PEPSE® Analysis of Generation Opportunities

Thomas W. McColloch

Rochester Gas & Electric Corporation

Abstract

RG&E is a summer peaking electric utility, and has had several years with peak demands that were higher than forecasted. To meet the anticipated future peak demands, RG&E conducted a capacity bidding auction to select suppliers to provide 50 MW of supply side peak power and 20 MW of demand side peak power. As part of the supply side effort, RG&E considered modifications to existing company facilities that could be used to generate electricity. The first was a modified combined cycle, utilizing the exhaust heat from a combustion turbine to preheat feedwater in a conventional steam turbine cycle. The second was the installation of turboexpander powered generators installed on existing natural gas pipeline pressure reducing stations. PEPSE was used to study the potential for electric production from these two systems.

Introduction

Rochester Gas and Electric Corporation serves the upstate New York area, with corporate headquarters in Rochester, New York. Electric generation consists of a 500 MW nuclear plant, five (5) coal fired units with a total output of 350 MW, hydro-electric stations on the Genesee River with a total output of 50 MW, and two (2) 18 MW combustion turbines. RG&E is also a partner with neighboring utilities for 200 MW of oil fired generation and 150 MW of nuclear.

RG&E recently conducted an auction for 50 MW of supply side and 20 MW of demand side peaking electrical generation. As part of this auction, RG&E studied potential opportunities for supplying this power within the company. This paper presents the results of studies performed on two systems.

Analysis of System Number 1

The first system consists of an existing 80 MW coal fired steam turbine and an existing 18 MW oil fired combustion turbine. The two units are on one site in close proximity. The steam turbine cycle is single reheat with 6 stages of feedwater heating. The combustion turbine is simple cycle with no heat recovery on the exhaust. This analysis considers installing a heat exchanger in the combustion turbine exhaust to heat feedwater in the steam cycle.

Steam Turbine Cycle Heat Balance

The vendors heat balance for the steam turbine cycle is shown in Attachment 1. The condensate enters feedwater 1 at 101 F and feedwater exits feedwater heater 6 at 499 F. The gross electrical output is 83 MW with a cycle heat rate of 7840 BTU/KWH.

Steam Turbine PEPSE Model

The PEPSE schematic for this cycle is shown in Attachment 2. The turbines are modeled as GE and all the feedwater heaters are in simplified design mode. The input deck is shown in Attachment 9.

Combustion Turbine Heat Balance

A heat balance for the combustion turbine is shown in Attachment 3. The turbine is fired with 30 GPM of No. 2 oil, and produces 18 MW with a heat rate of 15,000 BTU/KWH. The turbine exhaust temperature is 1000 F.

Combustion Turbine PEPSE Model

The PEPSE schematic for the combustion turbine is shown on Attachment 4. The turbine is a type 9 component and the combustor is a type 70. A control is added to the splitter "B" port flow to adjust the air flow rate to produce the desired combustor exit temperature. The input deck is shown in Attachment 10.

Modified Cycle Heat Balance

The modified cycle heat balance is shown in Attachment 5. The heat exchanger is added before feedwater heater 1, and the feedwater exit temperature is 350 F. There is no extraction flow to feedwater heaters 1 through 4, and reduced extraction flow to heater 5. The combustion turbine exhaust is cooled from 1000 F to 410 F. The electric output from the steam cycle increases to 90 MW with the heat rate decreasing to 7300 BTU/KWH.

Modified Cycle PEPSE Model

The modified cycle PEPSE schematic is shown in Attachment 6. The new heat exchanger is placed ahead of the first feedwater heater. The heat exchanger is a type 20 component, which makes it simple to specify the exhaust gas temperature exiting the exchanger. The extraction streams to feedwater heaters 1 through 4 are closed with a 60XXX6 card. The input deck is shown in Attachment 11.

Analysis of System Number 2

The second system considered for electric production is the installation of turboexpanders driving electric generators on natural gas pipelines. Typical gas pipelines have compressor stations located at regular intervals to maintain flow rates. The pipeline pressure at a customer connection point is normally much higher than required, and a pressure reducing station is installed to regulate flow. The pressure loss represents wasted energy, which can be recovered by expanding the natural gas through a turbine rather than through a control valve. A typical flow schematic for a turbine versus a control valve is shown in Attachment 7.

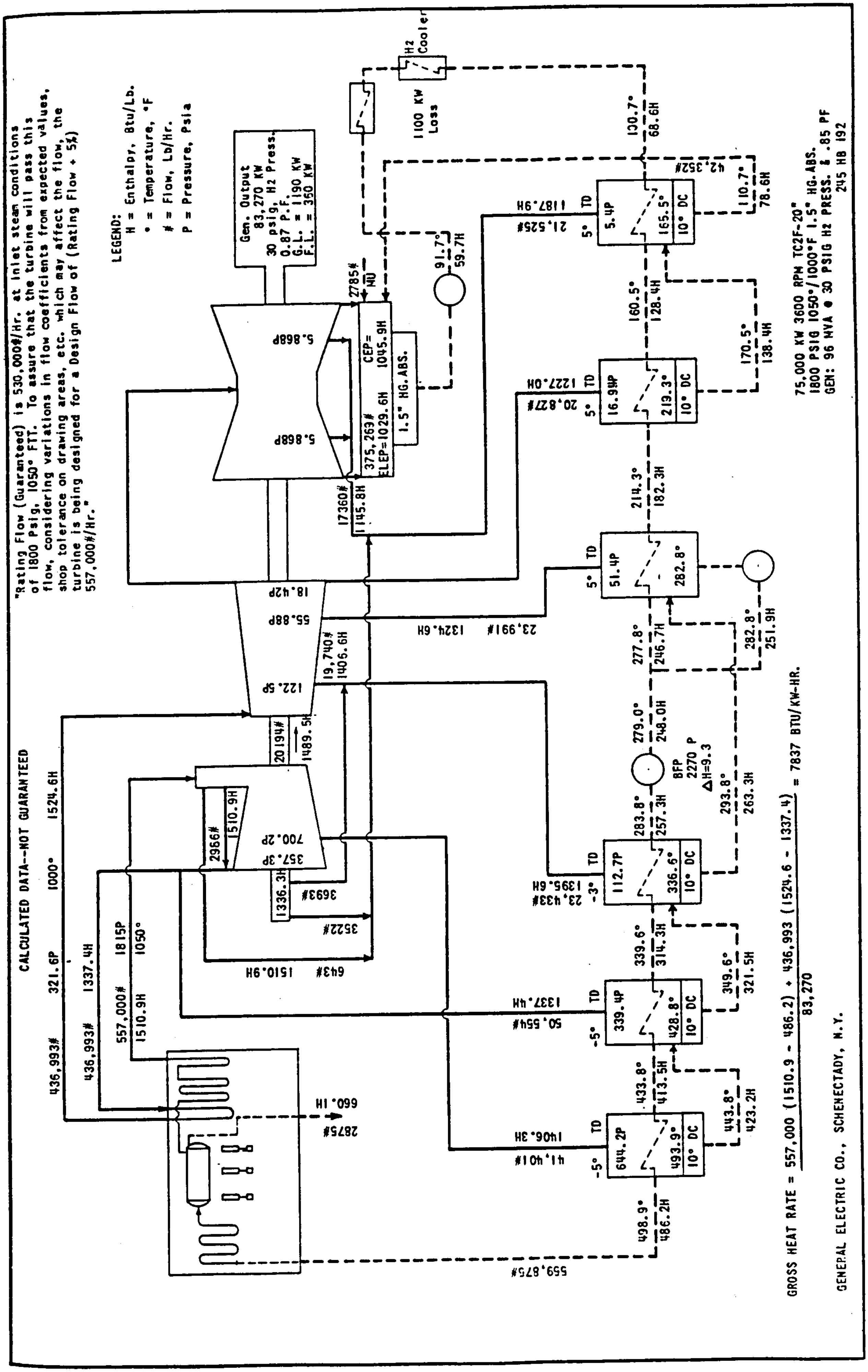
One problem with the turbine is that the exit temperature will be quite low. To help overcome this, the inlet can be heated, either with a natural gas fired heater or with a separate process located nearby that has waste heat. This improves the potential output from the turbine by keeping the exit temperature in a more useful range. A heat balance for the turbine with inlet heating is shown on Attachment 7.

