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Failure Modes and Effects Analysis (FMEA) of the ICS/NNI Electric Power Distribution Circuitry at the Oconee 1 Nuclear Plant

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Prepared for the
U.S. Nuclear Regulatory Commission
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FAILURE MODES AND EFFECTS ANALYSIS (FMEA) OF THE ICS/NNI ELECTRIC POWER DISTRIBUTION CIRCUITRY AT THE OCONEE 1 NUCLEAR PLANT

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LIST OF ACRONYMS AND ABBREVIATIONS

ac	alternating current
B&W	Babcock & Wilcox
BWST	borated water storage tank
CFT	core flood tank
dc	direct current
ECI	essential control and instrument
E/P	electric-to-pneumatic
ESPS	engineered safeguards protective system
FMEA	failure modes and effects analysis
FW	feedwater
HPI	high pressure injection
ICS	integrated control system
KI	ICS panelboard
KU	computer panelboard
LST	letdown storage tank
NNI	nonnuclear instrumentation
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PORV	pilot-operated relief valve
RB	reactor building
RC	reactor coolant
RCP	reactor coolant pump
RPS	reactor protective system
SAI	Science Applications, Inc.
SCR	silicon controlled rectifier
SG	steam generator
T_{avg}	temperature (average)
TMI	Three Mile Island
V ac	volts alternating current

ABSTRACT

The effects of nonnuclear instrumentation (NNI) and integrated control system (ICS) electric power supply failures have been analyzed for the Oconee Unit 1 nuclear plant. The instrument and control system power distribution circuits were analyzed to define a comprehensive set of 19 single-point failure modes. For each power supply failure, the failed and operating control system signal inputs were propagated through the partially energized control system circuits as well as the energized and deenergized output control devices to evaluate the initial plant response. In addition, the effects of the power supply failures on the principal control room parameter displays were combined with the initial plant response to the automatic control circuits to evaluate possible control room operator responses. Plant responses to the defined power supply failures are described in detail.

The automatic responses of the plant to the instrument and control system power supply failures were not found to be severe. This was due in part to post-Three Mile Island (TMI) modifications. Possible operator responses to spurious control room displays generally did not result in significant transients. Improved automatic transfer of control system input circuits to operable power supplies, automatic trip of feedwater pumps on loss of certain power supply branch circuits, and suppression of spurious alarms have been identified as possible ways to further limit the effects of transients induced by instrument power supply failures. A status review of the power supply failure alarms and applicable operating procedures was recommended to corroborate the adequacy of the information available to the control room operator following any power supply failure.

1.0 INTRODUCTION

1.1 BACKGROUND

A number of transients have occurred at Babcock & Wilcox (B&W) designed power reactors due to loss of non-Class-1E power supplies to the non-nuclear instrumentation (NNI) and the integrated control system (ICS). On March 20, 1978, loss of NNI power supply at the Rancho Seco Station resulted in a loss of feedwater combined with a substantial loss of control room information. This transient led to combined overcooling and repressurization of the primary system as a result of operator actions taken before the failed instrumentation was restored (ref. 1). On November 20, 1979, loss of power to a non-Class 1E 120-V ac single-phase power panel that supplied power to the NNI and ICS at Oconee Unit 3 resulted in control system malfunctions and a significant loss of information to control room room operators (ref. 2). On February 26, 1980, loss of a NNI power supply at Crystal River Unit 3 led to a transient that was considered to have several similarities to the TMI-2 accident (ref. 3).

As a result of the loss of instrument power at Oconee Unit 3, the Nuclear Regulatory Commission (NRC) issued IE Bulletin No. 79-27, which included requirements for all operating nuclear power facilities to review Class 1E and non-Class 1E buses supplying power to safety- and non-safety-related instrumentation which could affect the ability to achieve a cold shutdown using existing procedures (ref. 2).

The Crystal River Unit 3 incident and the apparently high frequency of such somewhat similar types of transients in other B&W-designed plants resulted in the NRC task force study and report NUREG-0667 "Transient Response of Babcock [and] Wilcox Designed Reactors," released April 2, 1980 (ref. 4).

A historical summary of 23 ICS/NNI power failures during operation was presented in NUREG-0667. Failures that were identified included inverter failure, an electrical short in a dc bus and in an ICS power receptacle, and a variety of unspecified shorts. Most, if not all, of these problems appear to have occurred more than one time, and approximately 50% of them were due to short circuits on cabinet-level ac or dc power buses. Another 30% were attributed to maintenance or troubleshooting activities. This experience suggests that the NNI and ICS ac and dc power supplies and signals are sensitive to short circuits at the cabinet level and that failures of these buses should be expected during plant operation.

1.2 SCOPE OF WORK

The Oconee Unit 1 instrumentation and controls consist of several major Class 1E and non-Class 1E instrumentation systems:

System	Principal Functions
Class 1E Safety Systems	
Reactor protective system (RPS)	Detection of abnormal plant operation and initiation of reactor scram. Input of selected buffered signals to ICS/NNI.
Engineered safeguards protective system (ESPS)	Detection of abnormal plant operation and initiation of plant safety equipment. Input of selected buffered signals to ICS/NNI.
Other Class 1E controls and instrumentation	Monitoring and indication of process parameters important to safety and control of safety equipment.
Non-Class 1E Systems	
Nonnuclear instrumentation system (NNI)	Monitoring and indication of plant parameters and control of selected nonsafety equipment.
Integrated control system (ICS)	Coordinated control of the main feedwater flow, reactor power, main turbine-generator power, and turbine bypass systems.

These systems are schematically shown in Fig. 1.1 together with the process parameter interconnections among them and their electrical power supplies.

This report presents the results of a failure modes and effects analysis (FMEA) of the power supplies to the Oconee Unit 1 ICS and NNI instrumentation systems. This study was performed for the NRC and carried out by Science Applications, Inc., (SAI) under the direction of Oak Ridge National Laboratory (ORNL). The objectives of this work are as follows:

1. Perform a FMEA of the NNI and ICS power supplies to identify systems output failures resulting from single power supply failures.
2. Evaluate the initial or near-term response of the plant to the failed outputs resulting from each postulated power failure.

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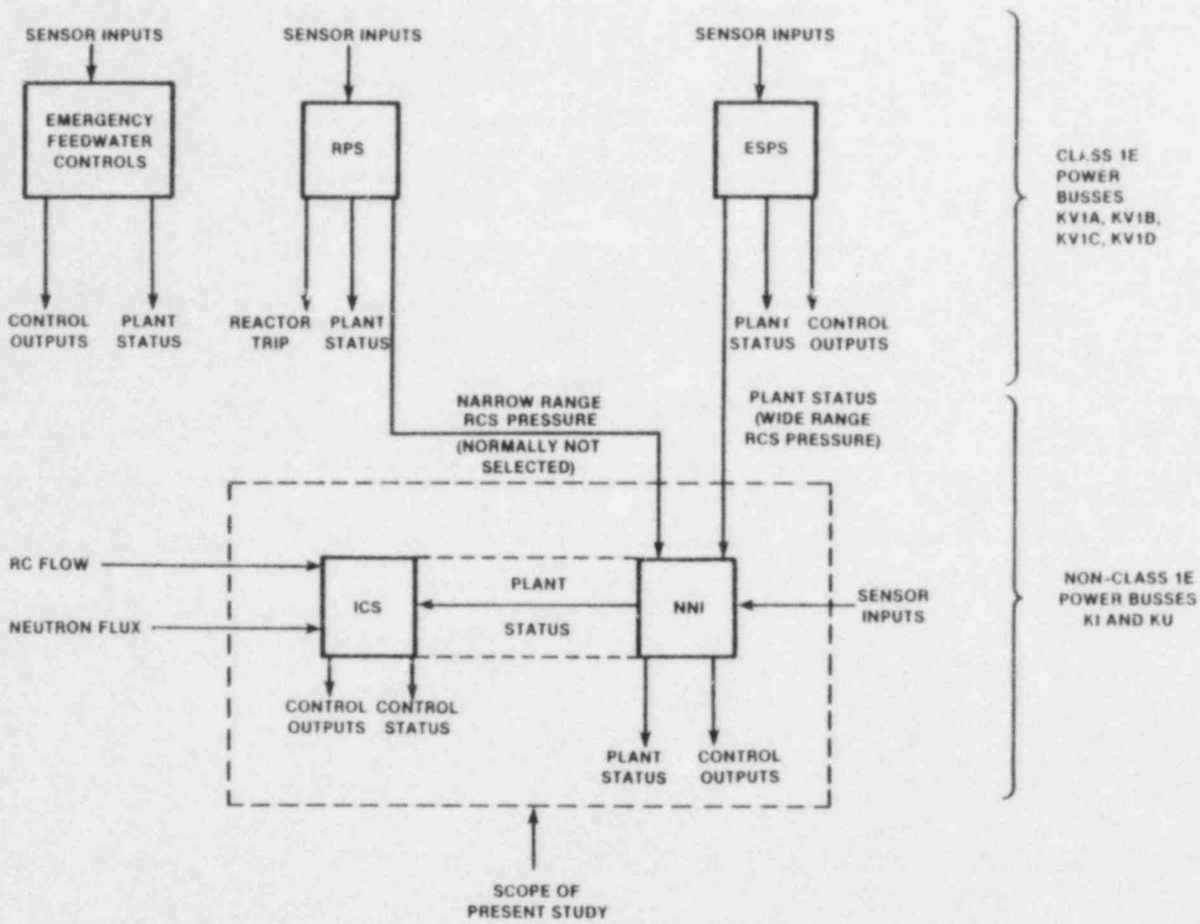

Fig. 1.1. Oconee Unit 1 instrumentation system and major interconnections.

3. Identify potential design modifications that would eliminate or reduce the frequency of the postulated power failures.

1.3 TECHNICAL APPROACH

The analysis of the ICS/NNI response to power supply failure was performed using an extended FEMA. The general technical approach used is illustrated in Fig. 1.2. The ICS and NNI power supplies were reviewed and potential failure modes were defined. The NNI process variable display failures and control actions were then identified for the distinct power supply failure modes. Failed NNI signals for the different power supply failure modes were identified and used to define inputs to the ICS, and ICS input failures were analyzed to predict the ICS response. ICS power supply failure effects were then combined with the signal propagation results as appropriate to predict net ICS response. Alarms and indications available to detect the resulting transient are also discussed.

This work included the development of a detailed data base for the power supply dependence of each instrument and control string in the Oconee Unit 1 ICS and NNI systems. By coding the power supply dependence along each string, it was possible to efficiently search and list the failed and operating outputs by tag number for each power supply failure mode.

This data base was designed so that future alternate power sources can be included in the data fields and search logic.

Specific steps performed as part of this analysis included the following:

1. Listing all ICS/NNI sensor-to-output device circuits and identifying the branch circuit supplying power to each module in each circuit.
2. Inputting the sensor-to-output circuits into a computerized data base.
3. Sorting the circuit data base to obtain a separate listing of circuits with deenergized components and energized circuits for each power supply failure.
4. Sorting each listing of energized and deenergized circuits into separate listings by output type [control outputs, computer inputs, alarms, indicators (meters), and chart recorders].
5. Specifying for each output type in the deenergized circuit listing the response of the output devices to each power supply failure by detailed circuit analysis.
6. Evaluating and specifying the initial automatic plant response to the deenergized control circuit outputs for each power distribution failure.
7. Evaluating the possible near-term operator responses and the resulting consequences to the plant based on the initial automatic

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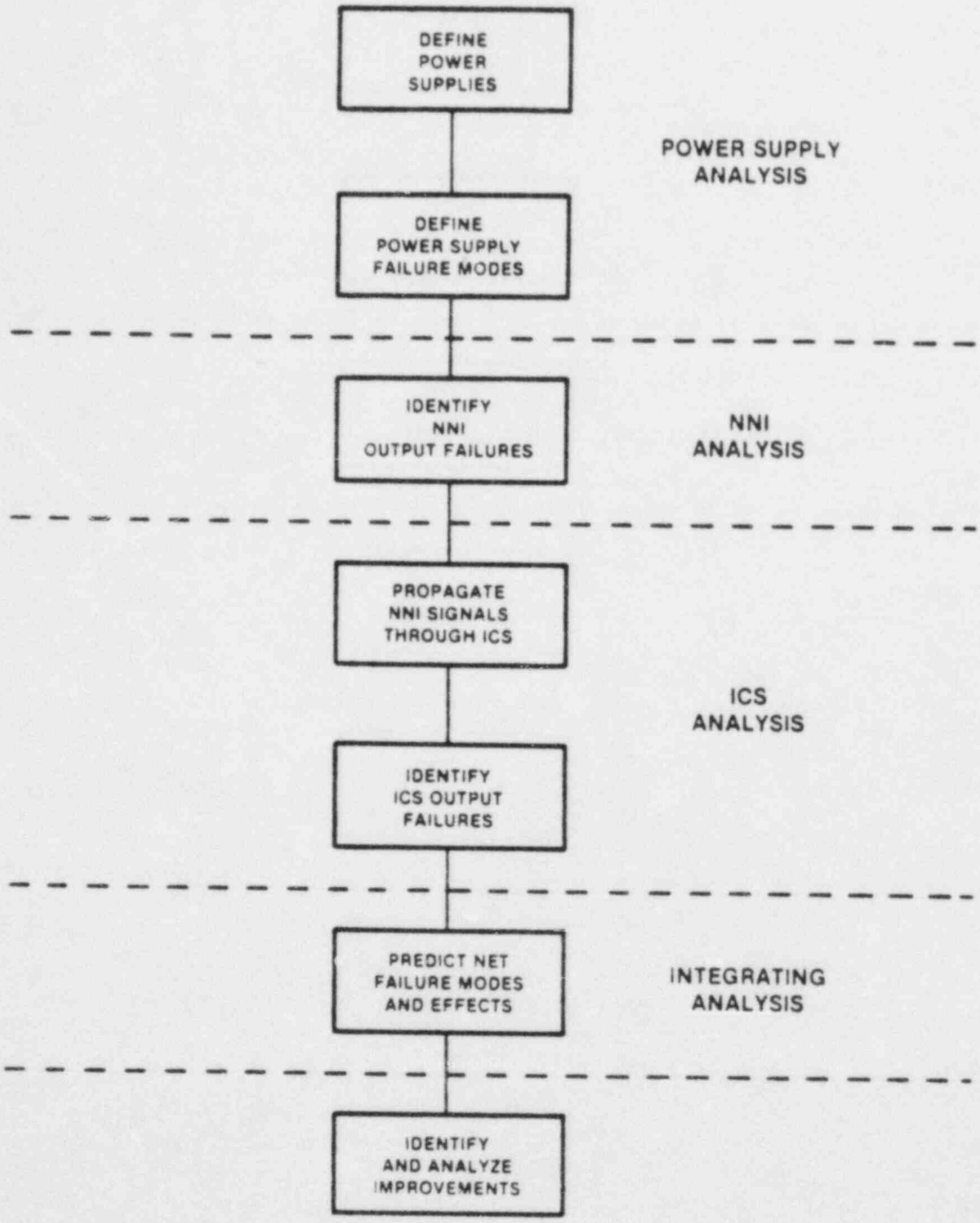

Fig. 1.2. Technical approach.

plant response and the energized and deenergized indication and alarm outputs displayed to the operator.

1.4 REPORT CONTENTS

This report describes the results of the ICS/NNI power supply by FMEA. The conclusions obtained from these results are summarized in Sect. 2. Brief descriptions of the ICS/NNI and their electric power distribution circuitry are given in Sects. 3 and 4. The results of the power supply FMEA for each power supply failure case are presented and briefly discussed in Sects. 5 through 20.

2. SUMMARY OF RESULTS

A detailed analysis of the effects of ICS/NNI electrical power supply failures has been performed for the Oconee Unit 1 nuclear power plant. This analysis consisted of determining the response of ICS/NNI output signals to single-point failures in the power supply circuitry. From these degraded signal combinations, the automatic response of the plant's controlled components and possible responses of the plant operators to degraded control room parameter displays were evaluated.

The ICS/NNI is supplied with 120-V ac power through five major branch circuits from ICS Panelboard KI: auto power (branch H), hand power (branch HX), emergency power (branches HEX and HEY), emergency steam generator level control power (branch H-EL)* and reactor control system (RCS) narrow range pressure transmitter power (branch KI-10). Auto power and hand power are distributed to ICS/NNI components through branch circuits H1, H2, H4, H5, H8, H1X, H2X, and H3X. In addition, computer panelboard KU can provide power to selected NNI circuits by manual transfer or automatic transfer if panelboard KI is deenergized.

