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A Division of North American Aviation, Inc.

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WRITTEN BY R.J. Hall SRE E.D. Bilbao SRE SECTION E. Young Edison Sodium Reactors Dept. GROUP Sodium Reactor Experiment UNIT		<h1 style="margin:0;">ATOMICS INTERNATIONAL</h1> <p style="margin:0;">A Division of North American Aviation, Inc.</p> <h2 style="margin:0;">TECHNICAL DATA RECORD</h2>		TDR NO. 3760 GO 7529 LEDGER ACCT. 3621 SUB-ACCT. 4375 TWR DATE 14 April 1959 PAGE 1 OF 28	
APPROVED BY: (SUPERVISOR) <i>G.E. Deegan</i> OTHER <i>L.S. [Signature]</i>		PROGRAM <p style="text-align: center;">SRE</p>			
PROJECT Engineering Improvements to the SRE					
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SUBJECT: SRE-Edison Plant Control System					
CONTENTS: I STATEMENT OF PROBLEM PAGE 1 II SUMMARY OF RESULTS AND RECOMMENDATIONS PAGE 2 III METHOD USED, DESCRIPTION OF EQUIPMENT, SAMPLE CALCULATIONS . . . PAGE 3 IV REFERENCES AND APPENDICES PAGE					
<div style="border: 1px solid black; padding: 5px;"> <p>I STATEMENT OF PROBLEM</p> <p>In April 1956 a meeting was held with the nuclear staff of Southern California Edison to discuss the control of the Edison steam plant that was proposed for the SRE. A decision was made to operate the SRE-Edison Plant as a load forcing system with an agreement that Edison would regulate feedwater flow to maintain the steam generator outlet sodium at a constant temperature. It was suggested that an integrated plant control system be incorporated in the SRE-Edison nuclear power station after the operations program had been in progress.</p> <p>Modern electrical power systems are controlled to match total generation to prevailing customer demand. It is desirable to secure the total generation with maximum efficiency. The power generating stations are operated as load following control systems using frequency sensing equipment and demand signals from load dispatch equipment to increase or decrease generation.</p> <p>The following objectives will be accomplished by incorporating plant controls in the SRE-Edison installation.</p> <ol style="list-style-type: none"> 1. Plant controls will test the capability of a sodium cooled atomic power reactor to operate as a load following control system, and to be controlled from an automatic load dispatch control center. This will improve the position of sodium cooled reactors in the atomic power reactor industry. </div>					

2. The different rates at which the SRE can change thermal power level with load demand, without affecting the heat transfer efficiencies or the stability of the reactor complex, will be determined.

3. The design of the Hallam reactor power plant controls will be proven by operating the SRE as a load following control system. The design of the SRE load following control system using the drum type boilers is similar to the design of the Hallam plant controls.

The instrumentation for the SRE plant control system will be a permanent installation; however, will be flexible to test design concepts for the advanced sodium cooled power reactors.

4. Experiments that require rapid changes in power level can be performed without creating a misbalance in the heat transfer systems between the two plants.

The SRE-Edison plant can be operated at any level, or at a steady state condition by manipulating one control. The system will automatically respond to the control setting (calibrated in megawatts output), and provide maximum efficiency between the turbine, heat transfer systems, and reactor.

5. The plant controls will be employed to set back the heat transfer system cooling rates simultaneously with a reactor setback. This will reduce the deviation between the center fuel channel temperature and the outer moderator channel temperature following a reactor setback.
6. The plant controls will be employed to set back the reactor and boiler-turbine equipment during short power failures. This will improve the continuity of operations when power failures affect the rotating machinery for the sodium pumps.

II SUMMARY OF RESULTS

This report gives a description of the plant control system that has been designed and developed for the SRE-Edison installation.

Control instruments, components, and hardware have been requisitioned for the control and electrical distribution system. The controllers and amplifiers will be modified on the instrument bench to adapt to the control system design. Bridge rectifier power supplies are being fabricated for the control slide wire circuits. A panel that will house the control instrumentation has been requisitioned and will be installed in the SRE control room adjacent to the SRE control console. Control switches and dials will be installed on the SRE control console and Edison control board. Two overhead conduits are being installed between the SRE and Edison plant. One conduit will carry shielded signal leads and the other AC lines.