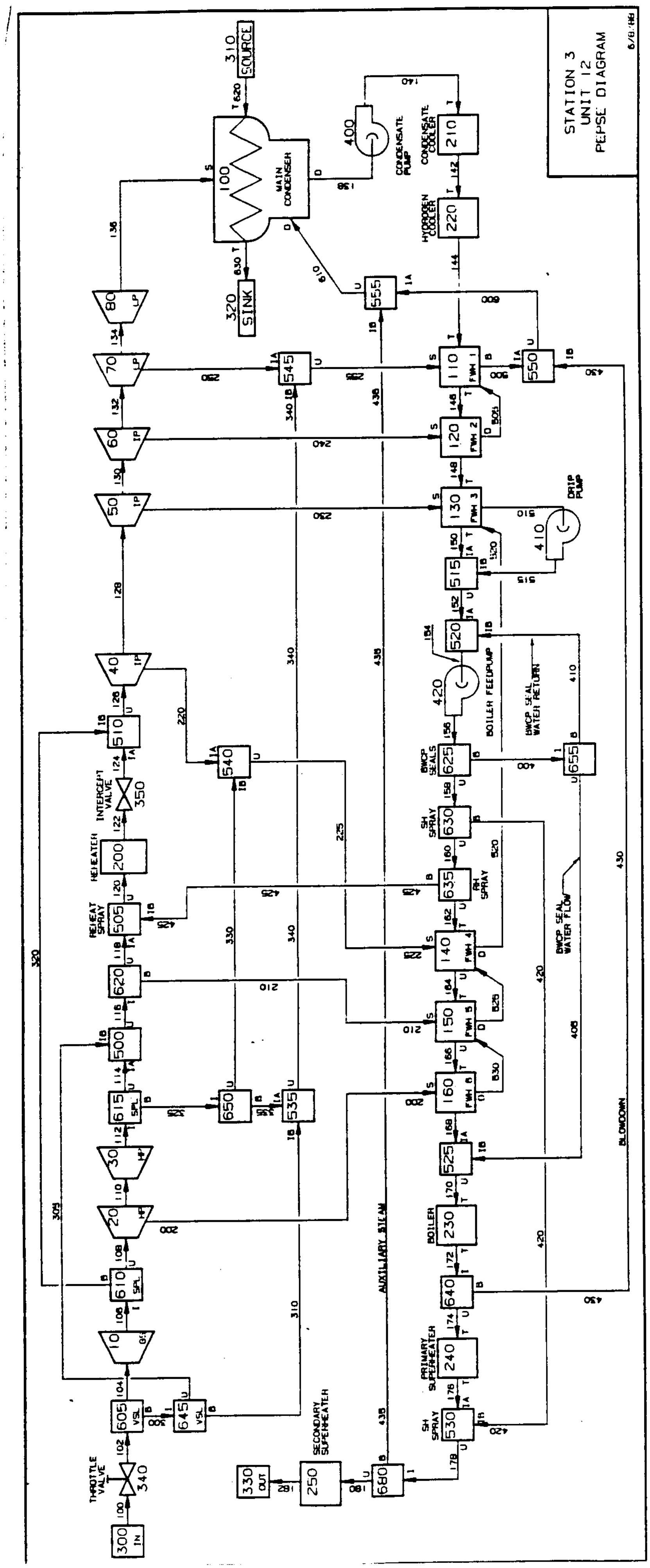
Turboexpander PEPSE Model

The PEPSE schematic for the turboexpander is shown in Attachment 8. The turbine is a type 9 and the combustor a type 70. The working fluid is specified with a 70XXX3 card, indicating it is a fuel with specific constituents. The input deck is shown in Attachment 12.

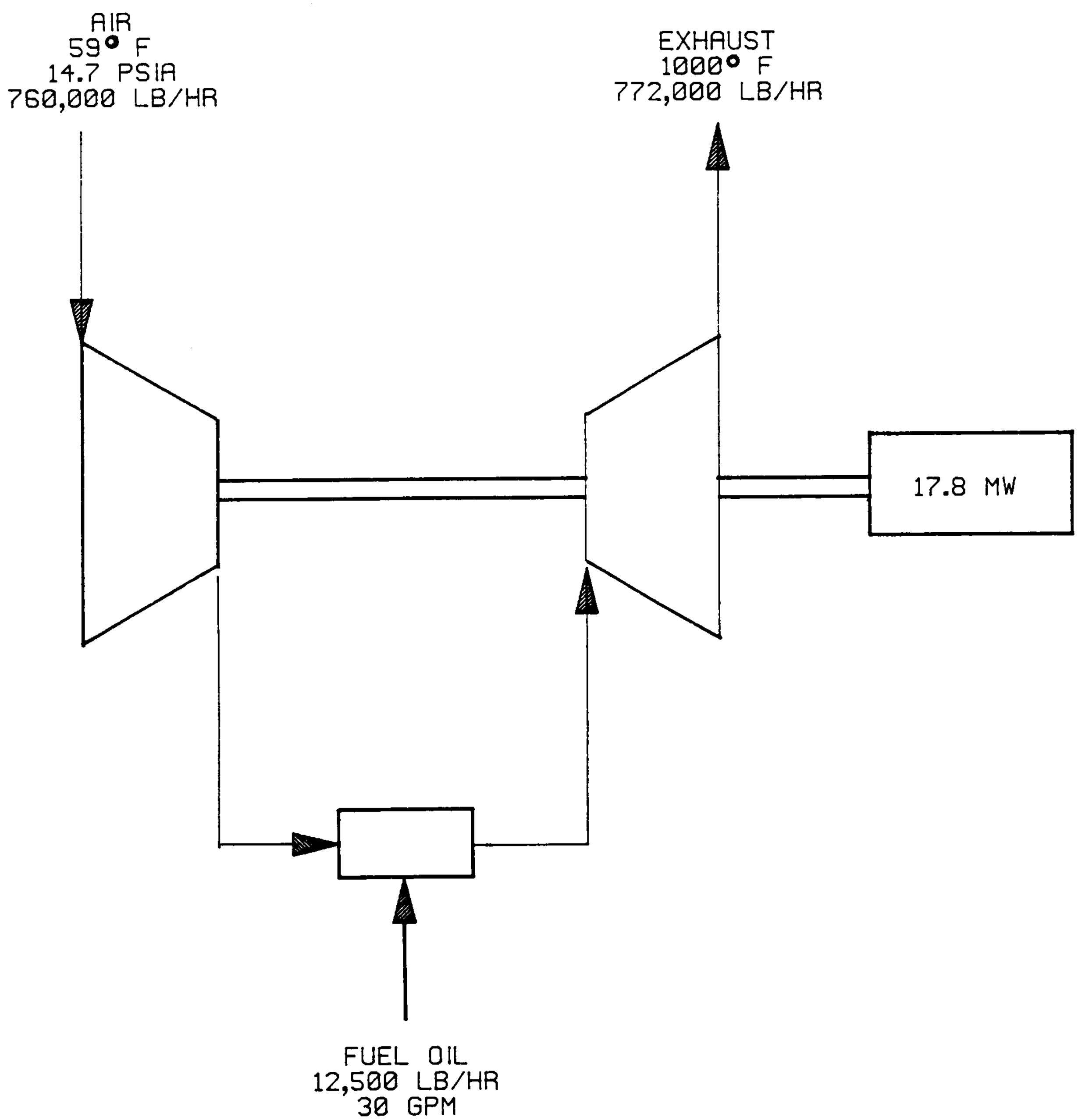
Conclusions

RG&E is not currently planning to implement either of the systems described here. Pipeline turboexpanders have been installed and are operating on large natural gas lines in Canada. The RG&E peak demand for electric generation occurs during the summer, when gas flow rates are low, so the turboexpander does not provide much generation when it is most needed. A cost estimate for the modified combined cycle must be performed to determine if it is attractive. That system does match the electric demand, in that the combustion turbine is operated as a peaking unit, and the incremental output from the steam turbine would occur at a time when it is most needed. The use of PEPSE helped simplify the analysis of these systems.

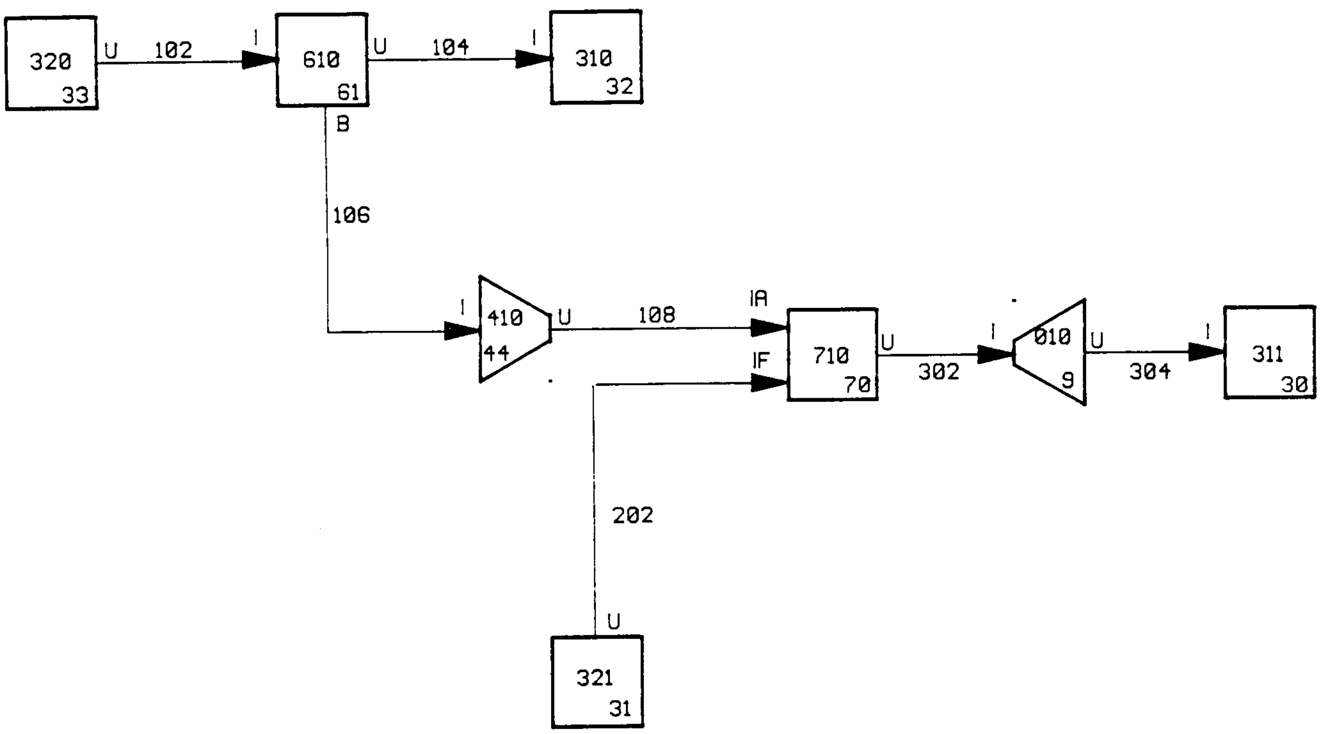

"Rating Flow (Guaranteed) is 530,000#/Hr. at inlet steam conditions of 1800 Psig, 1050° FTT. To assure that the turbine will pass this flow, considering variations in flow coefficients from expected values, shop tolerance on drawing areas, etc. which may affect the flow, the turbine is being designed for a Design Flow of (Rating Flow + 5%) 557,000#/Hr."
LEGEND:
H = Enthalpy, Btu/Lb.
° = Temperature, °F
# = Flow, Lb/Hr.
P = Pressure, Psia
Gen. Output
83,270 KW
30 psig, H2 Press.
0.87 P.F.
G.L. = 1190 KW
F.L. = 350 KW
H2 Cooler
1100 KW Loss
CALCULATED DATA--NOT GUARANTEED
436,993# 321.6P 1000° 1524.6H
436,993# 1337.4H
557,000# 1815P 1510.9H 1050°
BFP 2270 P ΔH=9.3
559,875#
75,000 KW 3600 RPM TC2F-20"
1800 PSIG 1050°/1000°F 1.5" HG.ABS.
GEN: 96 MVA @ 30 PSIG H2 PRESS. & .85 PF
245 HB 192
GROSS HEAT RATE = 557,000 (1510.9 - 486.2) + 436,993 (1524.6 - 1337.4) / 83,270 = 7837 BTU/KW-HR.
GENERAL ELECTRIC CO., SCHENECTADY, N.Y.