The results of the study are summarized in Tables 2.1 and 2.2 for the power supply branch circuit or combinations of branch circuits deenergized. Table 2.1 lists the principal automatic control circuit and plant responses to the power supply failures. The principal control room parameter display failures and possible operator responses resulting from power supply failures are listed in Table 2.2. A detailed description of the plant response to each power supply failure is provided in Sects. 5 through 20 of this report.

The conclusions resulting from the ICS/NNI power supply failure analysis are summarized below:

1. The automatic responses of the plant to power supply failures were not found to be severe. In part, this is due to the post-TMI modifications--in particular, the automatic trip of the main feedwater pumps on high steam generator level and subsequent automatic initiation and control of the emergency feedwater system. The principal spurious automatic responses were found to be:

    Several power supply failures resulted in opening or holding open the main feedwater control valves, which may result in an automatic high steam generator trip of the main feedwater pumps and automatic initiation and control of emergency feedwater. Manual throttling of main feedwater could avoid the high level trip in many cases.

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*The emergency feedwater control system is powered through the vital buses, not from H-EL.

Table 2.1 Summary of spurious automatic system responses to ICS/NNI power supply failures

Branch circuit failure	NNI spurious failure	ICS spurious response	Transfer to manual	Automatic system response
H1	Yes	No	Reactor power Turbine throttle Main and startup feedwater valves Main feedwater pump Pressurized spray valves Pressurizer heater Makeup flow control	Continued short-term plant operation without automatic control. Reactor/turbine trip in response to perturbations, with possible high-SG-level feedwater pump trip.
H2	Yes	No	Seal injection flow	Interlock reactor coolant (RC) pumps from being started.
H4	No	No	None	None
H5	No	No	None	None
H8	No	No	None	None
H	Yes	No	Branches H1 through H8 denergized, see above.	Branches H1 through H8 deenergized. Response described above.
H1X	Yes	Yes	None	Possible closure of turbine throttle, increase or decrease of reactor power, and reduction of feedwater pump speed will result in reactor/turbine trip. High-SG-level trip of feedwater pumps possible.
H2X	Yes	No	None	No immediate plant transient. The power supply for the letdown, makeup, and RC pump seal injection control valves electro/pneumatic (E/P) transducers transfers automatically to panelboard KU. Letdown transferred automatically to letdown storage tank.
H3X	No	No	None	None
HX	Yes	Yes	None	Branches H1X, H2X, and H3X deenergized. Response described above.

HEX	Yes	Yes	None	Pressurizer level and SG startup level and pressure transmitters are powered by branches HEX and HEY. If selected for control, a deenergized pressurizer level transmitter results in transferring coolant from the letdown storage tank to the pressurizer. A deenergized SG level transmitter results in increased main feedwater flow to the affected SG(s). A deenergized SG pressure transmitter results in loss of automatic control of turbine bypass valves.
HEY	Yes	Yes	None	See HEX above.
H-EL	No	Yes	None	No immediate plant transient. Startup feedwater control valves "freeze" in position.
KI	Yes	Yes	Branches H, HX, HEX, HEY, and H-EL deenergized. Letdown, makeup, and turbine bypass valve controls transferred to manual and energized via KU. Manual pressurizer spray and heater controls also available at ASP.	Branches H, HX, HEX, HEY, and H-EL deenergized. Automatic reactor, turbine, and feedwater pump trip. Automatic control of emergency feedwater and RC pump seal injection flow.
KU	Yes	No	None	If KU powered pressurizer level transmitter selected, coolant transferred from letdown storage tank to pressurizer.
KI-10	Yes	No	None	RCS narrow range pressure transmitter deenergized, resulting in a low indicated pressure. Pressurizer heaters would be energized and the pilot-operated relief valve (PORV) and spray valves closed, probably resulting in a high-pressure reactor trip.

Table 2.2 Summary of control room parameter displays' response to ICS/NNI power control failures

Branch circuit failure	NNI response	ICS response	Spurious alarms	Deenergized indications	Expected plant control operator response*
H1	Yes	Yes	Hi, lo pressurizer level Hi, lo RC T_{avg} Low SG A, B startup levels	Cold leg dT RCS loop A, T_{avg} SG A wide range level Loops A, B startup feedwater flow rate Digital T_{avg} indication RCS T_{avg} recorder Loop A, B feedwater flow recorder	Trip plant or manually attempt controlled runback.
H2	Yes	No	Lo RC pump seal dP Lo, hi seal injection and outlet flow rates	Seal dP Seal injection and outlet flow Letdown flow	Manual trip of reactor and RC pump possible.
H4	No	No	Hi, lo CFT pressure	One of two core flood tank pressure meters	Continued plant operation.
H5	No	No	Hi quench tank T, P, level Hi, lo reactor building (RB) sump level	Quench tank T, P, level RB sump level Liquid, gaseous waste flow, flow recorder	Continued plant operation.
H8	No	No	Hi reactor building pressure	RB pressure meter, recorder	Continued plant operation.
H	No	No	Branches H1 through H8 deenergized, see above	Branches H1 through H8 deenergized, see above	Loss of branch H (auto power) alarmed. Identification of cause of spurious indications increases likelihood of effective manual control by operator, including reactor trip and main feedwater control.
H1X	Yes	Yes	Hi, lo turbine hdr. pressure Hi, lo pressurizer level Hi SG level Hi RCS temperature, dT	Turbine hdr. pressure SG pressure SG level Main feedwater flow RCS temperature	Manual trip of reactor/turbine, manual trip of main feedwater pumps, and possible initiation of HPI.

H2X	Yes	No	Hi, lo letdown storage tank (LST) level	LST level LT-2	Opening flow path from borated water storage tank (BWST) to HPI pumps possible.
H3X	No	No	None	One of two CFT A, B pressure meters	Continued power operation.
HX	Yes	Yes	Branches H1X, H2X, and H3X deenergized, see above	Branches H1X, H2X, and H3X deenergized, see above	Loss of branch HX (hand power) alarmed. Operator expected to trip reactor, turbine, and feedwater pumps and regain manual control of selected components by manually transferring to KU power supply.
HEX	Yes	Yes	Lo pressurizer level if selected Lo SG level if selected Lo SG pressure if selected	Lo pressurizer level if selected Lo SG level if selected Lo SG pressure if selected	Loss of branch HEX (emergency power) alarmed. Operator expected to select energized transmitters.
HEY	Yes	Yes	Lo pressurizer level if selected Lo SG level if selected Lo SG pressure if selected	Lo pressurizer level if selected Lo SG level if selected Lo SG pressure if selected	Loss of branch HEY (emergency power) alarmed. Operator expected to select energized transmitters.
H-EL	No	Yes	None	None	Loss of branch H-EL (emergency SG level control power) alarmed in control room. No operator actions required during power operations. Use of emergency feedwater may be required following shutdown.
KI	Yes	Yes	Branches H, HX, HEX, HEY, H-EL deenergized, see above	Same as H, HX, HEX, HEY, H-EL deenergized, see above	Loss of panelboard KI (ICS panelboard) alarmed in control room. Operator expected to follow emergency procedure EP/O/A/1800/31, loss of KI bus.
KU	Yes	No	Lo pressurizer level if selected	Pressurizer level if selected, all computer outputs	Follow procedure for loss of plant computer. Select alternate pressurizer level signal for indication and control.
KI-10	Yes	No	Lo RCS pressure	RCS pressure	Identify spurious low RCS narrow range signal from comparison with RPS signals. Manually control pressurizer heaters, spray valve, and PORV.

*Other responses include the identification and repair of power supply failure.

- Most power supply failures resulted in the makeup control valve freezing in position (with manual control available) without significantly affecting RCS inventory. Failure of the power supply for the selected pressurizer level transmitter, however, opens the makeup valve. The operator, in this case, must manually control the makeup flow rate to prevent possible damage to the PORV and the operating high pressure injection (HPI) pump.

- Several power supply failures resulted in the pressurizer heaters remaining on or the pressurizer spray block valve remaining open if these components were energized or open at the time of power failure. The transient resulting is slow in either case; however, manual control is required.

2. Specific alarms were identified for failure of panelboard KI and branches H, HX, HEX, HEY, and H-EL. However, alarms for failure of lower level circuits (H1, H2, H4, H5, H8, H1X, H2X, and H3X) were not identified from available information. Alarms for these circuits, H1 and H1X in particular, and appropriate procedures for operator guidance are considered important to the rapid identification and manual mitigation of the resulting transients.

3. Possible operator responses to spurious control room displays resulting from power supply failures were evaluated qualitatively. In general, possible operator actions (or failures of the operator to perform an action) did not result in significant transients. Two potentially significant operator responses, however, were identified:

   - Following branch H, H1, or selected HEX or HEY failure at high reactor power and high steam generator level, the operator may close the main feedwater control valves. Due to the moderately long length of time that would elapse prior to requiring additional feedwater and the failure of the low-level alarm (spuriously energized by the power failure), the operator may fail to reopen the feedwater control valve prior to steam generator dryout. In this case automatic initiation of emergency feedwater is not expected since the main feedwater pumps are operating and only main feedwater pump trip initiates emergency feedwater.
   - Failure of the selected pressurizer level transmitter power supply will result in spurious low-level alarm and indication of pressurizer level and opening the makeup control valve. Although the operator should be alerted to the power supply failure by the ICS/NNI emergency power (HEX, HEY) failure alarms and should transfer to an operable transmitter, other events may distract him. The same power supply failure may result in reactor/

turbine trip, spurious low steam generator alarm and indication, increasing steam generator level, and main feedwater pump trip. If the pressurizer is allowed to fill and liquid is discharged through the PORV, valve damage could occur. Also, if the LST is allowed to drain (LST level is separately alarmed) and an alternate supply of water is not provided, damage of the operating HPI pump would occur.

4. During the power supply failure analysis, several modifications were identified which would prevent or moderate the effects of power supply failures. These modifications are suggested for review:

   - Transmitter selection relay power: The contact switches used to select one of two redundant transmitters frequently are powered by one of the transmitters' power supply in the ICS/NNI design. With proper selection, a power supply failure will result in an automatic transfer to the alternate energized transmitter. Modification of the HEX, HEY powered pressurizer and steam generator startup level transmitters' selection switches to this configuration is recommended (i.e., change the power supply of the transmitter selection relays to HEX or HEY and configure to allow automatic transfer on power supply failure. Also note, a more elegant, double-switch arrangement is used for the selection of the SGs' operate range level transmitters. This arrangement will allow automatic transfer on power supply failure regardless of the transmitter initially selected).
   - Automatic trip of feedwater pumps: Failure of branch H, H1, HX, or H1X is expected to cause a transient resulting in main feedwater pump trip (on high steam generator level). It is recommended that the pumps be tripped directly on loss of any of these power supplies (as they are on loss of panelboard KI) to minimize the effect of the transient.
   - Suppression of spurious alarms: The majority of alarm contacts are configured to alarm on power supply failure. The resulting spurious alarms are not expected to aid transient diagnosis and may mask operable alarms. It is recommended that the signal monitor alarm contacts be changed to an energize-to-alarm configuration.
   - Power supply failure alarms: Alarms for failure of branch circuits H1, H2, H4, H5, H8, H1X, H2X, and H3X were not identified from available information. If these circuit failures are not alarmed, it is recommended that alarms for branch circuits H1 and H1X be considered.

- Power supply failure procedures: The "Loss of KI Bus" emergency procedure is expected to be very useful in the manual recovery from KI failures, particularly in the identification of operable controls and indications. It is recommended that the power supply failure procedures be reviewed to determine whether lower-level power supply branch circuit failures are addressed and that specific instructions be added if they are not.
- Preferred transmitters: Preferred positions for transmitter select switches should be used where possible to reduce single power supply, failure dependence and/or subsequent automatic control response.

3. ICS/NNI FUNCTIONAL DESCRIPTION

The ICS/NNI is a series of fourteen electrical equipment cabinets containing the sensor and control circuits required for the controlled operation of the Oconee 1 nuclear steam supply system (reactor, steam generators, and associated supporting systems). The ICS portion of the system provides the integrated control of the feedwater flow rate to the system generators, the reactor core power, the reactor coolant temperature, and the pressure of the steam generated in the steam generators and supplied to the plant's high-pressure turbine. The NNI portion provides sensor input signals to the ICS, RCS inventory and pressure control, and control of selected auxiliary systems functions. In addition, the NNI provides plant parameter information to the plant operating staff through control room indicators, alarms, and the plant computer. More detailed descriptions of the functions performed by the ICS/NNI may be found in ref. 5.

The principal source of design information on the ICS/NNI used in this analysis is the Oconee ICS Instruction Book (ref. 6). This document shows the detailed ICS/NNI circuits and their sources of electric power. Available information supplied to ORNL by Duke Power was used to update several sources of information (refs. 7-12).

The major modifications incorporated in the analysis but not shown on the instruction book drawings are summarized below:

1. The use of panelboard KU (computer power) to power the RC pump seal injection automatic control circuit upon loss of panelboard KI.
2. The use of panelboard KU to power manual control circuits for makeup and letdown flow, turbine bypass valves, and pressurizer heater bank 2 from the control room or auxiliary shutdown panel.
3. The addition of manual control switches for the PORV and pressurizer spray valve in ICS Cabinet 13 powered independently of panelboard KI.
4. The use of ICS steam generator level signals to trip the main feedwater pumps on high level.
5. The use of ICS power (branch KI-10) to power the non-Class-1E RCS narrow-range pressure transmitter input to the NNI.

Due to the modifications which are known to have been made to the NNI/ICS, the possibility of additional changes not identified in available information is recognized. Uncertainties in the knowledge of the design have been identified where known.

3.1 NNI CONTROL OUTPUT SIGNALS

The NNI performs two general functions: measurement of plant parameters for plant control and control room indication, and control of selected RCS and auxiliary system functions. The equipment controlled by NNI and the associated NNI output identifications is listed in Table 3.1.

3.2 ICS SIGNAL INPUTS FROM NNI

The ICS controls main feedwater flow rate, reactor power, and steam pressure based on conditioned signals of plant parameters received from the NNI. These plant parameter signals are listed in Table 3.2.

3.3 NNI SIGNAL SELECT HAND STATIONS

In the NNI system, 26 hand stations are used to select sensors for control and indication. These hand stations control all NNI signal inputs to the ICS. In a number of cases, these signals have a mixed power supply dependence. In order to summarize these power supply dependencies, drawings were developed to show the signal power supply dependence for each hand station switch position (see Figs. 3.1 through 3.9).

Note that the hand station relay contacts are shown in the deenergized position.

3.4 ICS CONTROL OUTPUT SIGNALS

The control signals developed in the ICS for plant control are listed in Table 3.3. Identification of the controlled devices, the control signals type, and the ICS output identifications are provided.

3.5 COMPARISON OF BAILEY METER MODELS 721 AND 820 NNI/ICS DESIGNS

The three units of the Oconee Nuclear Station have the Bailey Meter Model 721 ICS and NNI system. This system distributes 120-V ac power directly to individual function modules as well as to sensors, relays, relay power supplies, and E/P valve controllers from a number of ac branch circuits. The responses of the 721 series ICS/NNI to power failures are described in this report.

Four of the seven operating B&W-designed plants (Rancho Seco, Davis Besse, Crystal River, and Arkansas Nuclear Stations) have Bailey Meter Model 820 NNI and ICS systems that provide functions similar to the 721 ICS/NNI. The 820 systems use two sets of bipolar dc power supplies fed from 120-V ac buses to distribute module and dc relay power to the NNI system, and a third set of bipolar dc power supplies distributes module and dc relay power to the ICS. The B&W-designed Bellefonte and

Table 3.1 Summary of NNI auxiliary control outputs

Output identification	Description
183-1/PLL 183/PLL	Lo-lo pressurizer level interlock for heater banks 1, 2, 3, and 4 (auto).
1RC3-PS8 (27/H1-RP)	High and low pressure control contacts for the PORV (relief valve RC-V3) (auto).
1RC3-PS5 1RC3-PS6 1RC3-PS7 183/BHO-2 183/BHO-3 183/BHO-4	High and low pressure control contacts for heater banks 2, 3, 4 (auto and manual).
1RC3-PIC	Analog signal to silicon-controlled rectifier (SCR) controller for heater bank 1 (auto and manual).
1RC3-PS3 83/M-O 83/M-C	High- and low-pressure control contacts for the pressurizer spray valve (auto and manual).
83-L/SSV	Open and close control contacts for pressurizer spray stop valve (manual).
1RC5A-TS 1RC5B-TS	Interlock contacts to prevent RC pump start on low RC temperature (auto).
1HP14-LS2	Control contact on low letdown storage tank level - function unknown, drawing 8032326 missing (auto).
1HP14-LR	Control contact to switch 3-way valve HP-V10 to divert letdown reactor coolant to the LST on low LST level (B&W elementary drawing 136129E missing) (auto)
1HP11-FS	Interlock contact to prevent RC pump start on low seal inlet header flow (auto).
1HP-25 E/P	Analog signal to control makeup flow (auto and manual).
1HP11-E/P	Analog signal to control pump seal inlet header flow (auto and manual).
1HP28-DPS1 1HP28-DPS2 1HP28-DPS3 1HP28-DPS4	Interlock contacts to prevent individual RC pump start on low seal pressure drop (auto).
1HP3-E/P	Analog signal to control letdown flow (manual).

