A Retrofit Integration of an Absorption Chiller with a Microturbine Array at an Office Building

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Richard L. Hack – PE, CEM
Pacific Regional CHP Application Center
University of California, Irvine

Overview

- Background /Opportunity
- Cooling Needs
- Power Generation Limitations
- System Limitations
- Performance Model
- Viability/Economics
- Operation Experience
- Future Efforts

Acknowledgements

- Eastern Municipal Water District:
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  For the foresight to investigate and capture the co-generation opportunity.

- South Coast Air Quality Management District
  - Howard Lange, Marty Kay

  For their support of microturbine applications

Background/Opportunity

- EMWD headquarters in Perris, CA had four Capstone C60 (60 kW) microturbines located on site.
  - SCAQMD 2001 microturbine distribution.
- First four units installed and operated by June 2003
- Unit installation designed and implemented by EMWD staff.
  - ASP training and exposure to outside contractor installations
- These four units have approx 19,500 hrs (avg) of operation, approx 375 starts, as of Sept 10, 2006

Background/Opportunity (cont'd)

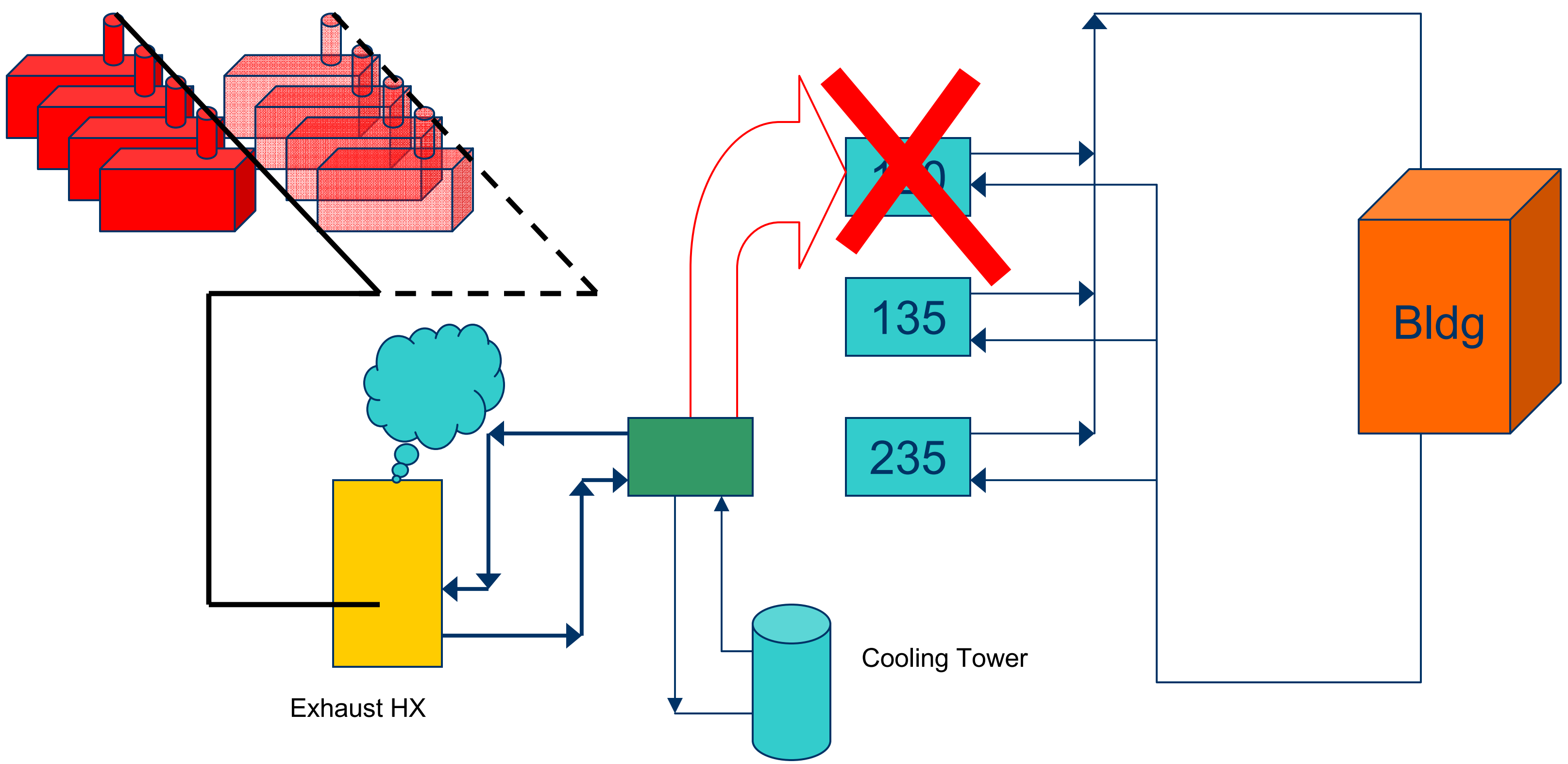
- Facility has three parallel electric chillers for a chilled water based HVAC cooling system loop.
- Desire to replace an aging, inefficient electric chiller with a microturbine exhaust driven absorption chiller
  - Increased overall system efficiency
  - Reduced electric power costs (energy and demand)
- Absorption Chiller to be sized to reduce occurrences of topping required by second chiller.
  - Size unit for approx 150 RT
- MINIMIZE FACILITY MODIFACTIONS!
  - Drop In Place