STATION 3
UNIT 12
PEPSE DIAGRAM

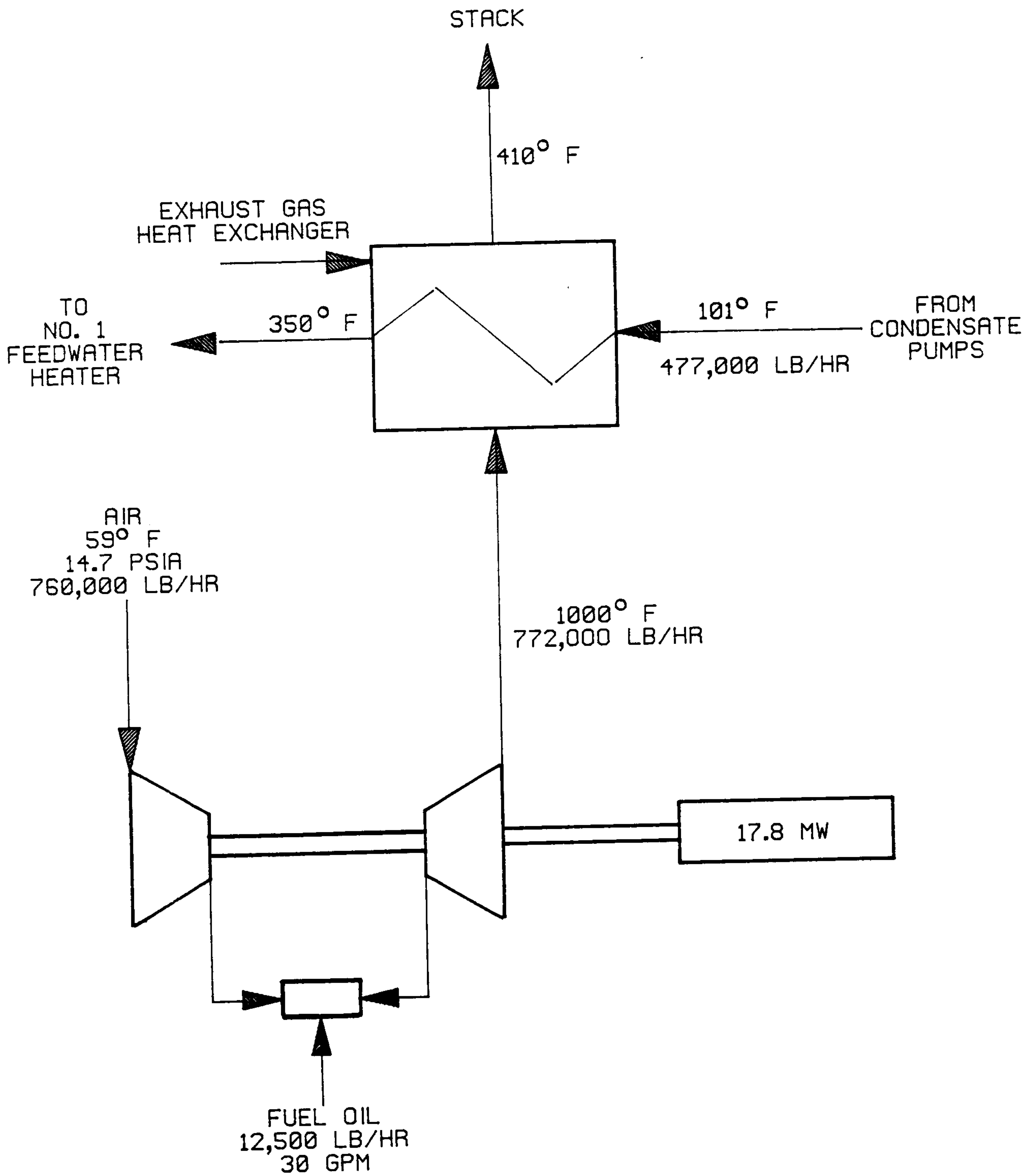
HEAT BALANCE - COMBUSTION TURBINE



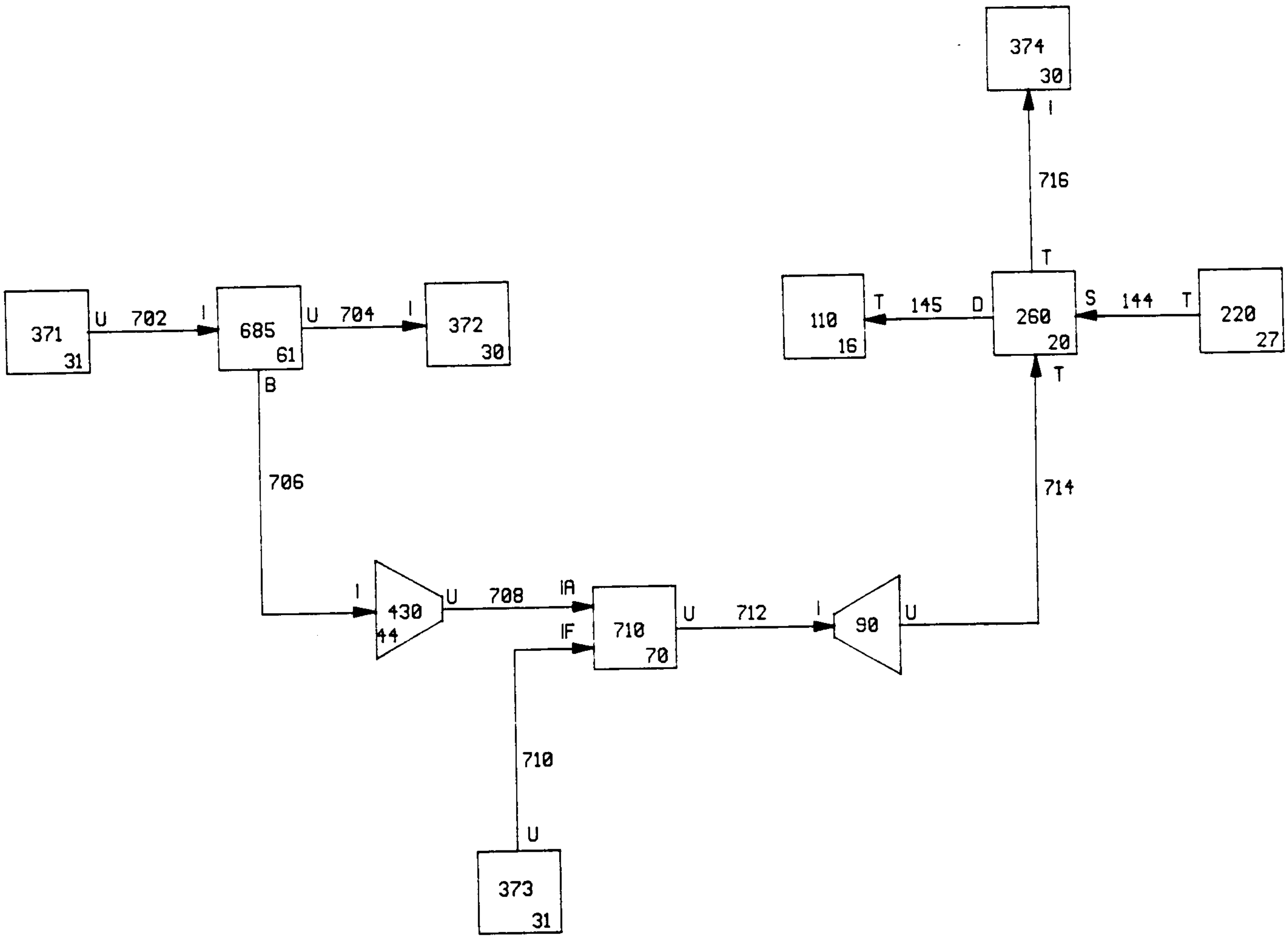
PEPSE SCHEMATIC - COMBUSTION TURBINE

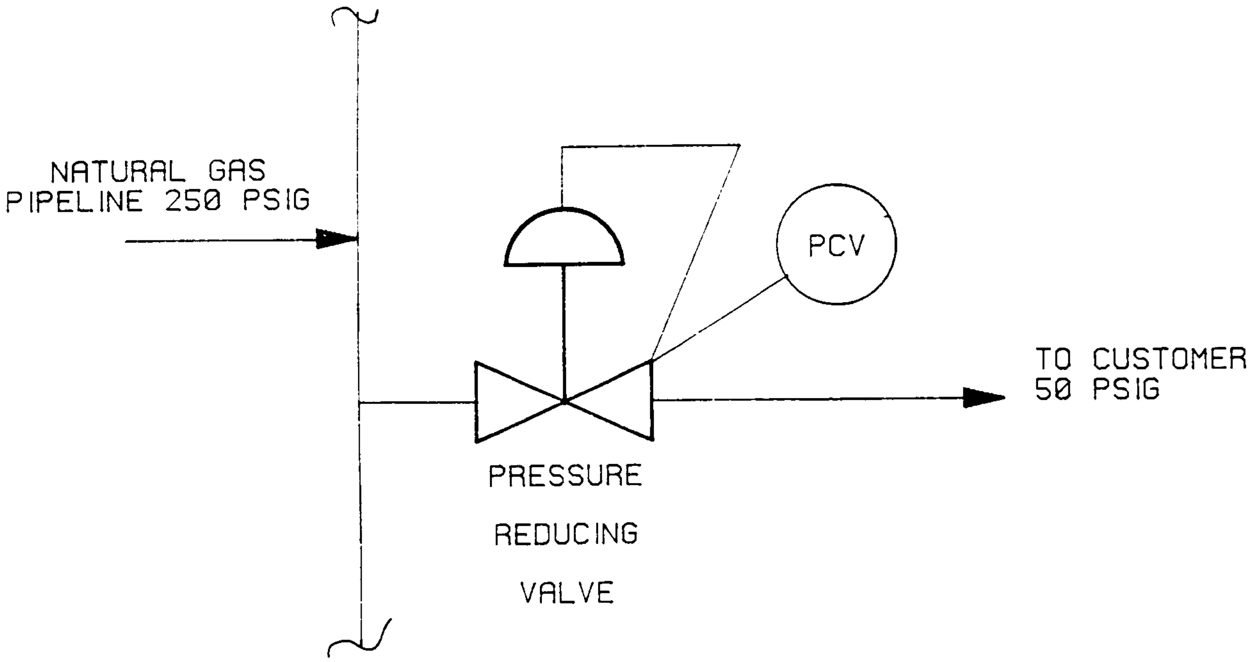


MODIFIED CYCLE HEAT BALANCE

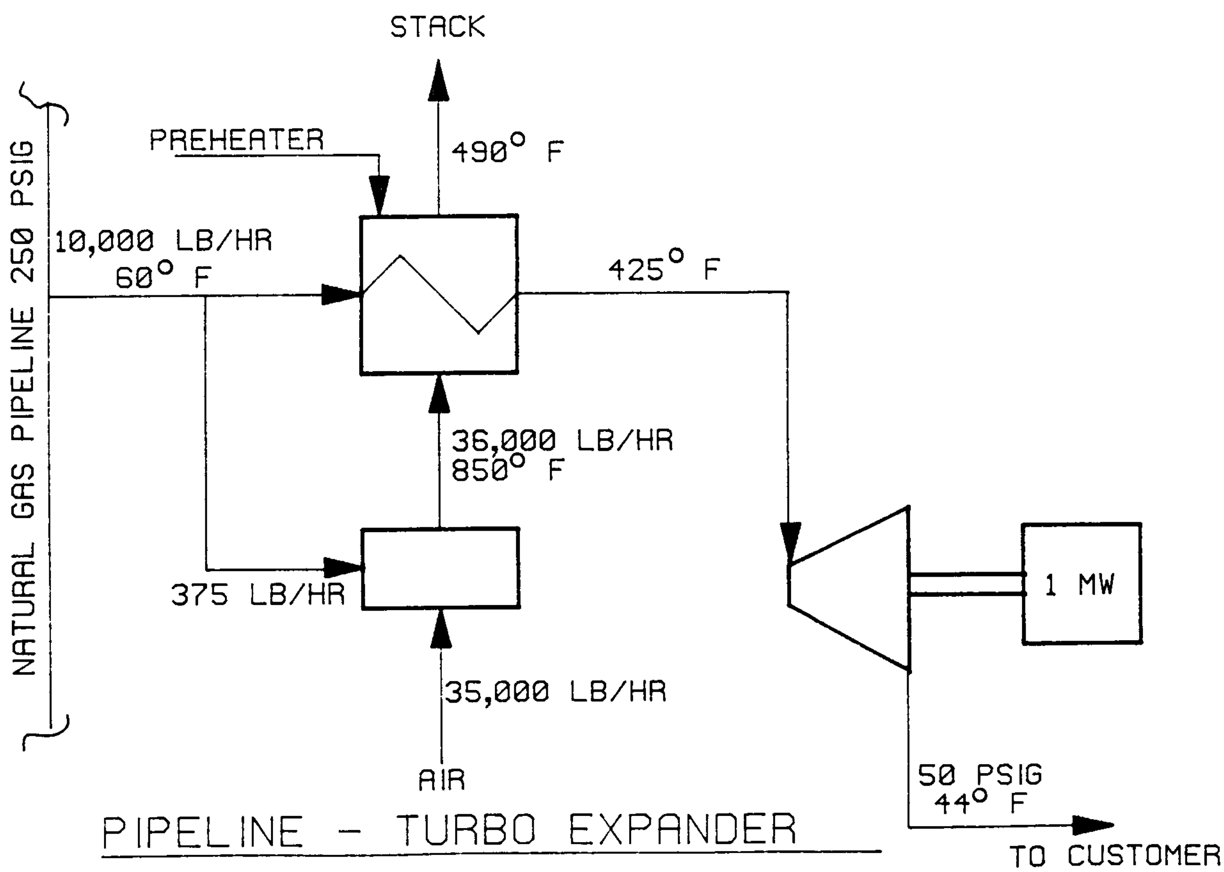


PEPSE SCHEMATIC - MODIFIED CYCLE



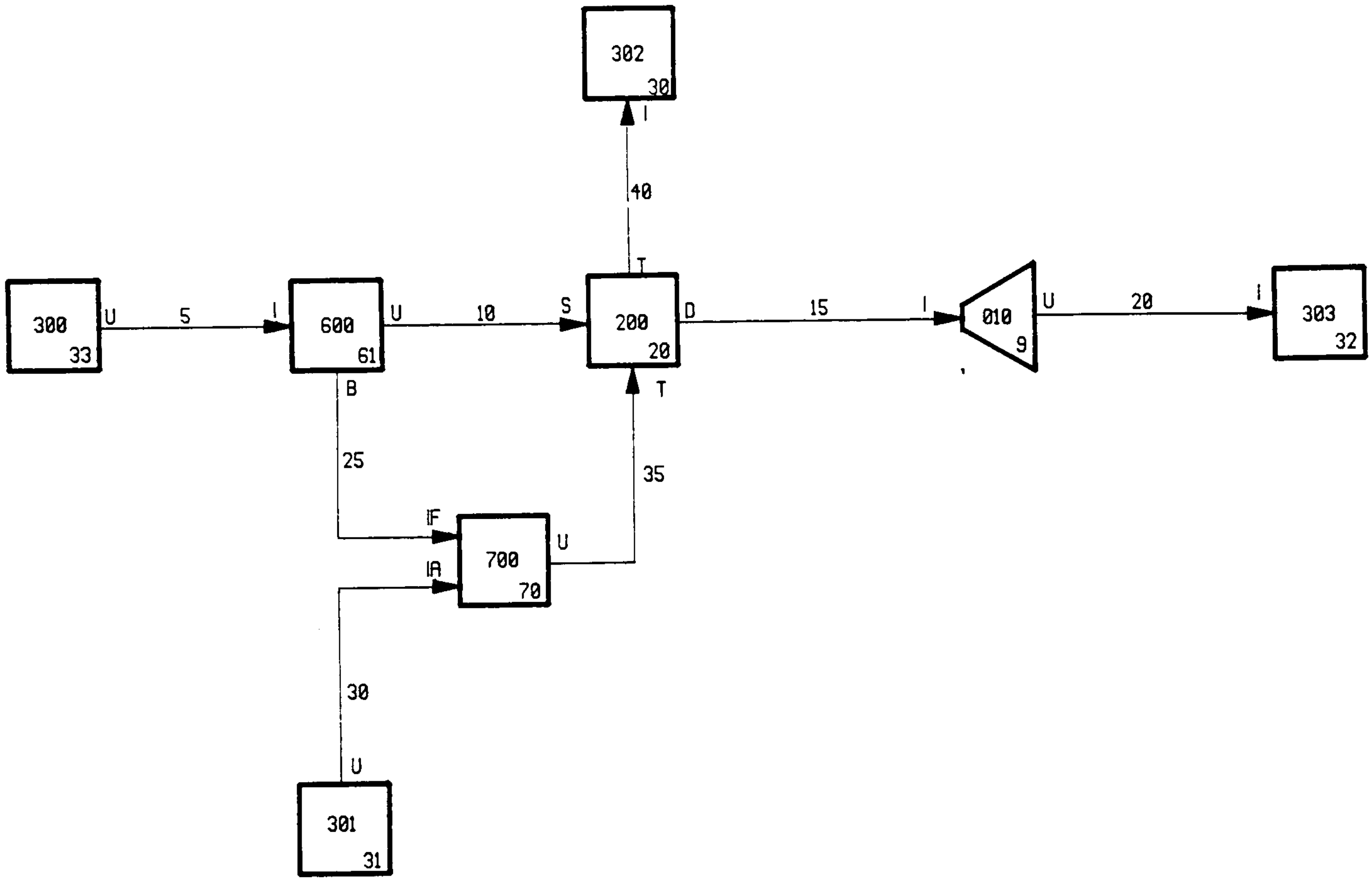


PIPELINE PRESSURE REDUCING STATION



PIPELINE - TURBO EXPANDER

PEPSE SCHEMATIC - TURBO EXPANDER



```
= RG&E BEEBEE STATION UNIT 12 BASE CASE
* MODEL FILENAME IS B12BASE
* MODEL INCLUDES THE FOLLOWING:
* FEEDWATER HEATERS IN SIMPLIFIED DESIGN MODE
* SCHEDULE FOR H2 COOLER HEAT INPUT
* SCHEDULE FOR GENERATOR VARIABLE LOSSES
* SCHEDULE FOR TURBINE EXHAUST LOSSES USING ANNULUS VELOCITY
* SCHEDULE FOR DRUM PRESSURE DROP
* SCHEDULE FOR PRIMARY SUPERHEATER PRESSURE DROP
* SCHEDULE FOR CONDENSATE PUMP HEAD VS CAPACITY
* SCHEDULE FOR BOILER FEED PUMP HEAD VS CAPACITY
* SCHEDULE FOR BFW PUMP EFFICIENCY
* COEFFICIENT 'A' FOR EXTRACTION LINE PRESSURE DROP
* SPECIFIED LEAKAGE CONSTANTS FOR SPLITTERS
* SPECIFIED TURBINE EFFICIENCY FACTORS
* SPECIFIED FLOW FOR REHEAT SPRAY
* TEMPERATURE CONTROL ON SUPERHEAT SPRAY FLOW
* SPECIFIED AUXILIARY STEAM LOAD
* Generic Input Data
010200 2 3 1 1 1
010201 3
011010 1 2 1 0 3600 96000. .87 45. 45.
011011 360. 1190.
012000 25 50. 50. 0. 0. 0. 0 1.E5
* Table Suppression
020001 NOPRNT
020002 NOPRNT
020004 NOPRNT
020005 NOPRNT
020006 NOPRNT
020007 NOPRNT
020010 NOPRNT
020011 NOPRNT
020012 NOPRNT
020013 NOPRNT
020014 NOPRNT
020015 NOPRNT
020016 NOPRNT
020017 NOPRNT
020018 NOPRNT
020020 NOPRNT
020021 NOPRNT
020022 NOPRNT
020023 NOPRNT
020024 NOPRNT
020025 NOPRNT
020026 NOPRNT
020031 NOPRNT
020032 NOPRNT
020033 NOPRNT
020034 NOPRNT
020035 NOPRNT
020037 NOPRNT
020038 NOPRNT
020040 NOPRNT
020042 NOPRNT
```

```
* GEOMETRY
* MAIN STEAM AND FEEDWATER STREAMS
501000 300, U, 340, I
501020 340, U, 605, I
501040 605, U,  10, I
501060  10, U, 610, I
501080 610, U,  20, I
501100  20, U,  30, I
501120  30, U, 615, I
501140 615, U, 500, IA
501160 500, U, 620, I
501180 620, U, 505, IA
501200 505, U, 200, T
501220 200, T, 350, I
501240 350, U, 510, IA
501260 510, U,  40, I
501280  40, U,  50, I
501300  50, U,  60, I
501320  60, U,  70, I
501340  70, U,  80, I
501360  80, U, 100, S
501380 100, D, 400, I
501400 400, U, 210, T
501420 210, T, 220, T
501440 220, T, 110, T
501460 110, T, 120, T
501480 120, T, 130, T
501500 130, T, 515, IA
501520 515, U, 520, IA
501540 520, U, 420, I
501560 420, U, 625, I
501580 625, U, 630, I
501600 630, U, 360, I
501610 360, U, 635, I
501620 635, U, 140, T
501640 140, T, 150, T
501660 150, T, 160, T
501680 160, T, 525, IA
501700 525, U, 230, T
501720 230, T, 640, I
501740 640, U, 240, T
501760 240, T, 530, IA
501780 530, U, 680, I
501800 680, U, 250, T
501820 250, T, 330, I
* EXTRACTION STREAMS
502000  20, E, 160, S
502100 620, B, 150, S
502200  40, E, 540, IA
502250 540, U, 140, S
502300  50, E, 130, S
502400  60, E, 120, S
502500  70, E, 545, IA
502550 545, U, 110, S
```

```
* PACKING LEAKOFFS
503000 605, B, 645, I
503050 645, U, 500, IB
503100 645, B, 535, IB
503200 610, B, 510, IB
503250 615, B, 650, I
503300 650, U, 540, IB
503350 650, B, 535, IA
503400 535, U, 545, IB
* OTHER SPLITTER LEAKOFFS
504000 625, B, 655, I
504050 655, U, 525, IB
504100 655, B, 520, IB
504200 630, B, 530, IB
504250 635, B, 505, IB
504300 640, B, 550, IB
504350 680, B, 555, IB
* DRAIN LINES
505000 110, D, 550, IA
505050 120, D, 110, D
505100 130, D, 410, I
505150 410, U, 515, IB
505200 140, D, 130, D
505250 150, D, 140, D
505300 160, D, 150, D
* MISCELLANEOUS LINES
506000 550, U, 555, IA
506100 555, U, 100, D
506200 310, U, 100, T
506300 100, T, 320, I
* TURBINE DATA
700100 4 1 1 1 1 1 8 0 36.04 0.
700108 .996198
700200 5 1 0 1 1 0. 1815. 1510.9 533177. 700.2 41401.
700300 5 1 1 0 1 0. 700.2 1406.3 491776. 357.3 0.
700400 6 1 0 1 2 1 0. 315.17 1523. 457187. 122.5 19740.
700408 .997539
700500 6 1 1 1 2 1 0. 122.5 1406.6 437447. 55.88 23991.
700600 6 1 3 1 2 1 0. 55.88 1324.6 413456. 18.42 20827.
