PERFORMANCE TESTING UPDATES
FROM DAIRYLAND POWER COOPERATIVE

BY

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INTRODUCTION

Dairyland Power Cooperative is a relatively small utility located in Western Wisconsin. Dairyland has seven coal fired units ranging in size from 20 MW to 360 MW. Total output capacity is approximately 1,000 MW. Dairyland services 28 cooperatives in Wisconsin, Minnesota, Iowa, Illinois and the upper part of Michigan. The primary load for the system is rural. Hence, the daily load curve features a double peak; one at 7:00 AM and one at 7:00 PM. All of Dairyland's units are load following and will drop to lower loads at night.

Of the seven units, three are 20 MW peaking units, which were built in the 1940s. All three of these units are located at the Alma Station. Except for yearly capability tests, there is no performance monitoring done on these units. The remainder of Dairyland's generation fleet is comprised of a 60 and 90 MW unit, both located at the Alma Station, a 360 MW unit located at the John P. Madgett (JPM) Station and another 360 MW unit at the Genoa Station. All four units have PMAX systems on them for performance monitoring. Dairyland is in the process of converting the PMAX systems from VAX based to NT based platforms. It is estimated that the conversion will be complete by the end of summer in 1999.

Dairyland maintains a staff of six people involved with performance monitoring. The performance staff is made up of two engineers at the corporate office, a computer technician at the corporate office (to maintain the various performance programs), and a performance technician at each of the Alma, JPM and Genoa Stations. The plants are all within 50 miles of the corporate offices. Data from each of the plants may be accessed at any of the plants as well as the corporate offices.

Dairyland has developed several tools, which enable the performance staff to conduct and evaluate performance information at all four units. Three of these tools will be discussed in this paper. These are:

1). A set of auto-test calculations on each of the PMAX systems.

2). Use of Excel spreadsheets to assist in the analysis of test data.

3). Use of a data validation program in conjunction with PMAX.

PMAX Auto-Test

The four major units in Dairyland's system are all subject to load following. This means that each unit must be tested at several points in order to develop an accurate heat rate curve. For JPM and Genoa, a total of eight test points for each unit are needed to develop a full load range heat rate curve. Alma #4 and #5 both need six test points to develop their heat rate curves. The result is a total of 28 heat rate tests, which need to be performed during the course of a year. This does not include additional tests conducted to get seasonal heat rate curves. Combine these heat rate tests with other specialized tests throughout the year and you end up with an awful lot of tests to conduct and analyze. Dairyland would need a much larger performance staff to accomplish just the testing and analysis, not to mention the day-to-day activities.

We developed a tool utilizing the PMAX system to help collect test data whenever the unit is at a "stable" condition. A stable condition is achieved after the unit has achieved the desired load and has reached thermodynamic equilibrium. During a stable condition, the load may fluctuate slightly. The amount of load fluctuation allowed is different with each unit. Utilizing the new Sequence on a Clock function available on PMAX, each PMAX system will automatically determine if the unit is at a stable condition and collect test data. Once the data is collected, it is stored in a test archive file for easy retrieval. Two sequences per unit are required to conduct the automatic testing. Figures 1 and 2 show flow charts for each of the two sequences. The first sequence determines the stability of the conditions and calculates the test values. The second sequence stores the test values to the archive file.

