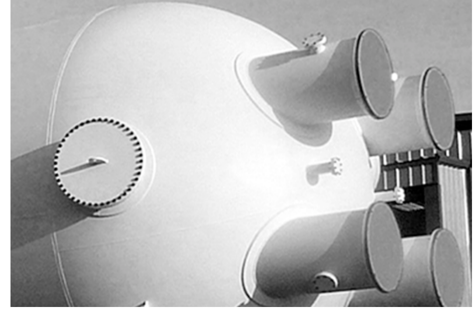
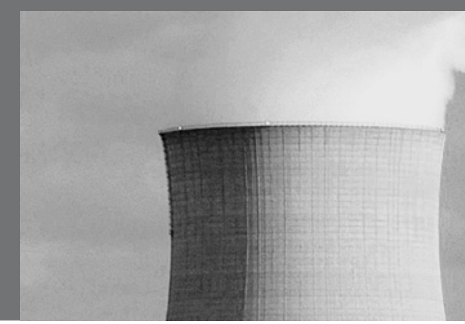


Spinning Reserve

Greg Alder, Scientech
Meagan Parmelee, AECI



AECI Fleet

- Combined Cycles
  - Chouteau Units 1 & 2
  - Dell
  - St. Francis Unit 10 & 20
- Simple Cycles
  - Holden 11, 12, & 13
  - Nodaway 1 & 2
  - Essex
- Coal Plants
  - Thomas Hill Units 1, 2, & 3
  - New Madrid Units 1 & 2

This study encompasses the CCGT and simple cycle plants at this time

Background

- Spinning reserve at a utility is the extra generating capacity available by increasing the power output of generators which are already connected to the power system
- Utilities keep generation capacity on reserve in the event of disruption of power supply and for demand requirements, to maintain consistent availability and reliability of providing electricity

Background

- AECI is a member of the SPP Reserve Sharing Group
- Partnership reduces individual operating reserves for each entity
- Accurate prediction of reserve power reduces risk and increases margins
  - To little: fines and penalties may result
  - To much: decrease margin and increased operating cost
- AECI teamed with Scientech to generate spinning reserve calculations for their fleet of plants including coal-fired, combined cycle and simple cycle
- Current capacities are a guess based on previous operation and current ambient conditions
- These calculations are performed using the PMAX on-line thermal performance monitoring software

Approach

- Gather Data to Generate Predictions
- Produce Spinning Reserve Calculations (curves/equations)
- Enter Curves and Equations into PMAX
- Develop Displays to Present Results
- Review and Tune Information as Needed
  - Using On-line Data – Plants in Service
  - Reviewing Historical Data and Results - Post Implementation

Data Gathering

- Obtain the Instrument Tags
- Equipment Limitations and Operating Boundaries
- Vendor Correction Curves
- Obtain Plant Historical Data
- Filter Historical Data
  - CCGT
  - GT
  - ST