Table 3.2 ICS signal inputs from NNI

Signal input	Indicated range	Voltage range	Process operating range
Temperature-compensated RC flow	0 to 100%	0 to 10 V	0 to 100%
Generated electric frequency	57 to 63 Hz	±50 MV	57 to 63Hz
Generated electric power	0 to 999 MW	0 to 100 MV	0 to 874 MW
Turbine header pressure	600 to 1200 psig	±10 V	0 to 900 psig
Steam generator A and B pressure	0 to 1200 psig	±10 V	0 to 925 psig
RC T_{avg}	520 to 620° F	±10 V	532 to 579° F
Neutron power	0 to 125%	0 to 10 V	0 - 10^9 nV
Temperature-compensated (FW) flow loops A and B	0 to 5.67 × 10^6 lbm/h	±10 V	0 to 5.3 × 10^6 lbm/h
Feedwater temperature	0 to 470° F	±10 V	0 to 455° F
ΔT RCS loops A and B T_{cold} ±10°F		±10 V	±10° F
RC T_{hot} wide range	0 to 650° F	±10 V	120 to 600° F
RC flow loops A and B	0 to 70 × 10^6 lbm/h	±10 V	0 to 65.66 × 10^6 lbm/h
Steam generator A and B operate range level	0 - 100%	±10 V	0 to 378 in.
Steam generator A and B startup range level	0 to 400 in.	0 to 10 V	0 to 378 in.
FW valve A and B pressure drop	0 to 100 psi	±10 V	0 to 35 psi

ORNL-DWG 84-15958

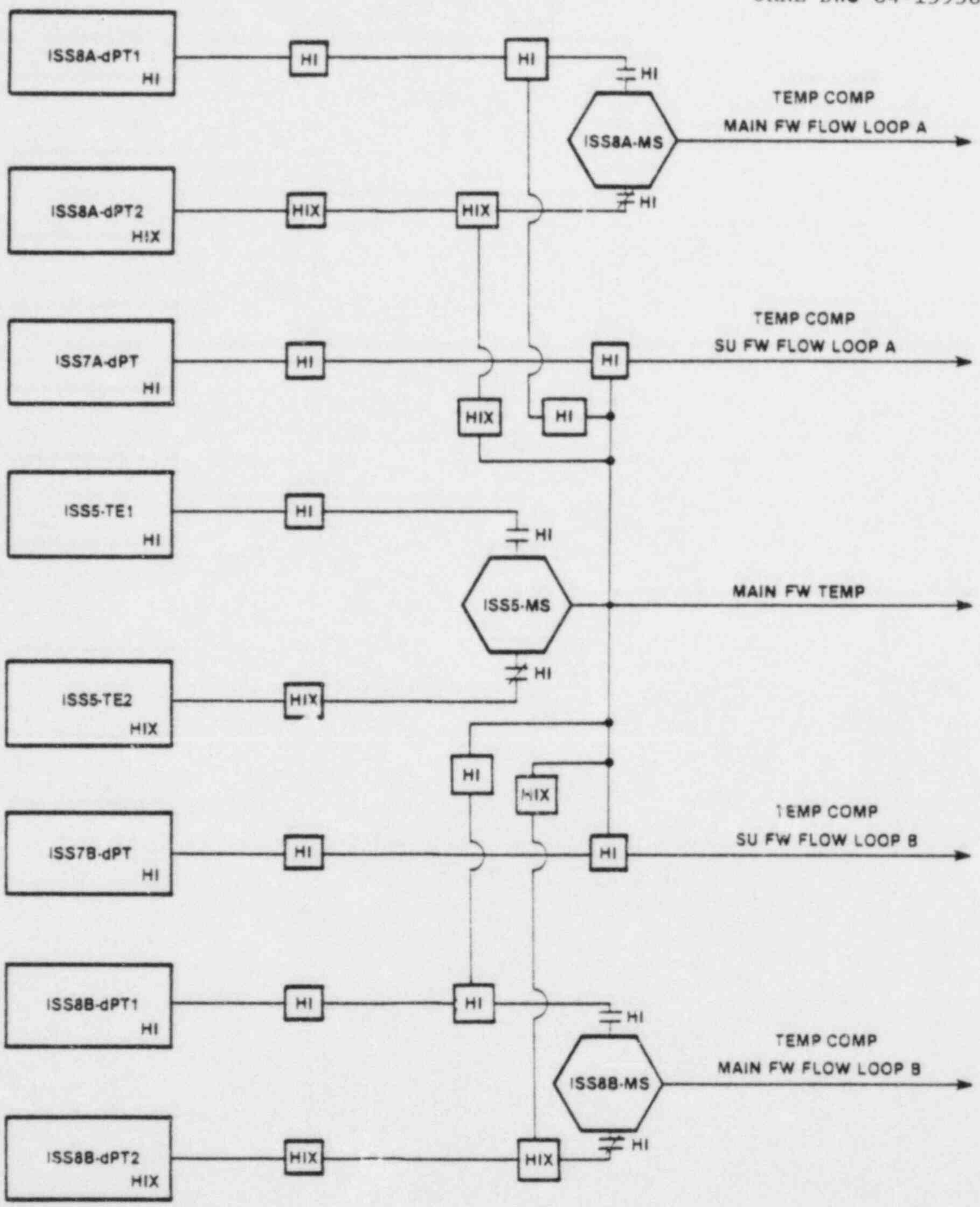
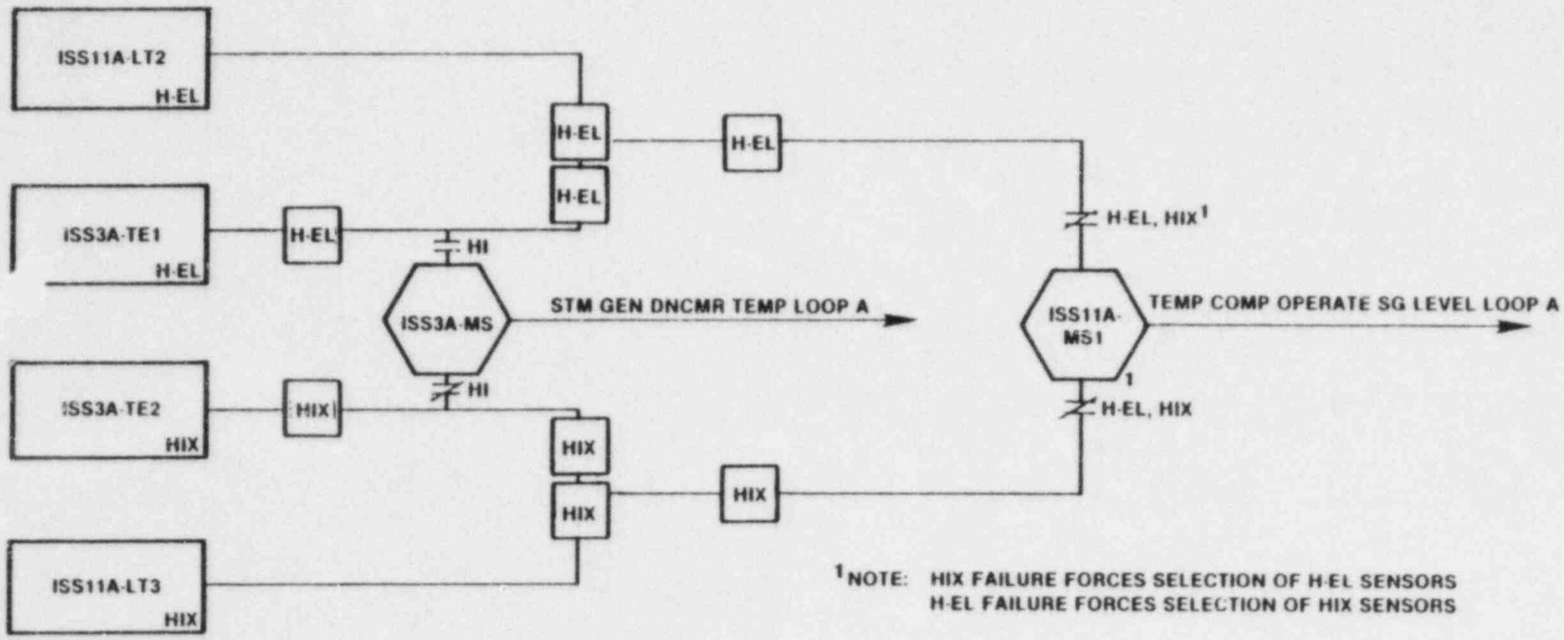


Fig. 3.1. Hand stations ISS8A, ISS8B, and ISS5.

ORNL-DWG 84-15959



[1]NOTE: HIX FAILURE FORCES SELECTION OF H-EL SENSORS
H-EL FAILURE FORCES SELECTION OF HIX SENSORS

Fig. 3.2. Hand stations ISS3A and ISS11A.

ORNL-DWG 84-15960

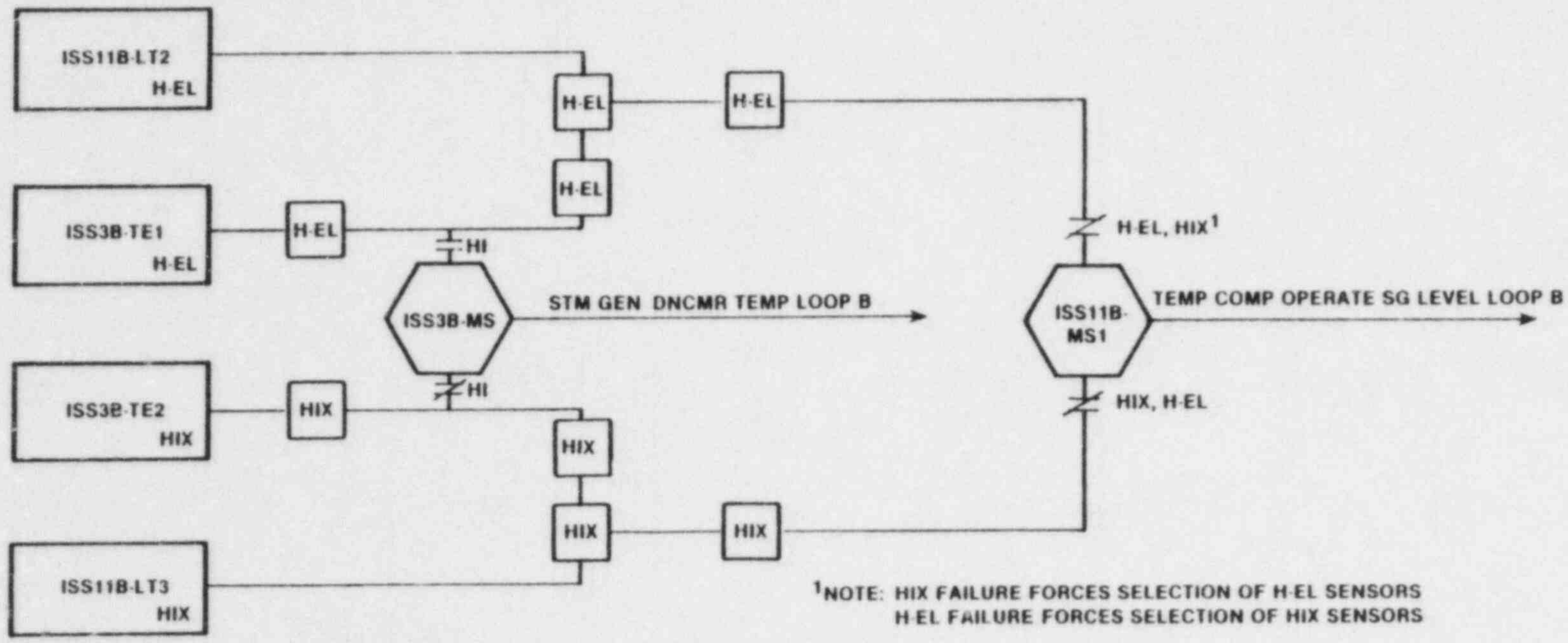


Fig. 3.3. Hand stations ISS3B and ISS11B.

ORNL-DWG 84-15961

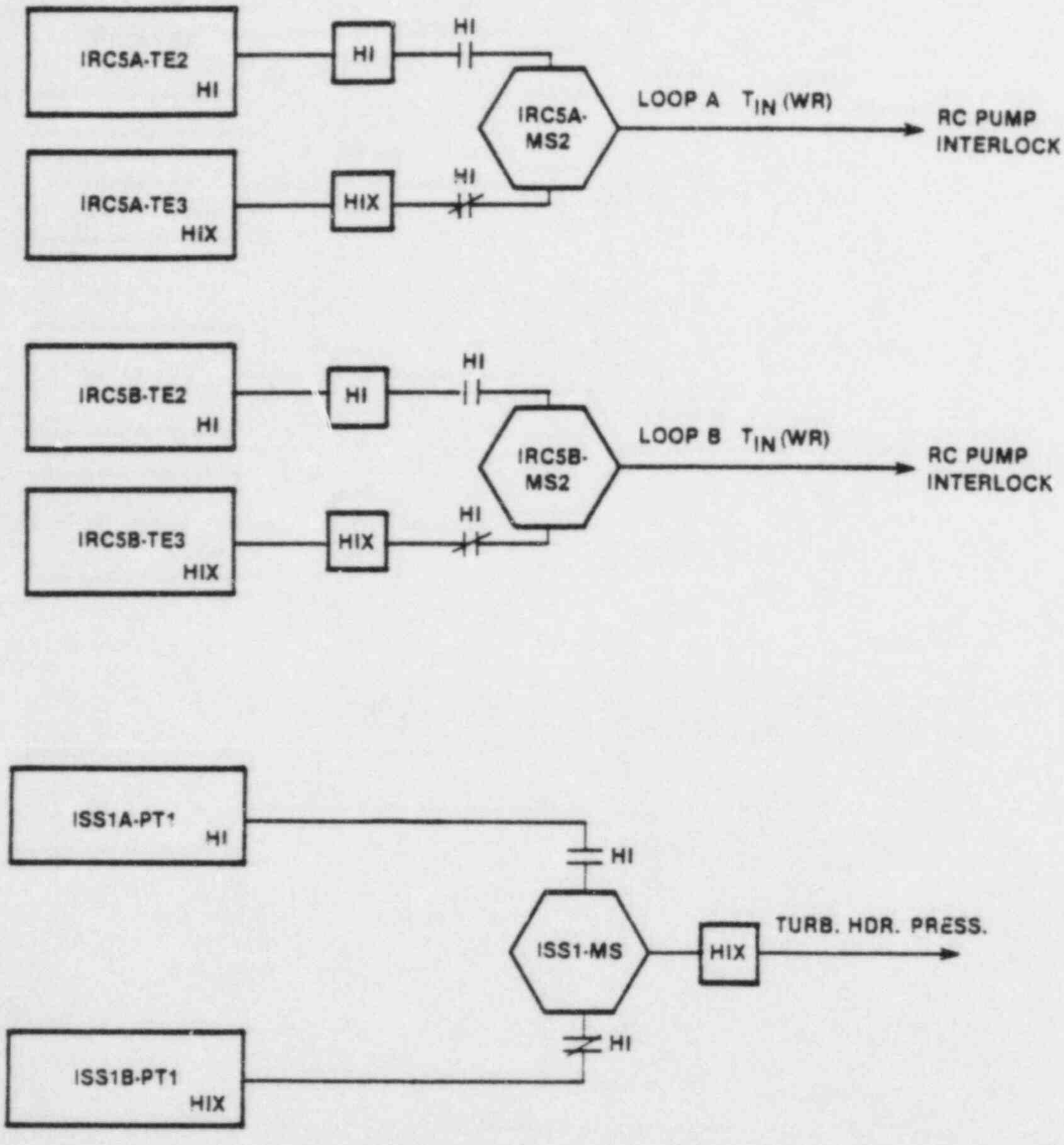


Fig. 3.4. Hand stations IRC5A, IRC5B, and ISS1.