700700 7 1 0 1 3 2 0. 18.42 1227. 392629. 5.868 17360.
700800 7 1 3 0 3 2 0. 5.868 1145.8 375269. -1.5 0. 26.17 0. 0. 0. 0. 0. 3 25.
* FW HEATER DATA
701000 10 1 2 0. -1.5
701100 16 1 70 -4 0. 2 2 0 0 1 0 0 2 2
701101 .527 .625 553. 274. 70. .8125 7.981 7.981 24.4 5.761
701103 10. .0002 .0003 0. .8125 0.
701106 148. 3.6 1. 8. .99 .92 .0002 .0003 0. .527
701107 .625 274. 70. .8125 .8125 0. 30. .5
701109 0 0 0. 0. 0. 0. 5. 1. 5.
701200 16 0 60 -4 0. 2 2 0 0 1 0 0 2 2
701201 .527 .625 590. 156. 70. .8125 7.981 7.981 14.2 3.826
701203 10. .0002 0. 0. .8125 0.
701206 85. 1.06 1. 6. .95 .94 .0002 .0003 0. .527
701207 .625 156. 70. .8125 .8125 0. 30. .5
701209 0 0 0. 0. 0. 0. 5. 1. 5. * This Card Helps Convergence of FWH2
```

```
701300 17 1 50 -4 0. 2 2 1 1 1
701301 .527 .625 569. 156. 70. .8125 7.981 7.981 10.02 9.75
701303 12. .0002 0. 0. .8125 0.
701309 0 0 0. 0. 0. 0. 5. 1. 5. * This Card Helps Convergence of FWH3
701400 18 1 40 -4 0. 2 2 0 0 1 2 2 2 2
701401 .459 .625 552. 316. 19. .8125 8.5 8.5 7.981 5.761
701403 18. .0002 .0003 0. .8125 0.
701404 92. 98. 3. 9. .95 .98 .0002 .0003 0. .459
701405 .625 316. 19. .8125 .8125
701406 148. 11. 5. 9. .97 .94 .0002 .0003 0. .459
701407 .625 316. 19. .8125 .8125 0. 30. .5
701500 18 1 620 -4 0. 2 2 0 0 1 2 2 2 2
701501 .459 .625 582. 448. 20. .8125 8.5 8.5 7.981 5.761
701503 21. .0002 .0003 0. .8125 0.
701504 99. 107. 3. 11. .95 .93 .0002 .0003 0. .459
701505 .625 448. 21. .8125 .8125
701506 116. 8.6 5. 11. .94 .95 .0002 .0003 0. .459
701507 .625 448. 20. .8125 .8125 0. 30. .5
701600 18 0 20 -4 0. 2 2 0 0 1 2 2 2 2
701601 .527 .625 624. 255. 16. .8125 8.5 8.5 5.761 3.826
701603 16. .0002 .0001 0. .8125 0.
701604 95. 41. 3. 8. .95 .98 .0002 .0003 0. .527
701605 .625 255. 16. .8125 .8125
701606 58. 4. 5. 8. .94 .93 .0002 .0003 0. .527
701607 .625 255. 16. .8125 .8125 0. 30. .5
* HEAT EXCHANGER DATA
702000 25 2 1000. .09992
702100 27 0.
702200 27 3.74E6
702300 25 2 .994865 0.
702400 25 2 850. 0.
702500 25 2 1050. 0. 0. 0. 1815.
* PUMP DATA
704000 41 250. 1. 1. 1. 0. 0.
704100 41 250. 1. 1. 1. 0. 0.
704200 41 2100. 1. 1. 1. 0. 8.7
* SOURCE SINK AND VALVE DATA
703000 33 1050. 1815. 557000.
703100 31 47. 26. 1.5E7
703200 30
703300 32
703400 35 -2. -2. -2. .3 1815. 1510.9 557000.
703500 34 .02
703600 34 .15
* MIXER DATA
705000 50 1
705050 51 1
705100 50 1
705150 50 1
705200 50 1
705250 50 1
705300 50 1
705350 50 1
705400 50 1
705450 50 1
705500 51 1
705550 51 1
```

```
* SPLITTER DATA
706050 68 0. 57.7267
706100 64 386.633
706150 64 505.423
706200 60 0. 50554.
706250 61 0. 0.
706300 61 0. 3000.
706350 61 0. 0.
706400 62 1.
706450 68 0. 52.1239
706500 64 721.182
706550 61 0. 0.
706800 61 0. 0.
* STREAM DATA
602000 2 .08
602100 2 .05
602250 2 .08
602300 2 .08
602400 2 .08
602550 2 .08
604300 5 25. 75.
604350 5 25. 75.
605100 1 7.981 50. 0. 0. 0. 0. 25.
* LP TURBINE EXHAUST LOSS CALCULATION
* GE 2007C USED FOR EXHAUST LOSS
870310 0.
870320 188640.
870330 .87
870340 1.
870350 .65
880100 OPVB 31 PHG PP 136 OPVB 10
880110 PP 136 PHV OPVB 10 OPVB 11
880120 PP 136 PHX HHACP 80 OPVB 12
880130 WW 136 MUL OPVB 11 OPVB 13
880140 OPVB 13 MUL OPVB 12 OPVB 14
880150 OPVB 14 DIV OPVB 32 OPVB 15
* EXHAUST LOSS FROM VELOCITY
800100 'EXHAUST LOSS VS. ANNULUS VEL'
810101      128.  150.  175.  200.  250.  300.  350.  400.  450.  500.
810111 0.   25.6  20.6  16.1  12.8  8.33  5.53  4.09  3.73  3.95  4.90
810102      550.  600.  650.  700.  800.  900.  1000. 1100. 1200. 1300.
810112      6.57  8.65  10.9  13.6  19.4  25.6  32.0  38.4  44.4  49.9
830100 1 OPVB 16 OPVB 15
880160 OPVB 34 SUB OPVB 12 OPVB 17
880170 OPVB 17 MUL OPVB 35 OPVB 18
880180 OPVB 34 SUB OPVB 18 OPVB 19
880190 OPVB 16 MUL OPVB 33 OPVB 20
880200 OPVB 20 MUL OPVB 12 OPVB 21
880210 OPVB 21 MUL OPVB 19 EXUSLS 80
* DETERMINE GENERATOR LOSSES
800200 'GENERATOR LOSSES'
810201    22.4  25.  30.  35.  40.  50.  60.  70.  80.  84.8  90.
810210 0. 478.  492. 520. 551. 586. 662. 756. 885. 1096. 1190. 1190.
830200 2 BKELEI 1 BKTURB 1
```

```
* DETERMINE HYDROGEN COOLER HEAT ADDED
800300 'HYDROGEN COOLER HEAT'
810301     21.5   31.8   42.1   51.9   60.9   68.4   76.2   83.3
