SYSTEM 80+^{TM} STANDARD PLANT DESIGN MEETING LOAD FOLLOW REQUIREMENTS FOR THE FUTURE

Deva R. Chari and Paul C. Rohr
ABB Combustion Engineering Nuclear Systems
a business unit of Combustion Engineering, Inc., U.S.A.

ABSTRACT

The capability of nuclear power plants to perform a wide range of load maneuvers is very important for electrical grids with large nuclear capacities. These maneuvers are required to assist in meeting peak load generation requirements and to maintain system stability during grid disturbances. The System 80+^{TM} Standard Plant, an evolutionary advanced light water reactor designed and licensed by ABB Combustion Engineering, includes advanced design features to accommodate a wide range of load maneuvers. The plant design, rated at 1400 MWe, satisfies all of the EPRI Advanced Light Water Reactor (ALWR) Utility Requirements Document (URD) requirements on load follow, and is capable of accommodating various planned power maneuvers, frequency control operations, and load rejections.

The System 80+ plant is designed for continuous operation in the reactor following turbine mode and includes these load follow capabilities:

1. Daily and/or weekend power maneuvering at load change rates up to 5% of rated plant power per minute,
2. step load changes, which provide spinning reserve capability,
3. Automatic response to grid frequency changes satisfying peak-to-peak power changes of 10% of rated plant power at a rate of 5% of rated power per minute, and
4. Load rejections from any power level without initiating a reactor trip and opening safety valves.

The System 80+ Standard Plant includes proven design features that have evolved over many years to form an integrated design that can accommodate the aforementioned load follow capabilities. One of the key design feature is the use of 25 Part-Strength Control Element Assemblies (PSCEA), (i.e., gray rods) which provide greater flexibility in performing load maneuvering while minimizing perturbations to the core power distribution. Strategies have been developed for the System 80+ Standard Plant to accommodate the various load maneuvers. The strategies demonstrate that the integrated actions of the plant control systems and, if necessary, the plant operator, are more than sufficient to maintain proper control of the reactor core and ensure that plant operating limits are not exceeded during the performance of these load maneuvers.

The strategies developed for System 80+ satisfy the following performance objectives:

Maintaining sufficient core operating margin during load maneuvers,

Satisfying fuel design requirements and operating limits during load maneuvers,

Minimizing chemical reactivity control operations and the generation of waste water as a result of load maneuvers, and Avoiding delays in return to power following planned down power maneuvers.

1.0 INTRODUCTION

Load following is required on all electric supply systems to: 1) change the system generating output as the load varies from minimum (base load) to the daily or seasonal maximum (peak load), and (2) provide system load regulation by adjusting power output to correct for variations in grid frequency and maintain reliability during various types of electrical system disturbances. In electrical supply systems where nuclear capacity constitutes a small fraction of the total capacity, such as in the United States (U.S.), nuclear units are principally operated at or near full power for base load electricity generation. This is because nuclear units have relatively low energy generation costs, and hence are more economical units to operate at full capacity than fossil units. However, in electrical supply systems where nuclear capacity constitutes a large fraction of the total capacity, such as the Republic of Korea (ROK), load follow operations of nuclear units are essential. The System 80+ standard plant is designed to accommodate a wide range of load follow operations.

2.0 SYSTEM 80+ LOAD FOLLOW CAPABILITIES

The System 80+ Standard Plant load follow capabilities are summarized and briefly discussed below (Table 1).

Table 1 System 80+ Standard Plant Load Follow Capabilities

Requirements	***System 80+***	***EPRI Utility Requirements Document***
Ramp Changes	+/- 5% per minute	+/- 5% per minute
Step Changes	+/- 10% step change	+/- 10% step change
Daily Power Maneuvering	100-50-100 power cycle over a 24 hour period	100-50-100 power cycle over a 24 hour period
Frequency Control	10% peak to peak at 5% per minute	10% peak to peak at 2% per minute
Load Rejection	100% load rejection capability (including turbine trips)	100% load rejection capability (including turbine trips)

Ramp Load Changes: These are defined as power level changes at ramp rates up to +/- 5% of rated power per minute. This capability allows System 80+ to accommodate rapid load changes and frequency control.

Step Load Changes: These are defined as changes in turbine power of at least ± 10% of rated power. This capability allows System 80+ to participate in frequency control of the electric grid both as primary and secondary spinning reserve.

Daily Power Maneuvering: These are defined as 24 hour power cycles with slow and rapid power level changes. A slow daily power maneuvering profile starts at 100% power, ramps down to 50% power over a two hour period, power remains at 50% from 2 to 10 hours and returns to full power over a two hour period. A rapid power maneuvering profile consists of a power reduction from 100 to 50% at a rate of 2 % to 5 % of rated power per minute, power remains at 50% from 2 to 10 hours at reduced power level, and returns to full power at a rate of 2% to 5% of rated power per minute depending upon the situation.

Frequency Control: The System 80+ plant is capable of satisfying peak-to-peak power change demands of 10% of plant rating at 5% per minute. This capability is provided both while operating at steady power levels and while performing daily power maneuvering.

Load Rejections: Load rejections of any magnitude can be accommodated from any power level without a reactor trip and without opening safety valves.

3.0 SYSTEM 80+ DESIGN FEATURES

The System 80+™ Standard Plant is an advanced power plant capable of generating 1400 megawatts electric. The System 80+ Standard Plant received Final Design Approval (FDA) from the U.S. Nuclear Regulatory Commission in July 1994, and Design Certification in May 1997. Design Certification allows a purchaser to apply for a single Combined Operating License under the conditions of the Code of Federal Regulations, Title 10, Part 52 (10 CFR 52) (CESSAR-DC, DCD).

In order to perform the various load maneuvers identified in Table 1, the core power distributions must be controlled to limit the duty cycle experienced by the fuel and to maintain core thermal margin within operating limits. Satisfying these two requirements during the load maneuvers places increased demand on the plant design; specifically, the core power distribution control system, the core protection and core monitoring systems, and plant control systems. The System 80+ Standard Plant includes proven design features that have evolved over many years to form an integrated design that can accommodate the aforementioned load follow capabilities. Some of the key design features are:

1. Digital core protection system which perform on-line computations of core thermal margin (DNBR) and core Linear Power Density (LPD) based on current core conditions;
2. Digital core monitoring system which use fixed in-core detector signals for on-line computations of core axial and radial power distributions, and core thermal margin;
3. Core design which includes twenty five Part Strength Control Element Assemblies (or gray control rods) to provide greater flexibility in performing power maneuvering and axial shape control without the need to make significant soluble boron concentration changes during the maneuvering;
4. Digital NSSS control systems to provide control of process variables (such as temperatures, pressure etc.) during the load maneuvers;
5. Megawatt Demand Setter (MDS) system which provides automatic load control from a remote dispatching station (i.e., Remote Frequency Control Capability); and
6. Reactor Power Cutback System (RPCS) which provides full load rejection capability.

