The QCNP control system consists of two independent digital computer control systems DCCX and DCCY with a combined reliability of 99.99%.

The DCC computers also provide process monitoring and control through the computer interface. A separate digital computer system, the Plant Display System (PDS), drives supplementary plant process monitoring displays and performs alarm annunciation. This system is designed to support higher levels of information processing in support of operator diagnostic and decision-making tasks and improve the operators awareness of the state of the plant at all times.

Safety Systems (Reactor Protection)

Automatic control and safety system functions give the operator a period of 2 hours before safety critical response is needed for single initiating events. Even for hypothetical "dual failure" events, where an initiating event is assumed coincident with a safety system failure, a grace period of 15 minutes is built-in to design.

Plant Computer Control

The plant control computers control all major functions including the reactor, the moderator, the heat transport, and the turbine systems. Continuous direct digital control of the reactor by manipulation of reactivity control devices offer optimum reactor performance at all times. In the event of detected abnormal conditions, direct digital control of reactor power using setback and stepback power reduction algorithms avoid tripping of the system by special safety shutdown systems. This permits quick correction of process abnormalities and a return to power production. Process control programs of the DCCs perform direct digital control of steam pressure, moderator temperature, steam generator level, heat transport system, turbine speed and load and fueling machines. The major processes are all under full computer control from all states

from zero-power hot to electricity generation with operator supervisory control (setpoint entry for overall plant state). Fuel handling is carried out on-line, with a high degree of computer control. The operator's role is to direct the steps digital control steps of the fueling operation.

QCNP Plant Information Management

The CANDU 6 plant display system (PDS) employs the new Advanced Control Centre Information System (ACCIS) technology and is designed to:

> Protect against obsolescence, support continued growth and changes to the system over the life of the station, and provides the platform for the various computerized operator display applications advanced alarm system, process monitoring displays, and large overview displays.

The Computerized Annunciation Message List System (CAMLS), validated in full-scope simulators using licensed operators from CANDU stations, is a digital system that achieves a reduction in station operating costs due to the following:

> Reduces operator distraction and cognitive workload, provides support for rapid and efficient upset response, plant stabilization, problem diagnosis, and rapid recovery actions.
> Improves operator communication and reduces communication errors
> Improves interpretation of plant state and its impact on operating goals
> Provides easier detection of secondary faults
> Prevents of equipment damage
> Reduces staffing required for monitoring during upsets and emergencies

The suite of CANDU 6 process monitoring displays has been updated to include a set of higher-level overview displays in addition to the system and component level displays that currently exist. The benefits attributed to the new displays include:

> Enhanced operator plant state monitoring and situation awareness
> Reduced operator cognitive workload
> Faster and more accurate diagnoses
> Reduction in human error
> Increase in error-catching by the operational staff
> Reduced in operating and maintenance costs
> Enhance information provided for the various emergency response facilities

Large Overview displays are a significant addition to the control room and are designed to improve support for situation awareness and operating crew teamwork. The displays

provide the operator with a vehicle to display any of the PDS displays in a format that supports viewing by everyone in the control room. The displays are therefore dynamic and can be selected to maximize the benefit to the operators for the different operating situations of the plant (shutdown/outage through power productions and emergencies). In addition to the benefits of the improved display suite, the use of central large screen displays provides the following benefits:

Enhanced operator communication and reduced communication errors
Enhanced human error recovery to permit corrections before the significant consequences are realized
Reduced in unplanned outages and enhanced recovery from planned and unplanned outages

The new CANDU 6 control room incorporates an enhanced main VDU-based sit-down console. Here a single operator can monitor and control normal plant operations from shutdown to full power, without requiring operation at stand-up panels. The four VDUs and improved console design and layout provide enhance operator support for:

Safety system and critical safety parameter monitoring at the console following an upset, and
Monitoring and diagnosis of plant processes including interrogation of annunciation.

The PDS is also designed to support the storage of data on-line for 24hrs and the extraction of data to off-line media to support process surveillance and health monitoring.

Conventional Systems

The control concept provides for conventional technology to control and monitor the plant during and following design basis events. It provides redundancy and reliability to plant control when assurance of the functioning of digital equipment may be difficult or of concern. The conventional panels are also used to control and maneuver the individual systems of the plant during shutdown states and portions of warm-up and cooldown for local system alignment. This permits operators to maintain training and familiarization with the controls algorithms that are designed to be independent of each other, to be immune to single faulty inputs and to do checks on their outputs. These requirements are met by ensuring that each program reads in all the inputs it requires, then control modules are designed to be independent of each other, to be immune to single faulty inputs and to do checks on their outputs. These requirements are met by ensuring that each program reads in all the inputs it requires, the control algorithms are designed to be independent of each other, to be immune to single faulty inputs and to do checks on their outputs.