Facility Description

- 110,000 sq-ft structure; 450 personnel
- Offices and command center for Municipality
- Existing cooling equipment: three parallel chillers; one loop.
  - 120 RT electric chiller
    - Low efficiency, older unit. Candidate for replacement
  - 135 RT electric chiller
  - 245 RT electric chiller
- Average Temperatures: [deg-F/deg C]

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
66/19	68/20	70/21	77/25	83/28	92/33	98/37	98/37	93/34	84/29	74/23	68/20
36/ 2	38/ 3	41/ 5	44/ 7	50/10	54/12	59/15	60/15	57/14	49/ 9	40/ 4	34/ 1

Facility Description



Cooling Needs

- Limited specific, time resolved cooling demand data.
- Mostly anecdotal
  - Nominally 20 RT minimum cooling.
  - Existing 120 RT unit insufficient April through October

Electric Demand

- Based upon 12 month history; July 2002 – June 2003
- Chose typical/random day each month
- Compiled hourly electric demand as retrieved from SCE data.
- Considered that day as typical for entire month.
- SCE TOU-8 rate structure

Power Generation Limitations

- For SCE, definition of qualifying facility requires:
  - Meeting PURPA efficiency requirements
  - Facility must be less < 10 kW ***<u>or</u>*** > 1 MW
- Integration of absorption chiller would meet first requirement
- Size of facility would be less than 1MW
- Result:
  - Cannot export electricity to grid.
  - Must regulate microturbine power production.