3.1 Core Protection System

In addition to the trip functions on parameters such as power level, pressurizer pressure, core protection for the System 80+ standard plant is provided by four redundant, safety-grade, digital Core Protection Calculators (CPCs) which have reactor trip functions for low departure from nucleate boiling ratio (DNBR) and high LPD. The CPCs satisfy their reactor trip functions by comparing calculated values of DNBR and LPD against limiting setpoint values. The calculations are based on live sensor signals for primary system thermal hydraulic parameters, three-segment ex-core detector signals for synthesis of axial power distribution, and CEA position signals which are accounted for in the synthesis of power peaking factors. This approach for core protection allows for on-line trade-off of system parameters to maximize the margin to the reactor trip setpoints.

3.2 Core Monitoring System

The core monitoring function is provided by the digital Core Operating Limit Supervisory System (COLSS) which provides the operator with automatic, on-line calculations of core power level and available margins to DNBR and LPD operating limits. COLSS, using information from the fixed self-powered rhodium in-core detector system, the positions of the control rod banks, and other process variables (such as primary coolant temperature, flow, and pressure) synthesizes the core power distribution and determines margins to limits on core power, Local Power Density (LPD), and DNBR

Table 2 System 80+ Core Parameters

Parameter		***Value***
Core Power		3931 MWt
Number of fuel assemblies		241
Active length of core		3.810 meters
Number of CEA (total)		93
12-element full-strength		48
4-element full-strength		20
4-element part-strength		25
Number of in-core instruments		61
Detector levels per instrument		5
Initial Core:	Cycle average burnup	~16,000 MWD/T
	Burnable poison type	Erbium

margin and provides on-line information to assist the plant operator in maintaining thermal margin and process parameters within acceptable ranges during maneuvers.

3.3 Core Design

The System 80+ core design consists of ABB CE advanced fuel design, full strength and part strength Control Element Assemblies (CEAs) and fixed in-core instrumentation (Table 2). The System 80+ Control Element Assembly (CEA) configuration features sequential insertion of three banks of regulating CEAs, two independent banks of part strength CEAs and two banks of shutdown CEAs (Figure 1). This configuration was chosen based on studies performed to optimize the CEA pattern to satisfy load follow requirements while minimizing the impact on safety analyses.

3.4 Control Systems

Changes in turbine demand result in rapid and potentially large increases in primary and secondary pressure. This is due to the mismatch between primary and secondary power levels that occurs during a load change. The larger the power mismatch, the greater the potential for both primary and secondary pressure transients. The System 80+ digital control systems are designed to cause the reactor to follow the change in turbine demand, and maintain process parameters within allowable limits. The four systems that play key roles in controlling the plant through a spectrum of load changes are the Reactor Regulating System (RRS), the Steam Bypass Control System (SBCS), the Reactor Power Cutback System (RPCS) and the Megawatt Demand Setter (MDS) system which provides automatic load control from a remote dispatching station (i.e., Remote Frequency Control Capability).

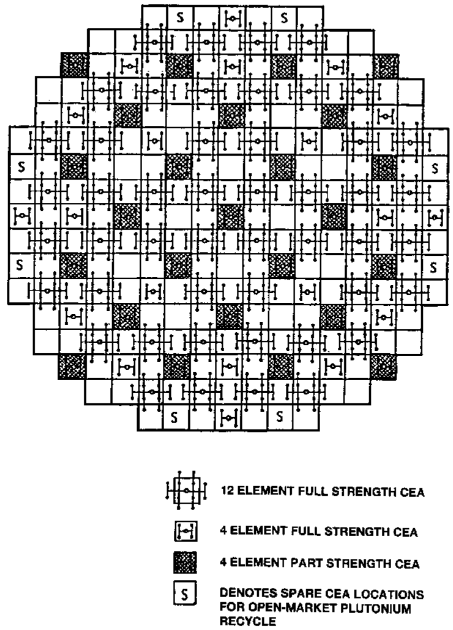

Figure 1 : System 80+ Control Element Assembly Locations

Reactor Regulating System: The RRS is used to provide signals to the Control Element Drive Mechanism Control System (CEDMCS) to automatically control and maintain the average primary coolant temperature (Tavg) within a specified band about the programmed reference temperature. The RRS provides automatic control of Tavg during normal steady state operations, during load follow changes, including step power changes and rapid ramp power changes, and during load rejections that are within the capability of the SBCS and the RPCS. The programmed reference temperature is a function of turbine load as sensed by turbine first stage pressure. The RRS also compares reactor power as indicated by the ex-core detectors for comparison with turbine power (load) to inhibit automatic CEA motion below 15% reactor power and to add additional dynamic stability to the control loop.

Steam Bypass Control System: The purpose of the SBCS is to automatically dissipate excess energy in the NSSS by regulating the flow of steam through the turbine bypass valves to the main condenser. In this way, the main steam header pressure is controlled to accommodate load rejections from any power without tripping the reactor (when operating in conjunction with the RPCS) or lifting either the pressurizer or steam generator safety valves. Furthermore, this permits the reactor to continue operating at a reduced power level within the capacity of the bypass valves while the turbine is re-started and quickly reloaded to that point. This significantly reduces the time required to return to full load after a turbine trip.

Reactor Power Cutback System: The RPCS is a control system designed to increase the plant availability by accommodating load rejections of various magnitudes or loss of one of the operating main feedwater pumps without challenging plant safety systems. The RPCS is designed to keep the reactor on-line by rapidly reducing reactor power, while control systems maintain process parameters within acceptable values. The turbine generator design is expected to maintain house load operations following load rejections.

Megawatt Demand Setter System: A unique feature of the System 80+ control system is the Megawatt Demand Setter (MDS) system. The system facilitates load-frequency control as typified by primary or secondary spinning reserve operations by regulating the load demand as necessary to permit the plant to produce the maximum power it is capable of generating while staying within acceptable limits. The MDS provides the capability to accept increasing or decreasing turbine load commands from either an Automatic Dispatch System (ADS) remote station, or the local MDS panel located in the main control room. The MDS permits the turbine to load the reactor (reactor follows turbine) whenever the reactor is not approaching a limit. This method permits the unit to respond more rapidly to power demand changes thus improving the control of the electrical grid system while enhancing safety and availability by maintaining the unit within its operating limits.