Conclusion

The QCNP overall plant control system is a combination of highly reliable, fault tolerant, multivariable computer control and automation plus a comprehensive operator information capability supporting plant operator supervision and coordination activities.

Some other benefits:

The Features:
    Improved Control Centre Layout
- Ergonomically designed consoles with improved operational support built-in (key procedures at hand, document/drawing layout space)
- Large Screen Displays - Team Oriented
  - The large overview displays are two video display units centrally located in the control room
  - Provides the operating team with information to remain up-to-date with the overall state and trend of the plant
  - Focuses operating staff attention on the areas of plant operation of most importance for the current operating goals and plant state (Situation Awareness - SA)
  - Establishes a clear link between overall state and trends of the plant and displays containing process and equipment detail (SA and Direct Task Support)
  - Provides a common frame of reference for control room staff communication and problem solving (Teamwork) that improves
    - operator communication and reduce communication errors
    - error detection through enhanced team work support
    - interpretation of plant state and its impact on current operating goals (e.g., heat sink states)
- Addition of dedicated emergency response facilities with full viewing of Plant Display System including Alarms and Alarm Interrogation
  - Technical Support Centre
  - Data links to off-site emergency coordination facility and ability to connect remote Plant Display Nodes

    Advanced Plant Display System - Proven, Off-the-shelf, Powerful
- The Technology
  - Off-the-shelf components in a modular design
  - High speed data distribution inside and outside the MCR
  - High level of Software QA
- The Functionality
  - Advanced design for computerized monitoring of plant functions related to supervisory control of systems
  - Alarms integrated into process monitoring displays
  - Advance alarm management and interrogation capabilities with access to alarm sheets
  - Plant, Safety, and Major function overview displays linked directly to lower level displays.
  - Advanced display navigation

The Benefits:

Enhanced Safety
- Improved emergency response capabilities through computerized plant safety state monitoring
- Displays and information available in the Technical Support Centre and transmitted to the off-site emergency coordination facility

Operating and Maintenance cost reduction
- Easier monitoring for technical specification/operating policy & procedure compliance
- Increased component and equipment protection from abnormal events
- Improved human performance in the areas of plant state monitoring and awareness, diagnosis and decision-making, error reduction and catching, communication, teamwork, vigilance, and workload
- Maintenance cost reduction through enhanced monitoring of processes and equipment
- Reduction in number, duration, or severity of unplanned outages
- Capability for Data transmission to technical process surveillance groups to support condition-based monitoring and other predictive maintenance systems.

Improved Operator Performance
- Enhanced operator plant state monitoring and situation awareness
- Improved awareness of the state of the plant and component health when controlling systems or components - reduced operator error, equipment protection
- Reduced operator cognitive workload
- Faster and more accurate diagnoses
- Reduction in human error and an increase in error-catching by the operational staff
- Improved display navigation - faster, more accurate display selection designed to match operational tasks
- Improved monitoring of computer systems health and performance
- Enhanced operator communication and reduced communication errors

Improved Operator Consoles
- Improved operational support and decreased Operating and Maintenance Costs
  enhanced support for Primary Upset and Emergency Response
  supports Independent Critical Safety Parameter Monitoring
  increased desktop layout space
  enhanced procedure storage and retrieval
  enhanced filing and bookshelf storage for administration, procedures, permits, etc.

Enhanced control room architecture
- based on human factors principles
- enhanced appearance/aesthetics
- improved operating staff vigilance and performance
- operational pride in the facility
- circadian rhythm control to improve operator performance in shift work applications.

Advanced alarm system: Computerized Annunciation Message List System (CAMLS)
Operationally Focused

The Features:
- Alerts operators to changes in plant conditions that may impact on safety and production
- Helps staff to effectively respond to all events and situations.
- Provides a clear and concise overview of the current problems or faults in the plant
- Provides an overview of the current state of the plant in the context of the current plant state (mode)
- Provides support for specific operational tasks:
  rapid and efficient upset response
  plant stabilization
  problem diagnosis
  recovery action planning and implementation
  rapid recovery from trip and return to power operation

- CAMLS has been validated in full-scope simulators using licensed operators at two different operating CANDU stations.

The Benefits:
- Up to 65% reduction in alarm data without the loss of relevant information
- Reduction in operator distraction
- Easier detection of secondary faults
- Prevention of equipment damage
- Support for plant upset recovery tasks
- Shorter return to power from outages or upsets
- Reduced operator workload and human error
- Improved operator diagnosis and decision-making
- Reduced staffing required for monitoring during upsets and emergencies
- Many $ saved in operating costs (estimated by several stations at >$500k per year in reduced operating costs)