Typical Instruments

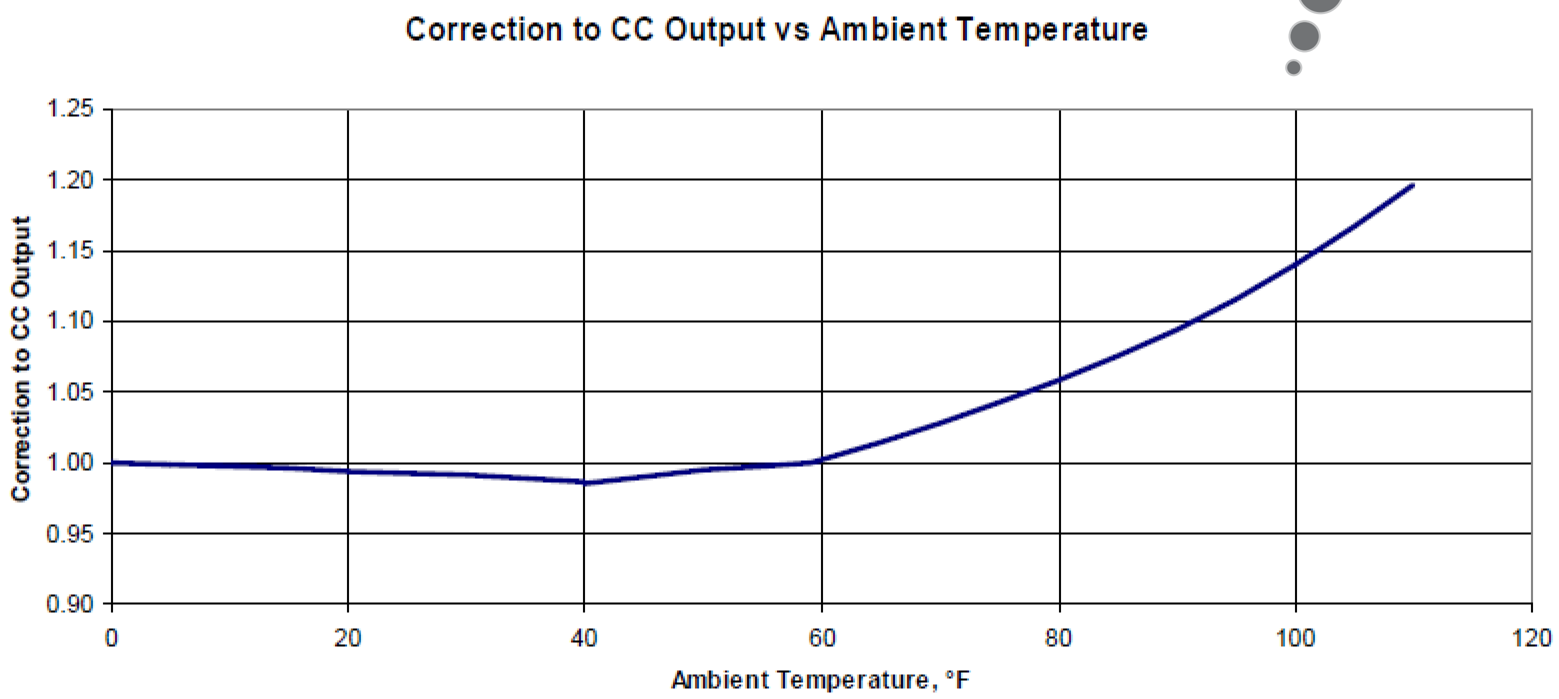
- GT Inlet Temperatures
- GT Inlet Humidity
- GT Compressor Inlet Temperatures
- GT Gross Generations
- GT IGV Positions
- GT LLC Digitals (On/Off)
- GT OTC Temperatures
- GT Anti-Icing Digitals (On/Off)
- Water or Steam Injection Flows
- Steam Turbine Gross Generation
- Condenser Circulating Water Inlet Temperature
- CCGT Gross Generation
- Plant Ambient Temperature and Humidity
- HRSG Duct Burner Flow or Digital (On/Off)

Equipment Limitations and Operating Boundaries

- Combined Cycles:
  - Load Limit Control
  - Outlet Temperature Control
  - Inlet Air Cooling/Heating Equipment Operational Boundaries
- Peakers:
  - Shaft Limitation
  - Inlet Air Cooling/Heating Equipment Operational Boundaries
  - Water Injection Operational Boundaries

Vendor Correction Curves

Sample Correction Curve – CCGT Plant



Plant Historical Data

- Plant Data Collection
  - Using the selected instruments, obtain plant historical data for at least one calendar year
  - One hour frequency or less is recommended to reduce uncertainty
  - To reduce uncertainty further, increase the data collection frequency
    - Note the spreadsheet size increases dramatically and filtering data can be more time consuming

Filtering Plant Historical Data

- Filtering of the plant data requires several steps
  1. Obtain the base uncorrected peak generation for each gas turbine and the combined cycle as a function of inlet temperature
  2. Apply correction curves (vendor, empirical, other) to correct the base peak generation

Filtering Plant Historical Data – Gas Turbines

- Filter each gas turbine historical data set to obtain a base peak generation as a function of inlet temperature
  - GT off-line, bad data sets containing instruments out of service
  - Isolate for inlet cooling, NOx control, water injection, de-icing, etc.
  - Bracket data for relative humidity for future correction for humidity impacts
  - Highest IGV positions
  - Look for LLC and/or OTC operation (if applicable)
- Remove outlying data points; typically those on the low side. Add a trend line and check the curve carefully for any errors or anomalies.
- Correct the base peak generation for:
  - relative humidity, inlet cooling, de-icing, water injection, NOx control, intercooling, rotor cooling, etc.
- Check the resulting corrected peak GT generation against any operating limits (generator, boundaries, etc.)

