Technical Paper

Development and Validation of a Dynamic Model of the Huntington Beach Unit 1 Fossil Power Plant using the Modular Modeling System

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TP1511

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ABSTRACT

A full plant dynamic model and two sub-models were developed for Southern California Edison's Huntington Beach Unit 1 fossil plant using the Modular Modeling System (MMS). The sub-models can be used on a PC with the MMS Workstation software. One sub-model includes the boiler, superheaters, attemperators, gas recirculation, economizer, air heater, turbines, feedwater control valves, and boiler feed pumps with hydraulic couplings and motors. The other sub-model includes the condensate pumps, feedwater heaters, deaerator, condensate booster pumps, feedwater control valves, and boiler feed pumps. The control system is modeled and options exist for cost function analysis and life expenditure studies for the turbine, economizer, and secondary superheater. Plant transient tests were performed to provide data for model validation. The testing consisted of a set of open-loop step tests and closed-loop ramp tests. The MMS model provided good comparisons with plant data for both sets of tests.

INTRODUCTION

The Southern California Edison Company (SCE) contracted with The Babcock & Wilcox Company (B&W) for the collection of plant data and the development of a dynamic model for the Huntington Beach Unit 1 fossil power plant. The model is based on the Modular Modeling System (MMS, Reference 1). The Huntington Beach plant is a drum type boiler rated at 215 MW and is fueled by gas and oil. The plant model will be used by SCE to evaluate plant and control system modifications, as well as improved plant operation procedures. It is anticipated that the modular nature of MMS will facilitate studies involving design modifications. This project is part of SCE's studies for plant life extension, cycling and heat rate improvements.

Most of this paper focuses on the model development portion of the project and the resulting comparison with plant data. The following sections review the plant transients for which data was collected, the model development, the comparison of model results with data, and a summary of modeling problems encountered including their resolution.

PLANT DATA FOR MODEL VALIDATION

A power plant model needs to agree with both steady state and dynamic plant behavior to provide confidence in any decisions affecting the plant operations and expenditures. Standard plant instrumentation frequently needs to be complimented by additional instrumentation and better recording methodology to obtain the level of plant data detail required for model validation.

Transient testing for the Huntington Beach Unit 1 was conducted during the week of March 30 to April 4, 1987. The data acquisition system hardware and software were supplied, configured, installed and operated by B&W personnel. Plant instrumentation was used where available and additional pressure transducers and thermocouples were supplied when required to accomplish the full scope of data acquisition needed for the tests.

A series of open-loop step tests and closed-loop ramp tests were performed. The open-loop tests with all controls except drum level on manual were performed to test the response of the system to a step change in one parameter without interference from the control systems. With the open-loop test data, the time constant of the model can be compared to the time constant of the actual unit. If a significant discrepancy exists, portions of the model can be reparameterized to provide a response more closely reflecting the response of the unit. The closed-loop ramp tests were performed with all controls in automatic to test the response of the control system and provide a comparison with the control system in the model.

The open-loop step tests that were performed on Huntington Beach Unit 1 were:

1. Fuel flow test at 110 MW
2. Fuel flow test at 200 MW
3. Throttle pressure test at 200 MW
4. Air flow test at 200 MW
5. Air flow test at 110 MW
6. High pressure feedwater heater test at 110 MW
7. Throttle pressure test at 80 MW
8. Main steam temperature test at 95 MW
9. Reheat steam temperature test at 95 MW
10. Main steam temperature test at 200 MW
11. Reheat steam temperature test at 200 MW
12. Turbine backpressure test at 107 MW

The closed-loop ramp tests performed on the unit were:

1. Variable pressure ramp up from 98 to 200 MW
2. Constant pressure ramp down from 200 to 112 MW
3. Variable pressure ramp down from 200 to 110 MW

MODEL DEVELOPMENT

Model Components

A full plant model and two sub-models were developed for Huntington Beach Unit 1. One sub-model, shown in Figure 1, includes:

boiler
superheaters
attemperators
gas recirculation
economizer

air heater
turbines
feedwater control valves
boiler feed pumps with hydraulic couplings and motors

The other sub-model, shown in Figure 2, includes:

condensate pumps
two low pressure closed feedwater heaters
deaerator
condensate booster pumps
three high pressure feedwater heaters
feedwater control valves
boiler feed pumps

It should be noted that the feedwater valves and boiler feed pumps are included in both sub-models. The full plant model is a combination of the two sub-models and also includes the condenser and a pipe in the extraction flow to feedwater heater No. 1. The full plant model had a total of 94 state variables.

The model contains several features that have not at this time been added to the standard MMS library. These developments have been implemented to reduce the model size to accelerate execution on a personal computer and to improve model stability at low loads. The features include:

- Net-Node macro for use with resistive modules in series to eliminate the need for connective nodes between the resistive modules.
- Closed feedwater heater macro which is used in conjunction with the Net-Node macro. This macro also includes coding for the drain valve, eliminating the need for a separate module for the valve.
- High and low pressure turbine macros that eliminate internal pressure nodes and the need for separate extraction pipe modules.
- Incompressible valve macro to be used with the Net-Node macro.
- Universal junction macro that allows flow streams to both join and separate from one module rather than requiring separate junction and divider modules.
- Simplified incompressible valve macro that eliminates all defined variables except valve conductance.

Revised versions of the economizer, superheater and regenerative air heaters were also used. Options also exist for cost function analysis and life expenditure studies for turbine rotor bore stress, economizer inlet water header stress, secondary superheater outlet header stress and tube creep.

Diagrams in Figures 1 and 2 show components in the boiler/turbine and feedwater train models. The control and cost function components are also included. The boundary parameters for the full plant model are shown in the diagrams and are listed in Table 1. The additional boundary parameters for the sub-models are shown in the two diagrams and are listed in Tables 2 and 3.

Control Functions

The control systems contained in the model include coding for throttle temperature, reheat temperature, drum level, deaerator level, throttle pressure and individual feedwater heater level controls using a number of proportional-integral (PI) controllers.