3.5 Core Operating Limits

The System 80+ design includes CPC and COLSS, which results in a large operating window that is very advantageous for load follow operations. In particular, the axial power shape [or Axial Shape Index (ASI)[1]] is allowed to vary over a wide range without an alarm or a trip, so long as DNBR and LPD are maintained within acceptable limits. The System 80+ ASI monitoring limit is +/- 0.28, while the trip limit is set at +/- 0.5. These monitoring and trip limits are valid at all power levels. Maintaining the ASI within monitoring limits will ensure that both fuel duty cycles and plant operating limits are not exceeded during load follow and frequency control operations.

4.0 SYSTEM 80+ LOAD MANEUVERING ANALYSES

The System 80+ Standard Plant is designed to accommodate a large number of allowable maneuvers within the normal plant operating space. To demonstrate these capabilities the following load maneuvers were analyzed:

- Rapid daily power maneuver at power ramp rates of 2% and 5% of rated power per minute
- Slow daily power maneuver at a power ramp rate of approximately 0.5% per minute
- 10% of rated power step increase (to demonstrate spinning reserve capability)
- Load rejections from full power

The System 80+ load follow simulations were performed using the three dimensional core physics design code ROCS and for an equilibrium cycle, which is typically more limiting than simulations performed using initial core cycle.

4.1 Daily Power Maneuvering

Typical electrical usage patterns call for the peak demand during the daytime working hours with reduced demand at night and on weekends. Hence, daily power maneuvers are characterized by (1) initial power, final power and lower power plateaus and (2) the ramp-time to change power level (Figure 2).

The capability of the plant to perform these load maneuvers requires strategies to control the core power distribution and ensure that plant operating limits are not exceeded. This is accomplished by the integrated actions of the plant control systems and, if necessary, the plant operator. A power change produces a change in core reactivity due to moderator temperature and fuel temperature feedback, and due to the

---

[1] ASI = (B-T)/(B+T) where B = power in bottom half of core, and T = power in top half of core power levels.

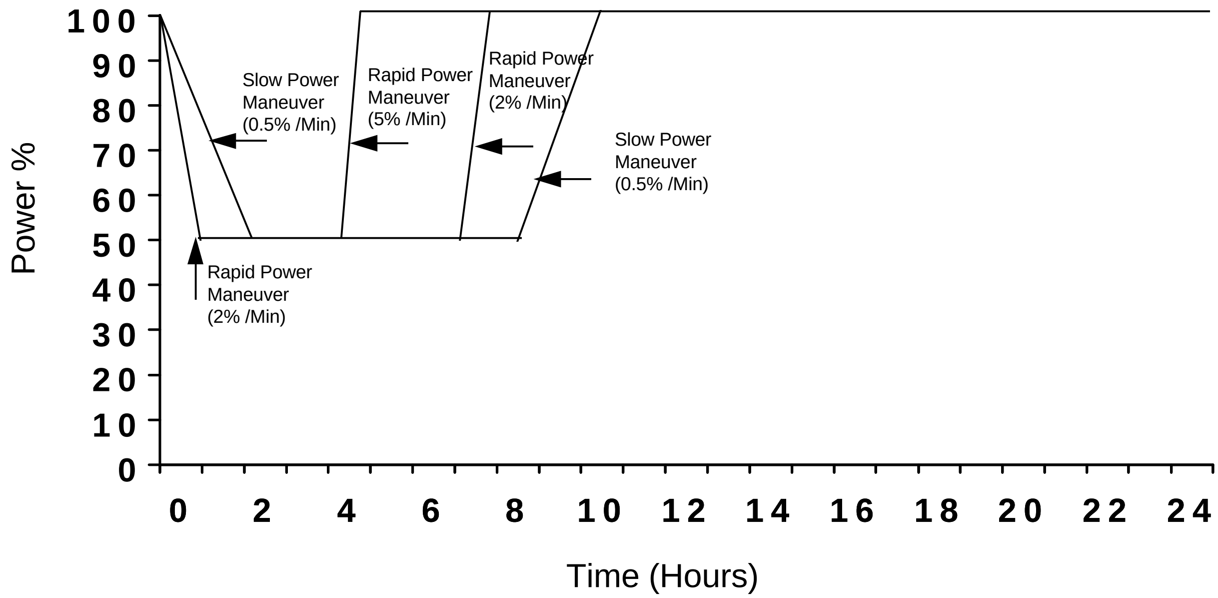

Figure 2 System 80+ Daily Power Maneuvers

ensuing xenon transient. Core reactivity compensation is provided by a combination of CEA motion, reactor coolant temperature changes and soluble boron concentration changes.

Daily power maneuvering can be readily accomplished, especially early in core life, by adding soluble boron to reduce power. In this operating mode, changes in the soluble boron concentration are used to compensate for the reactivity changes associated with the power defect, the build-up of transient xenon during low power operation, and the return to full operating power. Control rod insertion is limited, and used primarily for axial power shape control. Because of the limited use of control rods, perturbations to core power distributions and the fuel duty cycle are minimized. However, this method produces a large volume of waste water, and may not be practical if power maneuvering and frequency control operations are performed on a regular basis.

Performance of daily load maneuvers on a regular basis requires the use of both regulating and part strength CEAs to compensate for the reactivity changes associated with the power defect. The reactivity changes associated with the transient build-up of xenon is compensated by a combination of boron dilution, reactor coolant temperature changes and/or CEA motion. The System 80+ standard plant has the capability to perform a daily power maneuver without changing soluble boron concentration. However, soluble boron concentration changes and/or reactor coolant temperature changes are used to compensate for xenon reactivity if the use of CEAs to compensate for xenon reactivity results in an undesirable core power distribution. The results using the above strategy for System 80+ are described in the following sections.