Filtering Plant Historical Data – Combined Cycle

- Obtain base CCGT peak generation as a function of ambient inlet temperature
  - No simple cycle operation, no 1 on 1 operation for 2 on 1 units
  - Bad data sets containing instruments out of service
  - Isolate for inlet cooling, NOx control, water injection, de-icing, duct burners, etc.
  - Bracket data for relative humidity for future correction for humidity impacts
  - Highest IGV positions for GTs, review and compare maximum GT generations
  - Look for LLC and/or OTC operation (if applicable)
- Remove outlying data points; typically those on the low side. Add a trend line and check the curve carefully for any errors or anomalies.
- Develop a curve fit equation for circulating water temperature correction on generation. Use curves provided in thermal kits, capability and acceptance test reports or developed using empirical data or PEPSE.
- Correct the base peak CCGT generation for:
  - circulation water temperature
  - relative humidity, inlet cooling, water injection, de-icing, NOx control, intercooling, rotor cooling, duct burners, etc.
- Check the resulting corrected peak CCGT generation against any operating limits (generator, boundaries, etc.)

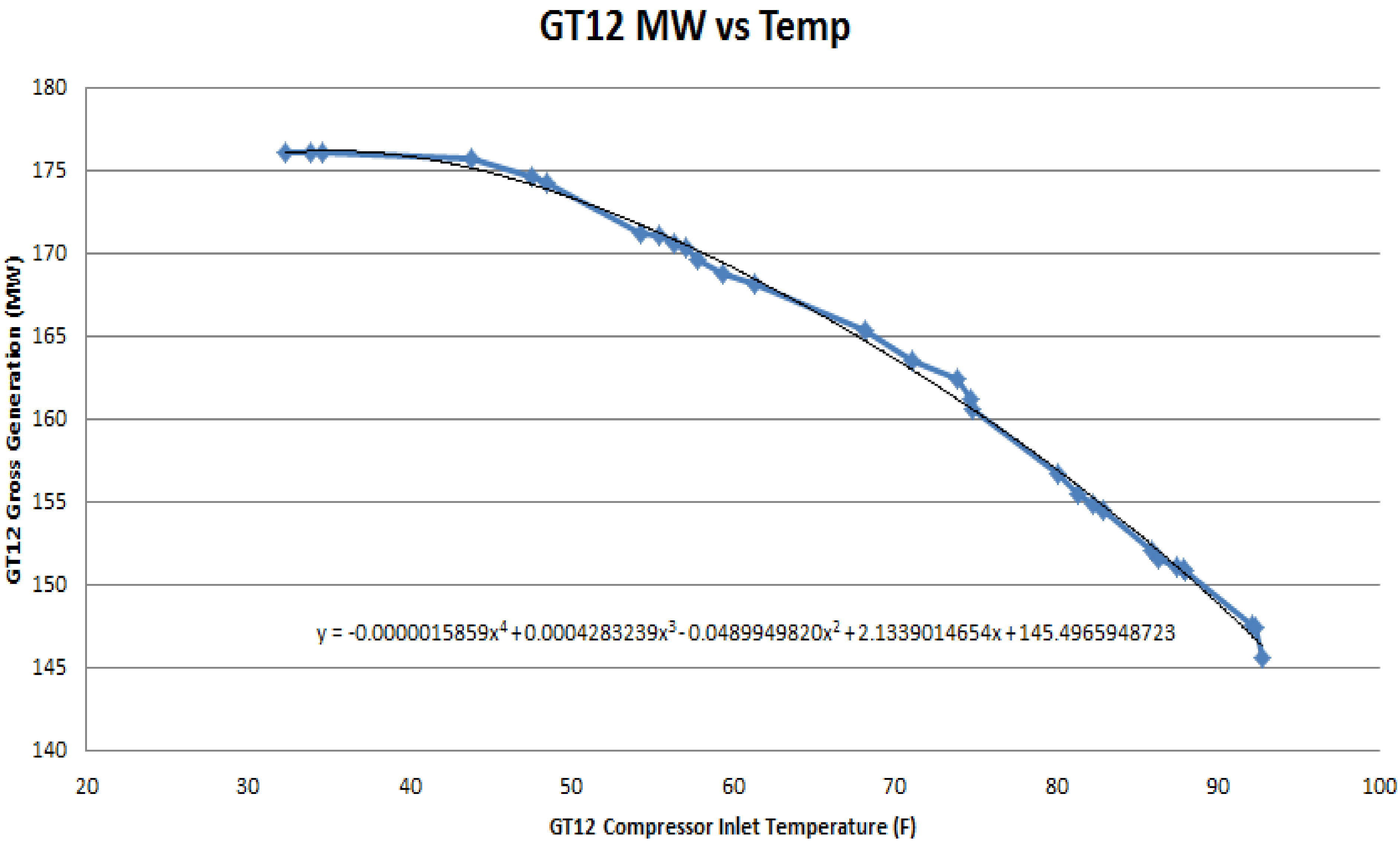
Filtering Plant Historical Data – Steam Turbine