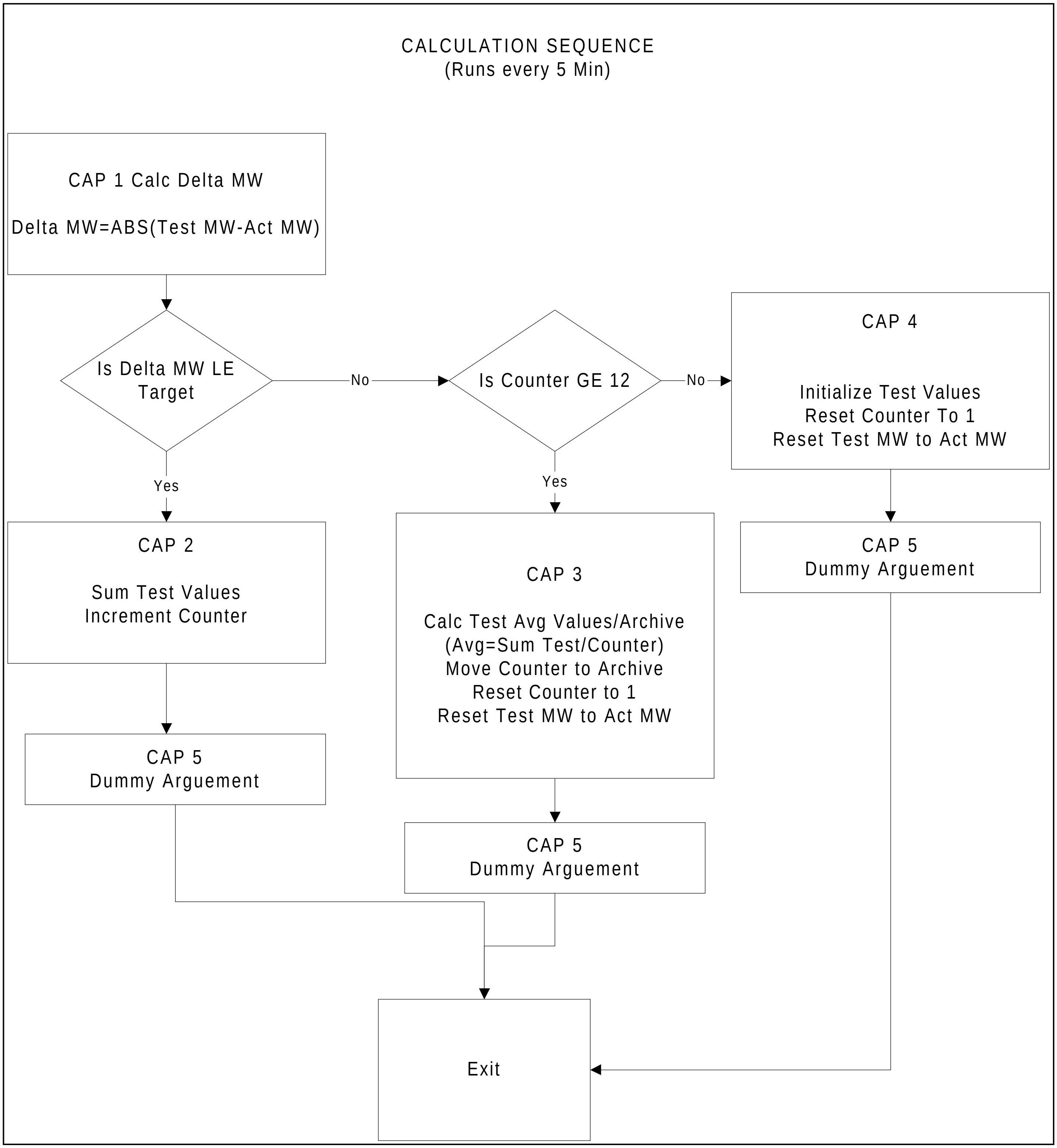

Figure 1
PMAX Auto Test Flow Chart

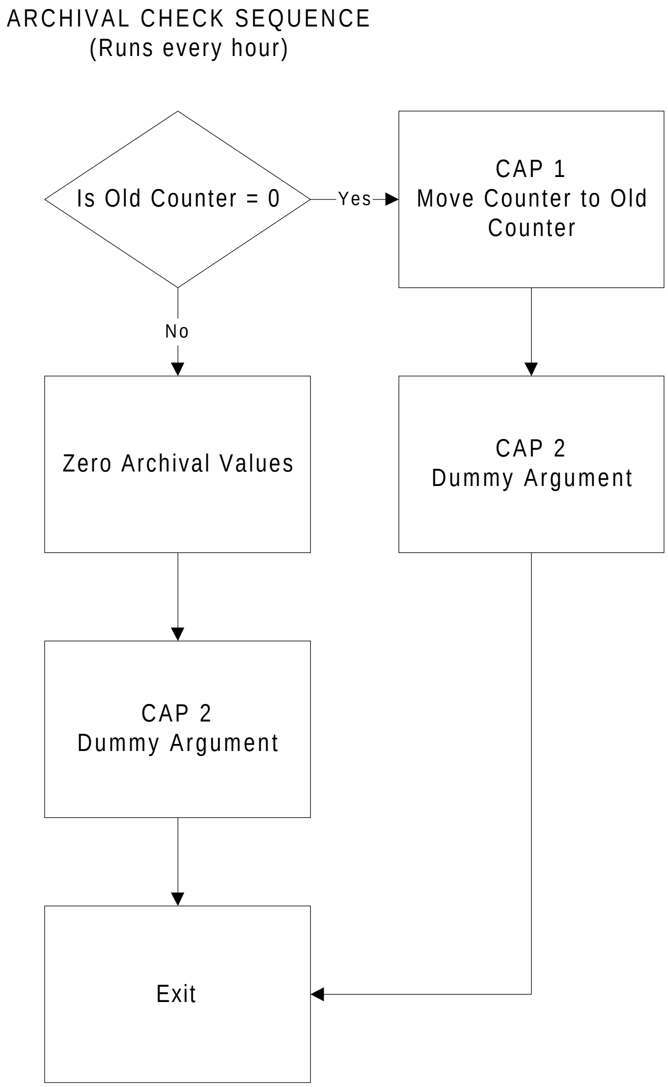

Figure 2
PMAX Auto Test Archive Flow Chart

Sequence on a Clock is a new function in the PMAX NT system. This function allows the user to start a given sequence at a given time interval. The user may specify the time intervals. This function allows and replaces the CAL function from the VAX based PMAX system. At Dairyland, we are using this function to also create logs for the various plants. In some of these logs, we are taking pulse counter and/or totalizer readings at specific intervals.

The steps, which make up the calculation sequence, are:

- Raw data is averaged on five-minute intervals.
- Every five minutes, PMAX compares the actual MW output with a “test” value.
- If the absolute difference between actual MW and test MW is less than or equal to a constant, then a counter is incremented and the actual test values are summed.
- If the absolute difference of actual MW and test MW is greater than the constant, the counter and test data sums are reset and the actual MW becomes the new test MW for comparison.
- Prior to resetting the counter and test data sums, the program looks at the value of the counter. If the counter is greater than or equal to 12, the program divides each test data sum by the counter to give an average for the time period. The averaged test data is then moved to a separate archive location. After performing the test averages, the counter and test data sums are reset.
- If the counter is less than 12, the counter and test data sums are reset.

The steps for the archival sequence involve moving test data to a separate archive location on an hourly basis. After the data has been archived, the archive locations are reset to a value of zero.

A set of generic values is created for each unit. These values are shown in Figure 3. The methodology is the same for each unit, only the data locations are changed.

Using this method, one can search the archive file for test MW values greater than zero. Any values that show up indicate a time period when the unit was at a “stable” condition.

	JPM	Alma 4	Alma 5
Target Delta MW	5	2	2
