AEP's Use of PEPSE® to Develop Heat Balance Diagrams and Input-Output Curves For Economic Load Dispatch

T. E. McCartney

American Electric Power Service Corporation

ABSTRACT

American Electric Power (AEP) places great importance on identifying heat rate deviations for each of its units, taking appropriate action to minimize unit heat rate, and dispatching load on a least cost of generation basis considering current levels of thermal performance for each of its units. This paper describes AEP's methodology to develop and validate their PEPSE heat balance models, prepare design heat balance diagrams, and expected heat rate, input-output and incremental heat rate curves for economic load dispatch.

INTRODUCTION

American Electric Power (AEP) owns and operates 46 fossil units with a net demonstrated capability of 20,515 MWN, which accounts for approximately 85% of total system generation. The balance is generated by two nuclear units and 67 hydroelectric units. Most if not all of AEP's fossil units operate at off-design conditions compared to original equipment specifications. For example, steam temperatures have been reduced to prevent coal ash corrosion, and exit gas temperatures are higher than design to stay above flue gas dewpoint temperatures and to prevent air heater pluggage. All of AEP's fossil units operate at higher than original design heat rates because of both off-design operation and continual equipment degradation.

AEP has undertaken a program to develop models of each series of fossil units on its system using PEPSE heat balance software for several reasons. First, AEP wanted to develop revised "design" heat balances that took into account changes in operating philosophy and equipment modifications since the units went into commercial operation. This enables AEP performance engineers to more accurately quantify heat rate deviations given a more realistic baseline. Second, using these same PEPSE models and factoring in results from routine performance tests, expected heat rate, input-output, and incremental heat rate curves which reflect actual unit operation are developed for each unit on the AEP System to update annually the system's economic load dispatch algorithm. This results in the AEP System minimizing its cost of generation for their customers. Finally, PEPSE models for each unit permit accurate analysis of thermal performance changes due to equipment and/or operational modifications.

BASE MODEL DEVELOPMENT

The first phase of developing a PEPSE model is to construct a base model which accurately matches the turbine vendor heat balances. The objective of this step is to develop a model which calculates the turbine expansion lines as accurately as possible at any load and backpressure.

A cycle schematic is developed using PEPSE components to represent all major turbine cycle equipment. The geometry shown on the vendor heat balance is used to lay out the schematic so that the base case model geometry is identical to that used by the vendor.

The component input data for the valves wide open (VWO) case is then input into the model. This data is obtained from the vendor heat balance, vendor thermal kit, and individual equipment design specification sheets.

To facilitate matching the vendor VWO heat balance, the model is initially made as simple as possible. All packing leakages are fixed, and schedules and operations are kept to a minimum. Initially, the only necessary schedules and operations included are those used for calculating generator losses and exhaust losses.

The General Electric (GE) turbine calculation procedure is used for all units, regardless of the actual turbine manufacturer. Many of AEP's units are composed of GE turbines which were designed before the GE procedure was developed. AEP's 1300 MW Series have Brown-Boveri machines, and several units have Westinghouse machines. As a result, the PEPSE calculated expansion lines must be altered to match the vendor expansion lines. The modifications are accomplished by setting iterative controls on efficiency multipliers and shape factors. The efficiency multipliers and shape factors calculated for the VWO case are input into the model and used for subsequent runs.

AEP's criteria for base case models are to match the turbine vendor VWO heat balance to within 200 KW of load, 0.1% of flows, and approximately 1.0 unit of state point (e.g. pressure, enthalpy). The criteria for state point may require minimal deviation if the unit was designed prior to the 1967 ASME Steam Tables.

When the vendor's VWO heat balance has been matched, the bulk of the work involved with the base case development has been completed. After obtaining the VWO match, the model is altered to enable load range calculations. Packing leakoff constants are calculated using iterative controls and equipment performance curves are input using schedules. The following schedules and curves are included:

1. Feedpump head and efficiency.
2. System resistance curves.
3. Pressure drops across reheater and extraction lines.
4. Throttle pressure and temperature.
5. Reheat temperature.
6. Condenser backpressure.
7. Feedwater heater terminal temperature difference (TTD) and drain cooler approach (DCA).
8. Miscellaneous flows such as blowdown, makeup, slag blowing, and combustion air heating.
9. Parameters to calculate net unit heat rate (NUHR):
    a. Auxiliary power.
    b. Boiler efficiency.