- Obtain peak generation of the steam turbine
  - Sum the corrected peak GT generation(s) and subtract from corrected peak CCGT generation to obtain the peak steam turbine generation. Check the resulting steam turbine peak generation against any operating limitations.
- Filtering plant historical data for steam turbine generation is a possible method to obtaining peak steam turbine generation
  - However, using the corrected CCGT and GT peak generations to obtain steam turbine peak generation is the simplest approach
  - More difficult to obtain the steam turbine generation from other plant historical information
  - Use this method to project peak generation for 1 on 1 operation with a 2 on 1 configuration

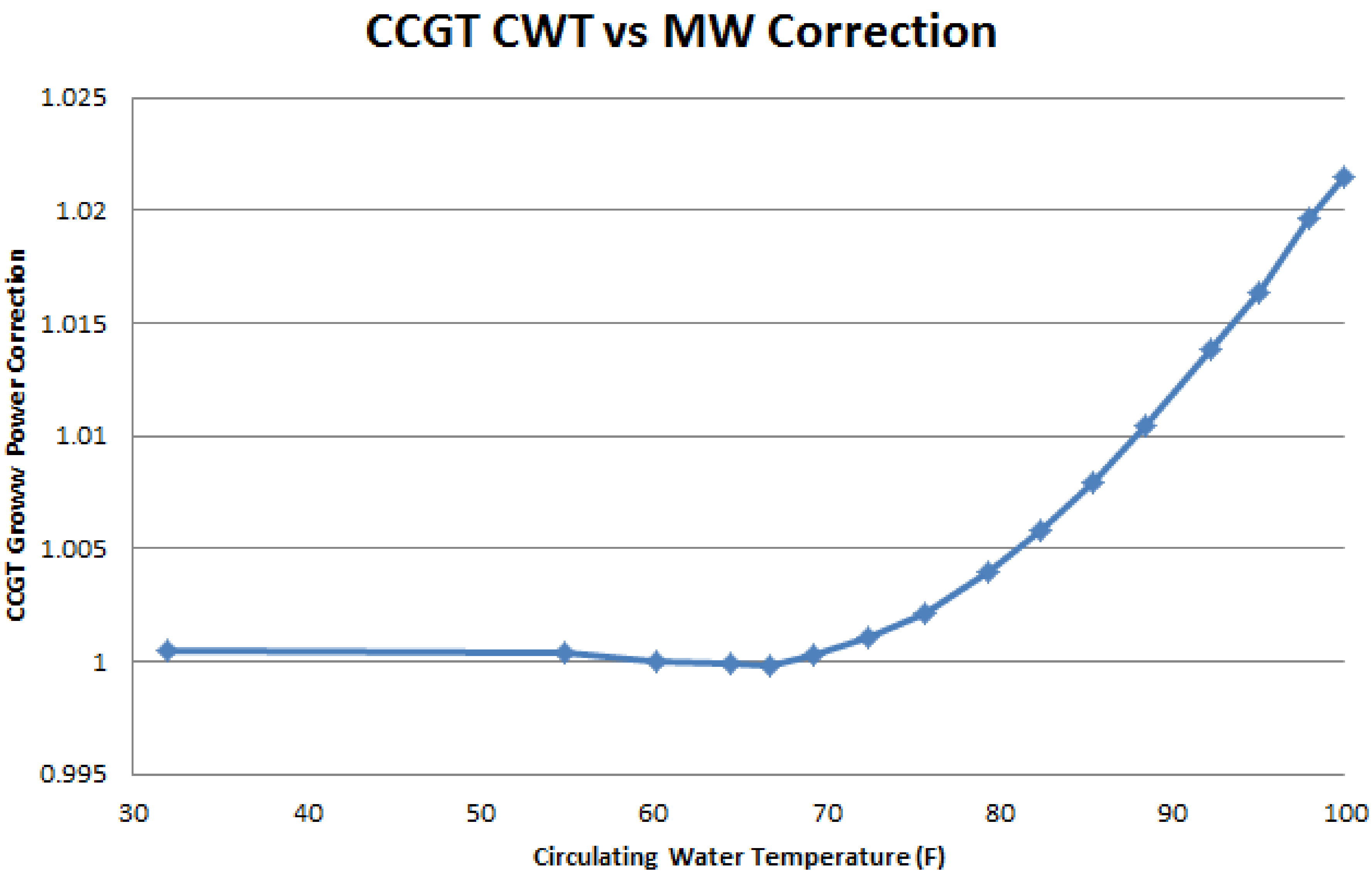
Sample Plant Data Filtering

	A	B	C	D	E	F	G	H
1	Description	U1 GT 12 ACTIVE POWER	U1 GT12 AIR INLET HUMIDITY	U1 GT12 AIR INLET TEMP	U1 GT12 IGV POSITION	U1 GT12 OTC TEMPERATURE (CH12MBY10FT010)	U1 12 Load Limit Control (CH12MBY10DU06006)	AMB TEMP
2	PI TAG	CH12MBY10CE901	CH12MBL10CM001	CH12MBL10CT001	H12MBY10DT040XQ	CH12MBY10FT010	CH12MBY10DU06006	CH10CXM01CT001
3	11/12/2013 18:59	176.0654449	42.56993484	34.4817276	107.8401642	1043.180542	Yes	34.39590836
4	2/15/2013 20:59	175.8171844	42.75653076	34.5788269	108.14888	1043.047363	Yes	33.18172836
5	11/14/2014 19:58	175.4870911	38.15977859	35.39434433	107.0781174	1047.004883	No	34.16973114
6	1/6/2013 18:59	174.887619	42.7952919	39.20929718	108.2193222	1047.647461	No	38.69258118
7	11/23/2013 15:59	173.317337	47.244133	40.40332413	108.3068542	1051.096191	No	39.82724762
8	11/12/2013 15:59	173.1986542	29.75120544	41.88103867	108.1462708	1051.36853	No	41.06451416
9	1/6/2013 17:59	172.8711853	37.48343277	42.73638153	108.1542511	1049.891724	No	41.18548965