Target Min Counter	12	12	12
Calc Seq	10	10	12
Delta MW	10-1	10-1	12-1
Sum Test	10-2	10-2	12-2
Avg Test	10-3	10-3	12-3
Init Test	10-4	10-4	12-4
Dummy	10-5	10-5	12-5
Arch Seq	11	11	13
Move Cntr			
Zero Arch			
MW Search	10692	18686	
Counter	10900	18900	19900
Test MW	10901	18901	19901
Delta MW	10902	18902	19902
Final Counter	10903		
Old Counter	10908	18908	19908

Figure 3
PMAX Auto Generic Values

The value of the test counter in the archive file tells how long the unit was at that condition. Over the course of a month, several data points may be collected at multiple loads.

Test Data Analysis

The PMAX auto-test function described above has the potential for creating a lot of test data. How does one evaluate this data in an efficient manner? PEPSE is a good program for determining unit performance, but does not do a good job if there are problems with the test data. A preliminary examination of the test data must be done prior to submitting the data for analysis with PEPSE. Dairyland Power Cooperative has developed spreadsheet templates which will evaluate the test data, submit the data to a PEPSE deck, and store the data and results in a database for future reference.

The spreadsheets developed at Dairyland involve using Excel 97, an add-in program call ENDRESULT, and the PMAX to Excel interface.   ENDRESULT is a program add-in, which enables Excel to calculate steam table and gas table calls plus curve fitting. This program is available from SEGA Inc. in Kansas City. The PMAX to Excel interface allows the user to directly transfer data from a PMAX system to an Excel spreadsheet. Knowing the test date, the time the data was archive, and the duration of the test enable the user to download the appropriate data to the spreadsheet. Figure 4 shows an example of a test data spreadsheet.

The spreadsheets are templates. After data is entered, the spreadsheet is saved with a unique name that encrypts the unit being tested and the date of the test. An example would be J5699A.XLS would indicate the test was performed at JPM (J), the date is 5/6/99, and A indicates this was the first test of the day. There may be other tests for that date. These would end with a B, C, etc.