4.1.1 Rapid Daily Power Maneuver (2% Per Minute Power Decrease And Increase)

Initially, the reactor is at 100% power at equilibrium xenon, a soluble boron concentration of 295 ppm (approximately 80% of cycle) and with PSCEA bank P2 fully inserted. The power reduction to 50% at a rate of 2% per minute is initiated by inserting PSCEA bank P1 fully into the core followed by the insertion of regulating CEA Banks 3 and 2 in fixed overlap mode. The reduced power level of 50% is reached in 25 minutes, with both PSCEA banks fully inserted and regulating CEA banks 3 and 2 inserted approximately 90% and 30%, respectively. The power level is held constant at 50% for the next 6 hours, which results in the maximum build-up xenon reactivity. The initial build-up of xenon is compensated by the withdrawal of PSCEA bank 1 to about mid-plane, which occurs at approximately 1 hour following the initiation of the power maneuver. The withdrawal of PSCEA bank 1 not only compensates for the xenon build-up but also allows the ASI to return to approximately the full power Equilibrium Shape Index (ESI) value. In addition, this CEA configuration (i.e., PSCEA bank 1 at mid plane, PSCEA bank 2 fully inserted, and regulating CEA banks 3 and 2 at 90% and 30% inserted, respectively) ensures that sufficient CEA reactivity is available to return to full power. The build-up of xenon (from approximately 1 hour to the time of maximum xenon) is compensated by reducing the soluble boron concentration. The soluble boron concentration is reduced by approximately 40 PPM to 255 PPM over the next 5.5 hours. At approximately 6.5 hours after the initiation of the power maneuver, the power is increased back to full power at a rate of 2% per minute by withdrawing both banks of PSCEAs and the regulating CEA banks 3 and 2. Full power is reached at approximately 7 hours after initiation of the power maneuver. Once full power is reached, PSCEA bank 2 is slowly inserted into the core to compensate for the decrease in xenon worth and also to re-establish the initial CEA configuration. Once PSCEA bank 2 is fully inserted, further compensation for xenon reactivity changes is accomplished by soluble boron changes. Over the next several hours, the decrease in xenon worth is compensated by increasing the soluble boron concentration by approximately 70 PPM (i.e., 30 PPM above the initial value at full power). At approximately 18 hours, the xenon worth begins to increase, which is compensated by decreasing the soluble boron concentration. Within the 24-hour period after initiation of the maneuver, the core returns to essentially the initial conditions, and is ready to repeat the load follow maneuver (Figure 3).

The figure shows the transient variation of ASI, the key control parameter ensuring that operating limits are not exceeded. During most of the power maneuver, the ASI is maintained within ± 0.05 of the Equilibrium Shape Index (ESI) and is always maintained within +/- 0.15. This is well within the ASI operating limits of ± 0.30, and far removed from the trip limits of ± 0.50. The figure also shows the variation of power level, soluble boron concentration, regulating CEA and PSCEA position during the maneuver.

4.1.2 Rapid Daily Power Maneuver (2% Per Minute Power Decrease And 5% Per Minute Power Increase)

In this scenario, a daily power maneuver similar to the previous maneuver is initiated at 2% per minute to 50% power. However, due to grid demand (postulated loss of power production from another unit), increase to full power is initiated at 3.5 hours and at a rate of 5% per minute (Figure 4). The figure shows the variation of power level, soluble boron concentration, regulating CEA and PSCEA bank position and ASI during the maneuver. As with the previous power maneuver, the ASI is always maintained within +/- 0.15, which is well within the ASI operating limits of ± 0.30, and far removed from the trip limits of ± 0.50.

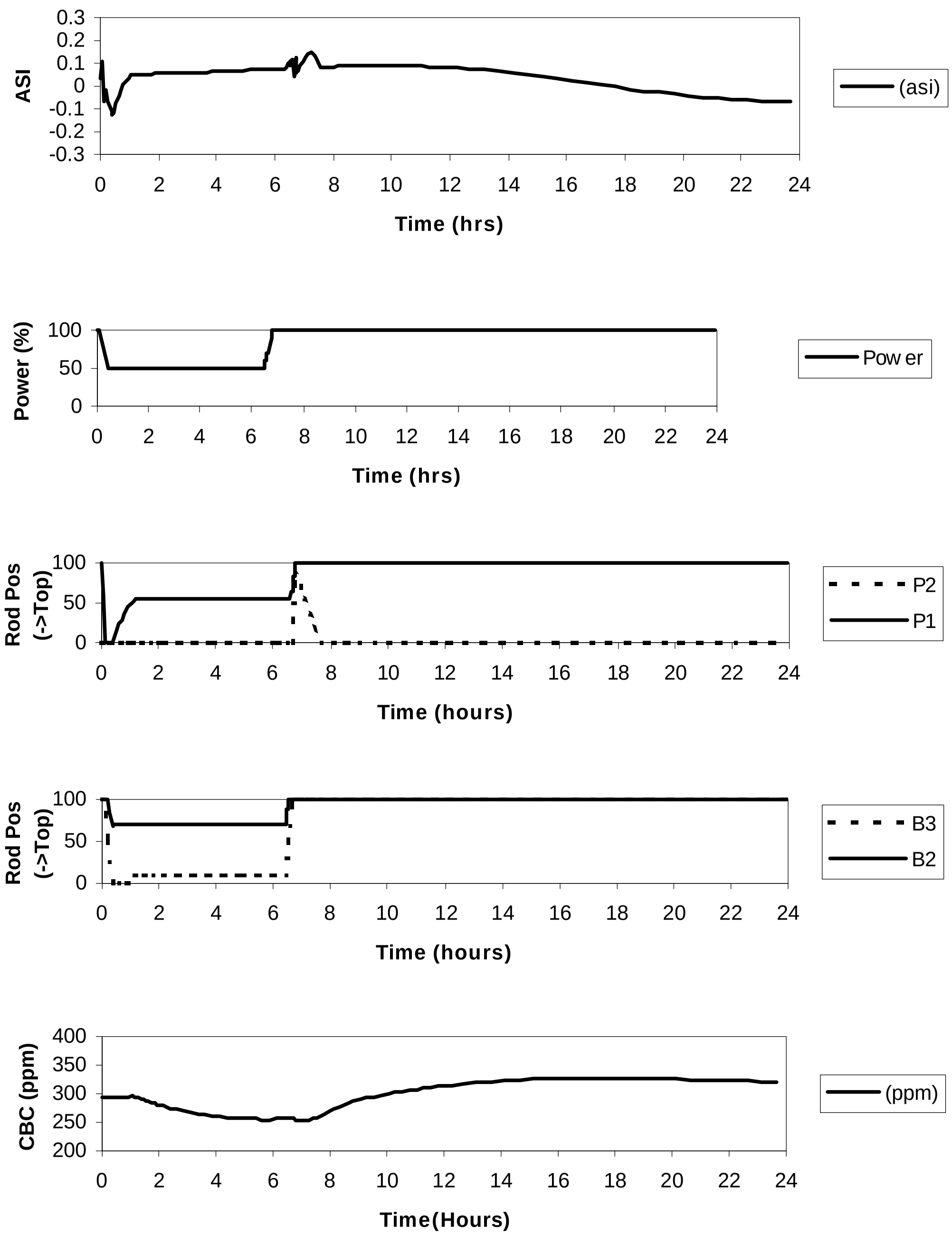

Figure 3 System 80+ Daily Power Maneuver

(2% per minute)