ORNL-DWG 84-15962

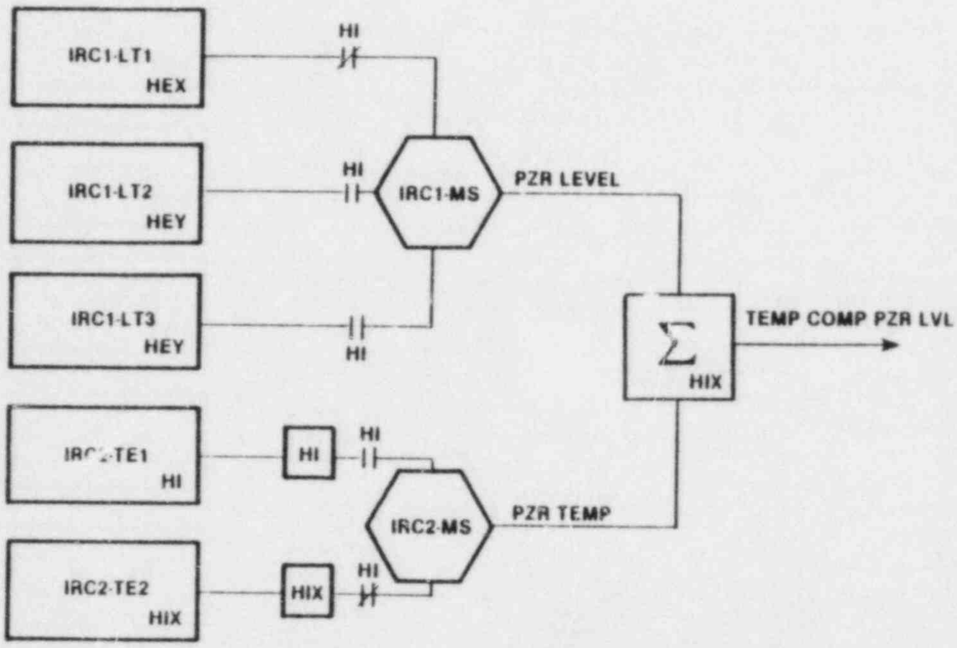


Fig. 3.5. Hand stations IRC1 and IRC2.

ORNL-DWG 84-15963

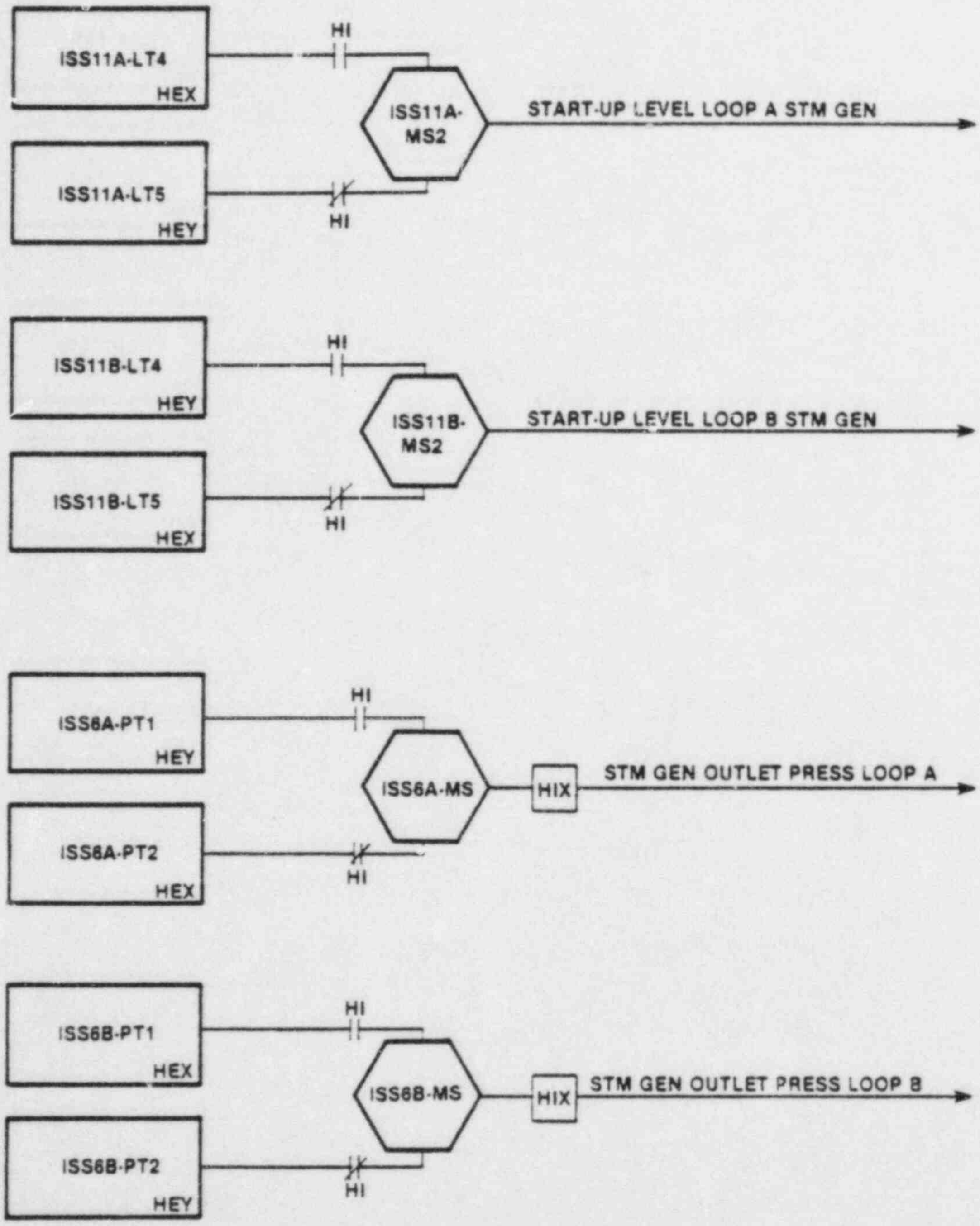


Fig. 3.6. Hand stations ISS11A, ISS11B, ISS6A, and ISS6B.

ORNL-DWG 84-15964

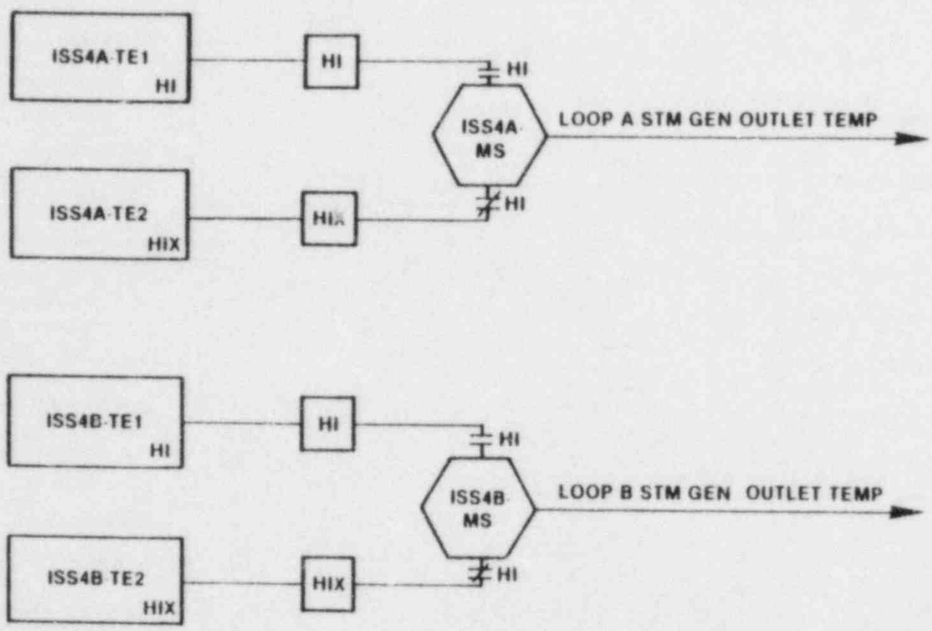


Fig. 3.7. Hand stations ISS4A and ISS4B.

ORNL-DWG 84-15965

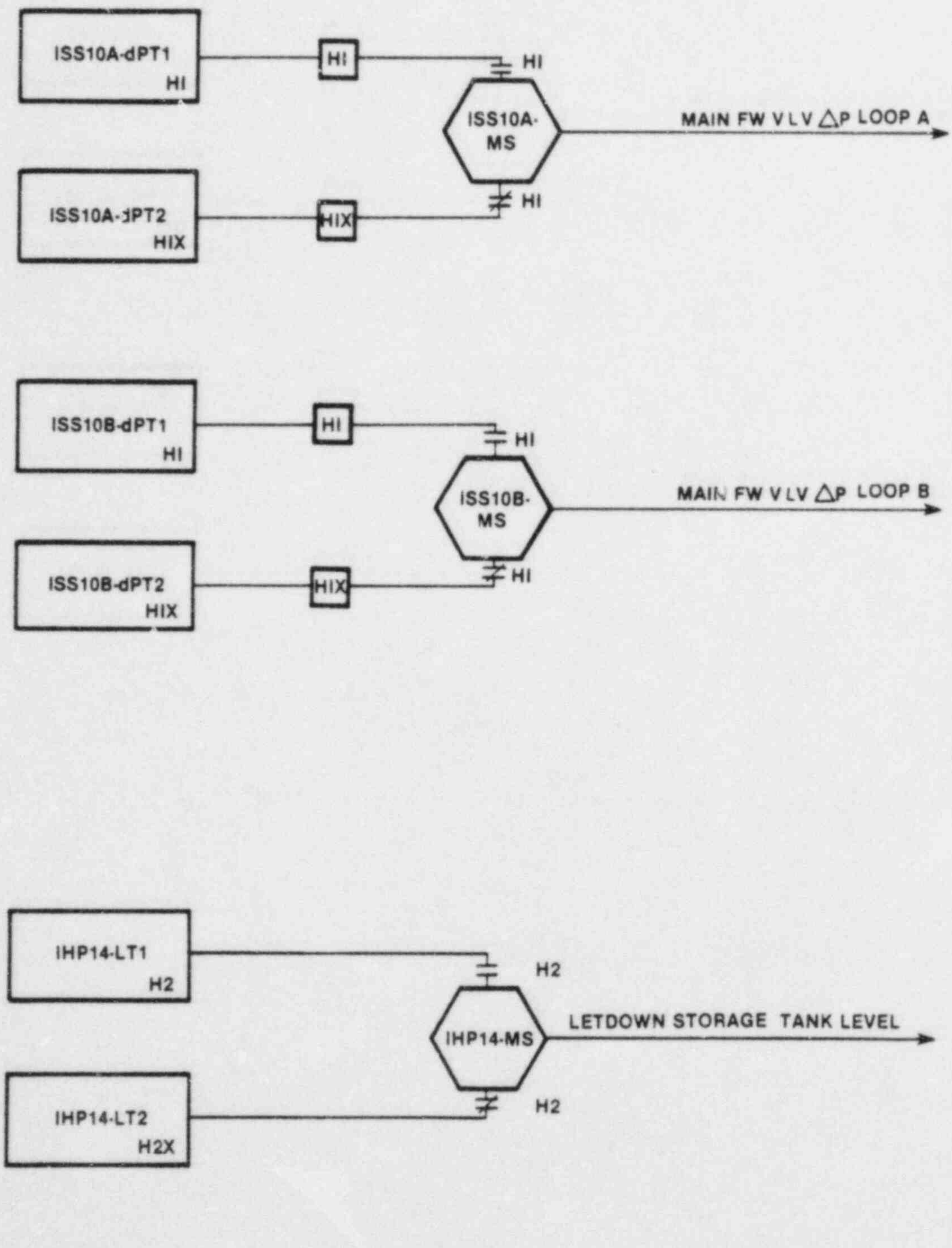


Fig. 3.8. Hand stations ISS10A, ISS10B, and IHP14.

ORNL-DWG 84-15966

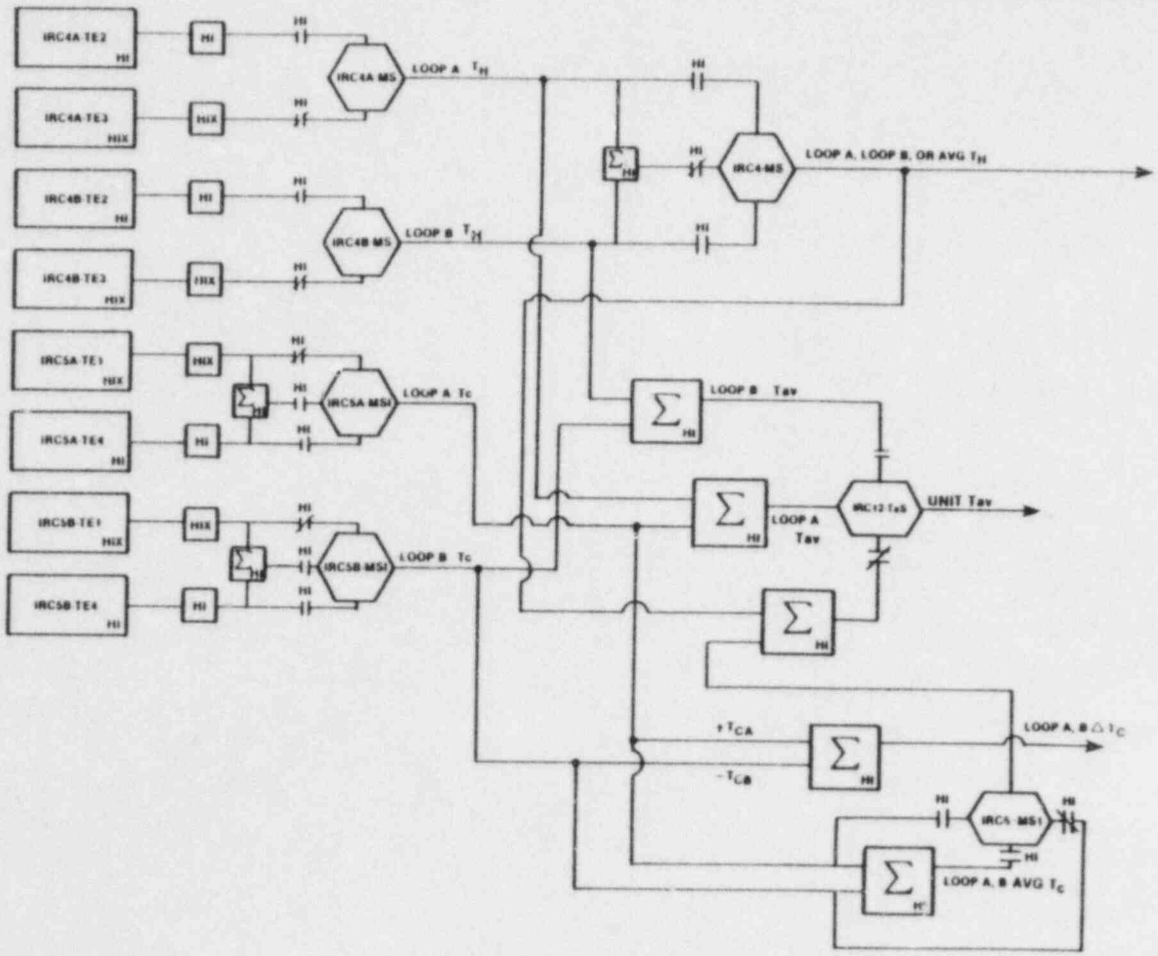


Fig. 3.9. Hand stations IRC4A, IRC4B, IRC5A, IRC5B, IRC4, IRC5, and IRC12.

Table 3.3. Summary of ICS control outputs

Output identification	Description
IC10-MSC (83/TCV)	Control contact to open and close turbine control control valves (auto and manual).
1MT6-E/P 1MT7-E/P 1MT13-E/P 1MT14-E/P	Analog signal to open and close turbine bypass valves (auto and manual).
1SSV2A-E/P 1SSV2B-E/P	Analog signals to open and close startup feedwater valves (auto and manual).
MFV-1A MFV-1B	Analog signals to open and close main feedwater valves (auto and manual).
IC36A-MCS IC36B-MSC	Analog signals to control main feedwater pump speed (auto and manual).
RC18.13 (86-1/RPI, 86-1/RPD)	Control contacts to insert and withdraw control rods (auto and manual).

WNP Nuclear Stations, now under construction, have an extended arrangement of the 820 NNI system where part of the NNI signals are obtained from redundant Class 1-E essential control and instrument (ECI) systems. The ECI signals are received through an optical isolation system that has additional bipolar dc power supplies.