III METHOD USED, DESCRIPTION OF EQUIPMENT

Modern steam plant control concepts are being incorporated in the SRE-Edison plant control system. This will make sodium cooled atomic power plants attractive to modern interconnected electrical distribution systems. The SRE-Edison plant has a small generator capacity; however, the control system is capable of controlling sodium cooled atomic power reactors of the several hundred megawatt size. Vital information will be collected for the control of large atomic power plants.

The reactor, heat transfer system, boiler and turbine are treated as a unit. The plant control system integrates this operation. In principle, the plant control system regulates the turbine admission valve and heat transfer systems to give the desired electrical generator output while maintaining uniform steam pressure and optimum reactor and heat transfer efficiencies.

Refer to Figure No. 1 and the schematic diagrams on pages 16 through 25.

Four methods of operation can be selected by a control selector switch.

Position No. 1: MANUAL CONTROL

Hand controls are used during reactor startup operations, and when a control function has deviated from established limits.

Position No. 2: REACTOR AND HEAT TRANSFER MANUAL - AUTOMATIC TURBINE FOLLOW

This position is used during the SRE experimental programs when it requires deviating from fixed temperature gradients, and it is desirable to operate the boiler-turbine equipment on automatic controls.

Position No. 3: AUTOMATIC LOAD FOLLOWING FOR ONCE THROUGH BOILER

The direct energy balance method is employed for this application. The steam pressure is maintained by adjusting the turbine admission valve, and the desired electrical generator output is controlled by adjusting the feedwater pumps and rate of sodium coolant flow through the boiler. With this direct energy balance method the turbine keeps in step with the boiler output, and the boiler input is directly controlled to give the desired generator output. The relative inherent storage capacity of the once through boiler is small, therefore, the heat transfer system is directly controlled to maintain a balance between required output and generated output.

The turbine control is basically composed of an output setter, generator frequency, and required output servos. These three servos are analogous to the synchronizing motor and admission valve position of the turbine.

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Sequence of Operation

1. Assume the load demand increases by 15% of the total generator capacity.
2. The output of the turbine generator is controlled or set by the output adjustment station, which adjusts the position of the output setter servo to increase the power by 15%. The position of the output setter servo can be controlled at the SRE control console, the Edison control console, or the Edison load dispatch control center. A selector switch determines the area of responsibility.
3. A minimum-maximum limiter is provided to keep the required output within the capabilities of the reactor, heat transfer system, and boiler-turbine equipment.
4. A rate of change setter is included to limit the maximum rate at which the required output servo can change, thus keeping within the inherent response characteristics of the reactor, heat transfer system, and boiler-turbine equipment..
5. The required output servo directly follows the setting of the output setter servo provided:
 - (1) generator frequency is at 60 cycles,
 - (2) no limit actions occur, and
 - (3) the rate of change is within the maximum rate of change setting.

Regardless of the rate of change, the required output servo will ultimately match the output servo when the generator is operating at 60 cycles and no limit actions persist. As generator frequency or turbine speed fluctuates, the required output servo will vary for a fixed setting of the output setter servo. This permits the unit to participate in the inherent system regulation to the same extent that the normal turbine governor participates.

The required output is, in effect, the control point against which the plant control system is matching generator output by regulating the heat transfer systems and turbine governor valve.

6. A thermal converter is connected between the line and load, and generates a DC millivoltage signal which is proportional to power output, hence steam flow input to the turbine. The signal is fed to the generated output servo.