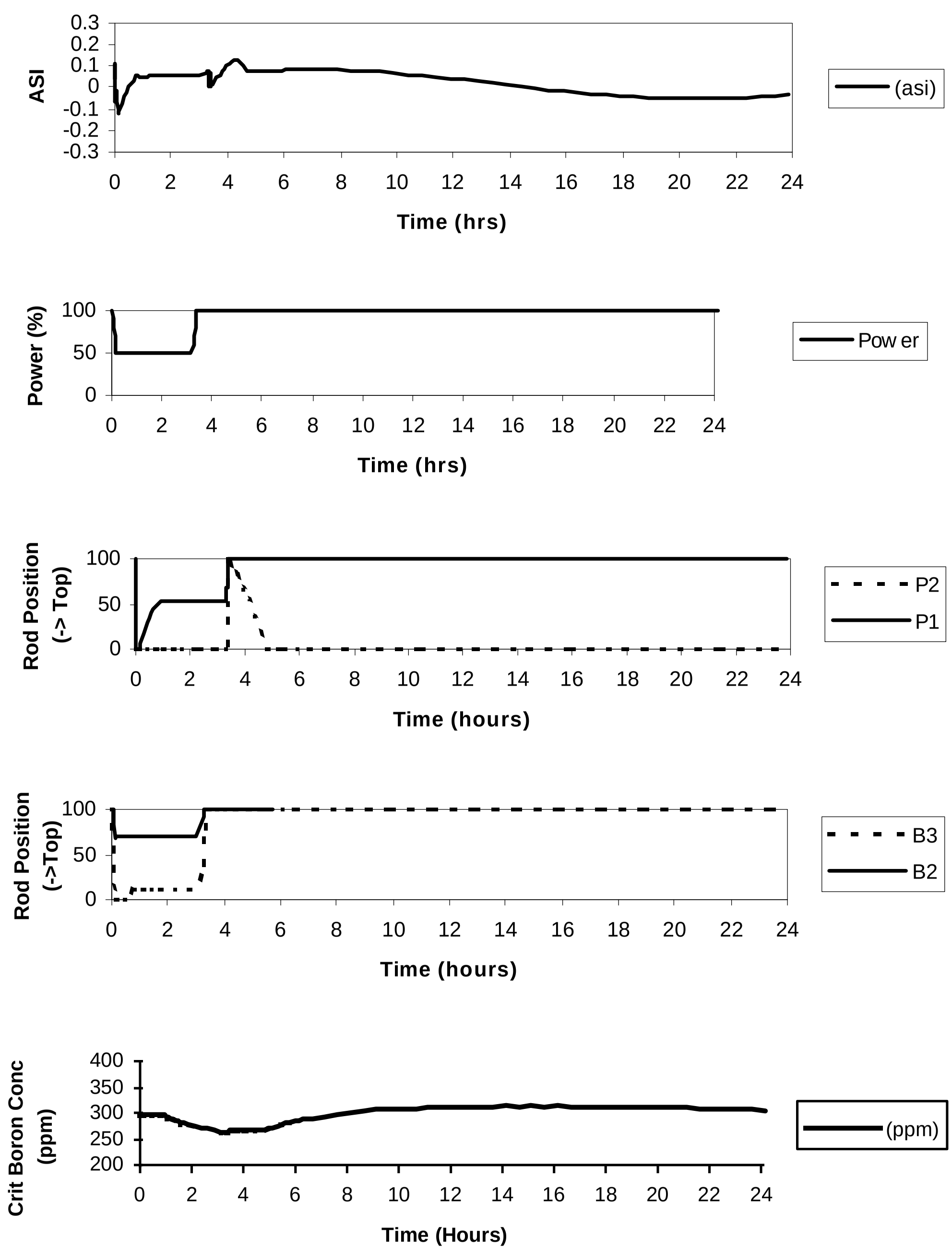

Figure 4 System 80+ Daily Power Maneuver
(5% Per Minute Power Increase)

4.1.3 Slow Power Maneuver

A slow daily power maneuver has also been examined for the specific case of a 100-50-100% power maneuver with a 2 hour ramp-down, a 6 hour hold at 50% power and a 2 hour ramp-up.

As with the rapid power maneuvers, initially the reactor is at 100% power and equilibrium xenon, a soluble boron concentration of 295 ppm and with PSCEA bank 2 fully inserted. The power reduction to 50% over a two hour period is initiated by inserting PSCEA bank 1 fully into the core followed by the insertion of regulating CEA banks 3 and 2 in fixed overlap mode. The reduced power level of 50% is reached in 2 hours with both PSCEA banks fully inserted and regulating CEA banks 3 and 2 inserted approximately 80% and 20%, respectively. The power level is held constant at 50% for the next 6 hours, which results in the maximum build up xenon reactivity. Unlike the rapid power maneuvers, the build up of xenon is compensated entirely by withdrawal of CEAs. Initially, the PSCEA bank P1 is withdrawn to approximately mid-plane, which is followed by the withdrawal of PSCEA bank P2 to approximately 75% inserted. The withdrawal of both PSCEA banks not only compensates for the xenon build-up, but also controls the axial shape and returns the ASI to approximately the initial value. Further compensation for xenon build up is compensated by withdrawal of regulating CEA banks 2 and 3 in a fixed overlap mode with regulating CEA bank 2 fully withdrawn and regulating CEA bank 3 inserted approximately 60%. At 8 hours after the initiation of the power maneuver, the power is increased back to full power at the slow rate of approximately 0.5% per minute. The regulating CEA bank 3 along with both PSCEA banks are withdrawn to reach full power. Once full power is reached at 10 hours, PSCEA bank 2 is slowly inserted into the core to compensate for the decrease in xenon worth and also to re-establish the initial CEA configuration. Once the bank is fully inserted, further compensation for xenon reactivity changes is accomplished by soluble boron changes. Over the next several hours , the decrease in xenon worth is compensated for by increasing the soluble boron concentration by approximately 35 PPM. At approximately 18 hours, the xenon worth begins to increase, and is compensated for by decreasing the boron concentration to essentially the initial value of 295 ppm. Within the 24-hour period after initiation of the maneuver, the core returns to essentially the initial conditions, and is ready to repeat the load follow maneuver (Figure 5).

The figure shows the transient variation of ASI, the key control parameter to ensuring that operating limits are not exceeded. During most of the power maneuver, the ASI is maintained within $\pm$ 0.05 of the ESI and is always maintained within +/- 0.20. This is well within the ASI operating limits of $\pm$ 0.30, and far removed from the trip limits of $\pm$ 0.50. The figure also shows the variation of power level, soluble boron concentration, and regulating CEA and PSCEA position during the maneuver.