Once the model is set up to calculate partial load performance, runs are made to match vendor partial load heat balance cases. The partial load cases are validated using the same matching criteria established for the VWO case. Partial load shape factors and efficiency multipliers may have to be calculated to obtain a satisfactory match. If this is the case, the shape factors and efficiency multipliers are scheduled as a function of throttle flow for future partial load runs.

The base case is also run at various circulating water temperatures for each load to verify that the low pressure turbine expansion line properly behaves at any load and backpressure. Vendor heat balances are generally calculated at a fixed backpressure of 1.5 in HgA; however, vendor backpressure correction curves can be used to verify that the model is calculating cycle performance properly.

WORKING MODEL DEVELOPMENT

The working model is the basis for calculating design and expected performance. To develop a working model, the base case model is modified to reflect the as-built geometry of the unit. In many cases, the unit's as-built geometry is different than the geometry shown on the vendor heat balances. For example, actual leakoff drain paths may be different, reheat attemperation may not be shown, and evaporators may not be included on the vendor balance. The objective is to model the unit according to the way it was actually built.

The working model geometry is determined from AEP flow diagrams, not existing AEP heat balances. This is desirable not only for accuracy, but also for maximum flexibility. The working model will allow calculation of any possible operating mode, since all heater strings, alternate drains and alternate feedpump turbine steam supplies will be modeled.

DESIGN HEAT RATE

As noted earlier, most if not all of AEP's fossil units operate at off-design conditions compared to original equipment specifications. From the standpoint of current operation, the original design heat balances are no longer a realistic baseline for quantifying heat rate deviations. For example, if a unit's main steam temperature has been reduced from 1050°F to 1000°F, there is no point in comparing actual heat rate to the 1050°F main steam heat balance, since the unit's maximum allowable main steam temperature is 1000°F.

The working model is used to calculate a new design heat rate. The schedules and operations defining the original unit design parameters must be modified to reflect changes in operating philosophy and equipment modifications since the unit went into commercial operation. AEP's 800 MW Series units are one example of units whose design heat rates have changed due to equipment modifications. As a result of recent economizer surface addition to the 800 MW units, a heat rate reduction of 200 Btu/KWH was realized. The reduction in heat input to the furnace and forced draft fan power contributed 100 Btu/KWH. A reduction in dry gas loss contributed 70 Btu/KWH, and reduced reheat attemperation rates contributed another 30 Btu/KWH. Obviously, if the design heat rate curves did not reflect this performance improvement, the baseline heat rate would be unrealistically high.

AEP has established a specific set of procedures for documenting the development of design heat rate working models. Taking into account equipment limitations, the following schedules are modified:

1. Steam temperatures that are the best attainable, given changes in the steam generator and/or limitations based on changes in operating philosophy.

2. Heater TTDs and DCAs.

3. Boiler efficiency,considering effects of fuel changes and air heater exit gas temperature limits.

4. Auxiliary power to reflect current loading.

Most original design curves do not include precipitators and other equipment modifications and/or retrofits.

5. Reheat attemperation schedule changes may be required in some cases due to temperature limits and/or boiler modifications.

Design heat rate curves must account for normal operating conditions which include discontinuities in the curve, such as changes in feedpump turbine steam supply and alternate heater drains during low load operation. For each segment of the heat rate curve, the model is run at a minimum of four load points per segment. Heat rate curves are generated at circulating water temperatures of $35^{\circ}F$, $65^{\circ}F$ and $80^{\circ}F$ for open circulating water systems, and $50^{\circ}F$, $75^{\circ}F$ and $100^{\circ}F$ for units with cooling towers. These curves are used to define the baseline for calculating heat rate deviations.

DESIGN HEAT BALANCES

AEP developed their own computer software for generating plots of heat balances. AUTOCAD graphics software is used to produce heat balance drawings on a VERSATEC plotter. To create a drawing, the plotting code is generated using an IBM-AT personal computer and a digitizing tablet. AEP's

Information Systems Department designed the system to enable quick drawing development and versatility for making drawing changes. Without the graphics terminal, the heat balance would have to be manually drawn to scale on graph paper, and then the pen commands would have to be coded, analogous to writing a FORTRAN code, based on the coordinates measured from the drawing. This work is eliminated by using the graphics terminal, since the software generates all of the pen commands and saves them in a file.