The 820 series NNI systems use two sets of bipolar power supplies typically designated "X" and "Y." An additional set of bipolar power supplies provide dc power to the ICS. Some redundancy in X- and Y-powered signals is available, although not all input signals to the ICS from the NNI can be selected from one supply or the other. The bipolar dc power supplies are operated in pairs, with the outputs from two separate supplies summed through diodes. The ac power input to a pair of the bipolar dc supplies typically is provided from different ac power buses. In this manner, a failure of a single ac bus will not interrupt the summed dc supply output.

The bipolar dc power supply outputs are monitored by a power supply monitor circuit. In the event either polarity drops below a set value, the power supply monitor will interrupt the ac power input to both dc supplies. In this manner, operation with a single power supply polarity is prevented. The power supply monitor will deenergize the dc power supplies in the event of a short circuit on the dc distribution wiring between the power supply output and the associated NNI or ICS modules.

The NNI/ICS bipolar dc power is distributed inside the system cabinets by wire wrap connections to module sockets. One wire is used to serve multiple modules in some cases. The potential exists for operation of multiple modules with single polarity due to physical separation of a power supply distribution wire. While possible, such events are not known to have occurred.

Due to the differing power distribution arrangements and the types of power supply failures, the plant responses to these failures differ. In the Oconee 721 ICS/NNI, a majority of the control circuitry is powered from 120-V ac auto power (branch H/H1) and hand power (branch HX/H1X). Failure of either of these power circuits results in most controlled devices remaining in position due to a transfer to "manual" or deenergized output devices (e.g., E/P controllers). Selected sensor devices (e.g., RCS pressure or SG level) are powered from separate power circuits. Failure of these power circuits results in energized control circuitry responding to failed input signals.

In the 820 designs, the majority of sensor and output devices are powered from one of the 120-V ac buses. The internal ICS/NNI circuitry, however, is powered from one of the two NNI bipolar dc power supplies or the ICS bipolar dc supply. Since any of the ac buses or bipolar dc power supplies may fail independently of the others, a much wider variety of power supply failure combinations is possible in the 820 model than in the 721 model ICS/NNI.

As an example, the 820 model ICS receives approximately 20 sensor input signals from the NNI. A majority of these inputs may be selected manually from either an X- or a Y- powered circuit. Thus, depending on the signal selection, the energized ICS-controlled devices could respond to a combination of input signals of which any one or more signals may be deenergized due to a failure of a single NNI bipolar dc power supply. Major transients of this type were initiated at the Rancho Seco and Crystal River stations due to loss of a bipolar dc power supply.

The 820 series NNI and ICS responses to power failures have been studied in depth by operating B&W-designed plants in response to NRC IE Bulletin 79-27. Failure modes have been identified and procedures and training developed for operator identification of the power supply failure states and identification of operable indicators and controls. In addition to the development of procedures and operations, the other steps taken include direct annunciation of power supply failure, tagging power supply dependence on indicators and controls, the use of standard sensor selections to reduce the number of potential transient styles, and some power supply modifications to reduce single-failure dependence.

4. POWER SUPPLY DEFINITION AND ANALYSIS

A one-line power distribution drawing (Fig. 4.1) was developed for the analysis of the ICS/NNI power supply dependencies. This diagram was used to identify unique single-failure modes and the associated ICS/NNI electrical loads. These failures then were used as input to the ICS/NNI power supply failure effects analysis.

The power supply failures analyzed corresponded to single failures at nodes in the power distribution drawing. Multiple independent failures in the power distribution system were not analyzed.

The ICS and NNI power supply system is a combination of ac power supply buses. Loss of ac power was considered to result from the associated ac bus failing to zero volts. As shown in Fig. 4.1, the ICS/NNI is powered from 118-V ac panelboard KI, with transfer of selected circuits to panelboard KU upon loss of KI. Panelboards KI and KU each are powered through inverters from 125-V dc buses DCA and DCB. In addition, these panelboards may be powered from 118-V ac regulated instrument bus KRA by automatic transfer (ref. 9).

From panelboard KI, power is distributed to the ICS/NNI through five separate branch circuits capable of being isolated by circuit breakers: KI-1, KI-3, KI-5, KI-9, and KI-22. The hand power, HX (KI-1), and auto power, H (KI-22), branches are distributed within the ICS/NNI cabinets through an additional three and eight circuit breakers, respectively (ref. 6). The individual branch circuits feeding the ICS/NNI are shown on Fig. 4.1 and listed in Table 4.1.

The circuits shown in Table 4.1 are considered separate failure points in the FMEA of the ICS/NNI power distribution circuitry. It is assumed that an arbitrary fault in the circuitry will be isolated by a circuit breaker, deenergizing all circuits fed through that breaker. Thus, a fault in the circuits fed by branch H1 may be isolated by the circuit breaker in H1 or the circuit breaker in the auto power branch, KI-22, or result in the entire KI panelboard being isolated from its power sources. The power circuits shown in Table 4.1 represent 18 separate electric power failures to be considered in the FMEA. However, although branch circuits could be identified, specific modules fed from branch circuits H3, H6, and H7 could not be identified.

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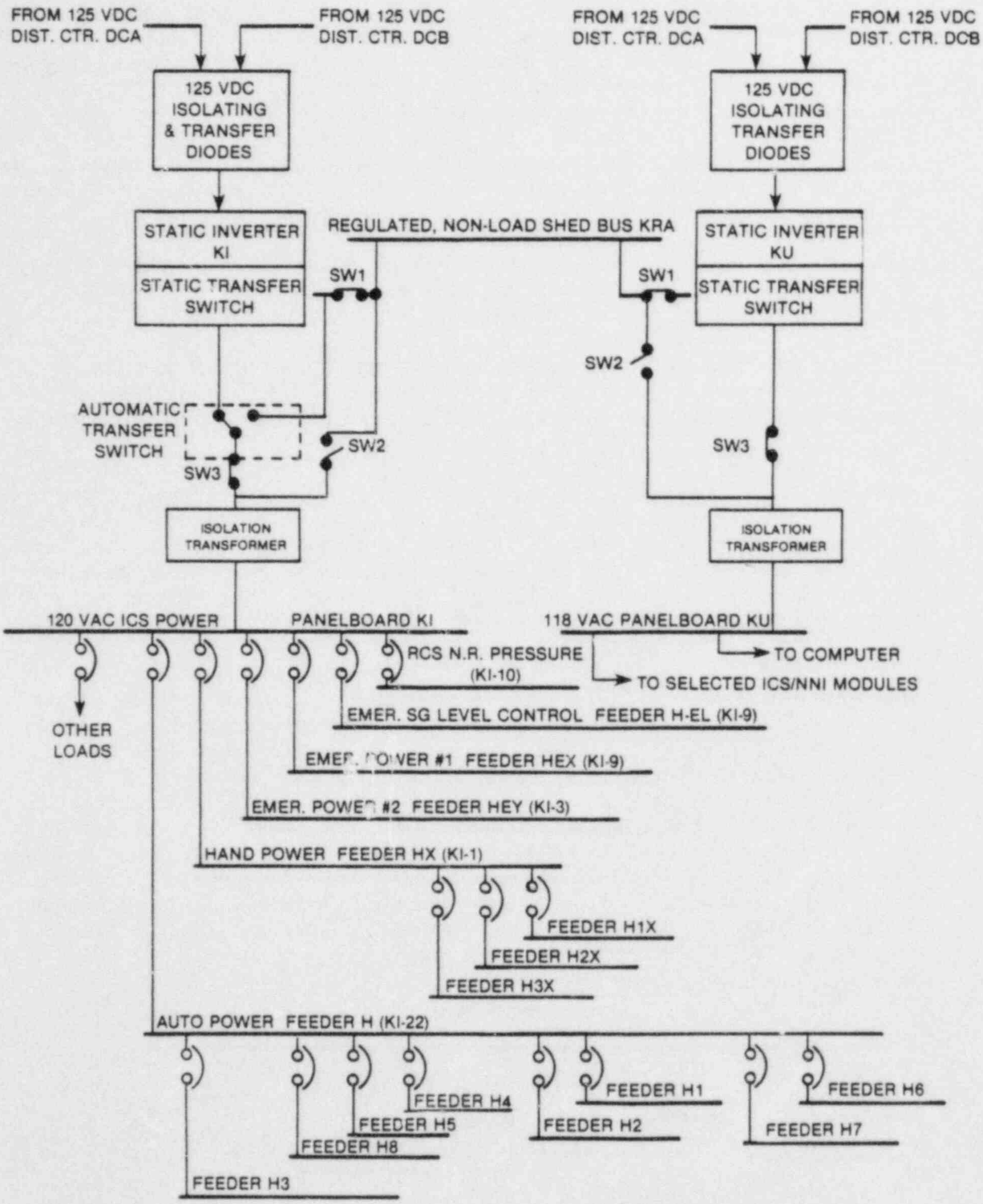

Fig. 4.1. Oconee 1 nuclear station ICS/NNI ac power supply.

Table 4.1. ICS/NNI electric power distribution circuits (118 V ac, 60 Hz, 1 phase)

1. ICS power panelboard KI

    1.1 Hand power, branch HX (KI-1)

        1.1.1 Branch H1X (HX to aux. shutdown panel), 10 A
        1.1.2 Branch H2X, 2 A
        1.1.3 Branch H3X, 2 A

    1.2 Emergency power #1, branch HEX (KI-5)

    1.3 Emergency power #2, branch HEY (KI-3)

    1.4 Emergency steam generator level control, branch H-EL (KI-9)

    1.5 Auto power, branch H (KI-22)
        1.5.1 Branch H1, 10 A*
        1.5.2 Branch H2, 10 A
        1.5.3 Branch H3, 2 A
        1.5.4 Branch H4, 2 A
        1.5.5 Branch H5, 2 A
        1.5.6 Branch H6, 2 A
        1.5.7 Branch H7
        1.5.8 Branch H8

    1.6 RCS narrow-range pressure, branch KI-10*

2. Computer power panelboard KU

*Per comments from Duke Power.

5. EFFECTS OF ELECTRIC POWER BRANCH H1 CIRCUIT FAILURES ON ICS/NNI CIRCUITS

5.1 NNI CONTROL RESPONSE

NNI control response to H1 power failures is shown in Table 5.1. No rapid transient is introduced, and manual controls remain available. The pressurizer spray valve would remain open until closed manually if it were open at the time of power failure. The pressurizer heaters would transfer to manual and remain energized until controlled manually if they were energized at the time of power failure. These controls would lead to changes in pressure and pressurizer level and could lead to a reactor trip unless controlled by the operator. The pressure-operated relief valve would fail closed, and any required pressure relief would be provided through a safety relief valve.

5.2 ICS CONTROL RESPONSE

ICS control response to H1 power failure is summarized in Table 5.2. The ICS control stations would switch to manual at the operating values existing at the time of power failure. If the power failure occurred during steady-state operation, the plant could continue to be operated under manual control. If the power failure occurred during a transient, it is likely that a reactor trip would result due to difficulty in balancing steam, reactor, and feedwater demand. If the power failure occurred immediately following a trip, there would be an initial tendency for overcooling until feedwater flow was manually matched to the reactor heat output. Such overcooling would be automatically terminated by a steam generator high-level trip of the main feedwater pumps.

5.3 AUTOMATIC SYSTEM RESPONSE

Failure of the H1 branch circuit would result in the automatic transfer of many automatic plant control circuits to the manual mode. This transfer would result in ICS reactor power, turbine throttle, main and startup feedwater valves, main feedwater pump, pressurizer spray valves and "on-off" pressurizer heater, and makeup flow controls transferring to manual and "freezing" these variables at their existing values. The PORV would close or remain closed, the SCR-controlled pressurizer heaters may be spuriously energized (with manual control available), and the turbine bypass valves would be automatically controlled, with manual control available only from the auxiliary shutdown panel.

Under these conditions the plant would continue to operate but would be unable to respond automatically to induced perturbations (e.g., continued pressurizer spray and/or heater operation, etc.). The major effect of such a perturbation would be a reactor/turbine trip followed by increasing level in the steam generators. Unless throttled by the

Table 5.1 NNI auxiliary controls response to H1 power failure

Item	Output identification	Description	Effect	Comments
1.	183-1/PPL 183/PLL	Pressurizer lo-lo level, interlock heater banks 1, 2, 3, 4	Relays 183/PLL and 183-1/PLL lose power. Will not cut off heaters on lo-lo- pressurizer level.	(Dwg. D8032338G)
2.	1RC3-PS3	Pressurizer spray valve RC-V1	Control relays are deenergized and automatic control is lost. Valve will remain closed or open depending on its position at time of power failure.	Manual control dependent on H1X is operable (Dwg. D8032338G).
3.	1RC3-PS5 1RC3-PS6	Pressurizer heater banks 2, 3, 4	Control relays are deenergized and automatic control is lost. Heater banks remain on or off depending on state at time of power failure.	Manual control dependent on H1X is operable (Dwg. D8032339E).
4.	None	SCR controlled heater bank 1	Heater bank may be energized due to low RCS pressure signal input to SCR controller.	Manual control is operable. Zero-V input signal should be compared to heater bank setpoint.
5.	1RC3-PS8	Relief valve RC-RV3 (27/HI-RP)	Control relays are deenergized and automatic control is lost. Valve will close or remain closed.	Per Dwg. 8032332E. Actual control relay not found. Manual control Operable.
6.	1HP-25 E/P	Makeup flow demand to makeup flow control valve	Probable transfer to manual. Valve remains in position existing prior to power failure.	Power to relay 83/LT not shown on Dwg. 8032338G.
7.	1RC5A-TS 1RC5B-TS	Reactor coolant Pump start interlock	Interlock relays are deenergized. Permits RC pump start at low RC temp.	

Table 5.2 ICS control response to H1 power failure

Item	Output identification	Description	Effect	Comments
1.	IC10-MCS (83/TCV)	Turbine throttle valve	Valve remains as is.	Cannot be increased or decreased by ICS. Manual controls operable.
2.	1MT6-E/P 1MT7-E/P 1MT13-E/P 1MT14-E/P	Turbine bypass valves	Manual control at ICS is lost.	Control automatically on steam generator pressure; manual control at aux. shutdown panel operable.
3.	RC18.13 (86-1/RPI 86-1/RPD)	Reactor power	Reactor power remains as is.	Cannot be increased or decreased by ICS. Manual control of control rods operable.
4.	IC36A-MCS IC36B-MCS	Main feedwater pump speed	Switches to manual at operating value.	Manual control operable.
5.	MFV-1A MFV-1B	Main feedwater valve position	Switches to manual at operating value.	Manual control operable.
6.	1SSV2A-E/P 1SSV2B-E/P	Startup feedwater valve position	Switches to manual at operating value.	Manual control operable.

operator, the main feedwater pumps would automatically trip on steam generator high level and the emergency feedwater system would start automatically.

5.4 CONTROL ROOM PARAMETER DISPLAY

The H1 failure would result in spurious alarms and deenergized meter indicators and recorders. High-and-low level pressurizer, high and low RC T_{avg}, and steam generator A and B low startup levels would be alarmed spuriously. The operator could verify that these contradictory alarms were spurious by the operable meter indications of these parameters.

Deenergized indications (bottom of scale) resulting from the H1 failure include cold leg dT, RCS loop A temperature and T_{avg}, steam generator A wide-range level, and Loops A and B startup feedwater flow rate. Also, the digital T_{avg} indication and recorders indicating RCS T_{av} and Loop A and B main feedwater flow would be deenergized. Specific indication or alarm of the H1 failure has not been identified from available information. If the operator reenergizes the H1 power failure, steady state operation of the plant under manual control while H1 is being restored is expected. If the power failure were not recognized, the expected response of the operator to the H1 power failure would be to trip the plant or manually attempt a controlled runback. A manual runback is considered difficult but possible with available indications and controls. If the operator succeeded, the plant would be shut down without a significant transient. If the attempt failed, the major result would be a reactor trip.

If the plant were tripped, either by the operator or automatically, the operator must manually throttle main feedwater to control the steam generator level (based on steam generator startup-range level indications). The operator may choose to isolate main feedwater and utilize the automatically controlled emergency feedwater system. If the operator failed to control level, the main feedwater pumps would be automatically tripped on steam generator high level and the emergency feedwater system would be started and controlled automatically.

The spurious low-level steam generator alarms may be significant in the manual control of steam generator level. The initial steam generator levels are expected to be high, which would require manual closure of the main and startup feedwater control valves. Since a period of time may elapse prior to requiring opening of the startup valves, the unavailability of low-level alarms could contribute to the failure to reopen the valves when required. This would lead to steam generator dryout.