10	2/15/2013 16:59	171.6705933	24.98478699	43.98739243	107.6000824	1050.501221	No	44.6666069
11	3/13/2013 20:59	169.7905121	34.06258011	47.95013428	108.2258301	1054.674438	No	46.53801727
12	1/23/2013 20:59	168.6968536	63.42769241	48.10647202	108.7075043	1054.87915	No	47.26477051
13	3/13/2013 19:59	167.3139343	27.80905533	50.12351227	108.8720016	1057.797974	No	50.11392975
14	3/27/2013 11:59	166.9453583	28.54904175	52.8319931	108.2735901	1062.586548	No	52.98331833
15	3/7/2013 10:59	166.6568604	25.33594894	55.71216965	106.4666519	1049.477783	No	55.80366898
16	4/25/2013 10:59	166.3866272	32.85261536	59.10531998	107.5810471	1064.500366	No	58.45957947
17	4/25/2013 12:59	162.6596832	20.22864342	65.83123016	106.8197861	1068.218506	No	65.51576233
18	4/25/2013 13:59	160.4580536	15.98579121	67.81183624	106.9994202	1067.300903	No	68.2898941
19	4/25/2013 15:59	159.3855743	16.36400795	69.6031723	106.9145584	1066.69458	No	69.89631653
20	7/31/2014 18:58	156.9697418	78.43345642	72.25627136	106.6175537	1064.561401	No	72.73649597
21	5/21/2014 12:58	155.9460144	63.3465004	76.00905609	106.8851852	1068.669922	No	75.91648865
22	6/7/2013 19:59	154.926651	39.61412811	77.17077637	107.2732239	1068.259521	No	78.30294037
23	7/19/2013 22:59	152.9624786	71.36826324	78.01047516	107.6351242	1066.399902	No	77.82098389
24	5/22/2014 12:58	152.4511414	52.83829117	80.77872467	107.1746368	1062.561157	No	81.04768372
25	8/12/2013 16:59	149.6674347	71.34812164	81.3433075	107.1935196	1051.577271	No	81.10762787
26	9/5/2014 9:58	147.9878235	61.09271622	82.14398956	107.8068314	1065.714478	No	82.58589172
27	9/12/2013 12:59	145.6837158	46.13477325	89.07084656	108.1732178	1065.769409	No	88.6780777
28	8/28/2014 14:58	142.8838959	36.74521637	89.51796722	107.1766586	1057.187256	No	90.34644318