The reduction in manhours since using the graphics software has been approximately 5 to 1. The factor which makes the graphics software system so useful is flexibility in making changes to the layout of the drawing. A person who is very proficient in coding the plotter commands would not be able to make changes, such as moving the location of steam seal leakoff flows, as quickly as a person who has fair proficiency on the graphics system.

An outstanding feature of AEP's heat balance plotting scheme is that once the basic drawing has been generated, plots of individual cases are drawn by the computer with no intermediate manual entry of numbers appearing on the heat balance. The output of a PEPSE case is saved on tape, and the parameters to be printed on the heat balance are accessed from the tape according to stream number, fluid property number, and/or operational variable identification.

Attachment 1 shows an example of a recently developed new design heat balance for Big Sandy Unit 1, a 260 MWN subcritical unit that went into commercial operation in 1963. The updated full load design heat rate of 9076 Btu/kwh is approximately 160 Btu/kwh higher compared to the original design heat balance. Of this 160 Btu/kwh difference, corrected design boiler efficiency contributed 90 Btu/kwh. An additional 65 Btu/kwh was added by reduced design steam temperatures. Originally designed for steam temperatures of 1050°F main steam/1050°F reheat, the unit's main steam temperature was derated to 1000°F in 1970 because of coal ash corrosion.

EXPECTED HEAT RATE

Using the working models and factoring in results from routine performance tests, expected heat rate, input-output, and incremental heat rate curves which reflect actual unit operation are developed for each unit on the AEP System to annually update the system's economic load dispatch algorithm. This results in the AEP System minimizing the cost of generation for their customers.

The most significant equipment deviations from design for most of AEP's units are turbine efficiencies. The working models are modified to reflect test turbine efficiencies by setting controls on efficiency multipliers to calculate the correct efficiencies. The inputs for intermediate pressure turbine groups and low pressure turbine groups were changed so that the IP and LP expansion lines are calculated separately. This allows independent manipulation of the IP and LP turbine efficiencies.

The original design and actual turbine efficiency curves for AEP's Mitchell Unit 2 800 MW unit are shown in Attachments 2-4. By incorporating the test turbine efficiency curves into the Mitchell Unit 2 expected heat rate working model, the actual turbine efficiencies are accurately calculated at any load.