- Throttle temperature is controlled by changing the superheat attemperator spray valve position.
- Hot reheat temperature is controlled by changing the gas recirculation. Controllers for reheat temperature acting on reheat attemperator spray are also included.
- Throttle pressure is controlled by changing the throttle valve position.
- Feedwater flow and drum level are controlled using two PI controllers. One controller acts on the coupler between the boiler feedpump and the motor to regulate the delta P across the feedwater valve. The feedwater valve position is then controlled such that the feedwater flow into the boiler follows the steam flow out of the boiler and at the same time controls the level in the drum. The effects of shrink and swell on the level are also included.
- Level in the deaerator is controlled by changing the valve regulating the water flow into the deaerator and the level control on each feedwater heater is by way of the drain valve position.

A PI controller also acts on fuel flow to match the sum of power from the two turbines to a power demand signal which is supplied either as a constant or as a function of time from a table. The throttle pressure setpoint is also provided either as a constant or as a function of time from a table. The names of setpoints in the control system are listed in Table 4.

The controls for the boiler/turbine model are the same as for the full plant except the level controls for the feedwater heaters and the deaerator are not present.

The controls for the feedwater train model include the level controls for the feedwater heaters and the deaerator. The feed pumps are used to control the delta P across the feedwater valve, as in the full plant model, but the feedwater valve is used in a different way. In this model the feedwater valve is used to control the pressure in the line to the economizer.

STEP TRANSIENT VALIDATION

Input data were prepared and the cases run for four step transients using the full plant MMS model. The model comparison with plant data for the specific transients are described below. For all of these tests the power in the model matched the power for the plant data. The steam flow in the model, however, is about 12% below the plant. Earlier, in preliminary runs, the transients were conducted with steam flow in the model about the same as in the plant data but with a 12% discrepancy in the power. The dynamic response in the present transients is about the same as in the preliminary tests indicating that the dynamic response is not a strong function of the initial value. It is observed when comparing the dynamic response of the model with the plant data that the shape of a response plot is much more important than the absolute value of the variable. Discrepancies between model and plant data can be reduced when the model is fined tuned. Verification should first be made that the variables in the model are the same as the plant data values and if no differences are found, then, the parameters in the high and low pressure turbines (e.g. efficiencies) can be changed such that both the power and steam flow match.

All the transients were conducted by starting the model in steady state at time(t)=0 with the controls off except for drum level. The transients were initiated by starting a change at 100 sec (60 sec in Test 3) and the data was collected out to 2000 sec. To be sure the model was in a sufficiently stable steady state, a base case was performed by starting the model at t=0 and collecting data to 2000 sec without making a change. The variables changed only slightly during this time.

In general the model data agree with the plant data very well in a dynamic sense. The size of the initiating steps to start the transients were adjusted in Tests 1, 2, and 3, however, the parameters in the model have not been adjusted except for a slight change to the flow conductance in the primary and secondary superheaters.

In comparing the plots of model and plant data, it will be noticed that the plant signals have more noise.

Turbine Throttle Pressure Test at 200 MW

This transient was initiated by closing down the turbine control valve (YHPT) in a ramp starting at 100 sec and ending at 160 sec. The size of the change was selected to give an increase in turbine throttle pressure which approximately matched the plant data. Model data for this test are compared with plant data in Figures 3 and 4. At approximately 600 sec into the test, the plant experienced a drop in power in the low pressure turbine of about 11% due to some reason not included in the model. It does not seem that this had a major effect on the other variables being compared, therefore, the test was retained. Except for initial starting values, the match with plant data is quite good. That is, the shape of the response closely approximates the plant data but the steam and feedwater flows in particular differ in absolute value.

Reheat Steam Temperature Test at 200 MW

This transient was initiated by reducing the gas recirculation (YGR) in two steps. The first was at 100 sec and the second was at 470 sec. The size at each step was selected to approximately match the increase in plant data for the throttle pressure. The match with plant data is also very good for this transient. The shape is similar to the plant data although the absolute values differ. Model data and plant data are compared in Figures 5 and 6.

Main Steam Temperature Test at 200 MW

The superheater attemperator spray valve was opened a small step at t=60 sec and a larger step at t=400 sec to start this transient. The size of the two steps were selected to approximately match the increase in plant data for the throttle pressure. Again, the comparison with plant data is quite good. The level in feedwater heater Number 1 reached an upper limit at approximately 1000 sec into this test. The limits for both the number 1 and 2 feedwater heaters were bypassed to get to 2000 sec.

Feed Flow Test at 200 MW

The fuel flow was reduced by 1.82% at t=100 sec to start this test. The air flow was not changed. This transient produced larger differences between model and plant data than did the other transients. Drum pressure, throttle pressure, feedwater flow and steam flow all dropped more in the model than the plant. Also the main steam temperature increased in the model but not for the plant. Some of the difference may be due to the fact that the fuel flow was changed in a step rather than a ramp. More of the difference, however,is probably due to the starting conditions. At the start of the transient, the main steam temperature was held down more in the model than the plant by spray flow. The spray flow was reduced in the transient which may have caused an increase in model steam temperature relative to that of the plant.

Ramp Transient Validation

The model is compared with plant data for an up ramp from 102 to 205 MW in Figures 7 through 10. All controls were active for this test. The power and throttle pressure for the model match the plant data very closely, as was to be expected, since the demand tables were made to match the plant data. The feedwater and steam flows have the same relative shape but differed in absolute value as noted in the transient test. The main steam temperature and hot reheat steam temperature are controlled more closely to their respective setpoint in the model than in the plant.

PROBLEMS ENCOUNTERED AND SOLUTIONS

Model development tasks are frequently accompanied by problems that have to be resolved to obtain an efficient running model. Below are discussed some topics that have been known to retard modeling progress.

Achieving Initial Steady State

After assembling the plant model with a control system, the next step is to determine a set of initial values for the state variables from which the plant can be started with a steady state condition for a specific power level. An often used technique is to provide estimates for the initial values and then to execute the dynamic model to achieve a steady state. This can be a difficult task for a large complex model. Frequently a variable will go out of range and stop the execution of the run before achieving a steady state. This behavior is due to the combination of a model not being in a steady state and the uncertainty for the gain values in the control system. Two techniques helped to overcome this problem for the Huntington Beach model. The ratio of proportional to integral gain was increased for several controllers, usually by decreasing the initial estimate for the integral gain. This action increased the damping ratio and provided control with little oscillation. Also, in running toward a steady state, it was helpful to turn the controls off by setting all gains to zero, make a short run (on the order of 100 seconds), and then continue a steady state run with the controls on. Through this process an initial steady state can be established. After comparing the model with plant data, some of the model parameters can be adjusted to improve system response. Steady states for different plant conditions can then be achieved by maneuvering the plant to those conditions by using the control system.