810310 0. 1.32E6 1.52E6 1.77E6 2.03E6 2.34E6 2.69E6 3.27E6 3.75E6
830300 3 BBHXGR 220 BKGRO 1
* DETERMINE FEEDWATER VALVE PRESSURE DROP
800400 'FEEDVALVE PRESSURE DROP'
810401   2.19E5 2.81E5 3.279E5 3.28E5 3.48E5 4.18E5 4.95E5 5.68E5
810410 0. .278   .234   .195    .270   .266   .241   .201   .159
830400 4 PDVS 360 WW 156
* DETERMINE ECONOMIZER DROP
800500 'ECONOMIZER DELTA P'
810501   2.19E5 2.81E5 3.28E5 3.48E5 4.18E5 4.95E5 5.68E5
810510 0. .005   .008   .009   .010   .013   .025   .027
830500 5 PDHXTU 230 WW 156
* DETERMINE PRIMARY SH PRESSURE DROP
800600 'PRI SH PRESSURE DROP'
810601   2.19E5 2.81E5 3.28E5 3.48E5 4.18E5 4.95E5 5.68E5
810610 0. .012   .014   .017   .019   .022   .026   .031
830600 6 PDHXTU 240 WW 156
* CONTROL FOR SUPERHEAT SPRAY FLOW RATE
840100 WWFIXB 630 840. 5.E-4 1. TT 178
840109 500. 5000.
* CONDENSATE PUMP CURVE
800700 'CONDENSATE PUMP HEAD-CAPY CURVE'
810701     1.0E5 1.5E5 2.0E5 2.5E5 2.579E5 2.58E5 3.0E5 3.5E5 4.0E5 4.5E5 5.0E5
810711 0. 670.  650.  620.  590.  580.    655.   650.  635.  620.  605.  590.
830700 7 PHEAD 400 WW 140
* BOILER FEED PUMP CURVE
800800 'BOILER FEED PUMP HEAD-CAPY CURVE'
810801     1.4E5 1.87E5 2.33E5 2.80E5 3.279E5 3.28E5 3.73E5 4.67E5 5.60E5 6.06E5
810811 0. 5750. 5700.  5600.  5400.  5200.   5725.  5700.  5600.  5400.  5300.
830800 8 PHEAD 420 WW 156
* BOILER FEED PUMP EFFICIENCY
800900 'BOILER FEED PUMP EFFICIENCY'
810901     1.4E5 1.87E5 2.33E5 2.80E5 3.279E5 3.28E5 3.73E5 4.67E5 5.60E5 6.06E5
810911 0.   .495  .595   .66    .70     .725   .57    .595   .66    .70    .715
830900 9 EFFPMP 420 WW 156
* ROUGHNESS FACTORS FOR FWH TUBESIDE DP
890011 RFNC 110 .0039 I
890021 RFNC 120 .0013 I
890031 RFNC 130 .00066 I
890041 RFNC 140 .0019 I
890051 RFNC 150 .0023 I
890061 RFNC 160 .0016 I
* CALCULATE STEAM TURBINE HEAT RATE
870060 1000.
880310 BBHXFL 200 ADD BBHXFL 230 OPVB 2
880320 OPVB 2 ADD BBHXFL 240 OPVB 3
880330 OPVB 3 ADD BBHXFL 250 OPVB 4
880340 BKGRO 1 MUL OPVB 6 OPVB 5
880350 OPVB 4 DIV OPVB 5 OPVB 7
* PRINT OPERATIONAL VARIABLES
890070 'STEAM TURBINE HEAT RATE, BTU/KWH'
890071 OPVB 7
890080 'GENERATOR ELECTRICAL OUTPUT, MW'
890081 BKGRO 1
*
.
```

```
= BEEBEE COMBUSTION TURBINE
* MODEL FILENAME IS BBCT
* SIMPLE CYCLE OIL FIRED COMBUSTION TURBINE
* CONTROL ON AIR FLOW TO PROVIDE 1725F TURBINE INLET TEMP
012000 25
010200 3,0,1,0,0
011010 1,2,5,0,3600,32000.,.85,45.,45.
011011 100. 300.
* TABLE SUPPRESSION
020001 NOPRNT
020002 NOPRNT
020004 NOPRNT
020005 NOPRNT
020012 NOPRNT
020013 NOPRNT
020016 NOPRNT
020020 NOPRNT
020021 NOPRNT
020022 NOPRNT
020023 NOPRNT
020025 NOPRNT
020026 NOPRNT
020028 NOPRNT
020034 NOPRNT
020037 NOPRNT
020042 NOPRNT
* GEOMETRY INPUT
501020 320, U, 610, I
501040 610, U, 310, I
501060 610, B, 410, I
501080 410, U, 710, IA
502020 321, U, 710, IF
503020 710, U,  10, I
503040  10, U, 311, I
* TURBINE DATA
700100 9 1 2 1 6
700106 15. 1000.
* SOURCE AND SINK DATA
703100 32
703110 30
703200 33 59. 14.7 2.E6
703203 AIR .6
703210 31 60. 30. 12500.
703213 FUEL 21300. SSVL 44.5 C .85 H2 .14 N2 .01
* COMPRESSOR DATA
704100 44 1 120. 1. .8
* SPLITTER DATA
706100 61 0. 1.E6
* COMBUSTOR DATA
707100 70 0 2 0 0.
* CONTROL ON EXCESS AIR TO PRODUCE DESIRED GAS TEMP
840100 WWFIXB 610 1725. 0. 1. TT 302
* OPERATIONAL VARIABLES
870010 21300.
870020 1000.
870030 3412.
```

```
* CALCULATE GROSS CYCLE HEAT RATE
880010 WW 202 MUL OPVB 1 OPVB 4
880020 BKGRO 1 MUL OPVB 2 OPVB 5
880030 OPVB 4 DIV OPVB 5 OPVB 6
* CALCULATE OVERALL CYCLE EFFICIENCY
880040 OPVB 5 MUL OPVB 3 OPVB 7
880050 OPVB 7 DIV OPVB 4 OPVB 8
* PRINT OUTPUT VARIABLES
890100 'GENERATOR ELECTRICAL OUTPUT, MW'
890101 BKGRO 1
890200 'GROSS CYCLE HEAT RATE, BTU/KWH'
890201 OPVB 6
890300 'CYCLE THERMAL EFFICIENCY'
890301 OPVB 8
*
.
```

```
= UNIT 12 MODIFIED COMBINED CYCLE
* MODEL FILENAME IS B12MOD
* MODEL INCLUDES THE FOLLOWING:
* HEAT RECOVERY BOILER AHEAD OF NO. 1 FWH
* FEEDWATER HEATERS IN SIMPLIFIED DESIGN MODE
* SCHEDULE FOR H2 COOLER HEAT INPUT
* SCHEDULE FOR GENERATOR VARIABLE LOSSES
* SCHEDULE FOR TURBINE EXHAUST LOSSES USING ANNULUS VELOCITY