System Limitations/Assumptions

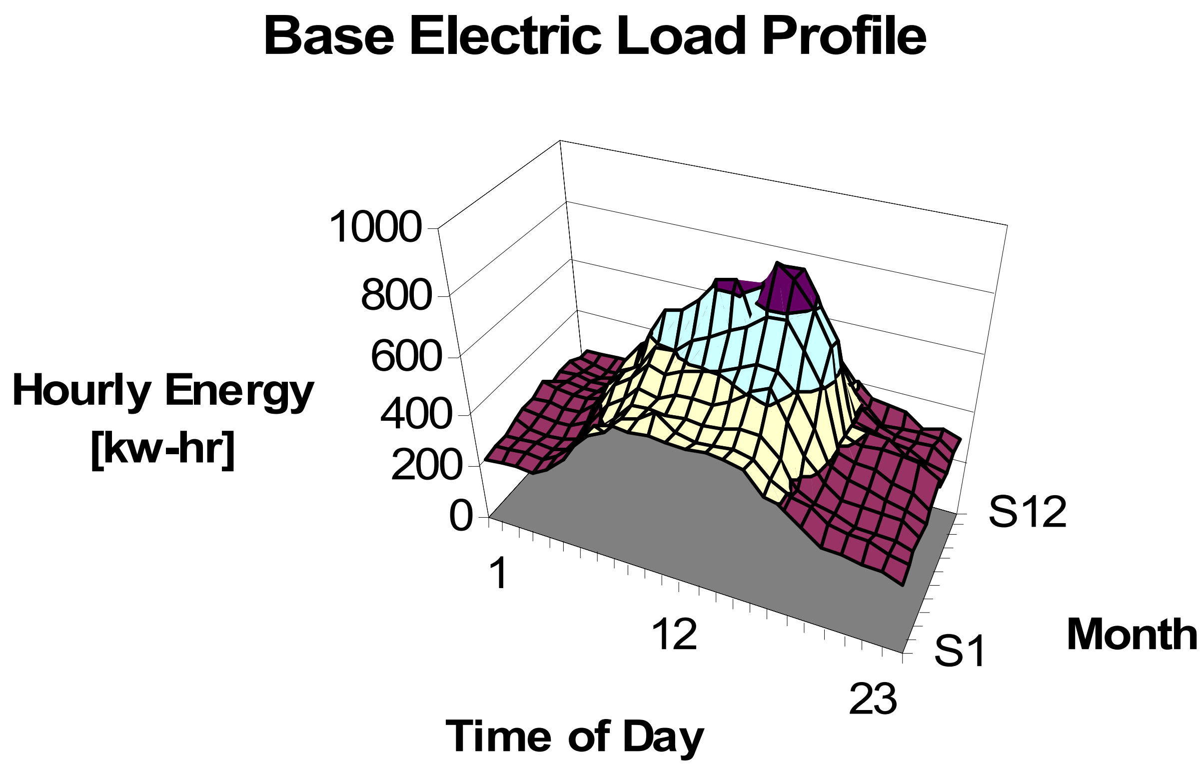
- Microturbine
  - 23% efficient (LHV) @ 60 F and lower
    - Approx 10 kW unrecoverable heat.
    - Balance of heat available in exhaust
  - Exhaust temp approx 550 deg F (288 C)
  - At full load, approx 400,000 btu/hr (117 kW) of useful exhaust heat per turbine

System Limitations/Assumptions (cont'd)

- Chiller – 150 RT (1.8 MMbtu/hr→527 kW)
  - Double Effect: Requires too high a temperature.
  - Single Effect Steam: Issues with handling steam.
  - Single Effect hot water: COP = 0.7
    - Simple reliable design
    - 200 – 205 F (93 – 95 C) working fluid temp
      - No issues with steam
    - 150 RT @ COP=0.7 → 2.57 MMBtu/hr (753 kW) heat input.
  - System Turndown to approx 30% of full load capacity.

Model of Cooling and Power Consumption

Historical consumption for 12 month period (immediately prior to study)