Run-time Improvement

The initial run-time performance was poor for the full plant model with 94 state variables using the Gear integrator option of the Advanced Continuous Simulation Language (ACSL, Reference 2). Approximately one half hour of CPU time on the HP 9000 (Series 500) was required for each second of model time when using the ACSL version 8E1/8F1. This was improved by a factor of 5000 for an open-loop step change case by changing two of the default Gear integration parameters. The parameters that were changed included the option for ACSL to calculate a double sided Jacobian, tsmitg=.true., instead of a single sided Jacobian and relaxing both the absolute and relative error criteria from 1.E-4 to 1.E-3. The better Jacobian approximation provides an improved predictor estimate for the Gear numerical integration algorithm and thus requires fewer Jacobian evaluations, which are computationally intensive calculations. Jacobian accuracy is more difficult to achieve within the single precision accuracy limitations for 32 bit computer systems. The plant model transient results were essentially the same for both sets of integration parameters. A more recent version of ACSL, 8L/8R, has been used to execute the same model and demonstrated better performance for the default values (about 2 times the 'best' result with the 8E1/8F1 version) and nearly the same run-time performance when the second set of integration parameters are used.

Establishing Boundary Conditions for Sub-Models

Often there is an incentive to examine only a portion of a full plant model. These incentives may be driven by a desire for a faster executing model or to fix a boundary condition for a specific plant condition of interest. Whatever the motivation, the ACSL has the flexibility to allow the user to be innovative in establishing the additional boundary conditions required by a sub-model.

The Huntington Beach full plant model forms a loop of components and requires relatively few boundary conditions. When this model was split into sub-models, additional boundary conditions were required for both sub-models at each point where a connection was broken. To each sub-model, these boundary conditions represent the part of the model that is missing and while interaction with those components is excluded it is desirable to make the boundary conditions vary in a given test as much like the missing components as possible. The boundary conditions are set up as tables for the boiler/turbine submodel with initial entries corresponding to the full model response for a particular ramp. The table entries must then be changed at run time for other conditions.

A different approach was used for the feedwater train model. The boundary conditions were made a function of the power demand where the functional relation was taken from the behavior of the full model. It is believed that this will extend the range of application of the sub-model without changing boundary conditions, however, the appropriateness of the boundary conditions must be examined for each use of the model.

Modifications to the controls were also required for the sub-models. For example, in the feedwater train, the water level in the drum does not exist and, therefore, is not available as an input to the control for the feedwater value. In this case, the feedwater flow was provided as a boundary condition and was made a function of power demand. The feedwater valve was then controlled to make the down-stream pressure from the valve equal to a setpoint which was a function of throttle pressure demand.

SUMMARY

A MMS model for the Huntington Beach Unit 1 has been developed and its dynamic response has been compared with plant data. The model matched the plant data quite well in most cases. Some fine tuning of model parameters is required to improve the agreement between the model and plant in steady state, to confirm that the controls in the model correspond to the plant controls and to investigate further the variation in steam temperatures in the fuel flow test. With these improvements, it is thought that the MMS model will provide a valuable tool to assess potential plant modifications and changes in operating procedures.

ACKNOWLEDGMENTS

The authors would like to acknowledge the contributions of other participants toward the model development: B. Meyer who performed the bulk of the initial parameterization and took part in the plant data acquisition; and L.P. Smith for providing the cost function coding.

REFERENCES

1. Modular Modeling System (MMS): A Code for the Dynamic Simulation of Fossil and Nuclear Power Plants, Babcock & Wilcox Company, March 1985.