In addition to feedwater control, the operator must manually control the makeup flow control valve, pressurizer spray valve, and pressurizer heaters to control pressurizer level and pressure. Although the pressurizer level alarms are unavailable, pressurizer level is not expected to vary significantly once RCS temperatures stabilize following reactor trip, and therefore immediate manual control of pressurizer level is not considered critical.

6. EFFECTS OF ELECTRIC POWER BRANCH H2 CIRCUIT FAILURES ON ICS/NNI CIRCUITS

6.1 NNI CONTROL RESPONSE

The only control failure resulting from a failure of branch H2 is the spurious interlock of the reactor coolant pump (RCP) start circuitry (see Table 6.1). H2 power must be restored to remove this interlock. Since no plant transient is involved, the failure should not affect normal operation. However, H2 power failure during a transient that involved RCP trips could prevent pump restart on demand. Since the pressurizer spray operates on core differential pressure, loss of reactor coolant flow would also prevent pressurizer spray operation and therefore affect pressure control. The pressurizer PORV would remain operational.

6.2 ICS CONTROL RESPONSE

H2 branch power failure would not affect ICS response or control functions. Normal operation would continue.

6.3 AUTOMATIC SYSTEM RESPONSE

The HPI (non-safety-related makeup and letdown functions) system instrumentation is powered via branch circuits H2 and H2X. Failure of branch H2 would not cause a plant transient due to automatic control actions; the only automatic actions resulting would be transfer of the seal injection flow control to manual at the existing flow rate and interlocking the RCPs to prevent their being started.

6.4 CONTROL ROOM PARAMETER DISPLAY

Failure of H2 would result in several spurious alarm signals (contact closures) and meter indications. Assuming that the control room alarm/annunciator circuits are powered separately from H2, low RCP seal dP would be alarmed for all seals. Low and high seal injection and outlet flow rates would also be alarmed. Meter indication of seal dP, seal injection flow, and seal outlet flow indicate low (bottom of scale). In addition to the RCP seal related parameters, the meter indication of letdown flow would be low. All other indicators, alarms, and recorders would remain operable. Specific indication of the H2 failure may be available but has not been identified from available information.

Following the H2 failure the plant would continue to operate normally without operator intervention. Operator response to the spurious alarms and indications is difficult to assess due to contradictory information (e.g., high and low flow alarms). Possible responses include manually increasing seal injection flow, tripping the RCPs, and establishing natural circulation in the RCS.

Table 6.1 NNI auxiliary controls response to H2 power failure

Item	Output identification	Description	Effect
1.	1HP11-FS	RCP interlock - low seal flow	Interlock relays are deenergized. Cannot start pumps due to indicated low seal flow.
2.	1HP28-DPS4 1HP28-DPS1 1HP28-DPS3 1HP28-DPS2	RCP interlock - low RCP B2, A1, A2, B1, SL #1, D/P	Interlock relays are deenergized. RCP are deenergized.
3.	1HP11-E/P	Seal inlet header flow E/P converter	Remains as is due to analog memory module.

7. EFFECTS OF ELECTRIC POWER BRANCH H4 CIRCUIT FAILURES ON ICS/NNI CIRCUITS

7.1 NNI CONTROL RESPONSE

H4 branch failure would not affect NNI control response. No change in operation would occur.

7.2 ICS CONTROL RESPONSE

H4 branch failure would not affect ICS control response. No change in operation would occur.

7.3 AUTOMATIC SYSTEM RESPONSE

The CFT pressure alarms and indicators are powered by branch circuits H3X and H4. No control circuits are powered by these power supplies, and consequently failure of H3X and/or H4 would not cause an immediate transient.

7.4 CONTROL ROOM PARAMETER DISPLAY

Failure of branch H4 would result in spurious CFT high- and low-pressure alarms and one of the two dual pressure meters failing low (bottom of scale). Operator response to these spurious indications and alarms is not expected to cause a plant transient.

Although redundant CFT level indications are provided in the control room (ref. 5), these circuits were not found in the CFT/NNI circuitry. Power sources for the CFT level circuitry could not be identified.

8. EFFECTS OF ELECTRIC POWER BRANCH H5 CIRCUIT FAILURES ON ICS/NNI CIRCUITS

8.1 NNI CONTROL RESPONSE

H5 branch power failure would not affect NNI control response. No change in operation would occur.

8.2 ICS CONTROL RESPONSE

H5 branch power failure would not affect ICS control response. No change in operation would occur.

8.3 AUTOMATIC SYSTEM RESPONSE

Branch circuit H5 powers waste disposal system display and alarms circuitry. No control circuits are powered by this power supply, and consequently failure of H5 would not cause an immediate transient.

8.4 CONTROL ROOM PARAMETER DISPLAY

Failure of H5 would result in quench tank temperature, pressure, and level being spuriously alarmed high and indicated low (bottom of scale). The normal reactor building (RB) sump level would be spuriously alarmed high and low and indicated low. Liquid and gaseous waste flows would be indicated low (bottom of meter scales), and the liquid waste recorder would stop. No operator actions affecting RCS operation are expected.

9. EFFECTS OF ELECTRIC POWER BRANCH H8 CIRCUIT FAILURES ON ICS/NNI CIRCUITS

9.1 NNI CONTROL RESPONSE

H8 branch power failure would not affect NNI control response. No change in operation would occur.

9.2 ICS CONTROL RESPONSE

H8 branch power failure would not affect ICS control response. No change in operation would occur.

9.3 AUTOMATIC SYSTEM RESPONSE

Branch circuit H8 powers RB pressure display and alarms circuitry. No control circuits are powered by this power supply, and consequently failure of H8 would not cause an immediate result.

9.4 CONTROL ROOM PARAMETER DISPLAY

Failure of branch circuit H8 would result in a spurious RB high-pressure alarm, the RB pressure recorder stopping, and the RB pressure meter indicating low (bottom of scale). No operator actions are expected to result from this failure because there are alternate building pressure indications available through the ESPS.

10. EFFECTS OF ELECTRIC POWER BRANCH H CIRCUIT FAILURES ON ICS/NNI CIRCUITS (FAILURE OF AUTO POWER)

The "auto power" branch H circuit feeds branch circuits H1 through H8. ICS/NNI instrumentation identified from available information utilized only branch circuits H1, H2, H4, H5, and H8. The instrumentation powered from branch circuits H3, H6, and H7 could not be identified.

10.1 NNI CONTROL RESPONSE

The NNI control responses to branch H failure have been listed in Tables 5.1 and 6.1 for failures of branches H1 and H2. Branches H4, H5, and H8 do not supply NNI control circuits. As discussed in Sects. 5.1 and 6.1, the pressurizer heater, spray block valve, and seal injection control valve would transfer to manual and remain in the operating state existing prior to the power failure. The PORV would close or remain closed.

10.2 ICS CONTROL RESPONSE

The ICS control responses to the branch H failure have been listed in Table 5.2 for failure of branch H1. Branches H2, H4, H5, and H8 do not supply ICS control circuits. The response of the ICS to a branch H failure, as discussed in Sect. 5.2, would be to transfer the reactor power, feedwater flow, and turbine throttle valve controls to manual. In this state the controlled devices cannot automatically respond to induced plant perturbations.

10.3 AUTOMATIC SYSTEM RESPONSE

As discussed above and in Sects. 5 and 6, failure of branch H is not expected to cause an immediate plant transient. However, upon failure of branch H many of the plant controls would transfer to manual and would be unable to respond automatically to induced plant perturbations. The effect of such a perturbation is expected to be an automatic reactor and turbine trip followed by increasing steam generator level. Unless the main feedwater flow is manually throttled, the main feedwater pumps would be tripped automatically on steam generator high-level and the emergency feedwater system would be initiated and controlled automatically.

10.4 CONTROL ROOM PARAMETER DISPLAY

Failure of branch H would result in a large number of spurious alarms and erroneous meter indications. These failed control room displays have been discussed in Sects. 5, 6, 7, 8, and 9.

In possible contrast to the above, branch H circuit failure is alarmed in the control room (ref. 8). With knowledge of the probable cause of the spurious alarms and indications, the operator would be expected to be capable of more rapid response to a possible reactor trip, including the manual throttling of main feedwater prior to a high-level, main feedwater pump trip.

11. EFFECTS OF ELECTRIC POWER BRANCH H1X CIRCUIT FAILURES ON ICS/NNI CIRCUITS

11.1 NNI CONTROL RESPONSE

NNI control response to H1X power failure is shown in Table 11.1. The pressurizer spray valve would remain in position at the time of power failure, and the pressurizer spray block valve would open. Pressurizer heater manual control would be lost, and the makeup flow control valve would function properly in automatic but would go to mid-position if manual control were attempted. The degraded pressure control will lead to a slow pressure transient and possibly to reactor trip.

11.2 ICS CONTROL RESPONSE

ICS control response to H1X power failure is shown in Table 11.2. The turbine throttle valves could close if the turbine-header pressure-sensor powered from H1X were selected. The turbine-bypass valves would close or remain closed due to loss of power to solenoid valves installed in the pneumatic lines between the electric-to-pneumatic (E/P) converters and the turbine-bypass valves' operators. Reactor power initially could increase, decrease, or remain constant depending on the change in indicated average reactor temperatures. This change would be determined by the temperature sensors selected for temperature control prior to the power failure. The main feedwater flow control valve would fail "as is" due to loss of power to the E/P converters, and the main feedwater pump speed probably would decrease due to a zero volt demand signal presented to the pump speed controller. The startup feedwater valve may open or close, depending on the input sensors selected, but would go to mid-position if the ICS hand control is placed in manual.

These control system responses are expected to result in a reactor trip due to spurious changes in reactor power resulting from degraded temperature signals and a probable decrease in feedwater flow rate resulting from the zero-volt main feedwater pump speed demand signal. Manual controls generally are disabled by failure of H1X. With the steam generators' pressure at 1050 psig (the lowest code safety valve lift pressure) and the main feedwater pump speed corresponding to the zero-volt signal, the main feedwater flow rate is expected to decrease to zero and the steam generators are expected to "dry out." Furthermore, unless the main feedwater pumps were manually tripped, automatic initiation of the emergency feedwater pumps would not be expected.

11.3 AUTOMATIC SYSTEM RESPONSE

Failure of the H1X branch circuit would cause a plant transient, probably resulting in reactor trip. The loss of H1X would result in a probable decrease in main feedwater pump speed (zero-volt speed demand

Table 11.1 NNI auxiliary controls response to H1X power failure

Item	Output identification	Description	Effect	Comments
1.	1RC3-PS3 83/M-O 83/M-C	Pressurizer spray valve RC-V1	Valve remains in position existing prior to power failure.	Loss of power to 83/A and 83/M-O and prevent automatic or manual operation.
2.	183/BHO-2 183/BHO-3 183/BHO-4	Pressurizer heater banks 2, 3, 4	Manual control loss. Automatic control expected to continue. Heaters would be deenergized if manual control was selected.	Dwg. D8032341 missing, may be relevant.
3.	None	SCR controlled pressurizer heater bank #1	Heater bank #1 will be deenergized or remain deenergized.	Loss of drive signal.
4.	1HP-25 E/P	Makeup flow control	If manual control at ICS hand station selected, valve will open or close to mid-position.	Auto control remains operable. Manual control at aux. shutdown panel or control room operable by manually transferring hand stations to KU power.
5.	83-L/SSV	Pressurizer spray block valve RC-V5	Valve opens.	Loss of power to 83-L/SSV.

Table 11.2 ICS control response to H1X power failure

Item	Output identification	Description	Effect	Comments
1.	IC10-MCS (83/TCV)	Turbine throttle valve	Valve may close due to apparent loss of turbine header pressure if sensor with H1X power is selected.	Sensor fails to 900 PSIA indicated; setpoint is 885 PSIG.
2.	1MT6-E/P 1MT7-E/P 1MT13-E/P 1MT14-E/P	Turbine bypass valves	Valves close due to deenergized solenoid valve isolating turbine bypass valves from instrument air supply.	
3.	RC18.13 (86-1/RPI, 86-1/RPD)	Reactor power	Increases, holds, or decreases reactor power.	Depends on temperature sensors selected and resulting increase, decrease, or constant value of T_{avg}.
4.	IC36A-MCS IC36B-MCS	Main feedwater pump speed	Probable decrease in speed.	Speed demand goes to 0 V value.
5.	MFV-1A MFV-1B	Main feedwater valve position	Valves "freeze" as is.	Loss of power to E/P.
6.	1SSV2A-E/P 1SSV2B-E/P	Startup feedwater valve position	Opens or closes in automatic depending on input sensors selected. 1/2 open when ICS hand control is put on manual.	Manual control at aux. shutdown panel operable.

Note: Probable initial undercooling and/or overcooling transient due to control rod response to temperature signal failures.

signals in a ±10-V range) and "freezing" the main feedwater control valves in position. Prior to reactor trip, if the H1X-powered turbine-header pressure signal were selected, the turbine throttle valve would close. Depending on the selection of RCS inlet and outlet temperature signals to the T_{avg} circuitry, the reactor power initially may be automatically increased, decreased, or remain constant.

Pressurizer heaters would be deenergized due to a spurious low-level interlock signal, and the pressurizer spray would continue either off or on depending on the spray valve position prior to the H1X failure. The pressurizer level control would operate properly in automatic but would drive the makeup control valve to mid-position if manual control were selected.

The freezing of the main feedwater control valve, the zero-volt feedwater pump speed signal, possible throttling of the turbine, and an increase or decrease in reactor power would be expected to lead to an automatic reactor trip. With the reactor and turbine tripped and the turbine bypass valves closed, feedwater flow would decrease to zero due to the decreased feedwater pump speed and the increased steam generator pressure. However, since the main feedwater pumps are not tripped, automatic initiation of the emergency feedwater system would not occur even if the steam generators were dry.

11.4 CONTROL ROOM PARAMETER DISPLAY

Failure of H1X would result in spurious high and low turbine-header pressure and pressurizer level alarms, steam generators A and B operate-range low-level alarms, and RCS hot-leg high-temperature and cold-leg dT alarms.

The several deenergized (bottom of scale indication) indicators and indicators with deenergized inputs could be interpreted to indicate a significant plant transient. The turbine header, steam generator pressure indicators, steam generator full-range and startup-range level indicators, feedwater flow indicators and the RCS loop A and B hot-leg and cold-leg temperature indicators would fail low. The T_{avg} indicators, while energized, may have failed inputs depending on manual selection. Specific alarm or indication of the H1X power failure has not been identified from available information.

The immediate operator response to the misinformation displayed in the control room is difficult to assess. If the operator takes no action, the transient would result in steam generator dryout and termination of secondary heat removal from the RCS as described in Sect. 11.3. The spurious indications and alarms, however, may suggest a steam line break or similar transient. Possible near-term operator responses may include manually tripping the reactor and turbine, manually initiating emergency HPI, manually initiating emergency feedwater, and/or tripping the main feedwater pumps.

With the operable steam generator startup-level indications available through the emergency feedwater control system, and the operable, H-EL powered, steam generator operate-range indications, the operator would be expected to manually initiate the emergency feedwater system and allow automatic control of steam generator level. Assuming that HPI were initiated, the operator would be expected to throttle HPI flow based on the operable pressurizer level indications and corroborated core subcooling indications (assuming emergency feedwater has been initiated). The manual initiation of HPI, however, may result in opening the pressurizer safety valves prior to throttling HPI due to the closed PORV (the PORV will close or remain closed due to the failure of H1X).

12. EFFECTS OF ELECTRIC POWER BRANCH H2X CIRCUIT FAILURES ON ICS/NNI CIRCUITS

12.1 NNI CONTROL RESPONSE

NNI response to H2X branch power failure is summarized in Table 12.1. Failure of branch H2X results in the automatic transfer of the power source for the deenergized makeup, letdown, and RCP seal injection control valves' E/P converters to panelboard KU. This transfer permits continued automatic control of the seal injection and makeup flow rates and manual control of the normally closed letdown valve.

12.2 ICS CONTROL RESPONSE

ICS response would not be affected by H2X power failure and normal control system operation would continue.

12.3 AUTOMATIC SYSTEM RESPONSE

Failure of branch H2X would not cause an immediate plant transient However, the letdown flow would be transferred automatically to the letdown storage tank (LST).

12.4 CONTROL ROOM PARAMETER DISPLAY

Spurious alarms resulting from the H2X failure indicate a high- and low-level LST. If the LST level transmitter LT-2 were selected, the control room meter would indicate low level. The operator may manually select transmitter LT-1 for indication, and the output of the deenergized and operable transmitter would be available through the plant computer. It is not known whether the H2X failure is alarmed in the control room from available information.