JPM PERFORMANCE TEST DATA

DATE
TEST:
NO. VLVS:

EUTBL	DESCRIPTION	UNITS		CORRECTED	STD CORR
1601	AH 61 SEC AIR IN TEMP	DEG F	101.45		
1602	AH 62 SEC AIR IN TEMP	DEG F	101.24		
1603	SEC AIR TO AH 61 TEMP	DEG F	105.30		
1604	SEC AIR TO AH 62 TEMP	DEG F	103.91	102.98	
1605	SEC AIR FROM AH 61 TEMP	DEG F	654.38		
1606	SEC AIR FROM AH 62 TEMP	DEG F	665.01	659.69	
1607	PRI AIR FROM AH 61 TEMP	DEG F	656.56		
1608	PRI AIR FROM AH 62 TEMP	DEG F	657.00	656.78	
1610	GAS TO AH 61 TEMP	DEG F	719.15		
1611	GAS TO AH 62 TEMP	DEG F	742.15	730.65	
1612	GAS FROM AH 61 TEMP	DEG F	313.23		
1613	GAS FROM AH 62 TEMP	DEG F	343.95		
1614	AH 61 GAS OUT TEMP	DEG F	330.47		
1615	AH 62 GAS OUT TEMP	DEG F	340.70	332.09	
1619	ECONOMIZER GAS OUT-WEST	DEG F	830.83		
1627	FW TO ECONOMIZER TEMP	DEG F	459.82		
1629	ECON OUTLET TEMP-EAST	DEG F	568.09		
1630	ECON OUTLET TEMP-WEST	DEG F	578.32	573.21	
1650	RH. BEFORE SPRAYS	DEG F	626.28		
1654	HOT REHEAT STEAM TEMP.	DEG F	962.13		
1660	THROTTLE STEAM TEMP	DEG F	948.44		
1664	FWH 63 EXTRACT TEMP.	DEG F	524.24		
1665	FWH 63 EXTRACT TEMP.	DEG F	535.90		
1666	FWH 63 EXTRACT TEMP.	DEG F	530.47	530.20	
1670	COND. TO FWH 61	DEG F	90.75		
1672	COND. TO FWH 62	DEG F	173.80		
1673	COND. FROM FWH 62	DEG F	233.79		
1674	COND. TO FWH 63	DEG F	234.02		
1675	COND. FROM FWH 63	DEG F	287.93		
1676	COND. TO BFP 61	DEG F	369.72		
1677	COND. TO BFP 62	DEG F	369.63	369.68	
1680	COND. TO FWH 64	DEG F	274.97		
1681	FWH 64 EXTRACT TEMP.	DEG F	715.56		
1682	FW FROM FWH 65 TEMP.	DEG F	409.20		
1683	FW TO FWH 65 TEMP	DEG F	373.65		
1685	FW FROM FWH 66 TEMP.	DEG F	460.03		
1686	FW TO FWH 66 TEMP.	DEG F	404.47		
1690	FWH 62 EXTRACT TEMP.	DEG F	290.00		
1692	FWH 61 EXTRACT TEMP.	DEG F	176.10		
1695	FWH 61 DRAIN TEMP.	DEG F	108.02		
1696	FWH 62 DRAIN TEMP.	DEG F	190.08		
1697	FWH 63 DRAIN TEMP.	DEG F	249.35		
1698	FWH 65 DRAIN TEMP.	DEG F	388.91		
1699	FWH 66 DRAIN TEMP.	DEG F	419.04		
1702	CNDSR CIRC WTR 61 IN	DEG F	33.82		
1703	CNDSR CIRC WTR 62 IN	DEG F	33.94	33.88	
1704	CNDSR CIRC WTR 61 OUT	DEG F	69.45		
1705	CNDSR CIRC WTR 62 OUT	DEG F	68.64	69.05	
1706	COND. FROM CONDENSER TEMP	DEG F	96.74		
1750	FWH 65 EXTRACT TEMP.	DEG F	856.46		
1753	FWH 66 EXTRACT TEMP.	DEG F	627.96		
1763	PRI SH. SPRAY TEMP-EAST	DEG F	780.39		
1764	PRI SH. SPRAY TEMP-WEST	DEG F	760.86	770.63	

COAL ANALYSIS DATA
PROXIMATE ANALYSIS
VOL (%)
S(%)
H2O (%)
ASH (%)
FIXED C (%)
BTU/LB

Data Reduction

Create PEPSE Deck

Print Test Summary

Print PEPSE Deck

Send Data To Database

Save File To Another Name

Figure 4
Example of Spreadsheet Input

Test data may be entered one of two ways depending on the way the auto-test was set up. If auto-test is being used to just provide a test MW and counter value, test data will have to be averaged. In this case, the user enters the start time and date and the end time and date or duration for all of the test data required. A separate page of the spreadsheet can be used to average test data. If the auto-test was set up to provide test averages for all test data, then the user simply brings over the data from the test date and archive time for one time period. Either way, once averaged data obtained, it may be copied into the data section of the template. It is best to have the spreadsheet calculate on a manual basis rather than automatic. On automatic, every time a new item of data is entered, the spreadsheet will recalculate. This is not only time consuming but can get very frustrating.