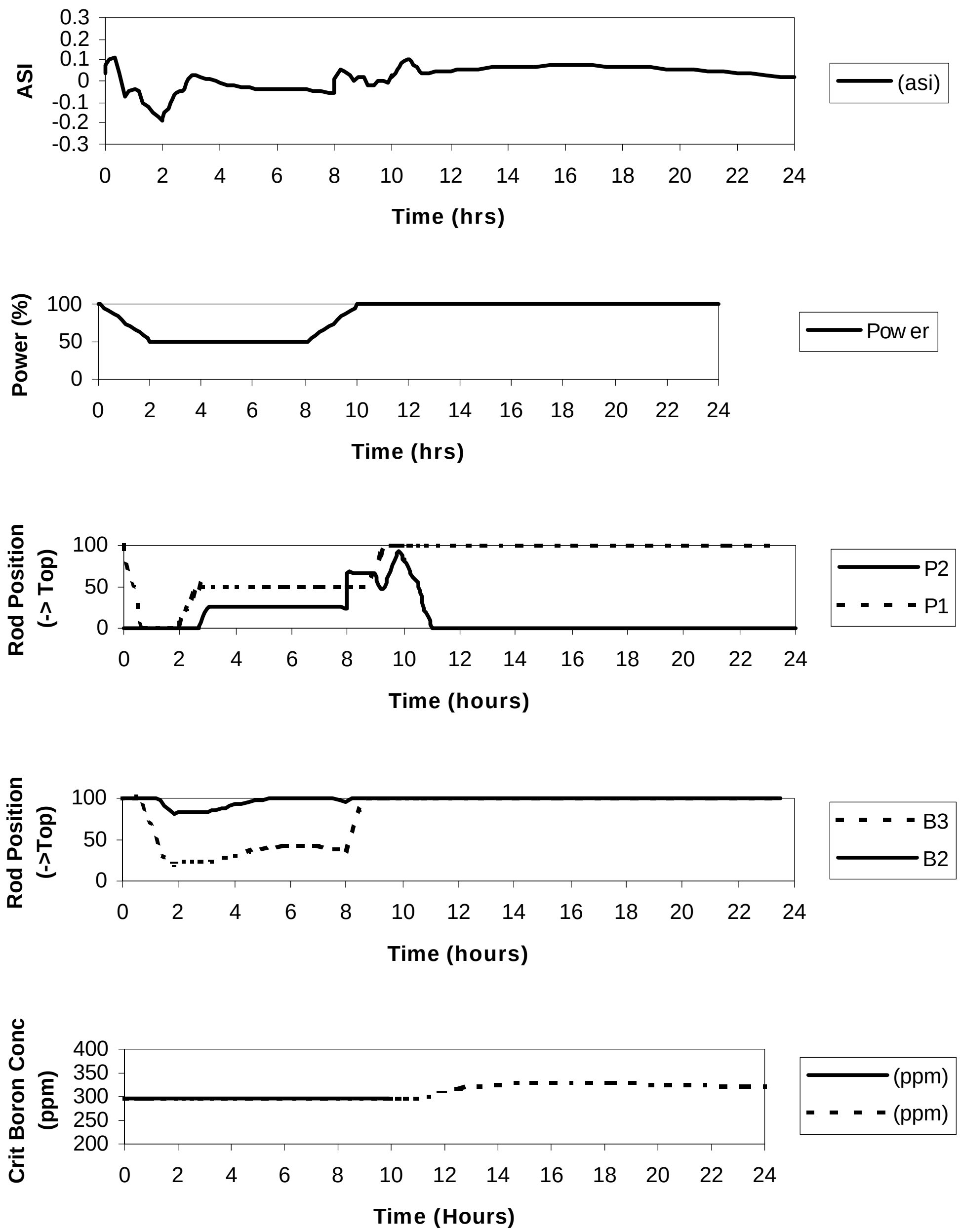

Figure 5 System 80+ Daily Power Maneuver
(100-50-100 over 2-6-2 hour)

In order to demonstrate the ALWR requirement that daily power maneuvers can be performed without making any changes to the soluble boron concentration, a slow power maneuver was simulated using CEA and coolant temperature changes to compensate for reactivity changes. As in the previous scenario, the reactor is initially at 100% power with PSCEA bank P2 fully inserted. The power reduction to 50% over a two hour period is initiated by inserting PSCEA bank P1 fully into the core followed by the insertion of regulating CEA banks 3 and 2 in fixed overlap mode. The reduced power level of 50% is reached in 2 hours with both PSCEA banks fully inserted and Regulating banks 3 and 2 inserted approximately 80% and 20%, respectively. The power level is held constant at 50% for the next 6 hours, which results in the maximum build-up of xenon reactivity. The build-up of xenon is initially compensated by withdrawal of PSCEA bank P1, followed by a reduction in cold leg temperature of approximately 5 degrees C. Since xenon has essentially reached its peak, further reactivity compensation is provided by gradual withdrawal of the regulating CEA banks in overlap mode. At 8 hours after the initiation of the power maneuver, the power is increased back to full power at the slow rate of approximately 0.5% per minute. The combination of PSCEA banks P1 and P2 together with regulating CEA banks 3 and 2, provide more than sufficient reactivity to increase power to 100%. Once full power is reached at 10 hours after the initiation of the power maneuver, PSCEA bank P2 then PSCEA bank P1 are slowly inserted into the core to compensate for the decrease in xenon worth. Once both PSCEA banks are fully inserted, xenon worth is compensated by increasing the coolant temperature back to its initial value. At approximately 18 hours after the initiation of the power maneuver, the xenon worth begins to increase, and is compensated by withdrawing PSCEA bank P1. Within the 24-hour period after initiation of the maneuver, the core returns to essentially the same initial conditions, and is ready to repeat the load follow maneuver (Figure 6).

The figure shows that the ASI is always maintained within ASI operating limits of $\pm$ 0.30. However the overall control of axial shape is not as favorable as when soluble boron changes are used to compensate for xenon reactivity changes. The figure also shows the variation of power level, soluble boron concentration, and regulating CEA and PSCEA bank position.