7. The error signal between the generated output servo and required output servo is fed to the SRE heat transfer servo.
8. As steam pressure changes due to the regulation of the heat transfer system, the steam pressure controller adjusts the admission valve to maintain steam pressure, with resultant change in generator output. The steam flow is increased until electrical generator output is increased by 15%, and the error signal is reduced to zero.
9. The control point of the steam pressure controller is automatically biased from the difference between required output and generator output servo positions. This bias occurs during fast load changes and thus provides maximum response of the boiler and turbine equipment. A pressure bias signal is fed to the heat transfer servo to reset the steam pressure to the control point when the admission valve position is changed by the above control function.
10. The feedwater inputs are adjusted as required to give desired temperatures throughout the convection and superheated steam circuits to match the heat transfer conditions established by the control system. This is accomplished by two element instrumentation that controls the feedwater pumps to maintain the sodium return from the boiler at a constant temperature.
11. The heat transfer servo controls the main secondary sodium pump control servo to increase the sodium flow rates. This matches the heat transfer system to the increased steam pressure requirements. The primary flow is slaved to the secondary flow by action of the primary control servo. A flow ratio control corrects for non linear conditions between the primary and secondary sodium loops. This provides for maximum heat transfer efficiencies across the main intermediate heat exchanger. In the event the main primary cold leg temperature deviates from established limits, a signal is provided to reset the flow ratio control.
12. The temperature gradient across the reactor is maintained by the neutron flux/temperature controller using a cascade control system. The controller will respond to changes in fuel exit sodium temperature and regulate reactor power by re-setting the desired neutron flux level.

Primary control of reactor power is maintained by controlling reactor neutron flux.

An anticipatory signal from primary sodium flow enables the controller to respond to fast load changes without excessive deviation of reactor outlet temperature.

Position No. 4: AUTOMATIC LOAD FOLLOWING FOR DRUM TYPE BOILERS

The conventional method of operation is employed for this application. The turbine admission valve will be controlled to give the desired electrical generator output, and the steam pressure will be maintained by controlling the rate of sodium coolant flow through the boiler. With this conventional method of operation the boiler, in effect, follows the turbine. This approach will be satisfactory because the drum type boiler units have relatively large inherent storage capacities.

Sequence of Operation

1. Assume the load demand increases by 15% of the total generator capacity.

Sequence No. 2 through No. 6 is the same as sequence No. 2 through No. 6 for the once through boiler operation.

7. The error signal between the generated output servo and required output servo is fed to the governor motor control servo. The servo controls the turbine admission valve to increase electrical output by 15% and the error signal is reduced to zero. With this method, the turbine governor motor is controlled to maintain a balance between the generator output and required output servos.
8. An anticipation signal from the difference between required output and generated output servos is fed to the heat transfer servo to supplement the steam pressure regulation of the boiler input. This initial control action is supplemented as required from the steam pressure controller to maintain a uniform steam pressure.
9. The feedwater flow is adjusted as required to give desired steam drum water level. This is accomplished by employing a conventional three-element feedwater control which uses level as a primary control and steam and feedwater flow as anticipatory control signals.

Sodium return temperature is a function of saturated steam temperature and will be fixed for any given operating conditions.

10. Same as No. 11 above.
11. Same as No. 12 above.

DEVIATION LIMIT CIRCUITS

The design of the SRE-Edison plant control system does not affect the present shutdown or setback interlocks in the SRE plant protective system. An abnormal condition or failure of a control circuit WILL NOT scram or set back the reactor. Deviation limit circuits are provided in

the plant control system to detect an abnormal condition or failure of a control function.

The following abnormal conditions will disrupt the automatic control system and freeze the plant on hand controls.

1. Excessive deviation between the required output servo and generated output servo.
2. Excessive deviation between the required output servo and reference control point in the main secondary sodium pump control circuits. Any failure beyond the reference control point in the existing sodium pump control circuits will be detected by the existing off-normal flow circuits.
3. Excessive deviation between the primary and secondary sodium flow.
4. Excessive deviation between the required reactor outlet temperature and measured reactor outlet temperature.

In addition to the above, the operator can freeze the plant to hand controls by actuating a manual push button or actuating the governor motor control switch.

The transfer from manual to automatic for all the systems except the flux temperature controller requires actuating a auto-man push button switch. However, the transfer cannot be made unless the hand control stations are adjusted to match the control set point with the measured variables, and the man-auto interlocks are satisfied.

The following limit actions block the travel of the required output servo.

1. Excessive deviation between the required output servo and generated output servo.
2. The generator output exceeds the minimum or maximum limit setter.

When an abnormal condition is detected, an annunciator alarm is given and a light indicates which control function has failed.

In addition to the aforementioned safety features of the SRE-Edison plant control system, mechanical limiters are provided for minimum-maximum generation, and a gear box is provided to mechanically limit the maximum rate of power change.