Once calculations are completed, the data may be viewed to determine its validity. If the data is valid, a macro may be activated to create a PEPSE deck. With the newer versions of PEPSE, the PEPSE run can be activated right from Excel. With older versions, the PEPSE run is activated manually. Figures 5 and 6 show examples of the PEPSE Input Deck developed by the spreadsheet, calculations available, and the test summary page.

Advanced Calibration Monitoring (ACM)

Advanced Calibration Monitoring (ACM) was installed at the JPM Station in 1998. This is a program, which looks at the incoming data and analyzes it for validity. This may sound like PMAX's Input Validation Module, but is actually quite different. Whereas the Input Validation Module looks at input data for validity, it is based on a given range of operation and curves. This does not account for any changes in operation or gradual changes in the instrument. ACM, on the other hand, compares how one piece of data is performing compared to all of the other inputs that are modeled. ACM is more dynamic and much more sensitive. We have tied ACM into the Input Validation Module on PMAX for both checking and replacing of values. Marcus Caudill of Performance

```
890010  'FEEDWATER FLOW'
890011   OPVB,  12, 2323236.7,  I
/
= JPM TURBINE TEST 3/7/96
890010  'FEEDWATER FLOW'
890011   OPVB,  12, 2323236.7,  I
890020  'THROTTLE PRESSURE'
890021  PPVSC,   10, 1816.12,  I
890030  'THROTTLE TEMPERATURE'
890031  TTVSC,   10, 958.92,  I
890040  'FIRST STAGE PRESSURE'
890041  PSIPV,   50, 1263.23,  I
890050  'HP EXHAUST PRESSURE'
890051  PSIPV,   70, 471.69,  I
890060  'HP EXHAUST TEMPERATURE'
890061  TEXIP,   70, 636.49,  I
890070  'HOT REHEATER PRESSURE'
890071  PPTORH, 120, 440.05,  I
890080  'HOT REHEATER TEMPERATURE'
890081  TTTORH, 120, 965.11,  I
890090  'CROSSOVER PRESSURE'
890091  PSIPV,  170, 179.46,  I
890100  'CROSSOVER TEMPERATURE'
890101  TEXIP,  170, 729.01,  I
890110  'CONDENSER PRESSURE'
890111   PPSH, 260, 0.79,  I
890120  'HTR 1 FWIN TEMPERATURE'
890121  TTDISP, 280, 96.45,  I
890130  'HTR 1 FWOUT TEMPERATURE'
890131   TTFO,  290, 176.16,  I
890140  'HTR 1 DRAIN TEMPERATURE'
890141   TTDO,  290, 111.94,  I
890150  'HTR 1 STEAM PRESSURE'
890151 PSIPV,   220, 8.75,  I
890160  'HTR 2 FWOUT TEMPERATURE'
890161    TTFO, 300, 235.37,  I
890170  'HTR 2 DRAIN TEMPERATURE'
890171  TTDO,   300, 192.14,  I
890180  'HTR 2 STEAM PRESSURE'
890181 PSIPV,   210, 27.42,  I
890190  'HTR 3 FWOUT TEMPERATURE'
890191   TTFO,  310, 288.31,  I
890200  'HTR 3 DRAIN TEMPERATURE'
890201  TTDO,   310, 250.86,  I