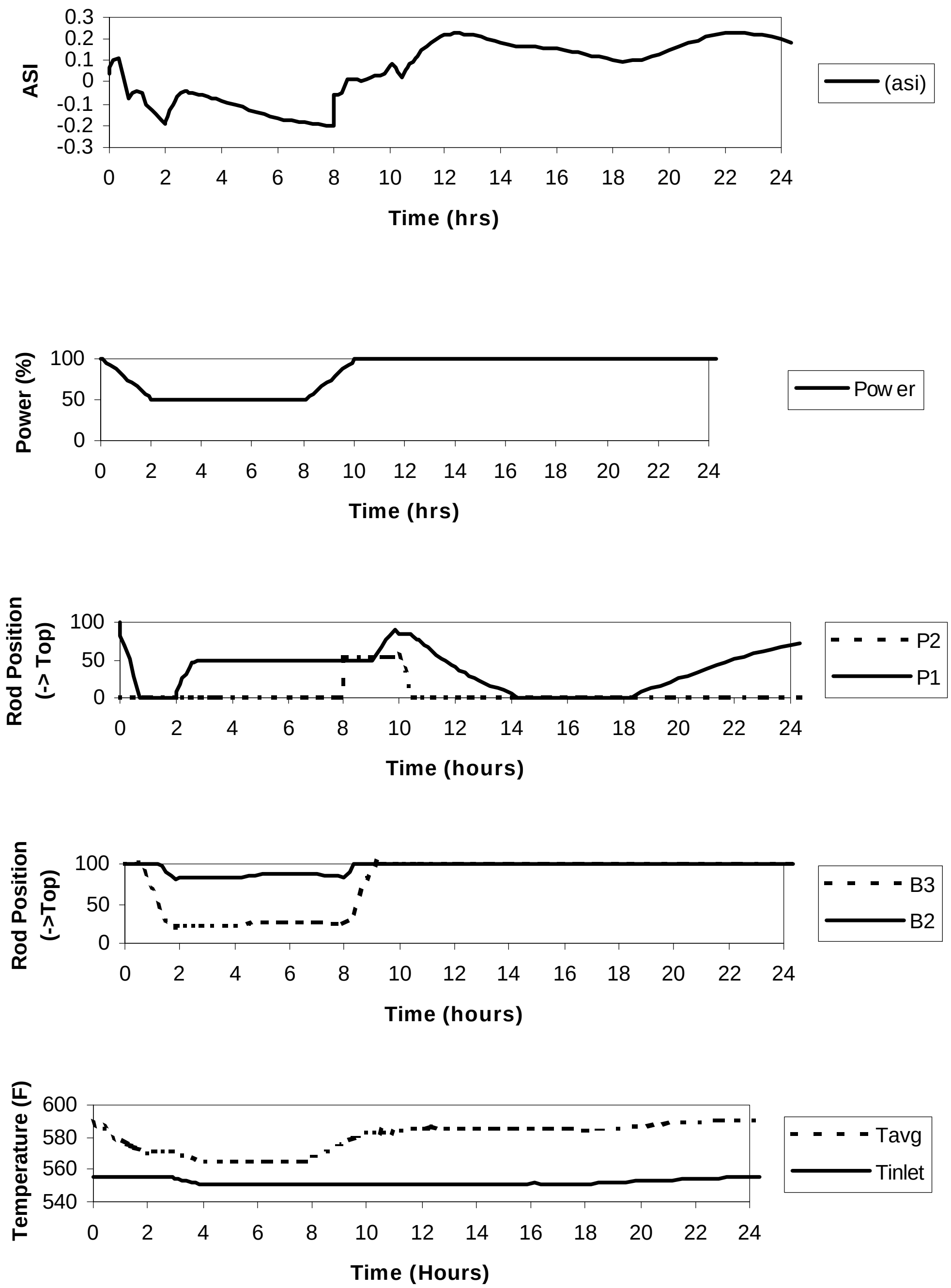

Figure 6 System 80+ Daily Power Maneuver
(100-50-100 over 2-6-2 hour)

4.2 Frequency Control

Plant capability to participate in frequency control operation is dependent on its capability to absorb step increases or decreases in steam demand, while operating at a relatively high power level. When operating in frequency control mode, changes in grid frequency caused by changes in electrical load demand cause the turbine generator control system to change the NSSS steam demand. The ability of System 80+ to participate in frequency control operation is demonstrated by a 10% step change in power from an initial power level of 85% power. The 10% step change is accommodated by the rapid withdrawal of PSCEA bank P2 which is withdrawn from the fully inserted position to approximately 15% inserted. The transient variation of ASI is well within the ASI operating limit of ± 0.30 (Figure 7).

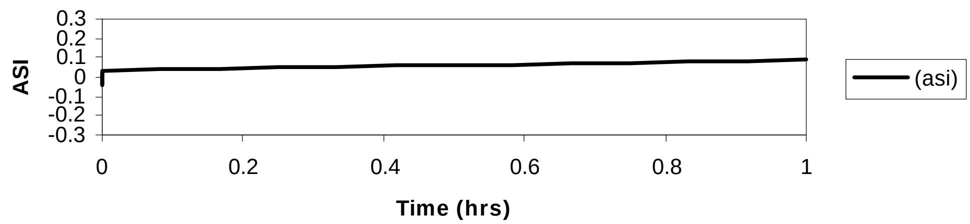

Figure 7 System 80+ Daily Power Maneuver
(10% Step Load Change)

4.3 Load Rejections

The System 80+ plant is designed to withstand a full load rejection without initiating a reactor or turbine trip. The means of accommodating load rejections is through the automatic actuation of the Reactor Power Cutback System in conjunction with other NSSS control systems. The load rejection capability is illustrated by the system simulation described below.

The loss of electrical load will actuate the power/load unbalance relay of the turbine control system, which will rapidly close the appropriate turbine valves. The rapid decrease in steam flow rate is sensed by the SBCS which quick opens all steam bypass valves and actuates the RPCS. In response to the RPCS actuation signal, the lead regulating CEA bank is dropped to reduce the core power to approximately 70%. The prompt decrease in core power is followed by a small increase in power due to temperature feedback effects. This power increase is mitigated by the RRS inserting CEAs sequentially until core power matches available steam bypass capacity. In response to the load rejection, the quick opening of all steam bypass valves mitigates the increase in primary and secondary pressure. The maximum primary and secondary pressure reached during the event is significantly below the opening pressure of primary and secondary safety valves. Once the reactor power is reduced, the SBCS assumes modulation control of the steam bypass valves to follow reactor power and avoid overcooling the NSSS. The control systems automatically stabilize the NSSS at this power level, with the SBCS modulating steam bypass valves to relieve the steam and maintain primary and secondary pressure at acceptable values (Figure 8).