2. Advanced Continuous Simulation Language (ACSL), Reference Manual, Mitchell and Gauthier Associates, Inc., 1986.

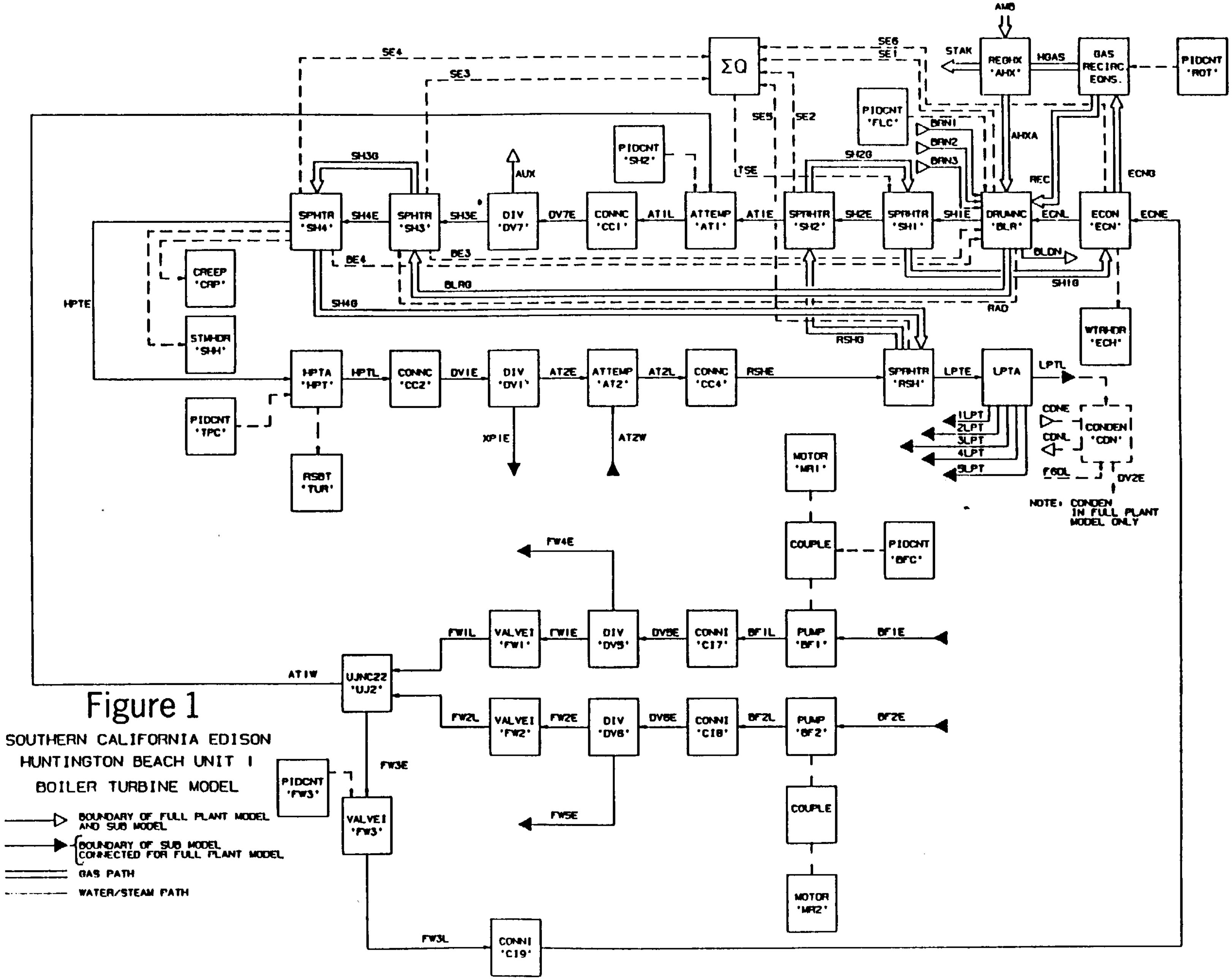

Figure 1

SOUTHERN CALIFORNIA EDISON
HUNTINGTON BEACH UNIT 1
BOILER TURBINE MODEL

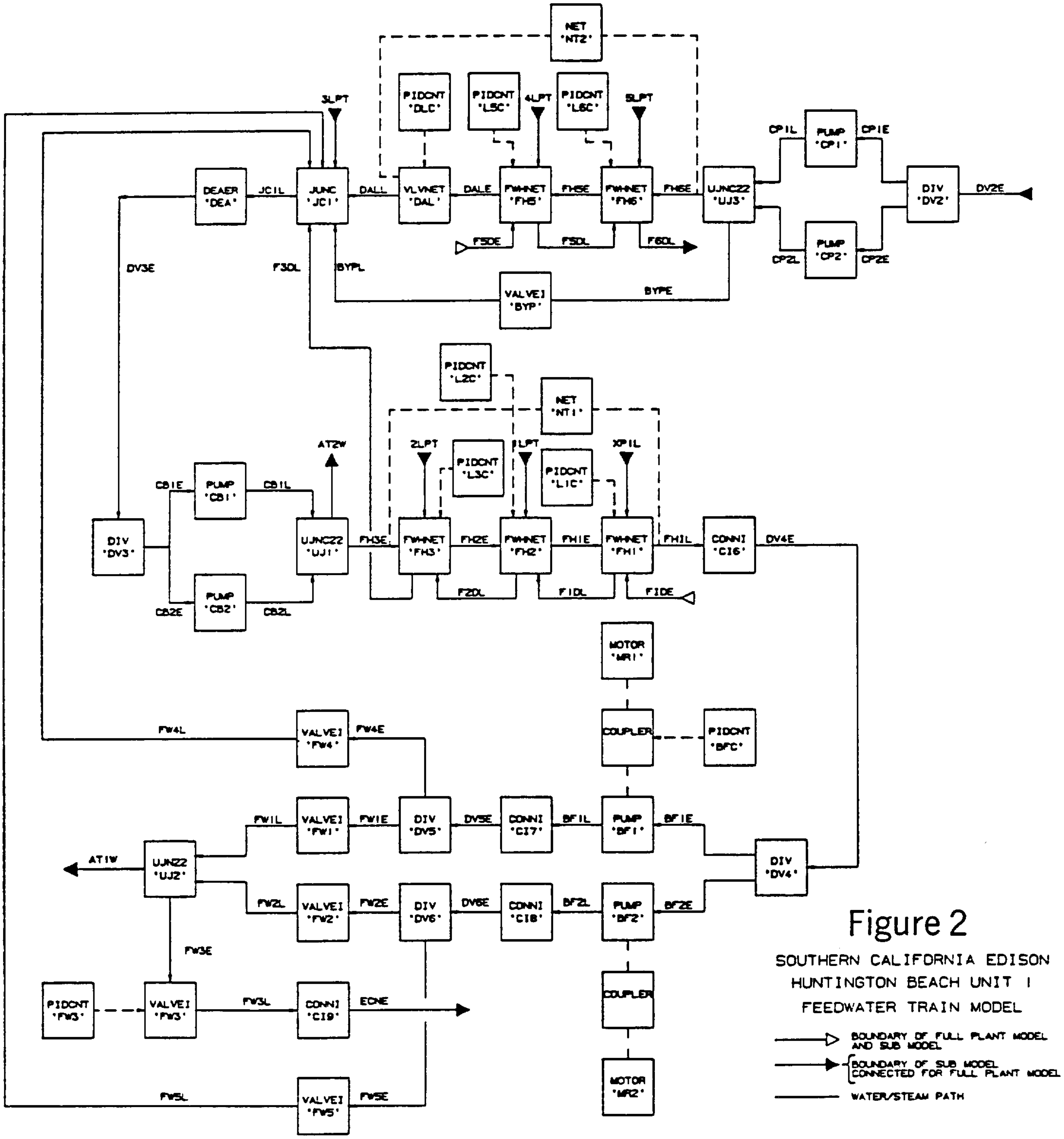

Figure 2

SOUTHERN CALIFORNIA EDISON
HUNTINGTON BEACH UNIT 1
FEEDWATER TRAIN MODEL

Figure 3 Turbine Throttle Pressure Test, HP Turbine Inlet Pressure

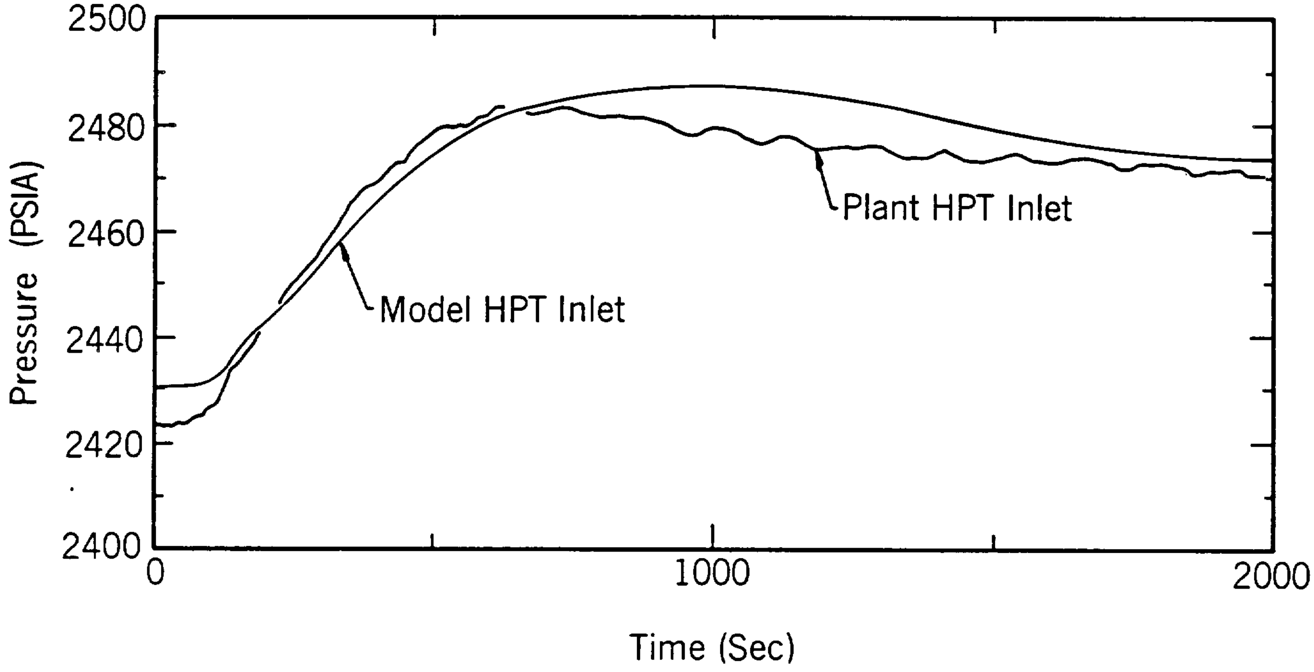

Figure 4 Turbine Throttle Pressure Test, Steam Temperatures

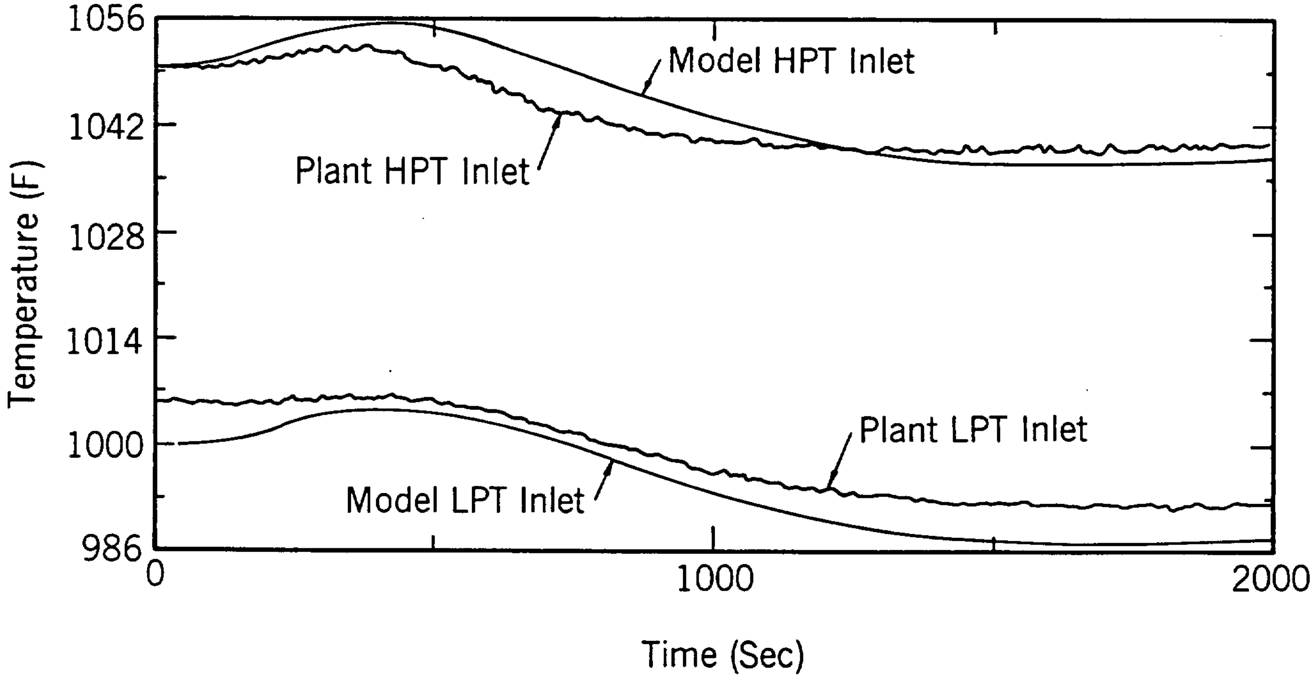