890210  'HTR 3 STEAM PRESSURE'
890211 PSIPV,   200, 80.21,  I
890220  'HTR 3 STEAM TEMPERATURE'
890221  TEXIP,  200, 543.71,  I
890230  'BFP DISCHARGE PRESSURE'
890231 PMPDIS,   330, 2049.50,  I
890240  'BFP DISCHARGE TEMPERATURE'
890241 TTDISP,   330, 376.31,  I
890250  'HTR 5 FWOUT TEMPERATURE'
890251   TTFO,  350, 411.61,  I
890260  'HTR 5 DRAIN TEMPERATURE'
890261   TTDO,  350, 386.97,  I
890270  'HTR 5 STEAM PRESSURE'
890271  PSIPV,  160, 291.94,  I
890280  'HTR 5 STEAM TEMPERATURE'
890281 TEXIP,   160, 859.58,  I
890290  'HTR 6 FWOUT TEMPERATURE'
890291  TTFO,   360, 443.94,  I
890300  'HTR 6 DRAIN TEMPERATURE'
890301   TTDO,  360, 418.46,  I
890310  'SUPERHEAT SPRAY FLOW'
890311    OPVB,  13, 84352.7,  I
890320  'REHEATER SPRAY FLOW'
890321  WWFIXB, 345, 64882.4,  I
890330  'GROSS POWER'
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JPM TURBINE EFFICIENCY

THROTTLE PRESS	PSIA	1814.70
THROTTLE TEMP	DEG F	948.44
FIRST STAGE PRESS	PSIA	1344.50
FIRST STAGE TEMP	DEG F	886.77
COLD REHEAT PRESS	PSIA	471.76
COLD REHEAT TEMP	DEG F	626.28
HOT REHEAT PRESS	PSIA	439.86
HOT REHEAT TEMP	DEG F	962.13
IP-1 PRESS	PSIA	288.82
IP-1 TEMP	DEG F	856.46
CROSSOVER PRESS	PSIA	173.06
CROSSOVER TEMP	DEG F	715.56
LP-1 PRESS	PSIA	76.82
LP-1 TEMP	DEG F	530.20

	HIN	HOUT	Hs	EFF	SIn	Sout
GOVERNING STAGE	1447.79	1427.27	1407.20	0.5056	1.5516	1.5667
HP-1	1427.27	1317.23	1300.55	0.8683	1.5667	1.5823
HP	1447.79	1317.23	1284.78	0.8009	1.5516	1.5823
IP-1	1501.82	1451.19	1440.23	0.8220	1.7381	1.7465
IP-2	1451.19	1383.60	1382.33	0.9816	1.7465	1.7476
IP	1501.82	1383.60	1372.57	0.9146	1.7381	1.7476
LP-1	1383.60	1296.59	1289.22	0.9219	1.7476	1.7551

	H	S				
THROTTLE	1447.79	1.5516	SUM Y	5633.2085		
GOV STAGE	1427.27	1.5667	SUM X	6.9871902		
HP-1	1317.23	1.5823	SUM X2	12.205352	SUM Y2	
HOT REHEAT	1501.82	1.7381	SUM XY	9838.3038		
IP-1	1451.19	1.7465	(SUM X)2	48.820827		
IP-2	1383.60	1.7476		39360.299		
LP-1	1296.59	1.7551	B	-12215		R2
			A	22745.8		

	IP-1	IP-2	LP-1
PRESS	244.87	142.06	67.44
Tact	857.26	725.37	575.09
Hact	1453.26	1390.11	1319.50
Hnew	1412.18	1398.99	1307.29
Tnew	777.87	742.94	550.30

JPM BOILER EFFICIENCY

JPM TEST SUMM

COAL ANALYSIS DATA

ULTIMATE ANALYSIS			
C (%)	0.53	AIR IN TEMP	102.98
H2 (%)	0.04	GAS OUT TEMP	332.09
O2 (%)	0.11	% EXCESS O2	1.82
N2 (%)	0.01	STACK CO2	13.09
S (%)	0.00		0
H2O(%)	0.27		0
ASH (%)	0.04		0.000666
BTU/LB	8915.00		

COMBUSTION CALCS

	INLET	WET GAS	DRY GAS	DRY GAS ASME
EXCESS AIR	%	10.601%	—	—
CO2	% By Vol	15.080%	17.035%	17.035%
O2	% By Vol	1.816%	2.051%	2.051%
CO	% By Vol	0	0	0
N2	% By Vol	71.606%	80.914%	80.940%