EDISON LOAD DISPATCH CONTROL CENTER

The power generation and interconnected power system operation of the Southern California Edison Company is controlled by a Desired Generation Computer.

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This instrument automatically determines optimum generation loading for the best economy of the entire Edison system. The computer routes control action to the individual stations to maintain the desired generation of the various sources at levels which give the best economy of power delivered to the load. In principle, the computer measures the difference between the desired generation and actual generation. This is determined by the area requirement and is a function of the system frequency. An incremental load adjust servo will detect any unbalance and will cause the system lambda (cost per unit of generated power) to advance until the incremental bus cost is high enough to create an increase in desired MW generation. The new desired generation compared with the actual generation determines the individual station requirements. Requirement servos determine whether any control action is directed to a station.

The SRE is a small unit in the Edison system. It does not have sufficient electrical capacity to add or subtract a block of power to the system which will deviate the system lambda sufficiently to satisfy the system desired generation. The SRE is unique, however, in that it is the only atomic energy plant on the Edison grid. Vital information can be collected on the behavior of a sodium graphite atomic power plant when receiving control signals from the load dispatch, desired generation computer. After the SRE-Edison plant control system has been installed and tested for satisfactory operation, it will be desirable to test the system by routing the same control signal to the SRE that is routed to one of the Edison's large central station generating units. The SRE will see the same control signals that are used in actual practice to control interconnected generation and transmission systems. Telemetering equipment will be loaned for this test by the same vendor (Leeds & Northrup Co.) that is supplying the instruments for the SRE-Edison control system.

COMPONENT DESCRIPTION

The following is a basic description of the individual circuits and components:

Reactor Flux/Temperature Controls

A two-pen recorder controller receives signals from a compensated ionization chamber and a fast time response fuel channel outlet thermocouple. These signals are compared with neutron flux and fuel channel temperature control setpoints. The error signals between the measured variables and control setpoints are fed to servo amplifiers. The neutron flux servo amplifier controls a servo motor which positions the regulating rods.

The fuel channel temperature servo amplifier controls a servo motor which adjusts the neutron flux setpoint to control the temperature gradient across the reactor. An anticipation signal proportional to primary sodium flow is fed to the reactor temperature servo for controlling reactor temperature when sudden load demand changes are imposed on the heat transfer system.

The control setpoints can be manually adjusted or positioned by a reactor programmer.

During the approach to power when a temperature gradient is being established across the reactor and heat exchangers, the reactor programmer automatically increases temperatures at pre-set rate.

Heat Transfer Servo

Experience with the SRE has proven the reliability and dependability of the magnetic flowmeter sensing elements. The principle which is being applied for the control of heat transfer system is to operate the primary and secondary sodium pump control systems as closed servo loops. The heat transfer servo motor, which receives its control from the load demand signals, is employed to move the control setpoint for the secondary closed servo loop. This method of control will provide stable operation of the heat transfer system.

Servo Amplifiers

The servo amplifiers are three element controllers with derivative and integral controls to adjust for the transfer function and time constants of the entire system. This will provide maximum heat transfer efficiencies. The change from manual to automatic is a bumpless transfer. This is accomplished by employing a man-auto relay to eliminate the buildup of a charge on the reset capacitors in the servo amplifier.

Electronic Relays

In principle, the electronic relay is an AC amplifier which detects an unbalanced AC bridge circuit and energizes one of two output relays. The phase difference between the unbalanced bridge circuit and output relay transformer determines which relay is energized. The AC amplifier is free of drift which is an advantage over DC circuits with inherent drift problems.

Required Output Servo

The required output servo motor is driven by a rate of change servo amplifier which receives its input from a special filtered DC bias signal. The difference between the bias signal and a feedback DC tachometer determines the speed of the required output servo. The DC bias signal is adjusted by a rate of change adjust.

Steam Pressure Controller

In principle, the steam pressure servo consists of a null balance type recorder-controller. A front control setter and associated bridge circuits produce an error signal proportional to the steam pressure deviation from control setpoint. The pressure sensing element is a strain gauge which is a variable resistance in a d-c bridge circuit. The steam pressure controller is capable of detecting pressure changes of 1/2 psi, and has a fast time response for control action.