Figure 5 Reheat Steam Temperature Test, HP Turbine Inlet Pressure

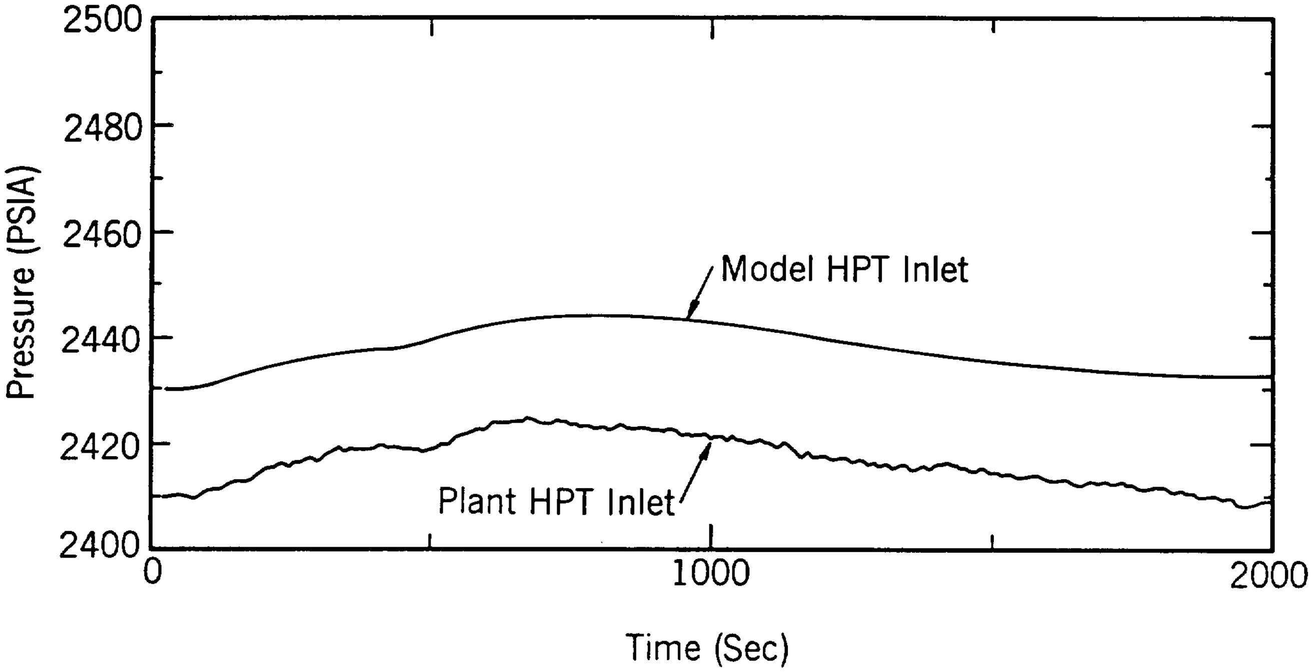

Figure 6 Reheat Steam Temperature Test, Steam Temperatures

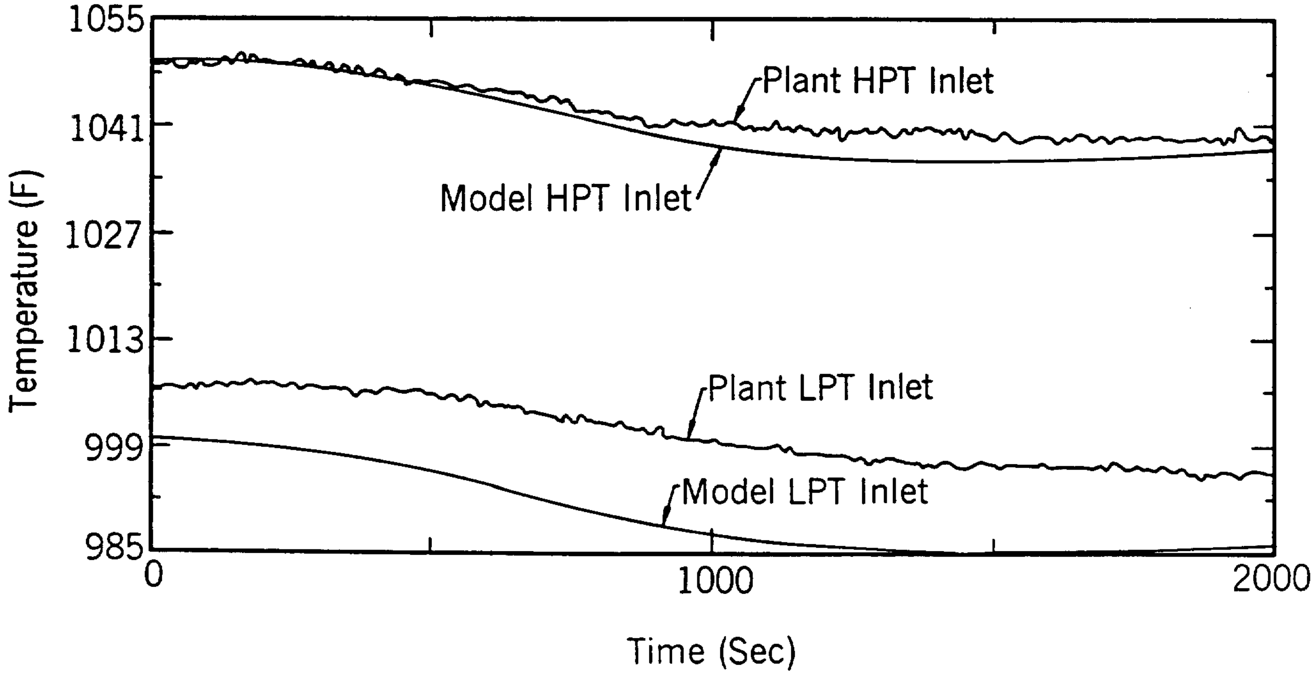

Figure 7 Up-Ramp Test, HP Turbine Inlet Pressure

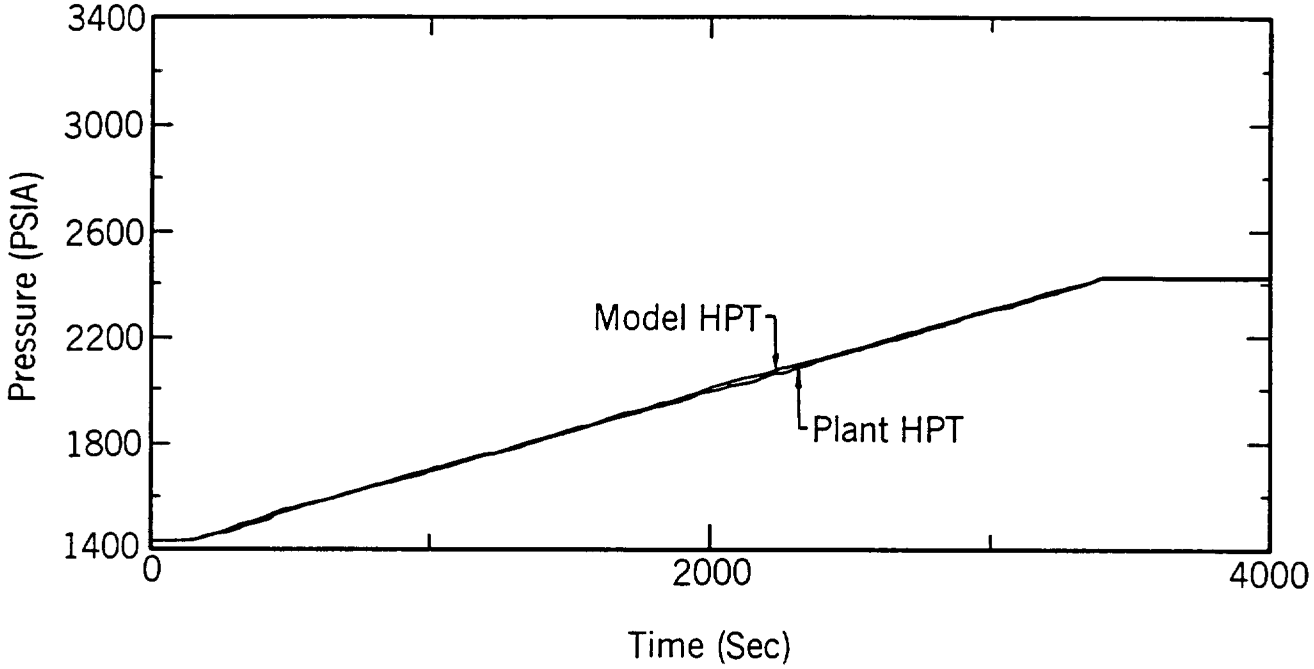

Figure 8 Up-Ramp Test, Steam Temperatures

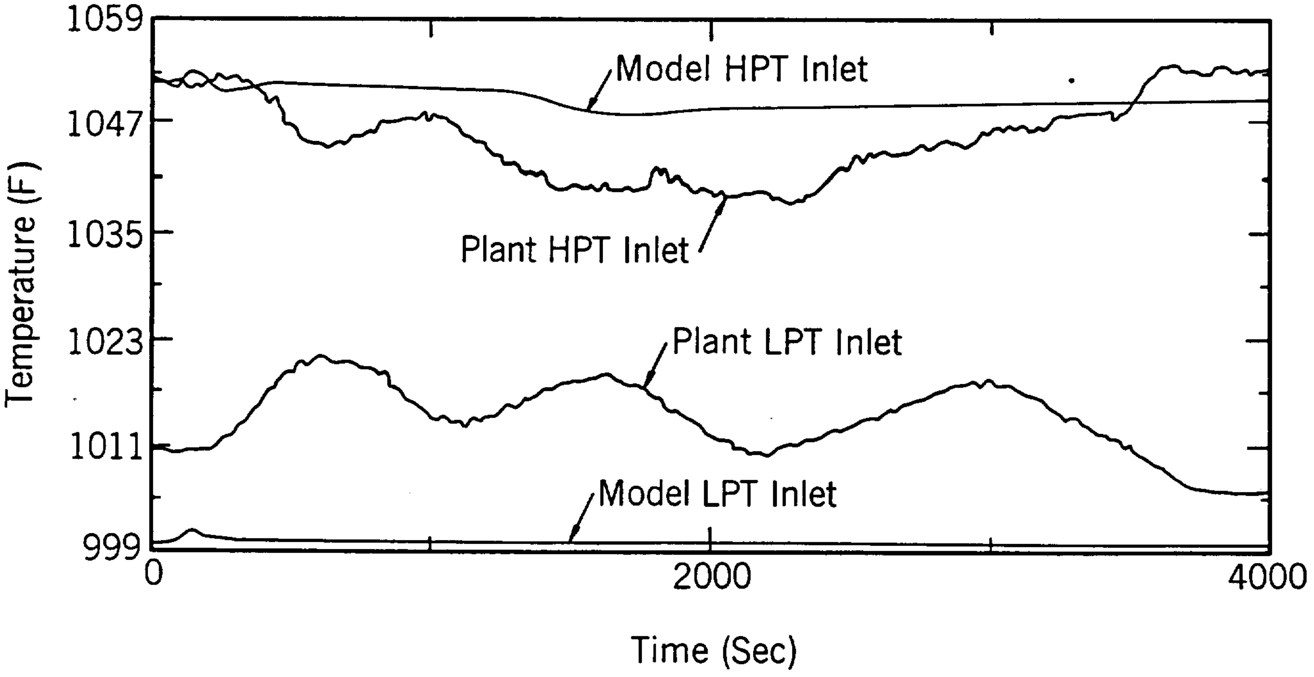

Figure 9 Up-Ramp Test, Steam Flow

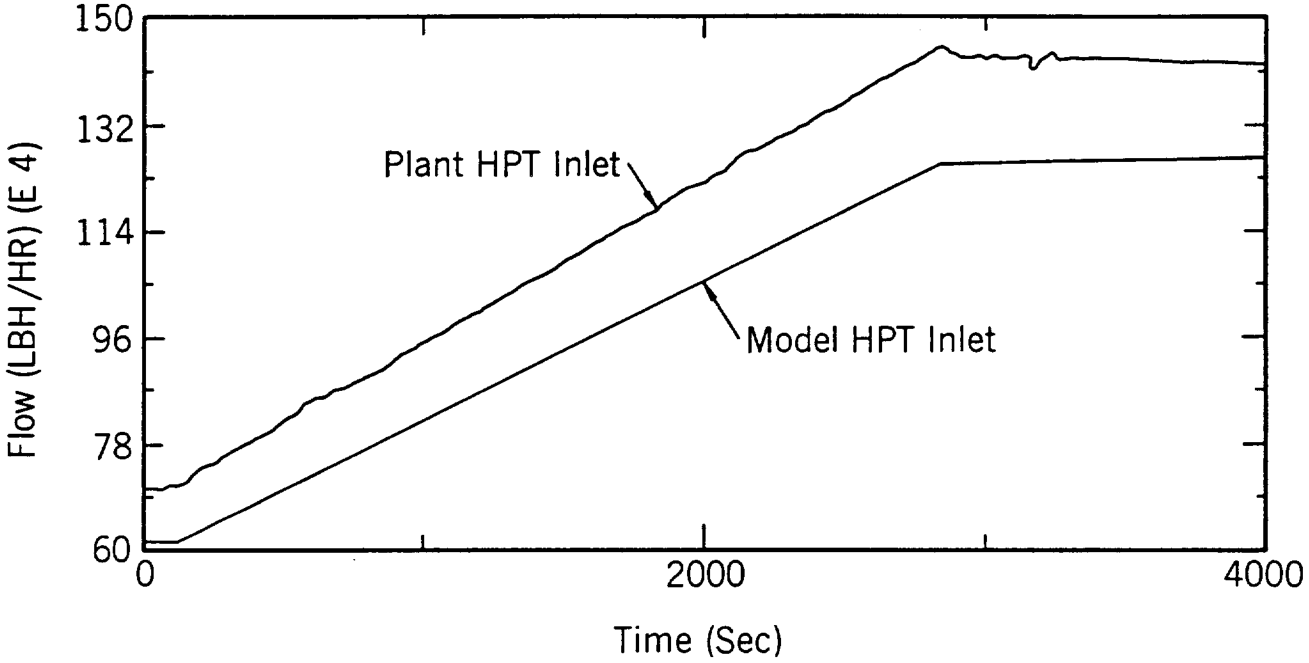

Figure 10 Up-Ramp Test, Power to Generators

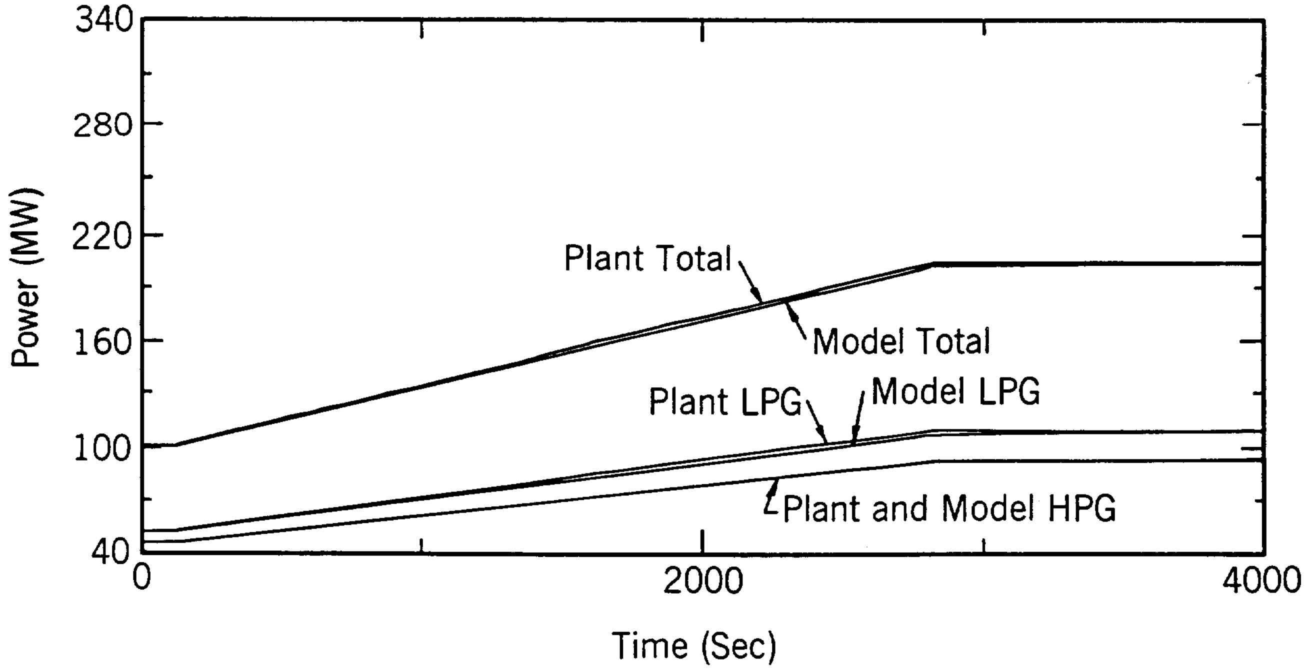

Table 1