Due to the contradictory information available to the operator, manual actions following an H2X failure are uncertain. The operator may choose to isolate makeup and letdown and/or provide an alternate supply of water to the HPI pumps from the BWST.

Table 12.1 NNI auxiliary controls response to H2X power failure

Item	Output identification	Description	Effect	Comments
1.	1HP25-E/P	Makeup flow control	Power source to E/P converter transferred to panelboard KU.	Power source for E/P transducer is transferred automatically to panelboard KU to allow continued automatic control.
2.	1HP3-E/P	Letdown flow control	Power source to E/P converter transferred to panelboard KU.	Power source for E/P transducer is transferred automatically to panelboard KU to allow manual control.
3.	1HP11-E/P	Pump seal inlet header flow	Power source to E/P converter transferred to panelboard KU.	Power source for E/P transducer is transferred automatically to panelboard KU to allow continued automatic control.
4.	1HP14-LS2	Low LST level	Unknown	
5.	1HP14-LR	Contact open or contact close low storage tank level to HP-V10	Letdown flow automatically transferred to the LST.	

13. EFFECTS OF ELECTRIC POWER BRANCH H3X CIRCUIT FAILURES ON ICS/NNI CIRCUITS

13.1 NNI CONTROL RESPONSE

H3X branch failure would not affect NNI controls, and normal operation would continue.

13.2 ICS CONTROL RESPONSE

H3X branch failure would not affect ICS controls, and normal operation would continue.

13.3 AUTOMATIC SYSTEM RESPONSE

Branch circuit H3X powers CFT A and B pressure displays. No control circuits are powered by this power supply, and consequently failure of H3X would not cause an immediate transient.

13.4 CONTROL ROOM PARAMETER DISPLAY

Failure of branch H3X would result in one of two dual meters failing low and indicating low (bottom of scale) pressure in CFT A and B. Since the operator can corroborate the operable redundant dual meter reading with high RCS pressure, immediate operator intervention, causing a plant transient, would not be expected.

14. EFFECTS OF ELECTRIC POWER BRANCH HX CIRCUIT FAILURES ON ICS/NNI CIRCUITS (FAILURE OF HAND POWER)

14.1 NNI CONTROL RESPONSE

Failure of the HX branch circuit would deenergize H1X, H2X, and H3X power. The effect on NNI control response would be the combination of effects described in Sects. 11.1 and 12.1; the H3X branch circuit does not power any NNI control circuit. The net result would be freezing the pressurizer spray valve in position and transferring the makeup valve to manual, with the valve remaining in an "as is" position.

14.2 ICS CONTROL RESPONSE

HX branch circuit failure would affect ICS control response through H1X power failure as described in Sect. 11.2. There would be a probable reactor trip due to either the RCS temperature sensor selection at the time of the power failure and/or the expected change in main feedwater flow rate. Following reactor trip, feedwater at a reduced flow rate is expected to continue until manually tripped or automatically tripped by steam generator high level. Emergency feedwater would be initiated and controlled automatically.

14.3 AUTOMATIC SYSTEM RESPONSE

Failure of the HX branch circuit would result in an immediate plant transient as discussed above and in Sects. 11 and 12. Depending on the manual selection of input signals, the turbine throttle valve may close, the control rods would be either inserted or withdrawn, and the turbine bypass-valves would close. The main feedwater flow would be expected to be reduced and the main feedwater control valves "frozen" in position. The makeup and letdown control valves would transfer to manual control and remain in position, and the letdown flow would automatically transfer to or continue to flow to the LST. The PORV would close or remain closed, but the pressurizer spray block valve and pressurizer heaters would remain in the operating state existing prior to the power failure.

The spurious control actions described above are expected to result in a rapid reactor and turbine trip. The steam generator levels are expected to increase at a rate dependent on the reduced capacity of the main feedwater pumps with a zero-volt speed demand signal. The increasing level in the steam generator would be expected to close the startup feedwater-control valves and subsequently the main block valves. This would result in either automatic control of main feedwater or a high-level feedwater pump trip and automatic initiation and control of emergency feedwater.

14.4 CONTROL ROOM PARAMETER DISPLAY

The spurious alarms and indications resulting from an HX failure have been discussed in Sects. 11.4, 12.4, and 13.4, for the failure of H1X, H2X, and H3X, respectively. In the case of an HX failure, however, the operator is alerted to the situation by the ICS hand power failure alarm (ref. 8). With knowledge of the HX failure, the operator is expected to be able to rapidly mitigate the transient and establish manual control. Actions the operator may take include manually tripping the main feedwater pumps and manually controlling makeup flow, pressurizer heaters, and spray valve by manually transferring their NNI/ICS power supplies to the KU panelboard.

15. EFFECTS OF ELECTRIC POWER BRANCH HEX CIRCUIT FAILURES ON ICS/NNI CIRCUITS (FAILURE OF EMERGENCY POWER #2)

15.1 NNI CONTROL RESPONSE

One of three pressurizer level transmitters is powered from branch HEX. If this sensor is selected at the time of power failure, the control system would respond by opening the RCS makeup flow control valve. This would lead to an increase in pressurizer level and pressure. An operable transmitter could be selected manually at the signal-select hand station. (The effects of HEX power failure are listed in Table 15.1.).

15.2 ICS CONTROL RESPONSE

One steam generator startup-level transmitter in loop A and one in loop B are powered from HEX. If a sensor powered by HEX were selected at the time of power failure, the loop feedwater valve would open due to indicated low level in the steam generator. This would result in an overfeeding transient that could be corrected either by manually selecting the alternate sensor or transferring the ICS loop feedwater control to manual. This transient would be terminated automatically by feedwater pump trip on steam generator high level. The remaining two startup-level transmitters are powered from HEY (Sect. 16.2).

One of the two steam pressure transmitters on each steam line is powered from HEX. If the HEX-powered transmitter(s) were selected for control at the time of the power failure, the turbine-bypass valves on the affected steam line would close or remain closed, with manual control available.

15.3 AUTOMATIC SYSTEM RESPONSE

Failure of the HEX branch circuit will deenergize one of two steam generator startup-level transmitters, one of two pressure transmitters on each steam generator, and one of three pressurizer-level transmitters.

If selected for plant control, the deenergized, HEX-powered level transmitter on each steam generator (LT-4 and/or LT-5) would generate a zero-volt signal (0- to +10-V range), opening the main feedwater control valves to that steam generator. Unless throttled, the increased feedwater flow to either steam generator would result in automatic trip of the main feedwater pumps, automatic initiation and control of the emergency feedwater pumps, and a reactor trip.

If the HEX-powered, pressurizer-level transmitter (LT-1) were selected for plant control, the deenergized transmitter would generate a zero-volt signal (0- to -10-V range), opening the makeup control valve and

Table 15.1 NNI auxiliary controls response to HEX power failure

Item	Output identification	Description	Effect	Comments
1.	1HP-25 E/P	Makeup flow	Makeup valve will close if pressurizer level transmitter LT-1 is selected.	Pressurizer level indicates full if level transmitter LT-1 is selected. Manual control operable. Manual selection of operable level transmitters LT-2 or LT-3 for auto control is possible.
2.	183-1/PLL	Low-low pressurizer level heater bank 1	Heater bank #1 will be cut off or interlock will be rendered ineffective if pressurizer level transmitter LT-1 is selected.	
3.	183/PLL	Low-low pressurizer level heater bank 2, 3, 4	Heater banks 2, 3, 4 will be cut off or interlock will be rendered ineffective if pressurizer level transmitter LT-1 is selected.	

deenergizing the pressurizer heaters through the low-level heater-interlock circuit. The continuous net transfer of coolant from the LST to the RCS (pressurizer) would compress the steam in the pressurizer, increasing RCS pressure and opening the pressurizer spray block valve. Unless makeup flow were manually throttled, the reactor would trip on high pressure and the RC (liquid) would discharge through the PORV.

The principal effect of the steam generator low-pressure signal, if selected, would be the defeat of the automatic operation of the turbine-bypass valves in the affected loop.

15.4 CONTROL ROOM PARAMETER DISPLAY

Failure of HEX would result in the signal inputs to several alarms and indicators failing low if selected.

If the transmitters powered by HEX were selected when HEX failed, steam generator low startup level and pressurizer low level would be alarmed spuriously. The "selected" steam generator A and/or B startup level and selected pressurizer level meters would indicate low level. The selected steam generator A and/or B pressure meters would indicate low pressure. The pressurizer level meter and the steam generator A startup-level on the auxiliary shutdown panel would also indicate low level (the pressurizer level and steam generator A startup-level signals are powered by HEX only).

The HEX power failure apparently is alarmed in the control room (ref. 8). This alarm is expected to be instrumental in the identification of the cause of the possible transient and subsequent recovery actions.

Although the transient possibly resulting from the HEX power failure could be terminated by the operator's manually selecting the alternate energized transmitter, the operator must identify the power failure before responding to the spurious alarms and indications. Due to the HEX power failure alarm, and the limited number of spurious alarms, effective operator intervention is possible. The operator may rapidly compare a steam generator low startup level reading with the operable operate-range and full-range readings. This should provide sufficient information for the operator to select the alternate transmitter and/or manually throttle the feedwater flow rate. In a similar manner the indicated steam generator low outlet pressure can be checked against either the turbine-header pressure- transmitter output through the computer, or by sequential selection of redundant transmitters for comparison.

A spurious pressurizer low-level reading can be checked against the outputs of the two other pressurizer level transmitters available through the computer. The operator may also sequentially select transmitters LT-2 and LT-3 for comparison. The rapid drop of indicated pressurizer

level without a corresponding drop in RCP pressure should lead the operator to suspect an incorrect output from the transmitter.

The consequences of the operator's failing to select an operable steam generator startup-level transmitter are limited to trip of the main feedwater pumps and automatic initiation and control of emergency feedwater. If the operator takes no action in response to the pressurizer low-level indications, the eventual liquid discharge through the PORV may damage the valve, possibly failing it open. As the pressurizer is filled and the operator is alerted to the low level in the LST, the operator must throttle makeup flow or provide an alternate supply of water to the HPI pumps to prevent damage to the operating HPI pump. Failure of the operator to select a correct steam generator pressure transmitter would result in the turbine-bypass valves remaining closed and lifting of the main steam safety valves following turbine trip.

16. EFFECTS OF ELECTRIC POWER BRANCH HEY CIRCUIT FAILURES ON ICS/NNI CIRCUITS (FAILURE OF EMERGENCY POWER #1)

16.1 NNI CONTROL RESPONSE

One of three pressurizer level transmitters is powered from branch HEY. If this sensor were selected at the time of power failure, the control system would respond by opening the RCS makeup flow control valve. This would lead to an increase in pressurizer level and pressure. An operable transmitter can be selected manually at the signal-select hand station. Auxiliary control responses to a HEY power failure are presented in Table 16.1.

16.2 ICS CONTROL RESPONSE

One steam generator startup-level transmitter in loop A and one in loop B are powered from HEY. If a sensor powered by HEY were selected at the time of power failure, the loop feedwater valve would open due to indicated steam generator low level. This would result in an overfeeding transient that could be corrected by either manually selecting the alternate sensor or transferring the ICS loop feedwater control to manual. This transient would be terminated automatically by feedwater pump trip on steam generator high level.

One of the two steam pressure transmitters on each steam line is powered from HEY. If the HEY-powered transmitter(s) were selected for control at the time of the power failure, the turbine-bypass valves on the affected steam line would close or remain closed, with manual control available.

16.3 AUTOMATIC SYSTEM RESPONSE

Failure of the HEY branch circuit may deenergize one of two steam generator startup-level transmitters, one of two pressure transmitters on each steam generator, and one of three pressurizer level transmitters, depending on the sensor selected for use. Branch circuits HEX and HEY each power one of the redundant pressurizer-level and one of the loop A and loop B steam generator-level and pressure transmitters. Thus, if the HEY-powered transmitters were selected, the response of the plant would be identical to that described for HEX power failure (see Sect. 15.3).

16.4 CONTROL ROOM PARAMETER DISPLAY

The HEY failure would result in the signal inputs to several alarms and indicators failing low if selected.

Table 16.1 NNI auxiliary controls response to HEY power failure

Item	Output identification	Description	Effect	Comments
1.	1HP-25 E/P	Makeup flow control	Makeup valve will close if pressurizer level transmitter LT-2 is selected	Pressurizier level indicates full if level transmitters LT-2 is selected. Manual control operable. Manual selection of operable level transmitters LT-1 or LT-3 for auto control is possible.
2.	183-1/PLL	Low-low pressurizer level heater bank 1	Heater bank 1 will be cut off or interlock will be rendered ineffective if pressurizer level transmitter LT-2 is selected.	
3.	183/PLL	Low-low pressurizer level heater bank 2, 3, 4	Heater banks 2, 3, 4 will be cut off or interlock will be rendered ineffective if pressurizer level transmitter LT-2 is selected.	

If the transmitters powered by HEY were selected when HEY failed, steam generator low startup level and pressurizer low level would be alarmed spuriously. The "selected" steam generator A and/or B startup level and selected pressurizer level meters would indicate low level. The selected steam generator A and/or B pressure meters would indicate low pressure. The steam generator B startup-level meter on the auxiliary shutdown panel would also indicate low level. (The steam generator B startup-level signal input to the auxiliary shutdown panel is powered by HEY only.)

The HEY power failure apparently is alarmed in the control room (ref. 8).

Similar to the HEX power failure case, a transient resulting from an HEY power failure could be terminated. The possible operator responses to spurious alarms and indications caused by an HEY power failure are identical to those described for the HEX power failure (see Sect. 15.4)

17. EFFECTS OF ELECTRIC POWER BRANCH H-EL CIRCUIT FAILURES ON ICS/NNI CIRCUITS (FAILURE OF EMERGENCY STEAM GENERATOR LEVEL CONTROL POWER)

17.1 NNI CONTROL RESPONSE

H-EL power failure does not affect NNI control system response or operation.

17.2 ICS CONTROL RESPONSE

One channel of steam generator operate level in each loop is powered from branch H-EL. These sensors are shown to be connected so that H-EL power failures automatically transfer ICS inputs to sensors powered from H1X. No change in ICS response or control functions would result.

17.3 AUTOMATIC SYSTEM RESPONSE

Failure of the H-EL branch circuit would have a minor effect on the operation of the plant. The only immediate effect would be to deenergize the E/P transducers for the startup feedwater valve. This would "freeze" the loop A and B valves in position. Although this failure would have no net impact during high power operation (greater than approximately 20% power), it could affect operation following plant shutdown. If the plant were tripped, the startup valves would not close to maintain the steam generator shutdown level and the main feedwater control-valve block valve would not close automatically. If the block valves for the startup and main feedwater control valves were not manually closed, the levels of the steam generators would continue to rise slowly. Eventually the main feedwater pumps would be tripped automatically on steam generator high level, and the emergency feedwater system would be automatically initiated and controlled (the high-level trip function would be performed by the H1X-powered, operate-range level transmitters in each loop).

17.4 CONTROL ROOM PARAMETER DISPLAY

The selected loop A and B steam generator operate-range level recorders and the steam generator A and B downcomer temperature meters have inputs powered from H-EL or H1X.

The H-EL power failure apparently is alarmed in the control room (ref. 8).

The two contact switches per loop used to select the H1X- or H-EL-powered transmitter input are positioned to allow an automatic transfer to the energized transmitter in the event of power failure.

Thus, the operate-range level displayed on the level recorder would be correct following an H-EL failure, and the high-level alarms would be operable. The existence of an H-EL power failure alarm and high-level alarms enhances the operator's ability to rapidly identify the transient cause and manually take appropriate action following reactor shutdown.

18. EFFECTS OF ELECTRIC POWER PANELBOARD KI CIRCUIT FAILURES ON ICS/NNI CIRCUITS (FAILURE OF ICS POWER)

18.1 NNI CONTROL RESPONSE

Panelboard KI failure would result in loss of branch circuits H, HX, HEX, HEY, and H-EL. As described in Sect. 10.1, 14.1, 15.1, 16.1, and 17.1, makeup flow, pressurizer heater, and spray valve would initially switch to manual. The pressure-operated relief valve would close or remain closed. Selected manual control station power sources would be switched automatically from panelboard KI to panelboard KU. The operator would be able to manually position the makeup flow control valves from the control room or auxiliary shutdown panel, pressurizer heater bank 2 from the auxiliary shutdown panel, and, if required, position the pressure-operated relief valve and spray valve from the control switches in ICS Cabinet 13.