* SCHEDULE FOR DRUM PRESSURE DROP
* SCHEDULE FOR PRIMARY SUPERHEATER PRESSURE DROP
* SCHEDULE FOR CONDENSATE PUMP HEAD VS CAPACITY
* SCHEDULE FOR BOILER FEED PUMP HEAD VS CAPACITY
* SCHEDULE FOR BFW PUMP EFFICIENCY
* COEFFICIENT 'A' FOR EXTRACTION LINE PRESSURE DROP
* SPECIFIED LEAKAGE CONSTANTS FOR SPLITTERS
* SPECIFIED TURBINE EFFICIENCY FACTORS
* SPECIFIED FLOW FOR REHEAT SPRAY
* TEMPERATURE CONTROL ON SUPERHEAT SPRAY FLOW
* SPECIFIED AUXILIARY STEAM LOAD
* CALCULATION FOR BFW PUMP HYDRAULIC AND BRAKE HP
* Generic Input Data
010200 2 3 2 1 1
010201 3
011010 1 2 1 0 3600 96000. .87 45. 45.
011011 360. 1190.
011020 2 2 1 0 3600 25000. .87 45. 45.
011021 100. 300.
012000 25 50. 50. 0. 0. 0. 0 1.E5
* Table Suppression
020001 NOPRNT
020002 NOPRNT
020004 NOPRNT
020005 NOPRNT
020006 NOPRNT
020007 NOPRNT
020010 NOPRNT
020011 NOPRNT
020012 NOPRNT
020013 NOPRNT
020014 NOPRNT
020015 NOPRNT
020016 NOPRNT
020017 NOPRNT
020018 NOPRNT
020020 NOPRNT
020021 NOPRNT
020022 NOPRNT
020023 NOPRNT
020024 NOPRNT
020025 NOPRNT
020026 NOPRNT
020031 NOPRNT
020032 NOPRNT
020033 NOPRNT
020034 NOPRNT
020035 NOPRNT
020037 NOPRNT
020038 NOPRNT
020040 NOPRNT
020042 NOPRNT
```

```
* GEOMETRY
* MAIN STEAM AND FEEDWATER STREAMS
501000 300, U, 340, I
501020 340, U, 605, I
501040 605, U,  10, I
501060  10, U, 610, I
501080 610, U,  20, I
501100  20, U,  30, I
501120  30, U, 615, I
501140 615, U, 500, IA
501160 500, U, 620, I
501180 620, U, 505, IA
501200 505, U, 200, T
501220 200, T, 350, I
501240 350, U, 510, IA
501260 510, U,  40, I
501280  40, U,  50, I
501300  50, U,  60, I
501320  60, U,  70, I
501340  70, U,  80, I
501360  80, U, 100, S
501380 100, D, 400, I
501400 400, U, 210, T
501420 210, T, 220, T
501440 220, T, 260, S
501450 260, D, 110, T
501460 110, T, 120, T
501480 120, T, 130, T
501500 130, T, 515, IA
501520 515, U, 520, IA
501540 520, U, 420, I
501560 420, U, 625, I
501580 625, U, 630, I
501600 630, U, 360, I
501610 360, U, 635, I
501620 635, U, 140, T
501640 140, T, 150, T
501660 150, T, 160, T
501680 160, T, 525, IA
501700 525, U, 230, T
501720 230, T, 640, I
501740 640, U, 240, T
501760 240, T, 530, IA
501780 530, U, 680, I
501800 680, U, 250, T
501820 250, T, 330, I
* EXTRACTION STREAMS
502000  20, E, 160, S
502100 620, B, 150, S
502200  40, E, 540, IA
502250 540, U, 140, S
502300  50, E, 130, S
502400  60, E, 120, S
502500  70, E, 545, IA
502550 545, U, 110, S
```

```
* PACKING LEAKOFFS
503000 605, B, 645, I
503050 645, U, 500, IB
503100 645, B, 535, IB
503200 610, B, 510, IB
503250 615, B, 650, I
503300 650, U, 540, IB
503350 650, B, 535, IA
503400 535, U, 545, IB
* OTHER SPLITTER LEAKOFFS
504000 625, B, 655, I
504050 655, U, 525, IB
504100 655, B, 520, IB
504200 630, B, 530, IB
504250 635, B, 505, IB
504300 640, B, 550, IB
504350 680, B, 555, IB
* DRAIN LINES
505000 110, D, 550, IA
505050 120, D, 110, D
505100 130, D, 410, I
505150 410, U, 515, IB
505200 140, D, 130, D
505250 150, D, 140, D
505300 160, D, 150, D
* COMBUSTION TURBINE LINES
507020 371, U, 685, I
507040 685, U, 372, I
507060 685, B, 430, I
507080 430, U, 710, IA
507100 373, U, 710, IF
507120 710, U,  90 ,I
507140  90, U, 260, T
507160 260, T, 374, I
* MISCELLANEOUS LINES
506000 550, U, 555, IA
506100 555, U, 100, D
506200 310, U, 100, T
506300 100, T, 320, I
* STEAM TURBINE DATA
700100 4 1 1 1 1 1 8 0 36.04 0.
700108 .996198
700200 5 1 0 1 1 0. 1815. 1510.9 533177. 700.2 41401.
700300 5 1 1 0 1 0. 700.2 1406.3 491776. 357.3 0.
700400 6 1 0 1 2 1 0. 315.17 1523. 457187. 122.5 19740.
700408 .997539
700500 6 1 1 1 2 1 0. 122.5 1406.6 437447. 55.88 23991.
700600 6 1 3 1 2 1 0. 55.88 1324.6 413456. 18.42 20827.
700700 7 1 0 1 3 2 0. 18.42 1227. 392629. 5.868 17360.
700800 7 1 3 0 3 2 0. 5.868 1145.8 375269. -1.5 0. 26.17 0. 0. 0. 0. 0. 3 25.
* COMBUSTION TURBINE DATA
700900 9 2 2 1 6
700906 15. 1000.
```

```
* FW HEATER DATA
701000 10 1 2 0. -1.5
701100 16 1 70 -4 0. 2 2 0 0 1 0 0 2 2
701101 .527 .625 553. 274. 70. .8125 7.981 7.981 24.4 5.761
701103 10. .0002 .0003 0. .8125 0.
701106 148. 3.6 1. 8. .99 .92 .0002 .0003 0. .527