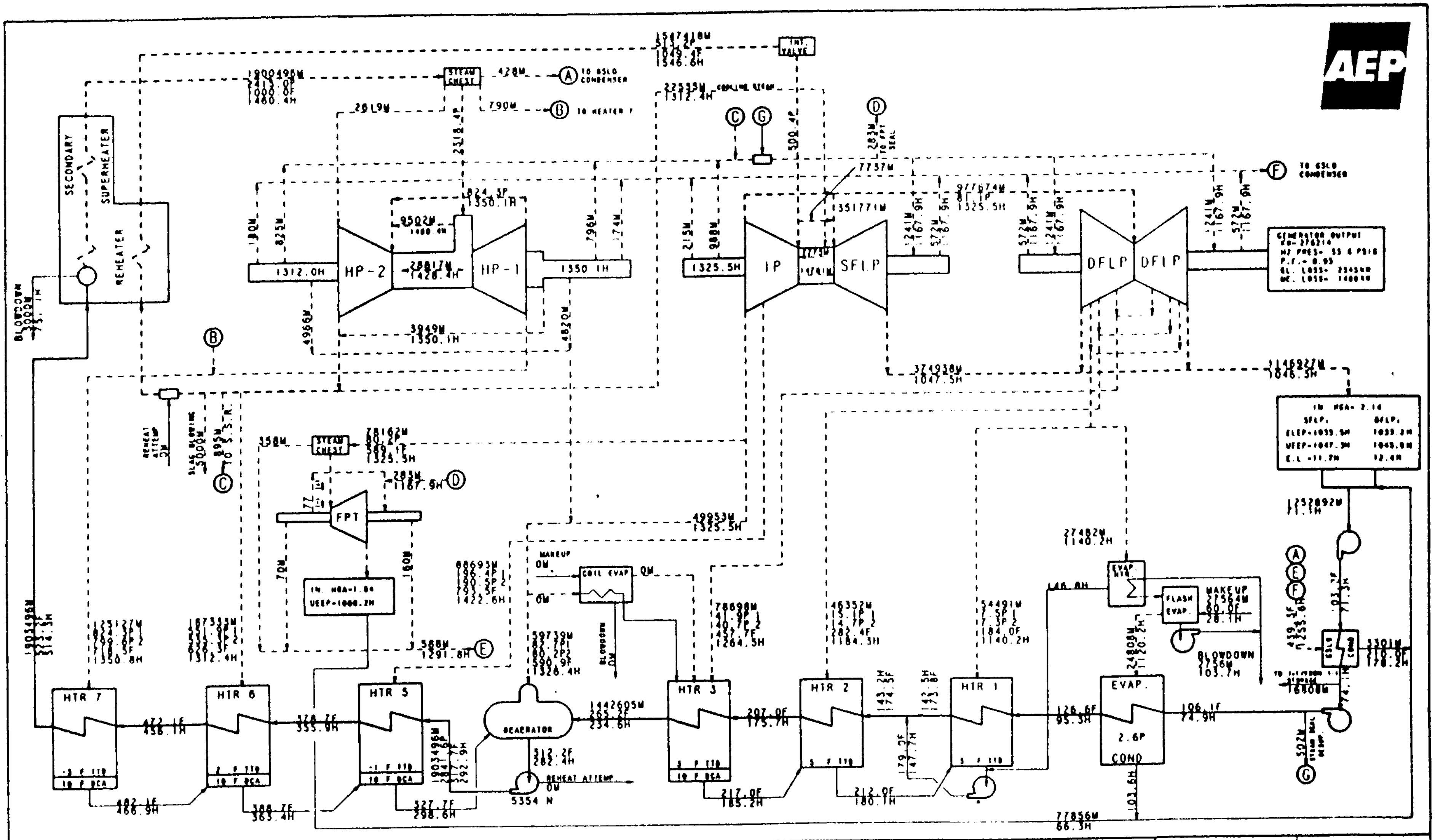
Other operating parameters are input by using schedules and/or operations. Examples include main steam pressure and temperature, reheat temperature, reheater pressure drop, reheat attemperation, auxiliary power, heater performance, pump performance, boiler efficiency, and miscellaneous flows.

The actual heat rate curves are annually updated to reflect equipment degradation, performance improvements brought about by equipment maintenance, and operational modifications. Thus, AEP's performance test program is used for more than just trending equipment performance. It provides accurate information for economic load dispatch.

AEP's procedure for developing expected heat rate curves is similar to their procedure for developing design heat rate curves. For each segment of the expected heat rate curve, the model is run at a minimum of four load points per segment. A third order input-output curve is obtained by curve fitting the four or more load points from the PEPSE runs. The first derivative of the input-output curve then gives a quadratic incremental heat rate curve. We are currently evaluating the use of decreasing incremental heat rates when the minimum incremental heat rate falls within the normal operating range of the unit, between minimum and full load.

SUMMARY

AEP has used PEPSE software and in-house software to calculate realistic baseline heat rate curves, draw design heat balances, and develop expected heat rate, input-output, and incremental heat rate curves which reflect actual unit operation for each of its units. As a result of this work, AEP is becoming better equipped for moving toward their goal of becoming a least cost power producer.



REFERENCE DATA AND NOTES

P1 - PRESSURE AT TURBINE FLANGE
P2 - PRESSURE AT SHELL INLET

HEAT BALANCE
CALCULATED BASED ON
MEAN OF VALVE LOOP
TURBINE EFFICIENCY.

DESIGN DATA REFERENCES

EXPANSION LINES	WEST CT-11664 WEST CT-11665A WEST CT-11679
EXHAUST LOSS	WEST #537880
GENERATOR LOSSES	B&W GO-1524
STM. GENERATOR	WORTH HYE-17064
CONDENSERS	I-R #31-18050
BOILER FEEDPUMP	GRISCOM-RUSSELL
FW HEATERS	SPEC. SHEETS

SYMBOLS

H - BTU/LB
P - LBF/SQ. IN.ABS.
M - LBM/HR
F - DEGREE F.
N - RPM
-- - STEAM
— - WATER

TURBINE EFF:

HPT	82.67 %
IPT	90.91 %
SFLPT	85.20 %
DFLPT	84.97 %

GROSS KW - 276214
GTHR (BTU/KWH) - 7825
NET KW - 266550
NUHR (BTU/KWH) - 9076

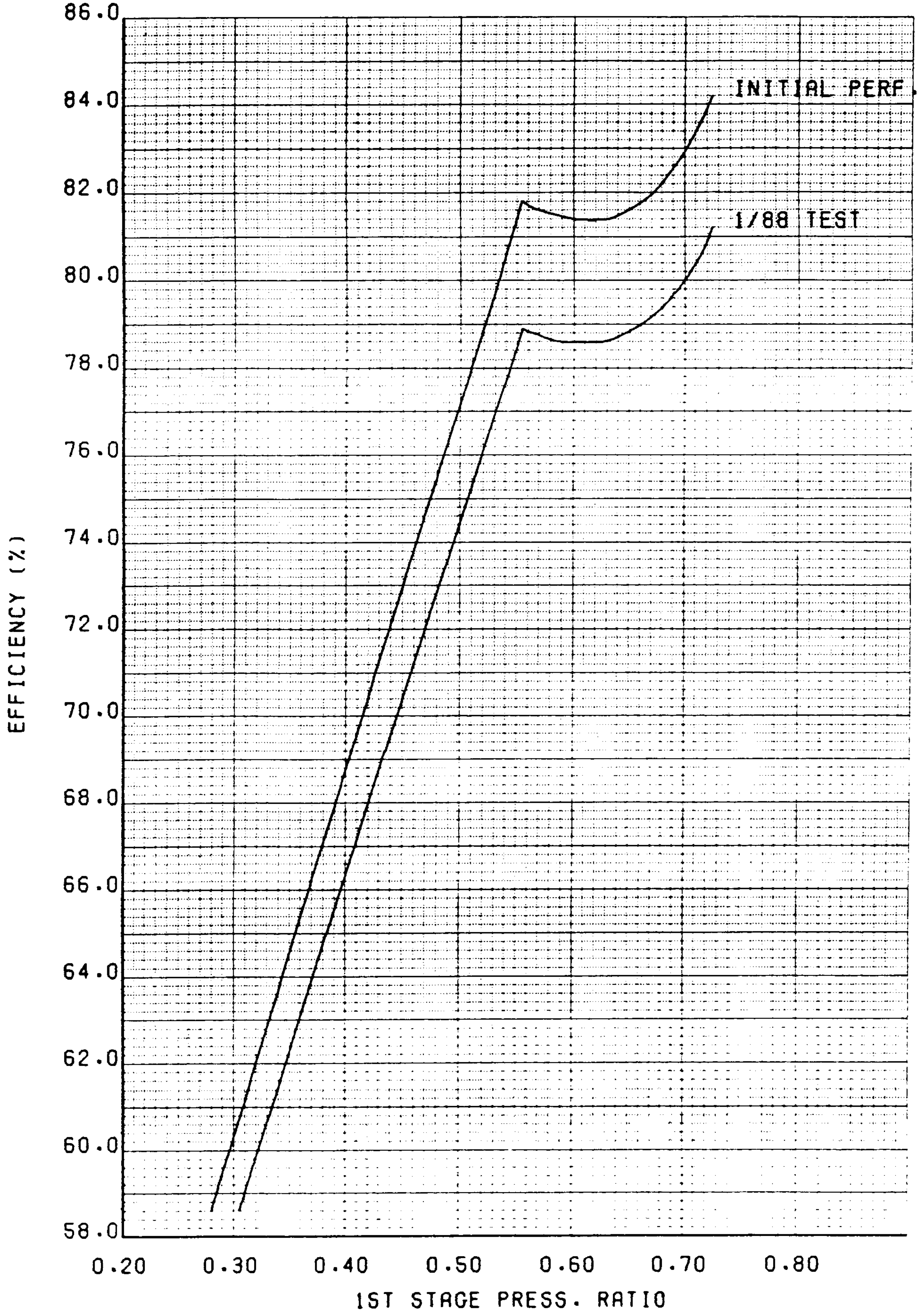
STEAM GEN. EFF. - 89.34 %
CIRC WATER TEMP. (F) - 75

CALC BY: F.E. MCCARTNEY	100% THROTTLE FLOW
APPR. BY M.L. WEARHOFF	DATE: FEBRUARY 22, [illegible]