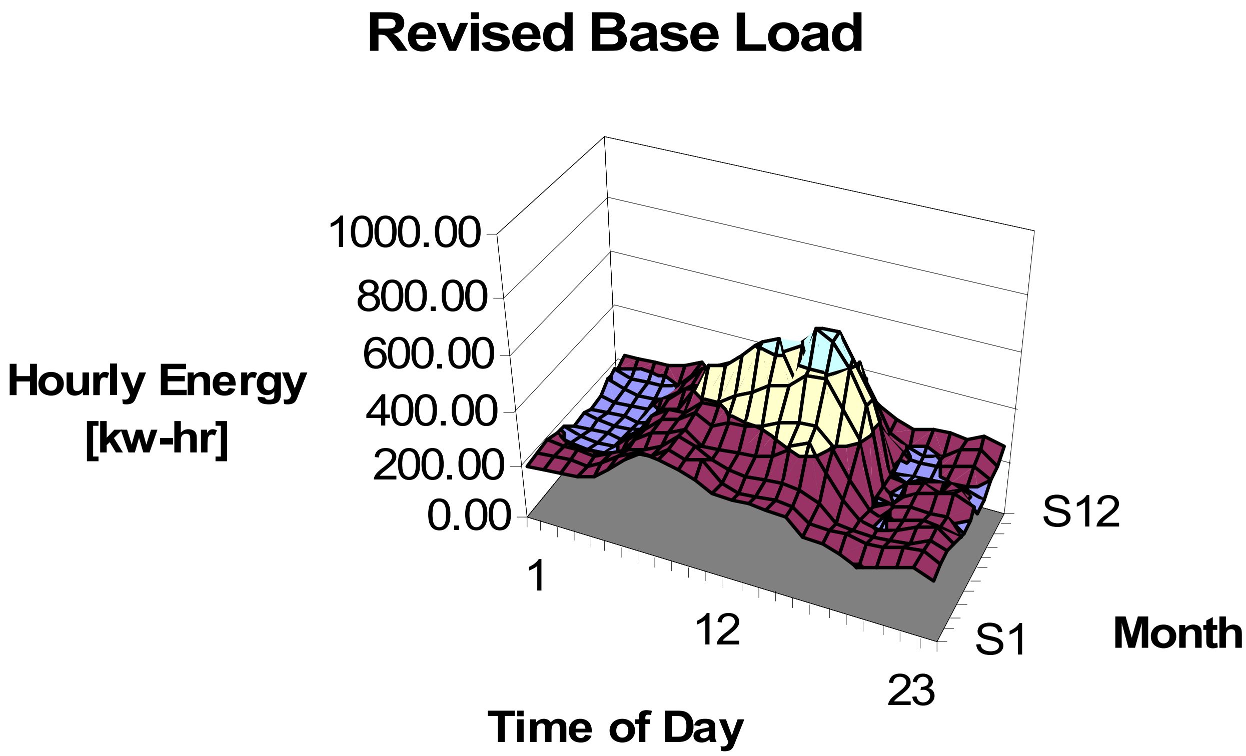


Model of Cooling and Power Consumption (cont'd)

- Impact of removal of 120 RT chiller
  - Reduction in demand proportional to refrigeration provided
  - 120 RT = 200 kW (COP approx 2.2)
  - Assumed 120 RT unit was primary unit.
    - Base unit for all but hottest days
  - Subtract electric demand contribution of 120 RT chiller

Model of Cooling and Power Consumption (cont'd)