Turbine Governor Control

An integral part of the Edison turbine-generator equipment is a turbine governor control which consists of an initial pressure regulator, a centrifugal speed governor of the fly-weight type, and a governor motor control for positioning of the turbine admission valve from a remote station.

The governor control will be paralleled by the thyatron control unit which directly controls the governor synchronizing motor. The thyatron control unit receives phase sensitive signals from the plant control system.

Precision Frequency Detector

In principle, the generation frequency detector is an integral frequency-sensitive bridge, able to detect variations from 60 cycles as small as 0.01 cycle. The recorder-controller initiates corrective action on the governor, so that speed droop is centered on 60 cycles for any load within unit capacity. Governor droop is not altered, but is continuously reset at 60 cycles when load changes cause departure from this base.

Thermal Converter

In principle, the thermal converter comprises an electrical circuit in which the difference of the power generated in two heaters is proportional to the power measured. The temperature difference so produced is measured by thermocouples. The EMF from the thermocouples is a measure of power.

The thermal converter is a measure of generator output and has been substituted for steam flow. When operating the boiler and turbine as a unit, electrical generator output, like steam flow, provides an indirect measure of heat input. The thermal converter has advantages over the steam flow measurement because of simplicity in design and installation, and the totalizing of multiple steam flow lines is easily accomplished, since there is no square root involved in the basic measurement.

Thyatron Control Unit

The thyatron control unit is a basic thyatron amplifier which regulates current through the governor motor armature. In principle, the thyatron inputs are controlled by the phase difference between the output transformer of the governor motor servo amplifier and the thyatron plate transformer. The thyatron control unit is custom designed to provide a stepping action for governor motors. This provides uniform control of the steam flow through the turbine, which is affected by the non-linear characteristics of the motor operated admission valve vs. steam flow.

Readout Instrumentation

The control console operator will not be flying blind on the SRE-Edison plant control system. The following readout and graphic information is provided for his observation and information.

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<u>RECORDER</u>	<u>RANGE</u>
Electrical Generation	0-10 MW
Required Output	0-10 MW
Steam Pressure	550 psi to 650 psi
Generation Frequency	59 to 61 cycles
Feedwater Flow	0 to 100,000 lbs/hr
Sodium Return Temperature	0-800°F
Steam Temperature	200-1200°F
Primary Flow	0-2300 gpm
Secondary Flow	0-2500 gpm
Reactor Inlet and Outlet Temperature	0-1200°F
Heat Exchanger Inlet and Outlet Temperature	0-1200°F
Fuel Channel Temperature	0-1200°F
Neutron Flux	0-100%

Convection Flow Control System

The convection flow control system has been in operation since April 1958. This system consists of controllers and eddy current magnetic brakes which restrict sodium flow and maintain system temperatures following a reactor scram. The present control system consists of a flow-ratio controller. The primary eddy current brake can either be controlled from a reactor temperature controller or manually controlled from the control console. The secondary brake controller is slaved to the primary brake controller with a flow ratio adjust to trim the primary-secondary flow ratios. This provides uniform control of the two loops to maintain the secondary system temperatures. The feedwater pumps are reduced to a minimum to maintain the sodium return temperature from the boiler following a reactor scram.

A fast restart operation, without appreciable loss of temperature gradients, is accomplished by re-establishing reactor power and reducing brake currents to maintain a balance between sodium flow and heat generation. The feedwater flow is gradually increased to maintain the boiler sodium return temperature.

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EQUIPMENT NOMENCLATURE AND LEGEND