701107 .625 274. 70. .8125 .8125 0. 30. .5
701109 0 0 0. 0. 0. 0. 5. 1. 5.
701200 16 0 60 -4 0. 2 2 0 0 1 0 0 2 2
701201 .527 .625 590. 156. 70. .8125 7.981 7.981 14.2 3.826
701203 10. .0002 0. 0. .8125 0.
701206 85. 1.06 1. 6. .95 .94 .0002 .0003 0. .527
701207 .625 156. 70. .8125 .8125 0. 30. .5
701209 0 0 0. 0. 0. 0. 5. 1. 5. * This Card Helps Convergence of FWH2
701300 17 1 50 -4 0. 2 2 1 1 1
701301 .527 .625 569. 156. 70. .8125 7.981 7.981 10.02 9.75
701303 12. .0002 0. 0. .8125 0.
701309 0 0 0. 0. 0. 0. 5. 1. 5. * This Card Helps Convergence of FWH3
701400 18 1 40 -4 0. 2 2 0 0 1 2 2 2 2
701401 .459 .625 552. 316. 19. .8125 8.5 8.5 7.981 5.761
701403 18. .0002 .0003 0. .8125 0.
701404 92. 98. 3. 9. .95 .98 .0002 .0003 0. .459
701405 .625 316. 19. .8125 .8125
701406 148. 11. 5. 9. .97 .94 .0002 .0003 0. .459
701407 .625 316. 19. .8125 .8125 0. 30. .5
701500 18 1 620 -4 0. 2 2 0 0 1 2 2 2 2
701501 .459 .625 582. 448. 20. .8125 8.5 8.5 7.981 5.761
701503 21. .0002 .0003 0. .8125 0.
701504 99. 107. 3. 11. .95 .93 .0002 .0003 0. .459
701505 .625 448. 21. .8125 .8125
701506 116. 8.6 5. 11. .94 .95 .0002 .0003 0. .459
701507 .625 448. 20. .8125 .8125 0. 30. .5
701600 18 0 20 -4 0. 2 2 0 0 1 2 2 2 2
701601 .527 .625 624. 255. 16. .8125 8.5 8.5 5.761 3.826
701603 16. .0002 .0001 0. .8125 0.
701604 95. 41. 3. 8. .95 .98 .0002 .0003 0. .527
701605 .625 255. 16. .8125 .8125
701606 58. 4. 5. 8. .94 .93 .0002 .0003 0. .527
701607 .625 255. 16. .8125 .8125 0. 30. .5
* HEAT EXCHANGER DATA
702000 25 2 1000. .09992
702100 27 0.
702200 27 3.74E6
702300 25 2 .994865 0.
702400 25 2 850. 0.
702500 25 2 1050. 0. 0. 0. 1815.
702600 20 350.
* PUMP DATA
704000 41 250. 1. 1. 1. 0. 0.
704100 41 250. 1. 1. 1. 0. 0.
704200 41 2100. 1. 1. 1. 0. 8.7
704300 44 2 120. 1. .8
```

```
* SOURCE SINK AND VALVE DATA
703000 33 1050. 1815. 557000.
703100 31 47. 26. 1.5E7
703200 30
703300 32
703400 35 -2. -2. -2. .3 1815. 1510.9 557000.
703500 34 .02
703600 34 .15
703710 31 59. 14.7 2.E6
703713 AIR .6
703720 30
703730 31 60. 30. 12500.
703733 FUEL 21300. SSVL 4.5 C .85 H2 .14 N2 .01
703740 30
* MIXER DATA
705000 50 1
705050 51 1
705100 50 1
705150 50 1
705200 50 1
705250 50 1
705300 50 1
705350 50 1
705400 50 1
705450 50 1
705500 51 1
705550 51 1
* SPLITTER DATA
706050 68 0. 57.7267
706100 64 386.633
706150 64 505.423
706200 60 0. 50554.
706250 61 0. 0.
706300 61 0. 3000.
706350 61 0. 0.
706400 62 1.
706450 68 0. 52.1239
706500 64 721.182
706550 61 0. 0.
706800 61 0. 0.
706850 61 0. 1.E6
* COMBUSTOR DATA
707100 70 0 2 0 0.
* STREAM DATA
602000 2 .08
602100 2 .05
*602250 2 .08
602256 CLOSE
*602300 2 .08
602306 CLOSE
*602400 2 .08
602406 CLOSE
*602550 2 .08
602556 CLOSE
604300 5 25. 75.
604350 5 25. 75.
605100 1 7.981 50. 0. 0. 0. 0. 25.
```

```
* LP TURBINE EXHAUST LOSS CALCULATION
* GE 2007C USED FOR EXHAUST LOSS
870310 0.
870320 188640.
870330 .87
870340 1.
870350 .65
880100 OPVB 31 PHG PP 136 OPVB 10
880110 PP 136 PHV OPVB 10 OPVB 11
880120 PP 136 PHX HHACP 80 OPVB 12
880130 WW 136 MUL OPVB 11 OPVB 13
880140 OPVB 13 MUL OPVB 12 OPVB 14
880150 OPVB 14 DIV OPVB 32 OPVB 15
* EXHAUST LOSS FROM VELOCITY
800100 'EXHAUST LOSS VS. ANNULUS VEL'
810101      128.  150.  175.  200.  250.  300.  350.  400.  450.  500.
810111 0.   25.6  20.6  16.1  12.8  8.33  5.53  4.09  3.73  3.95  4.90
810102      550.  600.  650.  700.  800.  900.  1000. 1100. 1200. 1300.
810112      6.57  8.65  10.9  13.6  19.4  25.6  32.0  38.4  44.4  49.9
830100 1 OPVB 16 OPVB 15
880160 OPVB 34 SUB OPVB 12 OPVB 17
880170 OPVB 17 MUL OPVB 35 OPVB 18
880180 OPVB 34 SUB OPVB 18 OPVB 19
880190 OPVB 16 MUL OPVB 33 OPVB 20
880200 OPVB 20 MUL OPVB 12 OPVB 21
880210 OPVB 21 MUL OPVB 19 EXUSLS 80
* DETERMINE GENERATOR LOSSES
800200 'GENERATOR LOSSES'
810201     22.4  25.   30.   35.   40.   50.   60.   70.   80.    84.8  90.
810210 0.  478.  492.  520.  551.  586.  662.  756.  885.  1096.  1190. 1190.
830200 2 BKELEI 1 BKTURB 1
* DETERMINE HYDROGEN COOLER HEAT ADDED
800300 'HYDROGEN COOLER HEAT'
810301     21.5    31.8    42.1    51.9    60.9    68.4    76.2    83.3
810310 0. 1.32E6 1.52E6 1.77E6 2.03E6 2.34E6 2.69E6 3.27E6 3.75E6