Excluding 120 RT chiller power consumption

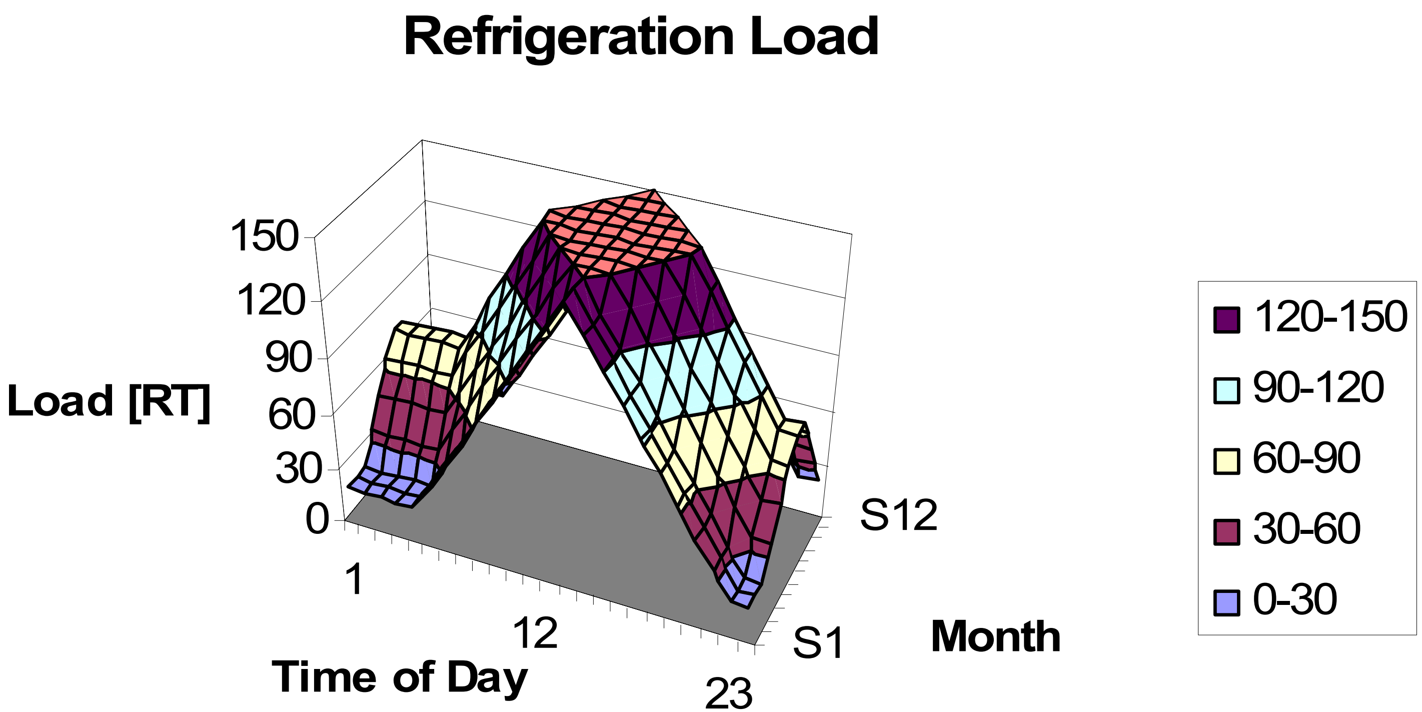


Model of Cooling and Power Consumption (cont'd)

- Modeling of refrigeration load
  - Minimum load of approx 20 RT (winter night).
  - Approx 120 RT required with ambient of 75 deg F Linear variation in refrigeration requirement with ambient
  - Extrapolate load to 150 RT based upon ambient
    - Goal output for absorption chiller
  - Additional electric load for other chiller operation already included in historical electric consumption data

Model of Cooling and Power Consumption (cont'd)

Desired Absorption Chiller Demand Profile



Model of Cooling and Power Consumption (cont'd)

- Chiller output is dependent upon heat input from turbine exhaust stream
- Turbine heat output dependent upon:
  - Ambient temp→ efficiency and power output
  - Electric power export limitations→ no back feed to the grid
  - Model assumed inefficiencies in heat exchanger transfer of exhaust heat to hot water.
    - 85% efficient
    - Approach temperature of 5 -10 F.

Model of Cooling and Power Consumption (cont'd)

- Chiller will not provide refrigerated output at turndown less than 30% (45 RT)
- Required refrigeration < 45 RT and any other shortfall in chiller output requires operation of other electric chiller and purchased power
  - Usually off peak
  - Other chiller more efficient w/ COP =3.4 at full load

Model of Cooling and Power Consumption (cont'd)

- Investigate two systems:
  - Existing 4 microturbines
    - Exhaust heat insufficient: 117 kW x 4 = 468 kW available vs. 753 kW needed
    - Co-fire an auxiliary burner (duct burner) to provide added heat.
    - Pro: Less chance of back feed and more flexibility
    - Con: Need to consume more fuel
  - Add 4 additional turbines (total of 480 kW):
    - Sufficient exhaust heat: 117 kW x 8 = 936 kW available vs. 753 kW needed.
    - Pro: Maximize opportunity for co-generation. One turbine redundancy
    - Con: More control to avoid back feed to grid

Viability/Economics

- Case 1: 4 MTGs + Aux Burner (TOU-8; $6.10 /MMbtu)