BOILER EFFICIENCY CALCS

	Btu/lb	Loss/HHV	Loss(%)
Cp Air	0.2398654	—	—

Figure 5
Example of Spreadsheet Calculations and PEPSE Deck

JPM TEST SUMMARY

DATE	#REF!				
GROSS MW	363.6				
NET MW	340.3				

TURBINE EFFICIENCIES

GOV STAGE	50.56%
HP-1	86.83%
HP SECT	80.09%
IP-1	82.20%
IP-2	98.16%
IP SECT	91.46%
LP-1	92.19%

FEEDWATER HEATERS

	HTR61	HTR62	HTR63	HTR65	HTR66
TTD	20.02	9.76	17.96	0.02	-1.41
DCA	17.27	16.29	15.56	15.25	9.84

		VOL	31.74
%C IN ASH	0.00	SULFUR	0.22
GAS OUT T	332.09	H2O	26.63
AIR INT	102.98	ASH	4.45
%O2	1.82	FIXED C	37.18
BLR EFF	92.56	BTU	8915

FLOWS

FEEDWATER FLOW(KLB/HR)	2561128	COAL MEASURED	390409
SH SPRAY FLOW(KLB/HR)	0	COAL CALCULATED	0
RH SPRAY FLOW(KLB/HR)	25581	% DIFF	0.00

HEAT RATES

	GROSS	NET
TURBINE	8246	8812
PLANT	8909	9521

RIVER T	33.9
BK PRESS	1.36

Figure 6
Example of Spreadsheet Summary Page

Consulting Services, Inc., presented a detailed paper on the functionality of ACM at the 1998 Heat Rate Conference. We will also be installing ACM on the Genoa PMAX system, once the conversion to NT is complete.

When we first started using ACM, the intent was to help the instrument technicians in reducing the number of periodic calibrations. We were finding several pieces of instrumentation that were being calibrated when they didn't need to be. What was really needed was a tool to assist the instrument technicians in determining when a piece of instrumentation needed calibration and if the instrument was starting to fail. To this end, we implemented ACM with approximately 260 input values. Each of these values was being scanned on 15-second intervals and analyzed over a 24-hour period. We found that the 24-hour period gave a good indication of failure or improper operation, it did not provide much information on long term trends.

Shortly after installation of ACM at the JPM plant, one of the performance staff noticed that one of the feedwater flow transmitters had failed. The plant had noticed the same thing and was trying to determine the time of failure. Using PMAX, a trend of both flow transmitters was displayed (Figure 7). The trends in Figure 7 show that one transmitter began to "straight line," thereby indicating the time of failure. Figure 8 shows a graph of the same data from the ACM program. The green line represents the failed transmitter and the yellow line represents the expected value as calculated by ACM. In this case, we would have been able to fill in appropriate data from ACM to backup the failed transmitter.