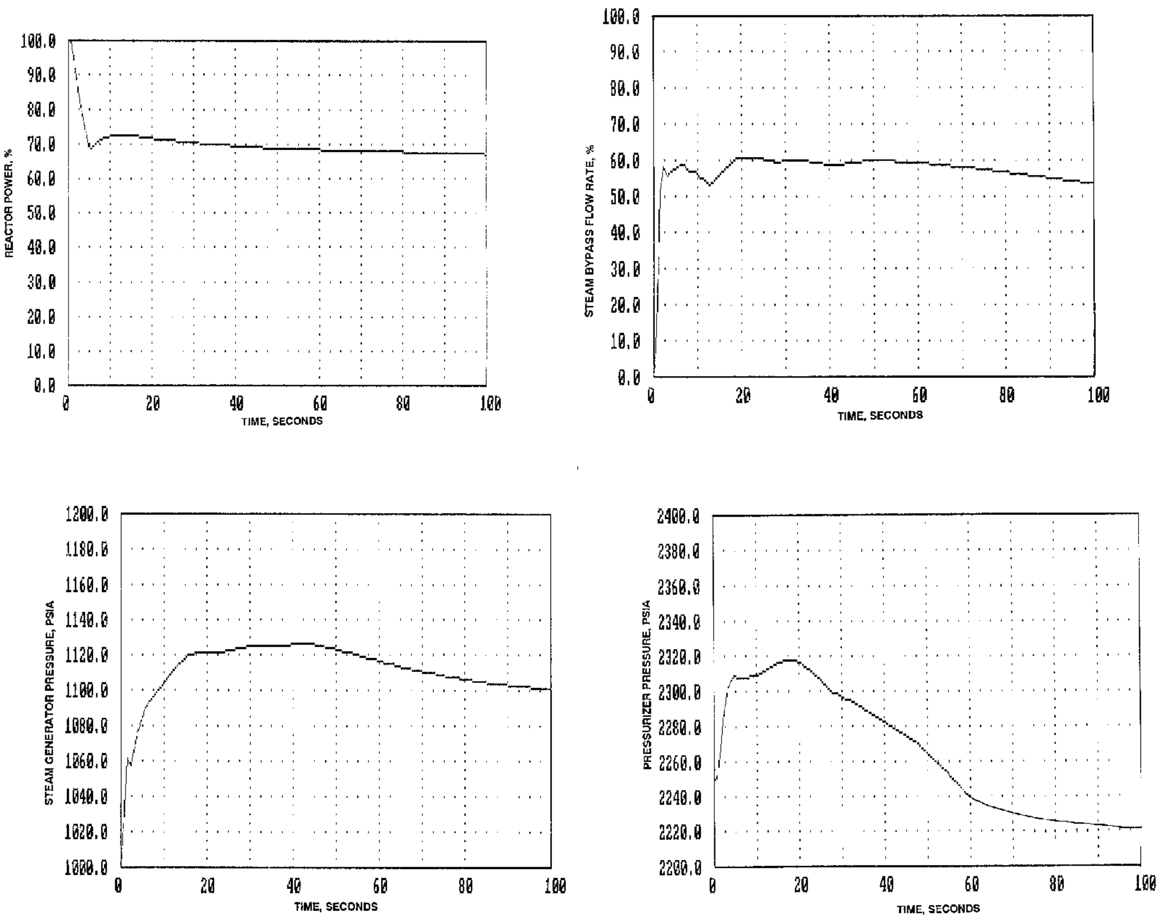

Figure 8 System 80+ Response To Full Load Rejection

5.0 LOAD FOLLOW EXPERIENCE

Although most nuclear power plants are currently operated as base load units for economic reasons, utilities have demonstrated the capability of ABB CE plants to accommodate load follow operations. Yonggwang Units 3 and 4 rated at 2825 MWth are System 80 plants located in the Republic of Korea (ROK) and achieved commercial operation in March 1995 and January 1996 respectively. During the initial startup both units performed numerous tests to demonstrate the capability of the System 80 plant to accommodate various load follow operations. These are described in the following sections.

5.1 Daily Power Maneuvers

Yonggwang Units 3 and 4 conducted a daily slow power maneuver test, demonstrating the power maneuvering capability of the ABB CE NSSS. A 100-50-100% power cycle test was carried out as part of the initial test program. During the maneuvering test, soluble boron concentration was changed to compensate for both power defect and xenon reactivity effects while PSCEA banks were used to control and maintain the ASI within the normal operating band. The test was successfully completed, and demonstrated the ability of the plant to conduct daily power maneuvers.

5.2 Step And Ramp Load Changes

Both Yonggwang Units performed tests to demonstrate the capability to accommodate step and ramp load changes from both high and low power levels. Load change tests were initiated at 95% power and consisted of a 10% step load decrease to approximately 85% power, followed by a 5% per minute ramp load decrease to 70% power. This was followed by a 5% per minute increase back to 85% power and then a 10% step change to 95% power. All of these load changes were successfully performed (Collier, Chari, et al, 1996).

5.3 Load Rejections

The successful operation of the RPCS to accommodate full load rejections has been demonstrated in number of ABB CE operating plants. The RPCS has been successfully tested and is in operation at all three Palo Verde Units, Waterford Unit 3 and at Yonggwang Units 3 and 4 (Chari, 1987)(Collier, Chari, et al, 1996). The successful operation of the RPCS at these units has resulted in avoiding numerous reactor trips, the normal consequence of load rejections at plants which do not have a RPCS. This has contributed significantly to increasing the overall availability factor at these plants.

6.0 CONCLUSIONS

The System 80+ Standard Plant can accommodate a wide range of load follow operations while maintaining the plant well within operating limits. These load follow operations include daily power maneuvering at various ramp rates, support of frequency control operations by accommodating 10% step changes in steam demand, and support of system load regulation by accommodating load rejections of all magnitudes, including a turbine trip. The System 80+ plant design accommodates all of these load follow operations while satisfying all key performance objectives:

- Maintaining sufficient core operating margin,
- Satisfying fuel design requirements and operating limits during load maneuvers,
- Minimizing chemical reactivity control operations and the generation of waste water as a result of load maneuvers, and
- Avoiding delays in return to power following planned down power maneuvers.

7.0 REFERENCES

Design Control Document (DCD) for the System 80+ Standard Plant.

System 80+ Standard Plant Combustion Engineering Standard Safety Analyses Report Design Certification (CESSAR-DC).

Collier, T.J., Chari, D.R., Kiraly, F. *Initial Startup and Operations of Yonggwang Units 3 and 4*. Presented at International Conference on Nuclear Engineering-4, New Orleans, 1996.

Chari, D.R. 1987. Technical Paper TIS-8210, *Experience with Reactor Power Cutback System*. Presented at the Topical Meeting on Anticipated and Abnormal Plant Transients at Nuclear Power Plants, Atlanta, Georgia.

8.0 KEY WORDS

System 80+, Load Follow, Power Ramp Rates, Load Rejections, Yonggwang Load Follow, Control Systems, Axial Shape Control, Load Transients, Frequency Control, Power Step Changes.