	Base		Scenario 1					
	MWh	$	Cap Factor	MWh (1)	$	NG [therms]	$	eff
Jan	277.3	$26,222.38	95.89%	36.50	$4,749.82	26,632	$16,425.96	40.05%
Feb	281.2	$26,339.15	98.72%	36.55	$4,385.12	27,153	$16,735.55	40.17%
Mar	278.6	$26,031.63	97.13%	37.53	$4,557.24	26,862	$16,561.98	40.11%
Apr	299.7	$28,642.39	94.46%	53.29	$6,439.42	27,597	$16,999.25	40.69%
May	323.8	$30,788.73	93.63%	62.73	$7,313.69	28,854	$17,746.43	48.25%
Jun (2)	356.4	$62,790.54	92.63%	91.76	$23,901.58	30,582	$18,774.25	45.02%
Jul (2)	396.3	$71,156.89	94.72%	134.40	$35,633.24	32,094	$19,673.53	43.05%
Aug (2)	378.9	$68,423.26	92.43%	116.00	$30,344.58	31,819	$19,509.46	42.22%
Sep(2)	333.9	$57,157.83	91.90%	74.85	$19,079.75	30,390	$18,660.16	44.77%
Oct	313.7	$29,856.19	92.89%	56.13	$6,670.20	27,830	$17,138.21	48.01%
Nov	285.8	$27,494.90	92.71%	41.71	$5,438.83	27,300	$16,822.52	40.41%
Dec	275.6	$25,374.78	96.33%	35.05	$3,994.28	26,812	$16,532.37	39.62%
Annual		**$480,278.65**	94.45%	776.50	**$152,507.75**	343,926	**$211,579.66**	42.70%
Savings			Approx $116,200 / year					
Install			Approx $650,000					
Payback			5.6 years simple payback					

(1) Electric energy to meet MTG generation short fall + power to meet refrigeration demand that is less than min. chiller operation
(2) Jun – Sept are SCE TOU-8 "summer peak" rate months

Viability/Economics (cont'd)

- Case 2: 8 MTGs (TOU-8; $6.10 /MMbtu)

	Base		Scenario 2					
	MWh	$	Cap. Factor	MWh (1)	$	NG [therms]	$	eff
Jan	277.3	$26,222.38	56.64%	6.35	$710.08	26,315	$16,237.21	46.95%
Feb	281.2	$26,339.15	58.14%	6.35	$710.08	27,026	$16,659.90	46.83%
Mar	278.6	$26,031.63	57.74%	6.35	$710.08	26,850	$16,555.58	47.04%
Apr	299.7	$28,642.39	61.18%	7.45	$803.68	28,477	$17,522.57	49.82%
May	323.8	$30,788.73	65.61%	0	$0	30,536	$18,747.12	60.17%
Jun*	356.4	$62,790.54	68.57%	14.69	$5,931.39	31,839	$19,522.03	61.55%
Jul*	396.3	$71,156.89	72.18%	44.60	$14,836.68	33,464	$20,487.84	60.80%
Aug*	378.9	$68,423.26	70.10%	35.89	$12,823.42	32,499	$19,914.40	61.11%
Sep*	333.9	$57,157.83	66.99%	5.64	$2,455.51	31,080	$19,070.52	61.45%
Oct	313.7	$29,856.19	64.07%	0	$0	29,778	$18,296.22	60.09%
Nov	285.8	$27,494.90	56.58%	7.45	$803.68	26,334	$16248.78	50.50%
Dec	275.6	$25,374.78	56.58%	6.35	$710.08	26,304	$16,231.03	47.68%
Annual		**$480,278.65**	62.86%	141.12	**$40,494.70**	350507	**$215,493.19**	54.50%
Savings			Approx $224,000 / year					
Install			Approx $850,000					
Payback			3.8 years simple payback					

(1) Electric energy to meet MTG generation short fall + power to meet refrigeration demand that is less than min. chiller operation
(2) Jun – Sept are SCE TOU-8 "summer peak" rate months

Viability/Economics (cont'd)

- Either incarnation of the microturbine/absorption chiller system appears economically viable:
  - 4 MTG + aux burner + 150 ton ab. chiller: < 6 years payback
  - 8 MTG + 150 ton ab. Chiller: < 4 years payback

- Even with limitations on power output to grid, the microturbine/absorption chiller could satisfactorily meet site electric and chilling demands for more than 50% of year.