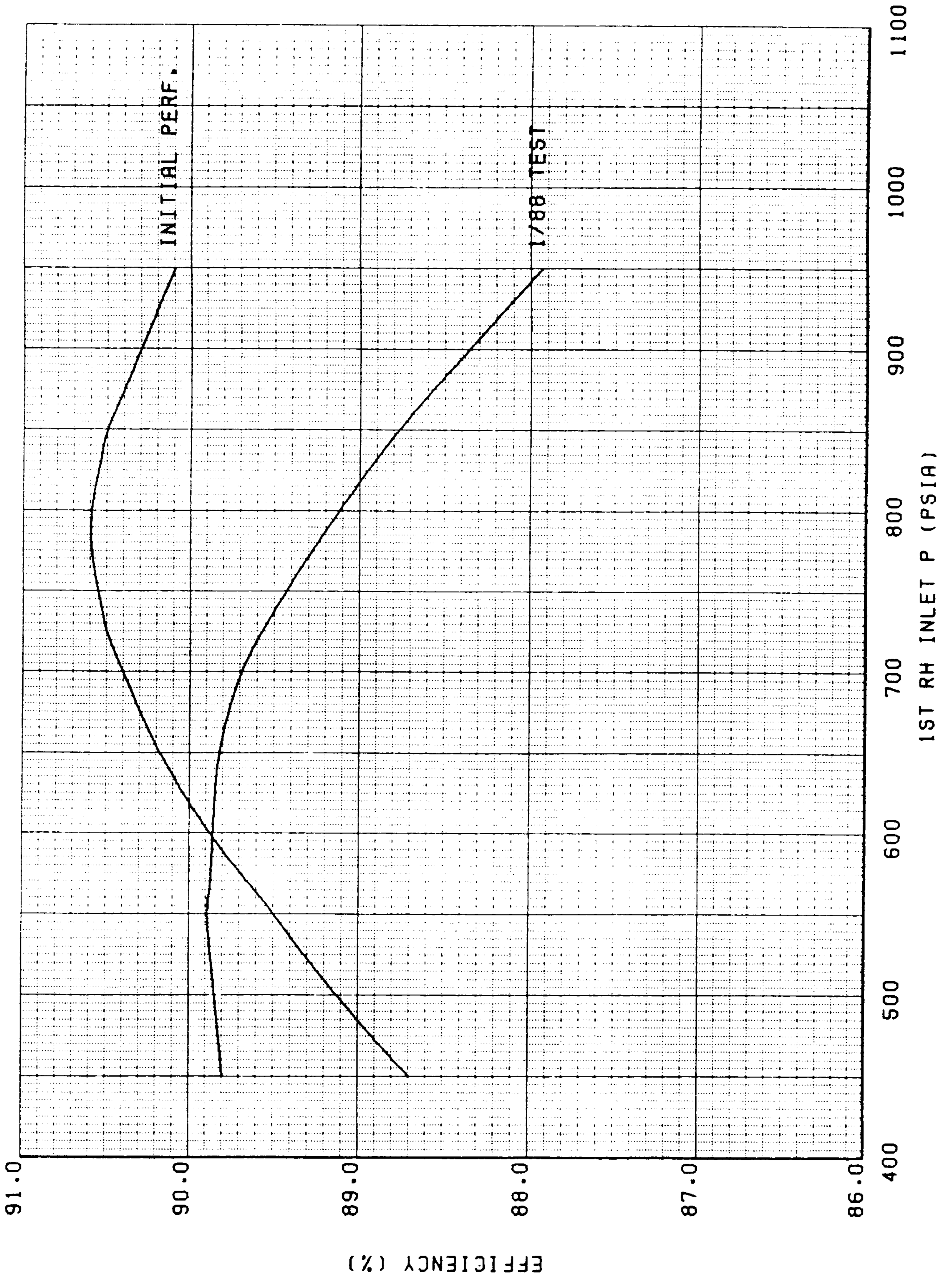
AMERICAN ELECTRIC POWER SERVICE CORP
F.P.E.D. - PERFORMANCE ENGINEERING SECT.

BIG SANDY PLANT
UNIT 1
KENTUCKY POWER

MITCHELL UNIT 2
HP TURBINE EFFICIENCY



ATTACHMENT 3



MITCHELL UNIT 2
1ST RH TURBINE EFFICIENCY

ATTACHMENT 4