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2A	PRIMARY FLOW SERVO	4F	FREQUENCY BIAS ADJUST SETTER
2B	SECONDARY FLOW SERVO	4G	RATE OF CHANGE ADJUST SETTER (AT EDISON)
2C	PRIMARY COLD LEG TEMPERATURE SERVO	4H	RATE OF CHANGE ADJUST SETTER (AT SRE)
2D	SECONDARY SYSTEM REFERENCE RHEOSTAT SERVO	4J	GOVERNOR PRESSURE DEVIATION RESPONSE SETTER
2E	PRIMARY SYSTEM REFERENCE RHEOSTAT SERVO	4K	PRIMARY SYSTEM COLD LEG BIAS ADJUST
2F	FREQUENCY SERVO	4L	PRIMARY SYSTEM NON-LINEARITY ADJUST SETTER
2G	GENERATOR OUTPUT SERVO	4M	PRESSURE BIAS ADJUST SETTER
2GM	GOVERNOR MOTOR FEEDBACK POTENTIOMETER	4N	ANTICIPATION BIAS ADJUST SETTER
2H	HEAT TRANSFER CONTROL SERVO	4RH	HEAT TRANSFER DEVIATION HIGH SETTER
2J	REACTOR NA EXIT TEMPERATURE SERVO	4RL	HEAT TRANSFER DEVIATION LOW SETTER
2K	REACTOR FLUX SERVO	4SH	PRIMARY-SECONDARY FLOW DEVIATION HIGH SETTER
2L	REACTOR TEMPERATURE SETPOINT SERVO	4SL	PRIMARY-SECONDARY FLOW DEVIATION LOW SETTER
2M	REACTOR FLUX SETPOINT SERVO	4U	REACTOR TEMPERATURE DEVIATION LOW SETTER
2P	STEAM PRESSURE SERVO	4V	REACTOR TEMPERATURE DEVIATION HIGH SETTER
2R	REQUIRED OUTPUT SERVO	4W	REACTOR FLUX DEVIATION LOW SETTER
2S	OUTPUT SETTER SERVO	4X	REACTOR FLUX DEVIATION HIGH SETTER
3A	GENERATION DEVIATION HIGH LIMIT CONTROL RELAY	PB1	MANUAL TRANSFER TO AUTOMATIC
3B	GENERATION DEVIATION LOW LIMIT CONTROL RELAY	PB2	SRE MANUAL CONTROL INITIATION
3C	GENERATION DEVIATION HAND CONTROL LIMIT RELAY	PB3	EDISON MANUAL CONTROL INITIATION
3D	GENERATION MAXIMUM LIMIT RELAY	PB4	EDISON MANUAL INITIATION RESET
3E	GENERATION MINIMUM LIMIT RELAY	PB5	FLUX-TEMPERATURE SAFETY CIRCUIT RESET
3F	REQUIRED OUTPUT CONTROL RELAY	SW1	AUTOMATIC TEMPERATURE CONTROL SWITCH
3GA	HEAT TRANSFER DEVIATION LIMIT RELAY HIGH	SW2	FLUX-TEMPERATURE SYNCHRONIZING SWITCH
3GB	HEAT TRANSFER DEVIATION LIMIT RELAY LOW	SW3	TEMPERATURE PROGRAMMERRAISE-LOWER SWITCH
3H	PRIMARY-SECONDARY SYSTEM DEVIATION LIMIT RELAY	SW4	REACTOR AUTO-MANUAL SWITCH
3J	SPARE		
3L	REACTOR TEMP. DEVIATION HIGH LIMIT CONT. RELAY		
3M	REACTOR TEMP. DEVIATION LOW LIMIT CONT. RELAY		
3N	REACTOR FLUX DEVIATION HIGH LIMIT CONT. RELAY		
3P	REACTOR FLUX DEVIATION LOW LIMIT CONT. RELAY		
4AH	GENERATION MAXIMUM LIMIT SETTER		
4AL	GENERATION MINIMUM LIMIT SETTER		
4B	STEAM PRESSURE SETTER		
4C	GENERATOR OUTPUT DEVIATION LIMIT SETTER		
4DH	GENERATION DEVIATION HIGH LIMIT SETTER		
4DL	GENERATION DEVIATION LOW LIMIT SETTER		

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EQUIPMENT NOMENCLATURE AND LEGEND