Viability/Economics (cont'd)

- In summer peak periods, turbines could operate at full power, reducing energy and demand charges.

- Refrigeration demand was not met by absorption chiller alone. However, operation of a second chiller was reduced approx 50% over base case.

Economic Study Conclusion

- Engineering and Economic study suggests that it is possible to integrate a 150 RT chiller with microturbines.
- Despite added capital cost, EMWD chose the 8 microturbine + absorption chiller as most desirable.
- Decision to proceed with installation of system as proposed : June 2004

Installation

- Analysis formed basis for decision of EMWD to proceed with RFP
  - 8 microturbine system chosen for more advantageous payback and redundancy offered by "spare" MTG
- RFP "on the street" in Summer 2004.
- Order let to York on Sept 2004
  - Turn-key system from MTG exhaust on.
  - Approx $650,000 contract value.
- 4 additional turbines provided by SCAQMD
  - Unsolicited proposal for co-generation application with absorption chiller

Installation (cont'd)

- Project Manager: Toussaint Williamson – EMWD
- Funding Partner: Self Funded
  - Partial funding from SGIP: approx $200K
- Engineer-PEETech Systems
- Design/Build: York

Installation (cont'd)

- Work initiated in January 2005
  - Second wettest winter in Calif. history slowed progress
- SCE Interconnect Agreement
  - Expansion of existing installation (initial four turbines)
  - Concern about back-feeding to the grid
    - Facility does not meet SCE criteria for QF
- Gas.
  - Shift from utility supplied to market and future contracts.
- Initial system operation in early May 2005
  - Eight 60 kW Capstone microturbines
  - Cain Heat Exchanger
  - Evapco Cooling Tower
  - York single effect hot water Li-Br chiller, 150 ton

Installation (cont'd)

- Utilization of reclaimed water for cooling tower;
  - Municipal water district
  - Sensitive to water use/reuse.
  - Reclaimed water inexpensive
  - Partial Treatment of water required
    - 2-stage 10 micron filter
    - 2-stage activated charcoal filter for chlorine
    - Bio-cide, bromide, sulfuric acid treatment for stability
- Facility turbine output controlled with feedback from watt-hour meter
  - No net export to the grid.
  - Capstone Power Server to Control with meter feedback

Installation (cont'd)

- System installation prompted significant upgrade of building electrical switch gear to accommodate additional power.
  - Approx $500,000 electrical system effort
  - Not exclusive to support MTGs
- Total system expenses: approx $1.2 M
  - Includes $500,000 electric upgrade
  - Recycled water treatment system
  - Recall all turbines were obtained through AQMD distributions.
- On going commissioning and tuning occurring through May 2005.
  - Initial performance somewhat short of design expectations


cain
4
3
2
1
26 7:15 AM


26 7:20 AM


YORK
YORK
Vacuum Pumps

Operational Experience

- Operational Reliability;
  - >90% availability for first 6 months after installation
    - Downtimes for system commissioning and tuning.
    - Balance of plant very reliable
      - Old and new turbines have not had any mechanical failures
      - Copeland compressors (2 old, 2 new) 100% reliable
  - Operation Less Reliable through 2006
    - Compressor Failures
    - Degraded/Marginal operation on two older turbines

Operational Experience (cont'd)

- Cooling Output is not to spec: 150 RT
  - HX:
    - Design: 205 F out, del-T = 15 F @ 300 gpm
    - Actual: 192 F out, del- T = 10 F @ "300" gpm (???)
  - Initially, 120 RT with turbines at 8 x 55 kW avg output.
  - Tuning (Oct) improved output: approx 135 RT
  - COP based upon turbine exhaust heat loss = 0.58
  - Apparent issue with excessive water flow.
    - Temp. of hot water entering chiller too low for proper operation