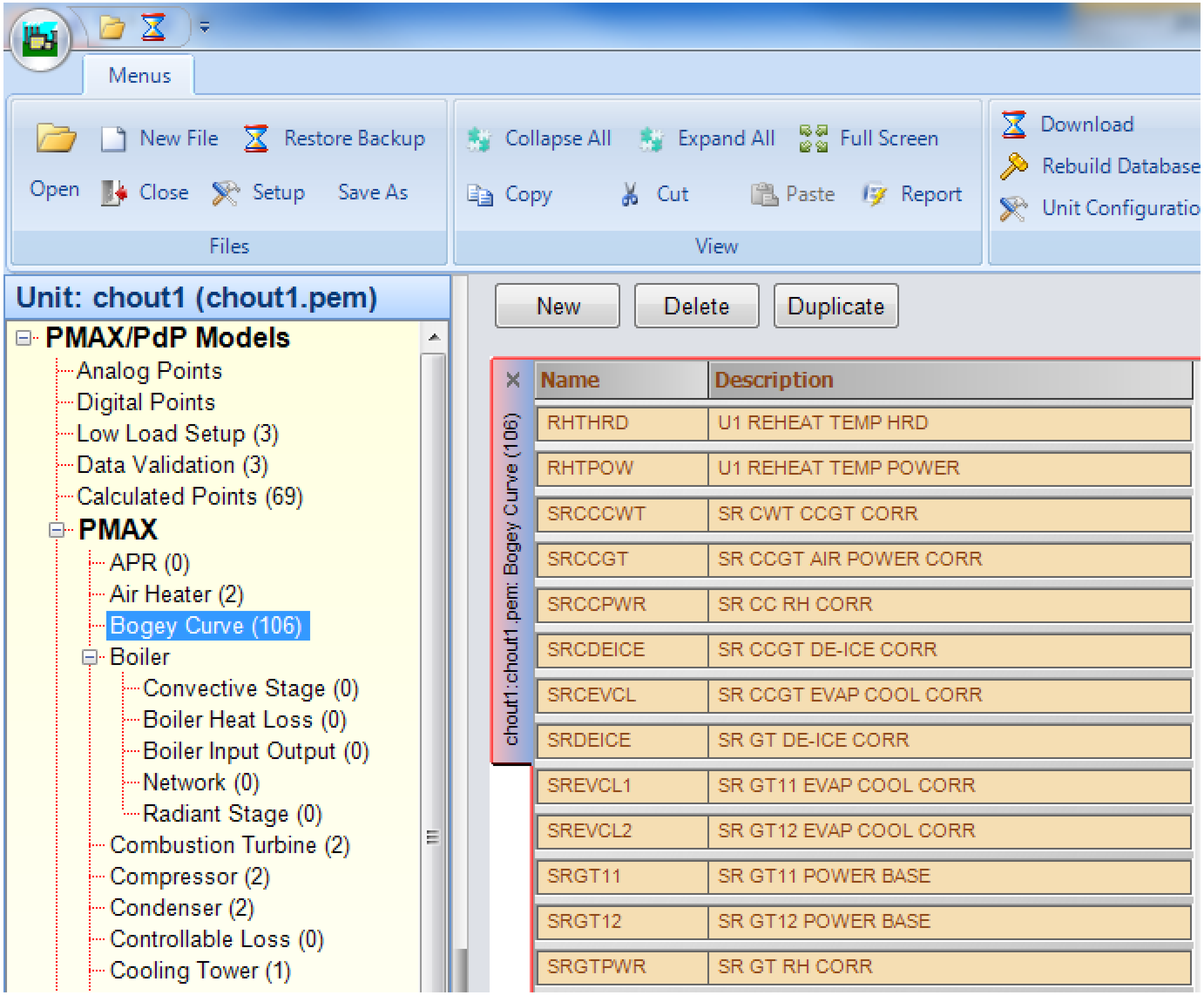
Sample Plant Data Curve – Uncorrected Base GT Generation