18.2 ICS CONTROL RESPONSE

Panelboard KI failure would result in loss of branch circuits H, HX, HEX, HEY, and H-EL. A loss-of-feedwater transient would occur due to a spurious steam generator high-level trip of the main feedwater pumps, reactor, and turbine. There would be an automatic initiation and control of emergency feedwater. Selected manual-control stations would be switched automatically from panelboard KI to panelboard KU. This would allow the operator to manually position the turbine-bypass valves from the auxiliary shutdown panel. (The position of the valves prior to manual control is unknown. Since the power supplies for the E/P converters and interposed solenoid valves are automatically transferred to KU, the turbine-bypass valves would be in manual and may be open if open at the time of power supply failure.)

18.3 AUTOMATIC SYSTEM RESPONSE

The response of the plant to a failure of panelboard KI (including all branch circuits) would be a loss-of-main-feedwater transient, combined with makeup flow, pressurizer heater (group 2), PORV, spray valve, and turbine-bypass valve controls switching to manual. Failure of KI would result in a spurious steam generator high-level trip of the main feedwater pumps due to the ICS high steam generator level bi-stables being deenergized, followed by reactor and turbine trip. There would be an automatic initiation and control of emergency feedwater.

Selected manual-control station power sources would be switched automatically from panelboard KI to KU. This allows the operator to manually position makeup-flow control valves from the control room, the turbine-bypass valves and pressurizer heater bank 2 from the auxiliary

shutdown panel and, if required, position of the PORV and spray valve from ICS Cabinet 13 control switches. The RC pump-seal injection, control-valve controls are transferred to KU, which results in continued automatic control of seal injection flow.

Following the reactor trip, the steam generator level would be controlled by the emergency feedwater control instrumentation and steam generator pressure would be controlled by the main steam safety valves. The makeup control valve would not change position, and its control would transfer to manual. Although the pressurizer level would initially decrease due to the reactor trip, the level would be expected to stabilize. Pressurizer heaters would be deenergized (or remain deenergized). The spray valve is expected to remain closed but would remain open if it were open at the time of the power failure, and a slow RCS depressurization would result.

18.4 CONTROL ROOM PARAMETER DISPLAY

Following loss of the KI panelboard, a majority of the control room alarms would be spurious (assuming that the specific control room alarm annunciators are powered separately from KI). In addition, the majority of the control room meter indications, recorders, and computer parameter displays would be erroneous.

In spite of the numerous spurious alarms and indications presented to the operator, the operator would be expected to rapidly diagnose the problem as a major power supply failure. By checking the ICS inverter (KI) trouble alarm and alarms of the major ICS branch circuits (H, HX, HEX, HEY, H-EL), the operator should recognize the loss of the panelboard and refer to the specific emergency procedure, on loss of KI bus.

The emergency procedure directs the operator to verify automatic actions, manually control pressurizer level (makeup and letdown), and attempt to reenergize the ICS/NNI. The procedure directs the operator to use specific controls and indications powered by vital power supplies (KVIA-KVID) and the computer panelboard KU. By following the emergency procedure, the operator would be expected to maintain the plant in a stable shutdown state.

If the operator fails to recognize the KI failure, the possible actions he may or may not take are speculative. If the operator takes no action, the pressurizer level would slowly increase or decrease and, if the pressurizer spray valve were "frozen" in an open position, the RCS pressure would slowly decrease. The reactor response to operator actions depends on how and to which alarms he responds.

19. EFFECTS OF ELECTRIC POWER PANELBOARD KU CIRCUIT FAILURES ON ICS/NNI CIRCUITS (FAILURE OF COMPUTER POWER)

19.1 NNI CONTROL RESPONSE

Original NNI/ICS designs indicate that NNI controls do not use power from panelboard KU. Information received from Duke Power Company indicates that the power source for pressurizer-level transmitter LT-3 has been changed to panelboard KU. In this case, the reactor coolant makeup valve would close if pressurizer-level transmitter LT-3 were selected at the time of panelboard KU power failure. Manual control of the valve is operable, and automatic control could be restored by manual selection of one of the other two pressurizer-level transmitters.

19.2 ICS CONTROL RESPONSE

ICS controls do not use power from panelboard KU unless there is a failure of panelboard KI. Therefore, single failure of KU would not affect ICS controls or response.

19.3 AUTOMATIC SYSTEM RESPONSE

Failure of the KU panelboard may cause a plant transient if the KU powered pressurizer level transmitter (LT-3) were selected for plant control. If this transmitter were selected, the makeup valve would be opened and the pressurizer heaters deenergized. Unless the operator manually throttled makeup flow, the pressurizer level would continue to increase eventually resulting in initiating pressurizer spray, tripping the reactor, and opening the PORV.

19.4 CONTROL ROOM PARAMETER DISPLAY

Upon loss of the KU panelboard, assuming that the KU powered pressurizer level transmitter were selected, pressurizer low level would be alarmed and indicated. The pressurizer level output could be compared to the alternate level outputs by sequential selection of the three transmitters or the auxiliary shutdown panel indication (LT-1).

Specific indication or alarm of the KU failure could not be identified from available information. However, an emergency procedure for loss of the plant computer apparently exists (ref. 13).

If the operator takes no action in response to this possible transient, the pressurizer would fill and the LST level would be alarmed low. The operator must throttle makeup flow or provide an alternate source of water to the HPI pumps to prevent damage to the operating pump. Auxiliary control responses to a KU panelboard power failure are listed in Table 19.1.

Table 19.1 NNI auxiliary controls response to panelboard KU power failure

Item	Output identification	Description	Effect	Comments
1.	1HP-25 E/P	Makeup flow	Makeup valve will close if pressurizer level transmitter LT-3 is selected.	Pressurizer level indicates full if level transmitter LT-3 is selected. Manual control operable. Manual selection of operable level transmitters LT-1 or LT-2 for auto control is possible.
2.	183-1/PPL	Low-low pressurizer level heater bank 1	Heater bank 1 will be cut off or interlock will be rendered ineffective if pressurizer level transmitter LT-3 is selected.	
3.	183/PLL	Low-low pressurizer level heater bank 2, 3, 4	Heater banks 2, 3, 4 will be cut off or interlock will be rendered ineffective if pressurizer level transmitter LT-3 is selected.	

20. EFFECTS OF ELECTRIC POWER BRANCH KI-10 CIRCUIT FAILURES ON ICS/NNI CIRCUITS (FAILURE OF RCS NARROW-RANGE PRESSURE TRANSMITTER POWER)

20.1 NNI CONTROL RESPONSE

The original system design for Oconee provided the narrow-range pressure signal used for the PORV and pressurizer heater control from one channel of the reactor protection system (RPS). Information received from Duke Power Company indicates that the normal RCS pressure input to the ICS/NNI is from a non-Class 1E transmitter powered from branch circuit KI-10. In Table 20.1, the specific response of the control circuits with RCS pressure inputs are listed for failure of branch KI-10.

A KI-10 branch circuit failure will result in a zero-volt RCS pressure signal input to the PORV, spray valve, and pressurizer heater control circuits. This could result in the heaters being energized and the PORV and spray valve being closed. In the event this failure occurred, the operator would be able to manually control the indicated devices.

20.2 ICS CONTROL RESPONSE

The ICS does not use RCS narrow-range pressure for control. The ICS would continue to maintain effective control of steam pressure and feedwater flow rate following the expected reactor trip.

20.3 AUTOMATIC SYSTEM RESPONSE

The automatic response of the plant to a zero-volt RCS pressure signal would be to energize the pressurizer heaters and close the PORV and the spray block valve. The resulting increase in RCS pressure would be expected to result in a high-pressure reactor trip and lifting of the pressurizer code safety valves.

20.4 CONTROL ROOM PARAMETER DISPLAY

The effect of deenergizing the RCS pressure transmitter results in a recorded and alarmed low RCS pressure in the control room and indicated low pressure on the shutdown panel meter. The expected high-pressure reactor trip and indicated and alarmed low RCS pressure should prompt the operator to compare the spurious low RCS pressure indications with 1E narrow-range RCS pressure signals. Once the spurious signal is identified, the operator may manually control the pressurizer heaters, spray valve, and PORV, if required, or transfer to the 1E signal from the RPS for automatic control.

Table 20.1 NNI auxiliary controls response to branch KI-10 power failure

Item	Output identification	Description	Effect	Comments
1.	1RC3-PS8 27/H1-RP	PORV (relief valve RC-RV3, RC-V66)	PORV will close or remain closed.	Zero-V narrow-range pressure signal is expected to be below "open set-point pressure. Manual control operable.
2.	1RC3-PS5 1RC3-PS6 1RC3-PS7	Pressurizer heaters	Heater banks 1, 2, 3, & 4 may be energized due to low indicated RCS pressure.	Zero-V narrow-range pressure signal should be compared to setpoints for heater banks 1, 2, 3, & 4. Manual control operable.
3.	1RC3-PS3	Pressurizer spray valve (RC-V1)	Spray valve will close due to low indicated RCS pressure.	Zero-V narrow-range pressure signal should be compared to spray valve setpoint. Manual control operable.

If the operator takes no action, RCS pressure will be limited by the pressurizer code safety valves if required. Continued discharge through the safety valves will result in heatup and pressurization of the quench tank. Quench tank temperature is alarmed. Pressurizer level is maintained automatically by the makeup valve controls.

21. RESPONSE TO DUKE POWER COMPANY COMMENTS

An interim report addressing the automatic responses of the ICS/NNI control circuits in response to power supply failures (ref. 15) was prepared by Science Applications, Inc. (SAI). This interim report was sent to Duke Power Company for review and comments. The substance of their comments has been incorporated in this extensively rewritten and expanded final report.

Specific responses to Duke Power Company comments are provided below. The page and table number references have been deleted since they refer to earlier drafts of the report numbering and are not applicable here.

21.1 LETTER FROM R. L. GILL (DUKE POWER COMPANY) TO A. P. MALINAUSKAS (ORNL) JANUARY 5, 1984

Comment 1: The valve should be called pressurizer spray valve [versus spray block valve].

Response: The nomenclature has been revised (p. 36).

Comment 2: The unit for steam generator pressure is psig.

Response: The units have been revised from psia to psig (p. 18).

Comment 3: Sentence should read "Thus a fault in the circuits . . . or the circuit breaker in the auto power branch . . . ."

Response: The sentence was corrected to include the fact that protection is also provided by the circuit breaker in the auto power branch. See Sect. 4 (p. 31).

Comment 4: The fuse for branch H2 is a 10-A fuse.

Response: Table 4.1 reflects the 10-A fuse rating (p. 33).

Comment 5: The valve described is the pressurizer spray valve [versus spray block valve]

Response: The nomenclature has been revised (Item 2, Table 5.1) (p. 50).

Comment 6: The statement is made:

"Although the operator would be able to position these devices, it is not known whether he would have adequate plant status information to maintain effective control."

Duke considers that adequate plant status information to maintain effective control is available. The basis for this is as follows:

Following both the 1979 Oconee 3 incident the 1980 Crystal River III incident, Duke undertook an extensive investigation of the Oconee instrumentation system design. Commitments were made in Duke letters to the NRC dated March 24, March 28, and April 14, 1980. By confirmatory order dated April 17, 1980, the NRC agreed with the committed actions and concluded that they "should reduce the probability of a similar future power loss causing unexpected plant responses and allow the plant operator to better cope with losses of instrumentation and control functions."

The details of the committed actions were included in Duke letter dated July 23, 1980, a copy of which has been previously provided to ORNL.

We believe that the above statement should be revised to clearly reflect the above conclusion.

Response: The quoted statement was made in an interim report prior to the analysis of the response of indicators and alarms to power supply failures. This final report specifically addresses the responses of both indicator and alarm circuits and control circuits to failures of panelboard KI, KU, and circuits fed from these panelboards.

Based on our analysis, we concur with the quoted NRC evaluation, which refers to a loss of panelboard KI (ref. 14). As addressed in Sect. 18, the transient resulting from a loss of KI is stabilized automatically, the loss of the panelboard is alarmed specificially, and the operator is given clear and detailed guidance on the actions to be taken in the subsequent recovery in the emergency procedure "Loss of KI Bus" (ref. 8). However, we could not identify similar alarms and emergency procedures for failures of many of the circuits fed from panelboard KI. We believe that alarms and emergency procedures for these circuits would be useful to the operator in recovering from circuit failures, as indicated in Sect. 2, Item 4. For further discussion of control room annunciators and displays, see Sects. 5.4, 6.4, 7.4, 8.4, 9.4, 10.4, 11.4, 12.4, 13.4, 14.4, 15.4, 16.4, 17.4, 18.4, 19.4, and 20.4.

21.2 LETTER FROM K. S. CANADY (DUKE POWER COMPANY) TO A. P. MALINAUSKAS (ORNL), PAGE 7, FEBRUARY 18, 1985.

Comment 1: Narrow-range RCS pressure is normally used for NNI pressure control.

Response: In Fig. 1.1, the RCS narrow-range pressure input <u>from the RPS</u> was shown as "normally not selected." It is our

understanding that the normal RCS narrow-range pressure sensor input for the NNI control circuits is part of the NNI and powered from panelboard KI (p. 3).

Comment 2: The procedure is for the loss of the computer, not for loss of KU.

Response: Table 2.2 and Sect. 19.4 have been modified to reflect a loss of plant computer procedure (p. 11).

Comment 3: CFR should be CFT in Table 2.2.

Response: "CFR" has been changed to "CFT" for branch circuit failure H4. Also "continued pump objection" was changed to "continued power operation" for branch circuit failure H3X (p. 10).

Comment 4: The unit for steam generator pressure is psig (Table 3.2).

Response: Turbine header and steam generator pressure units have been corrected. Also the "ΔT RCS loops A and B T_{cold}" have been corrected (p. 18).

Comment 5: A key to the symbols in Figs. 3.1 through 3.9 would be helpful.

Response: Sensors are designated by rectangles, modules or groups of modules by squares, and switches by hexagons. In each case, the branch circuit supplying power has been noted (p. 19-27).

Comment 6: The valve referenced in Item 2, Table 5.1 and Item 1, Table 11.1 is the pressurizer spray and not the pressurizer spray block valve.

There are two valves in the pressurizer spray line: the pressurizer spray valve, which is under NNI control for pressure control, and the pressurizer spray block valve. Please revise the nomenclature in the whole report.

Response: References to the spray valve and spray block valve have been modified (p. 36, 50).

Comment 7: The operator response to an H1 power failure would be to maintain steady state conditions and attempt to restore H1. This would avoid unnecessary trips.

Response: This operator response has been added to Sect. 7.4 (p. 41).

Comment 8: Indication for RCS NR pressure can also be fed from RPS Channel A as the alternate source.

Response: This availability of this alternate power source has been included in Sect. 20.4 (p. 75).

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1. Casto, W. R., Selected Safety Related Events Reported in July and August 1978. Nuclear Safety, Vol. 19, No. 6, November-December 1978, pp. 765-767.

2. "Loss of Non-Class-1E Instrumentation and Control Power System During Operation," U.S. Nuclear Regulatory Commission IE Bulletin No. 74-77, November 30, 1979.

3. "Analysis and Evaluation of Crystal River-Unit 3 Incident," NSAC-31/INPO-1, March 1980.

4. "Transient Response of Babcock-Wilcox Designed Reactor (Draft)," NUREG-0667, April 2, 1980.

5. "Oconee Final Safety Analysis Report," Duke Power Company, July 1982.

6. Oconee 1 Integrated Control System (ICS) - Instruction Book, Bailey Meter Co., March 15, 1977.

7. Letter from R. L. Gill (Duke Power Company) to R. C. Kryter (ORNL), October 19, 1982.

8. Oconee Emergency Procedure EP/O/A/800/3, Loss of KI Bus (ICS Power), January 21, 1981.

9. Auxiliary Control System Schematic Diagram, Steam Supply, No. D8032344D, Bailey Meter Company, June 1978.

10. Letter from R. L. Gill (Duke Power Company) to A. P. Malinauskas (ORNL), January 5, 1984.

11. Letter from R. L. Gill (Duke Power Company) to James D. White (ORNL), February 1, 1984.

12. Oconee Line Diagrams O-705 and O-705-A, 120-V ac and 125-V dc Station Auxiliary Circuits and 120/240-V ac Station Auxiliary Circuits.

13. Letter from R. L. Gill and A. L. Lotts, Review of Draft Reports on the Project for Safety Implications of Control Systems, August 31, 1983.

14. Letter from William Parker to Harold Denton, Review of NUREG-0667, July 23, 1980.

15. Interim Report: Failure Modes and Effects Analysis for the ICS/NNI Electric Power Distribution Circuitry, August 26, 1983.

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