R1 OUTPUT SETTER MOTOR BRAKE RELAY
 R2 OUTPUT SETTER CONTROL RELAY - DECREASE
 R3 OUTPUT SETTER CONTROL RELAY - INCREASE
 R4 OUTPUT SETTER CONTROL RELAY - SRE
 R5 OUTPUT SETTER CONTROL RELAY - EDISON
 R6 OUTPUT SETTER CONTROL RELAY - LOAD DISPATCHER
 R7 REQUIRED OUTPUT SETTER RELAY - INCREASE
 R8 REQUIRED OUTPUT SETTER RELAY - DECREASE
 R9 OUTPUT SETTER RUNBACK RELAY
 R10 REACTOR SETBACK RELAY
 R11 SPARE
 R12 DEVIATION LIMIT INTERLOCK RELAY - HIGH
 R13 DEVIATION LIMIT INTERLOCK RELAY - LOW
 R14 DEVIATION LIMIT HIGH GENERATION RELAY
 R15 DEVIATION LIMIT LOW GENERATION RELAY
 R16 SPARE
 R17 SPARE
 R18 MANUAL CONTROL RELAY
 R19 AUTOMATIC TURBINE FOLLOW (REACTOR MANUAL)
 CONTROL RELAY
 R20 AUTOMATIC LOAD FOLLOW (DIRECT ENERGY BALANCE)
 CONTROL RELAY
 R21 AUTOMATIC LOAD FOLLOW (CONVENTIONAL)
 CONTROL RELAY
 R22 HEAT TRANSFER CONTROL RELAY - DECREASE
 R23 HEAT TRANSFER CONTROL RELAY - INCREASE
 R24 HEAT TRANSFER CONTROL MOTOR BRAKE RELAY
 R25 DEVIATION LIMIT SAFETY RELAY
 R26 MANUAL-AUTO TRANSFER INTERLOCK RELAY
 R27 EDISON MANUAL CONTROL RELAY

R28 SECONDARY FLOW CONTROL RELAY - DECREASE
 R29 SECONDARY FLOW CONTROL RELAY - INCREASE
 R30 PRIMARY FLOW CONTROL RELAY - DECREASE
 R31 PRIMARY FLOW CONTROL RELAY - INCREASE
 R32 AUTO GOVERNOR CONTROL RELAY
 R33 AUTOMATIC HEAT TRANSFER AUXILIARY RELAY
 R34 AUTOMATIC TURBINE FOLLOW AUXILIARY RELAY
 R35 MANUAL HEAT TRANSFER AUXILIARY RELAY
 R36 GENERATION DEVIATION LIMIT AUXILIARY RELAY
 R37 HEAT TRANSFER DEVIATION LIMIT AUX. RELAY
 R38 PRIMARY-SECONDARY DEVIATION LIMIT AUX. RELAY
 R39 REACTOR TEMP. DEVIATION LIMIT AUX. RELAY
 R40 GOVERNOR MANUAL CONTROL AUXILIARY RELAY
 R41 SRE MANUAL CONTROL RELAY
 R42 GOVERNOR VALVE LIMIT RELAY
 R43 MANUAL LOCKOUT AUXILIARY RELAY
 R50 FLUX-TEMPERATURE DEVIATION LIMIT RELAY
 R51 FLUX-TEMPERATURE DEVIATION LIMIT AUX. RELAY
 R52 AUTOMATIC REACTOR CONTROL RELAY
 R53 MANUAL REACTOR CONTROL RELAY
 R54 AUTOMATIC FLUX CONTROL RELAY - DECREASE
 R55 AUTOMATIC FLUX CONTROL RELAY - INCREASE
 R56 PROGRAMMER OUTPUT RELAY
 R57 REACTOR SETPOINT RELAY - INCREASE
 R58 REACTOR SETPOINT RELAY - DECREASE
 R60 SECONDARY PUMP MANUAL DECREASE RELAY
 R61 SECONDARY PUMP MANUAL INCREASE RELAY
 R62 PRIMARY PUMP MANUAL DECREASE RELAY
 R63 PRIMARY PUMP MANUAL INCREASE RELAY

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FIGURE NO. 1
SRE-EDISON PLANT CONTROL SYSTEM
BLOCK DIAGRAM

Switch S1 CONTROL SELECTOR SWITCH
Position S1-1 MANUAL CONTROL
S1-2 REACTOR AND HEAT TRANSFER
MANUAL - AUTOMATIC TURBINE
FOLLOW
S1-3 AUTOMATIC LOAD FOLLOWING FOR
ONE THROUGH BOILER - DIRECT
ENERGY BALANCE CONTROL
S1-4 AUTOMATIC LOAD FOLLOWING FOR
DRUM TYPE BOILERS -
CONVENTIONAL CONTROL