Sample Correction Curve – Circulating Water Temperature



Produce Spinning Reserve Calculations – PMAX Curves



Produce Spinning Reserve Calculations – PMAX Curves

SRCCCWT

Modified: 5/5/2015 9:44:20 AM Project: chout1

Description: SR CWT CCGT CORR

Notes: From 2013 Capability Testing Document

Prepared By: G. Alder

Number of Curves: 1 Number of secondary independent variables

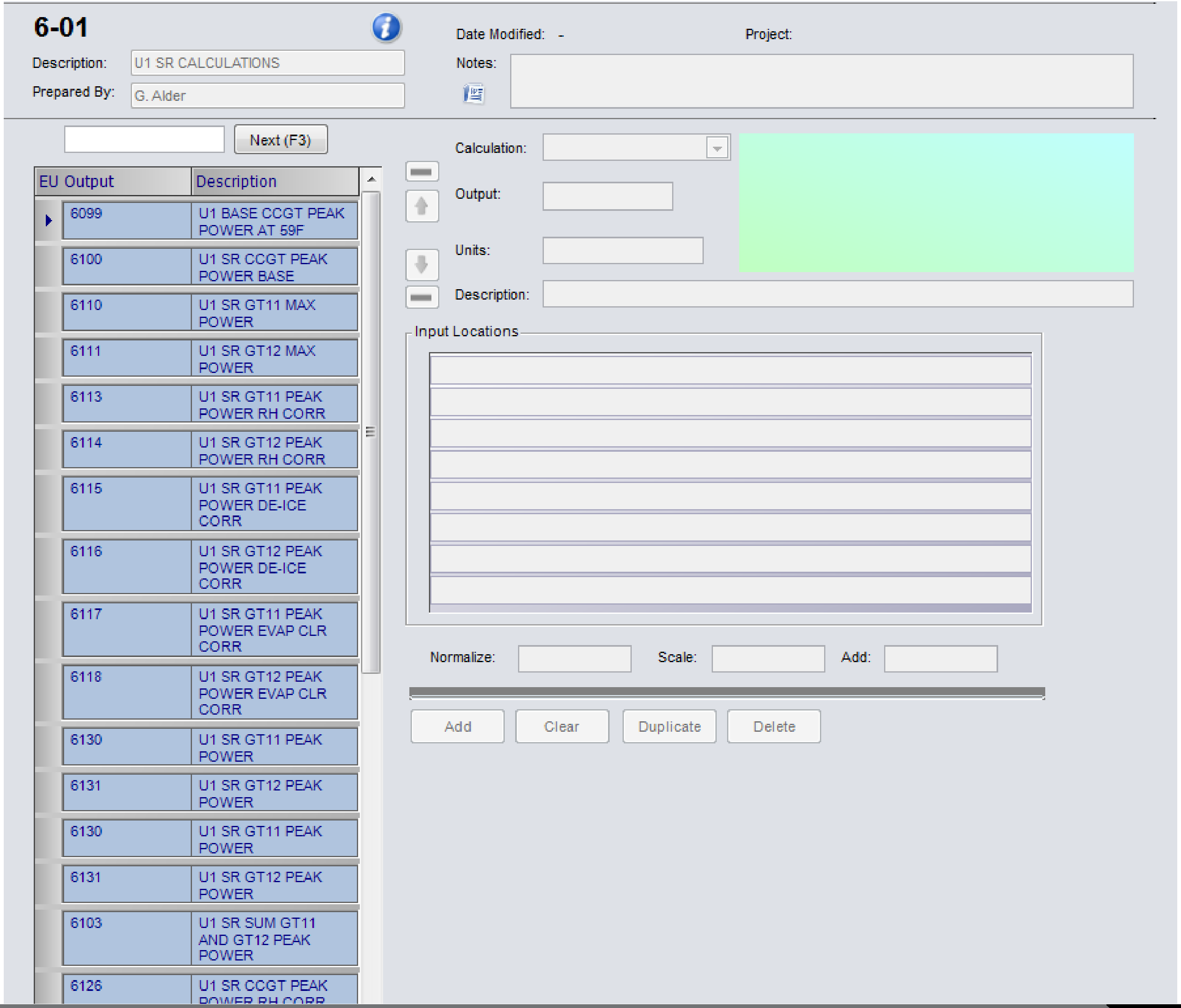
	Data Point	Description	Units
X	PN01045	CWT	DEG F
Y	PN06106	GROSS	MW
Z			

Z is the secondary independent variable

X is the primary independent variable Y is the dependent variable

	X	Y(1)
1	32	1.0005
2	55	1.00038
3	60.2	0.999973
4	64.5	0.999962
5	66.8	0.999824
6	69.3	1.00034
7	72.5	1.00112
8	75.7	1.00217

Produce Spinning Reserve Calculations – PMAX C-Points



CURTISS-WRIGHT

Presentation of Results

03-AUG-15 11:38:07 | BAD 49 | IVM 1 | Health | Alarm

Steam Cycle, GTs, and Plant Corrections

Chouteau 1

Mode: 2x1

Gross Power (MW)	436.8
Plant Load (%)	85.6

	GT/HRSG 11	GT/HRSG 12
Evap Cooler:	Off	Off

Net Power (MW)	428.6
Station Service (MW)	8.2
Net Unit Heat Rate (Btu/kWh)	7032

GT Information	GT In Temp	Comp In Temp	RH	OTC T	LLC
GT 11	84.3	84.3	55.8	1061.4	0
GT 12	81.5	81.5	50.2	1065.6	0

Gas Turbines	Actual	SR Raw	SR RH C	SR RH DICE C	SR RH DICE ECLR C	SR Peak
GT 11 Gross Power (MW)	146.9	150.5	150.5	150.5	156.1	156.1
GT 12 Gross Power (MW)	145.2	148.0	148.0	148.0	153.1	153.1

Steam Turbine Information	CW Temp
Steam Turbine	83.5

Steam Turbines	Actual	SR Peak
ST Gross Output (MW)	144.7	144.7

CCGT Total	Actual	SR Raw	SR RH C	SR RH CWT C	SR RH CWT DICE C	SR RH CWT ECLR C	SR Peak
Gross Output (MW)	433.8	441.2	441.1	438.2	438.2	450.7	450.7