Operational Experience (cont'd)

- Cooling Output is not to spec: 150 RT
  - Shortfall in absorption chiller output required the part load operation of electric chiller more than expected
    - Energy and Peak Demand Charge penalty
  - Absorption chiller output reduced due to non-zero minimum of electric chiller.
    - Ideally want absorption chiller to work at full load for maximum economic advantages

Operational Experience (cont'd)

- Turbine Performance is degrading
  - Older turbines from initial deployment have 19,500 hours (avg), approx. 350 starts
    - Two are producing approx. <25 kW maximum
    - Other two produce approx. 40 kW maximum
  - Newer turbines (approx 10,000 hrs, 100 starts) are producing at good levels, > 53 kw gross on cool days.

Operational Experience (cont'd)

- Efficiencies
  - Overall System gas to electricity: 22 % LHV,
    - Very warm summer in 2005 & 2006 → reduction in efficiency
    - Degraded performance of older turbines hurts
    - Hard to separate: one gas meter, net electric meter
    - 45 kW Parasitic losses include
      - Gas compressors: 4 Copeland: 20 kW
      - Water circulating pumps for absorption chiller 15 hp
      - Cooling tower and pump: 20 hp

Operational Experience (cont'd)

- Efficiencies
  - Overall System "co-gen" efficiency:
    - How to define??
    - Electric power out + chilling.
      - (kW + btu/hr) / energy input
      - (420 kW +121 RT)/ 5.92 MMbtu/hr (LHV)
      - **48.7% LHV**
      - Anticipated design efficiency approx 59%
    - No continuous monitoring implemented at this time. Average values based upon spot recording of data, cumulative kW-hr generated, cumulative gas meter, and logs of chiller output

Operational Experience (cont'd)

- Economics
  - Natural Gas prices surge: Despite long term contracts
    - $6.10 MMbtu during study
    - $7.50 MMbtu at start of commissioning
    - $11.40 MMbtu in Oct 2005;
      - Units shut down in late Oct.
      - Cheaper to buy off grid both the electric power gen even with the co-gen consideration.
      - Limited use while prices fluctuated
      - More consistent operation since May/June

Operational Experience (cont'd)

			April	May	June	July	Aug	Sept	Oct	Nov	Dec
Gas											
	Cost	2004		$9,873.36	$18,500.71	$13,919.40	$15,584.20	$13,396.80	$12,564.64		
		2005		$4,069.84	$17,779.06	$24,558.14	$21,818.51	$28,502.26	$36,348.89		
Electric											
	Cost	2004		$15,880.26	$51,636.90	$66,871.47	$69,365.78	$89,625.19	$30,673.82		
		2005		$31,585.77	$48,903.70	$49,041.67	$57,198.16	$51,825.74	$18,779.91		
Savings				$9,902.00	($3,454.85)	($7,191.06)	($5,933.31)	($22,693.99)	$11,890.34		($17,480.88)

Red = Savings

- Savings May – Oct: approx $17,500
- May: Turbines off for construction compared to 2004
- Sept Gas: $8.90 / MMbtu
- Oct Gas: $11.40 / MMbtu
- Penalty for system down: approx **$20,000** peak demand charge to monthly bill for 15 min window.

Future Efforts

- Address shortfall in chiller performance
  - Suspect heat exchanger; hot fluid temps drop under high chiller loads
- Address performance degradation of older turbines.
- Install data acquisition system or integrate with facility’s EMS system
  - Currently, manual start and stop

Future Efforts (cont’d)

- Address transition load changeover/hand-off
  - Start of electric chillers is abrupt and artificially places absorption chiller in non-base load condition, wasting energy. Need to be either predictive, “softer start” or store chilled water for transition period to keep absorption chiller base loaded as much as possible.
- Better scheduling of MTG / chiller operation to meet economics of gas vs. electric tariffs.

Thank You

Contact Info:
Richard L. Hack – PE, CEM
PEETech Systems
(951) 371-4310
rhack1@comcast.net