Another example of the use of ACM involved the West Primary Air Flow Transmitter at JPM. The plant had been experiencing some problems with this transmitter for several days. The operators claimed the unit was operating strangely at lower loads. A look at the ACM plots for the previous few days showed the West Primary Air Flow transmitter to be fluctuating between 200 KPH and its maximum of 531 KPH. The predicted value did not show this fluctuation, neither did the East Primary Air Flow Transmitter. Shortly after this fluctuation was noticed, the transmitter failed completely. This again is shown

Figure 7
PMAX Trend of Two Feedwater Transmitters

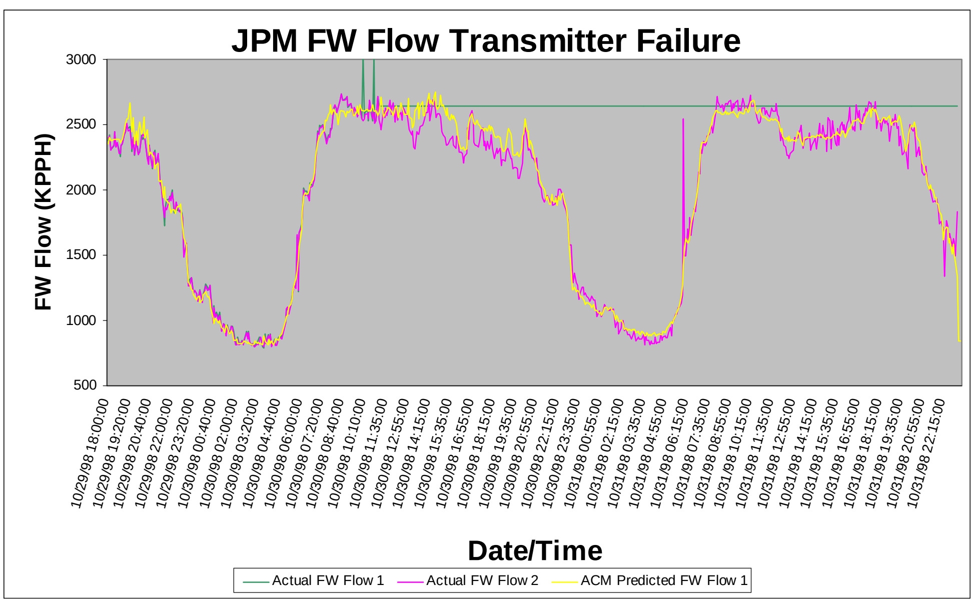

Figure 8
ACM Plot of Feedwater Transmitter

in Figure 9. At this time, we were just learning how to use the new system and didn't know what to be looking for. This incident showed how valuable a tool ACM can be, even with such definitive input as "the boiler is acting strangely at low loads."

ACM will not tell you what is wrong, but that something has changed. It is up to the experience of the operations, instrument, and performance staffs to determine what caused the change. This was illustrated when the operators took a heater out of service. We had not modeled any conditions with heaters out of service. As soon as the heater was taken out of service, we started getting discrepancies on feedwater outlet and drain outlet temperatures, as well as steam pressure. ACM didn't know what had happened, but knew a change from its modeled values had occurred. Looking at the data, we could tell exactly when the operators took the heater out of service.

We are currently in the process of developing several ACM models for trending. These models encompass three different time frames: every 24 hours, one to three months, and six months to one year. The 24-hour model is used to look at operational changes and/or tuning changes made within a couple of days. This information is helpful in identifying the effects in operational and instrument changes.

The modeling range of six months to one year is used to look at long-term trends. We expect to see indications of instrument drift and problems and be able to react to them prior to failure. The modeling is the same, but data is sampled once a week and then analyzed on a monthly basis.

The modeling range of one to three months is for intermediate effects and to closely monitor long-term indications.

We are also in the process of developing ACM models for performance indices. These will be used on both the intermediate and long term ranges.

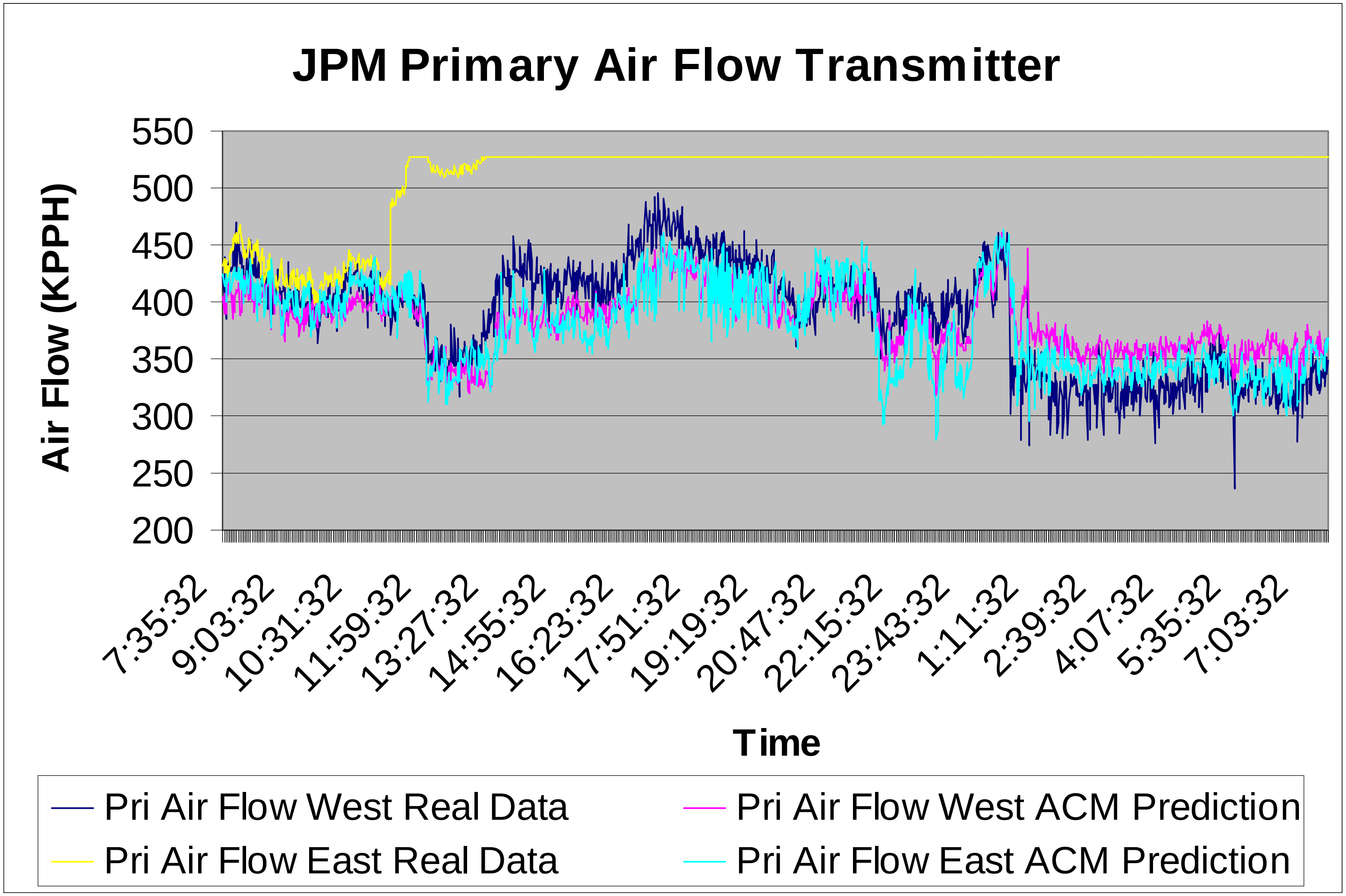

Figure 9
ACM Plot of Air Flow Transmitter