Switch S2 OUTPUT SETTER CONTROL SELECTOR
Position S2-A SRE CONTROL STATION
S2-B EDISON CONTROL STATION
S2-C LOAD DISPATCH CONTROL STATION
Switch SW1 REACTOR MANUAL AUTOMATIC SELECTOR
SWITCH
Position SW1-M MANUAL CONTROL
SW1-AU AUTOMATIC CONTROL

LEGEND
T: TEMPERATURE
P: PRESSURE
F: FLOW
L: LEVEL
HCS: HAND CONTROL STATION
M: MOTOR
MOR: MOTOR OPERATED RHEOSTAT
POV: PNEUMATIC OPERATED VALVE
MOC: MOTOR OPERATED CONTROL

GENERATOR FREQUENCY SERVO

OUTPUT SETTER AND REQUIRED OUTPUT REMOTE INDICATORS

STEAM PRESSURE SERVO

GENERATED OUT REMOTE INDICATOR

Single Line Block Diagram

CONVENTIONAL VERSUS DIRECT ENERGY BALANCE CONTROL

Two important variables which are affected by load-following control systems are steam pressure at the turbine and frequency or load conditions. A situation can exist where a succession of load changes on the network will place an individual power plant in one of the following conditions:

- Example A. High frequency and high steam pressure.
- Example B. High frequency and low steam pressure.
- Example C. Low frequency and high steam pressure.
- Example D. Low frequency and low steam pressure.

Refer to Figure No. 2.

In example A, when employing the conventional method of control, pressure error signal No. 1 will call for a decrease in reactor power. Load error signal No. 3 will call for a decrease in governor valve position, increasing steam pressure which will call for a further decrease in reactor power. The results of this operation would be several adjustments of both reactor power and governor valve position to bring the variables back to desired conditions.

In example A, when employing the direct energy balance method of control, pressure error signal No. 1 and load error signal No. 2 will call for a decrease in reactor power. Load error signal No. 3 will call for a decrease in governor valve position. Simultaneously, with this operation, pressure error signal No. 4 will call for an increase in governor valve position. The result is a decrease in steam pressure and load because of decreased reactor power, thus conditions are corrected without changing governor valve position.

Examples B, C, and D can be reasoned in a like manner; however, in all four suppositions unnecessary control action can be eliminated by the direct energy balance type of control. Proportional signal No. 5 will improve the conventional type of control by eliminating time constants due to the inherent storage capacity of the process system.

SRE PERFORMANCE TESTS

The automatic flux/temperature controller which is an integral part of the SRE-Edison plant control system has operated satisfactorily since October 1958.

The two-element feedwater controller for the once-through boiler and the three-element feedwater controller for the drum-type boiler have been placed in operation and perform satisfactorily.

Tests have been performed with the SRE to simulate load following control operations. The tests were accomplished by manually operating the heat transfer cooling rates, and operating the reactor and turbine-generator equipment on automatic. The results of these tests, which have been reported previously, indicate that the sodium graphite reactor is very stable during fast load changes.

FIGURE NO. 2

CONVENTIONAL AND DIRECT ENERGY BALANCE CONTROL

	No. I		No. II		No. II	
	Load	Pres.	Gov.	Reac. Power	Gov.	Reac. Power
A	+	+	DEC.	DEC.	0	DEC.
B	+	-	DEC.	INC.	DEC.	0
C	-	+	INC.	DEC.	INC.	0
D	-	-	INC.	INC.	0	INC.

No. I (1, 3 & 5) Conventional Method of Operation

No. II (1, 2, 3, 4 & 5) Direct Energy Balance Method of Operation

Further tests are being conducted to collect data to determine the control parameters for the servo amplifiers. The following information is required:

1. Residence time of the drum-type boiler.

The plant control system is vitally concerned with the relative storage and associated dynamic response characteristics of the boiler.

2. Residence time of the once-through boiler.

With the once-through boiler the plant control system must be able to accommodate the reduction in relative storage capacity.

3. Time constants of the heat transfer system including the time constants of the control apparatus.

4. Non-linear characteristics of the primary and secondary sodium flow over the entire range of operation.

5. Linearity of the governor motor control (steam flow vs. admission valve position).

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