BOUNDARIES FOR FULL PLANT MODEL

Boundary	Path Name	Required Values
Air Intake	AMB	H, T
Exhaust Stack	STAK	None
Boiler Blowdown	BLDN	W
Auxiliary Steam	AUX	W
Cooling Water Entering Condenser	CDNE	P, H, R, T
Cooling Water Leaving Condenser	CDNL	P
Fuel	BRN1-3	H

Table 2

BOUNDARIES FOR BOILER/TURBINE MODEL

Boundary	Path Name	Required Values
Intake to Boiler Feedpumps	BF1E and BF2E	P, H, R
Inlet to Bypass Valves	FW4E and FW5E	W
Extraction Flow to Feedwater Heater No. 1	XP1E	W
Spray Flow for Reheat Attemperator	AT2W	P, H, R YAT2 = 0.0
Extraction Flows from Low Pressure Turbine	1LPT	P
	2LPT	P
	3LPT	P
	4LPT	P
	5LPT	P
Exhaust from Low Pressure Turbine	LPTL	P

Table 3

BOUNDARIES FOR FEEDWATER TRAIN MODEL

Boundary	Path Name	Required Values
Leaving Condenser	DV2E	P, H, R, T
Drain from Feedwater Heater No. 6	F6DL	P
Extraction Flows from Low Pressure Turbine	1LPT 2LPT 3LPT 4LPT 5LPT	W, H, T W, H, T W, H, T W, H, T W, H, T
Extraction Flow to Feedwater Heater No. 1	XP1L	W, H, T, R
Spray Flow for Reheat Attemperator	AT2W	W (W = 0.0)
Spray Flow for Superheat Attemperator	AT1W	W
Feedwater Flow to Economizer	ECNE	W

Table 4

CONTROL SYSTEM SETPOINTS

Name	Setpoint For:
LBLRSP	Boiler Level, in.
KDLSP	Delta P Across Feedwater Valve, psi
CSSHSP	Steam Temperature into HP Turbine, °F
CRSHSP	Steam Temperature into LP Turbine, °F
KTPSP	Throttle Pressure if from Constant, psia
PTDTB (Table)	Throttle Pressure if from Table, psia
KMWD	Power if from Constant, MW
PWDTB (Table)	Power if from Table, MW
LFH1SP	Level Feedwater Heater No. 1, in.
LFH2SP	Level Feedwater Heater No. 2, in.
LFH3SP	Level Feedwater Heater No. 3, in.
CDEASP	Level Deaerator, in.
LFH5SP	Level Feedwater Heater No. 5, in.
LFH6SP	Level Feedwater Heater No. 6, in.