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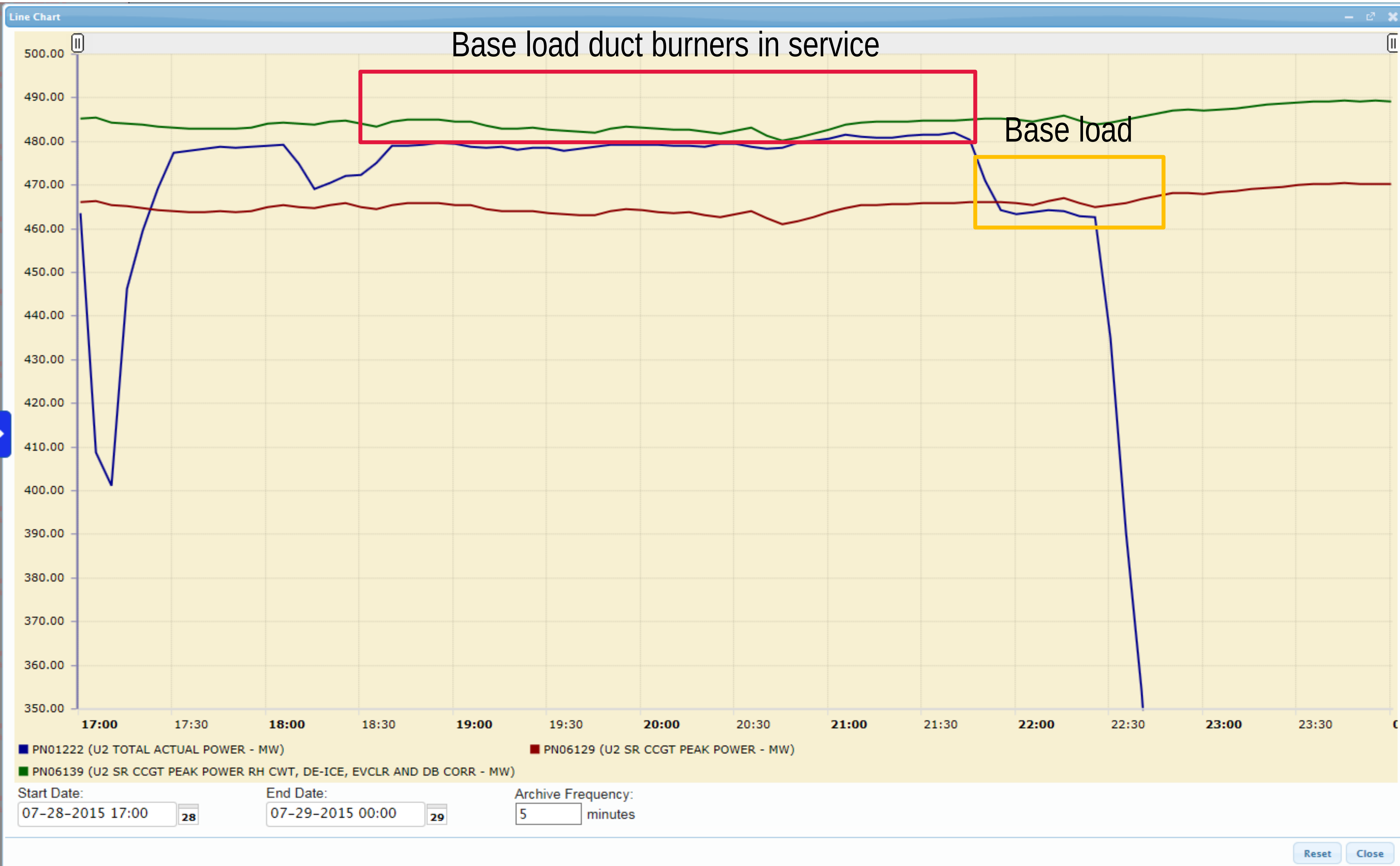
Presentation of Results



Summary and Future Efforts

- PMAX provides the calculation capability to implement the curves and equations to predict peak generation. Additionally, the logic checking capabilities in PMAX help to determine operating limits and equipment in and out of service.
- Additional efforts are continuing for AECI generating units to check and adjust the predicted peak generations to current and historical data to improve prediction accuracy.
- The AECI spinning reserve application, once completed and fully implemented, has the potential to provide dispatch centers with spinning reserve predictions at other utilities.

CURTISS-WRIGHT

Questions?