830300 3 BBHXGR 220 BKGRO 1
* DETERMINE FEEDWATER VALVE PRESSURE DROP
800400 'FEEDVALVE PRESSURE DROP'
810401    2.19E5 2.81E5 3.279E5 3.28E5 3.48E5 4.18E5 4.95E5 5.68E5
810410 0. .278   .234   .195    .270   .266   .241   .201   .159
830400 4 PDVS 360 WW 156
* DETERMINE ECONOMIZER DROP
800500 'ECONOMIZER DELTA P'
810501    2.19E5 2.81E5 3.28E5 3.48E5 4.18E5 4.95E5 5.68E5
810510 0. .005   .008   .009   .010   .013   .025   .027
830500 5 PDHXTU 230 WW 156
* DETERMINE PRIMARY SH PRESSURE DROP
800600 'PRI SH PRESSURE DROP'
810601    2.19E5 2.81E5 3.28E5 3.48E5 4.18E5 4.95E5 5.68E5
810610 0. .012   .014   .017   .019   .022   .026   .031
830600 6 PDHXTU 240 WW 156
```

```
* CONTROL FOR SUPERHEAT SPRAY FLOW RATE
840100 WWFIXB 630 840. 5.E-4 1. TT 178
840109 500. 5000.
* CONTROL ON EXCESS AIR TO COMB TURBINE
840200 WWFIXB 685 1725. 0. 1. TT 712
* CONDENSATE PUMP CURVE
800700 'CONDENSATE PUMP HEAD-CAPY CURVE'
810701    1.0E5 1.5E5 2.0E5 2.5E5 2.579E5 2.58E5 3.0E5 3.5E5 4.0E5 4.5E5 5.0E5
810711 0. 670.  650.  620.  590.  580.    655.   650.  635.  620.  605.  590.
830700 7 PHEAD 400 WW 140
* BOILER FEED PUMP CURVE
800800 'BOILER FEED PUMP HEAD-CAPY CURVE'
810801    1.4E5 1.87E5 2.33E5 2.80E5 3.279E5 3.28E5 3.73E5 4.67E5 5.60E5 6.06E5
810811 0. 5750. 5700.  5600.  5400.  5200.   5725.  5700.  5600.  5400.  5300.
830800 8 PHEAD 420 WW 156
* BOILER FEED PUMP EFFICIENCY
800900 'BOILER FEED PUMP EFFICIENCY'
810901    1.4E5 1.87E5 2.33E5 2.80E5 3.279E5 3.28E5 3.73E5 4.67E5 5.60E5 6.06E5
810911 0.  .495  .595   .66    .70     .725   .57    .595   .66    .70    .715
830900 9 EFFPMP 420 WW 156
* ROUGHNESS FACTORS FOR FWH TUBESIDE DP
890011 RFNC 110 .0039 I
890021 RFNC 120 .0013 I
890031 RFNC 130 .00066 I
890041 RFNC 140 .0019 I
890051 RFNC 150 .0023 I
890061 RFNC 160 .0016 I
* CALCULATE STEAM TURB HEAT RATE
870060 1000.
880310 BBHXFL 200 ADD BBHXFL 230 OPVB 2
880320 OPVB 2 ADD BBHXFL 240 OPVB 3
880330 OPVB 3 ADD BBHXFL 250 OPVB 4
880340 BKGRO 1 MUL OPVB 6 OPVB 5
880350 OPVB 4 DIV OPVB 5 OPVB 8
* CALCULATE COMB TURB HEAT RATE
870070 21500.
880410 WW 710 MUL OPVB 7 OPVB 9
880420 BKGRO 2 MUL OPVB 6 OPVB 10
880430 OPVB 9 DIV OPVB 10 OPVB 11
* CALCULATE OVERALL HEAT RATE
880510 OPVB 4 ADD OPVB 9 OPVB 12
880520 OPVB 5 ADD OPVB 10 OPVB 13
880530 OPVB 12 DIV OPVB 13 OPVB 14
* PRINT OPERATIONAL VARIABLES
890100 'STEAM TURB GEN ELECT OUTPUT, MW'
890101 BKGRO 1
890200 'COMB TURB GEN ELECT OUTPUT, MW'
890201 BKGRO 2
890300 'STEAM TURB HEAT RATE, BTU/KWH'
890301 OPVB 8
890400 'COMB TURB HEAT RATE, BTU/KWH'
890401 OPVB 11
890500 'OVERALL HEAT RATE, BTU/KWH'
890501 OPVB 14
*
.
```

```
= RG&E NATURAL GAS TURBOEXPANDER
* MODEL FILENAME IS TURBOEXP
* SLIPSTREAM USED TO PREHEAT GAS TO TURBINE
* PIPELINE UPSTREAM CONDITIONS ARE 60F, 250 PSIG
* PIPELINE DOWNSTREAM CONDITIONS ARE 50 PSIG
012000 25
010200 3,0,1,0,0
011010 1,2,5,0,3600,1000.,.85,45.,45.
011011 3. 10.
* TABLE SUPPRESSION
020001 NOPRNT
020002 NOPRNT
020004 NOPRNT
020005 NOPRNT
020012 NOPRNT
020013 NOPRNT
020016 NOPRNT
020020 NOPRNT
020021 NOPRNT
020022 NOPRNT
020023 NOPRNT
020024 NOPRNT
020025 NOPRNT
020026 NOPRNT
020028 NOPRNT
020034 NOPRNT
020036 NOPRNT
020037 NOPRNT
020042 NOPRNT
* GEOMETRY INPUT
500050 300, U, 600, I
500100 600, U, 200, S
500150 200, D, 010, I
500200 010, U, 303, I
500250 600, B, 700, IF
500300 301, U, 700, IA
500350 700, U, 200, T
500400 200, T, 302, I
* TURBINE DATA
700100 9 1 2 1 1
700101 .85 65.
* HEAT EXCHANGER DATA
702000 20 425.
* SOURCE AND SINK DATA
703020 30
703010 31 60. 15. 50000.
703013 AIR
703030 32
703000 33 60. 265. 10000.
703003 FUEL 21300. SSVL 44.5 C .754 H2 .234 N2 .012
* SPLITTER DATA
706000 61 0. 375.
* COMBUSTOR DATA
707000 70 0 2 0 0.
* CONTROL ON AIR
840100 WWVSC 301 850. 0. 1. TT 35
```

```
* OPERATIONAL VARIABLES
870010 21300.
870020 1000.
* CALCULATE CYCLE HEAT RATE
880010 WW 25 MUL OPVB 1 OPVB 3
880020 BKGRO 1 MUL OPVB 2 OPVB 4
880030 OPVB 3 DIV OPVB 4 OPVB 5
* PRINT OUTPUT VARIABLES
890010 'GENERATOR ELECTRICAL OUTPUT, KW'
890011 OPVB 4
890020 'CYCLE HEAT RATE, BTU/KWH'
890021 OPVB 5
*
.
```