MEASUREMENT AND VERIFICATION PLAN

FOR

ONE PENN PLAZA

Revised

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Submitted to:

New York State Energy Research and Development Authority
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1. Introduction

A Peak Coincident Distributed Generation (PCDG) system is being installed at One Penn Plaza in New York. The system is being installed by Endurant Energy, LLC on behalf of the building owner, Vornado Realty Trust. Both entities will own the power plant.

The system includes three Caterpillar engine-driven generators that are being installed on the 12th floor setback. The engines will each provide 2055 kW into power bus that feeds a bank of five power converters (AC-DC-AC inverters). The power converters feed the 5 separate 480 VAC electrical services within the building (Switchboards B to F).

Each engine has a Cain heat recovery steam generator (HRSG) with a rated output of 4000 lb/h at120 psig. Hot water from the engine jacket is used to provide thermal input (HX-04) into the return side of the perimeter heating loop(s). Jacket water also is used to heat condensate entering the deaerator (HX-01) before it is sent to the three HRSGs.

Measured data are being collected at 15-minute intervals on this system so that NYSERDA can confirm the requirements for the performance-based portion of the incentive for the Aggregated Peak Load Reduction Program (APLRP). The collected data will loaded into the NYSERDA CHP database (chp.nyserda.org) over the two year performance period. The data will be analyzed to confirm:

- Power output during the summer peak demand period meets the program requirements,
- The thermal and power output meet the requirements of 60% fuel conversion efficiency (FCE) as defined in the NYSERDA CHP Manual.

2. Instrumentation

The Distributed Control System (DCS) at the site has more than 1200 points. The schematics given in Figure 1 through Figure 4 indicate the locations of the data points necessary to quantify system performance. Table 1 lists this points and provides the associated DCS “tag” associated with each point. The annotated photographs and DSC screenshots in Appendix A also show the locations of these points.

Figure 1 shows how the jacket water loop system interfaces with the hot water heating system and cooling tower. The heat added to the perimeter heating loop through HX-04 is determined by (**FHW, THWS, THWR**). Temperature **TJWS** provides an indication of the effectiveness of HX-04. The heat rejected to the cooling tower through HX-02 and HX-03 will be determined by (**FCW, TCWS, TCWR**).

Figure 2 shows the steam side of the system. **FS** measures the mass flow of steam from the three HRSGs. The pressure **PSH2** and the condensate temperature **TCO** be used to determine the enthalpy (or energy content) of the steam (the calculations are given in Appendix B). Steam from the low pressure side of the system (**FSL**) was originally intended to feed the deaerator, but it actually only serves the AHUs that heat the engine enclosure[1] – therefore this thermal use is no longer considered a parasitic load.

Figure 3 shows the condensate return and deaerator system. The temperature of the condensate in the receiver tank (**TCI**) and the temperature leaving HX-01 (**TCO**) can be used with the condensate flow (**FC**) to determine the useful thermal input provided by jacket water.

Figure 4 shows the electrical one line schematic of the system. The power output from each engine (**WG1, WG2, WG3**) is fed into the 4160 Volt bus. This power provides for parasitic electrical loads in the cogen enclosure (**WP**) and also feeds the transformers that feed the power converters. The parasitic load power were not directly measured since it can be determined by the difference between converter and generator output. Power Converters 1 to 5 feed power (**WC1_kW, WC2_kW, WC3_kW, WC4_kW, WC5_kW**) into the five electrical services (Switchboards B, C, D, E, F).

The utility consumption on each Switchboard is measured by the import power transducer on each power converter (**WC1_kWi, WC2_kWi, WC3_kWi, WC4_kWi, WC5_kWi**).

[1] The steam piping layout was confirmed during the December 2010 site visit.

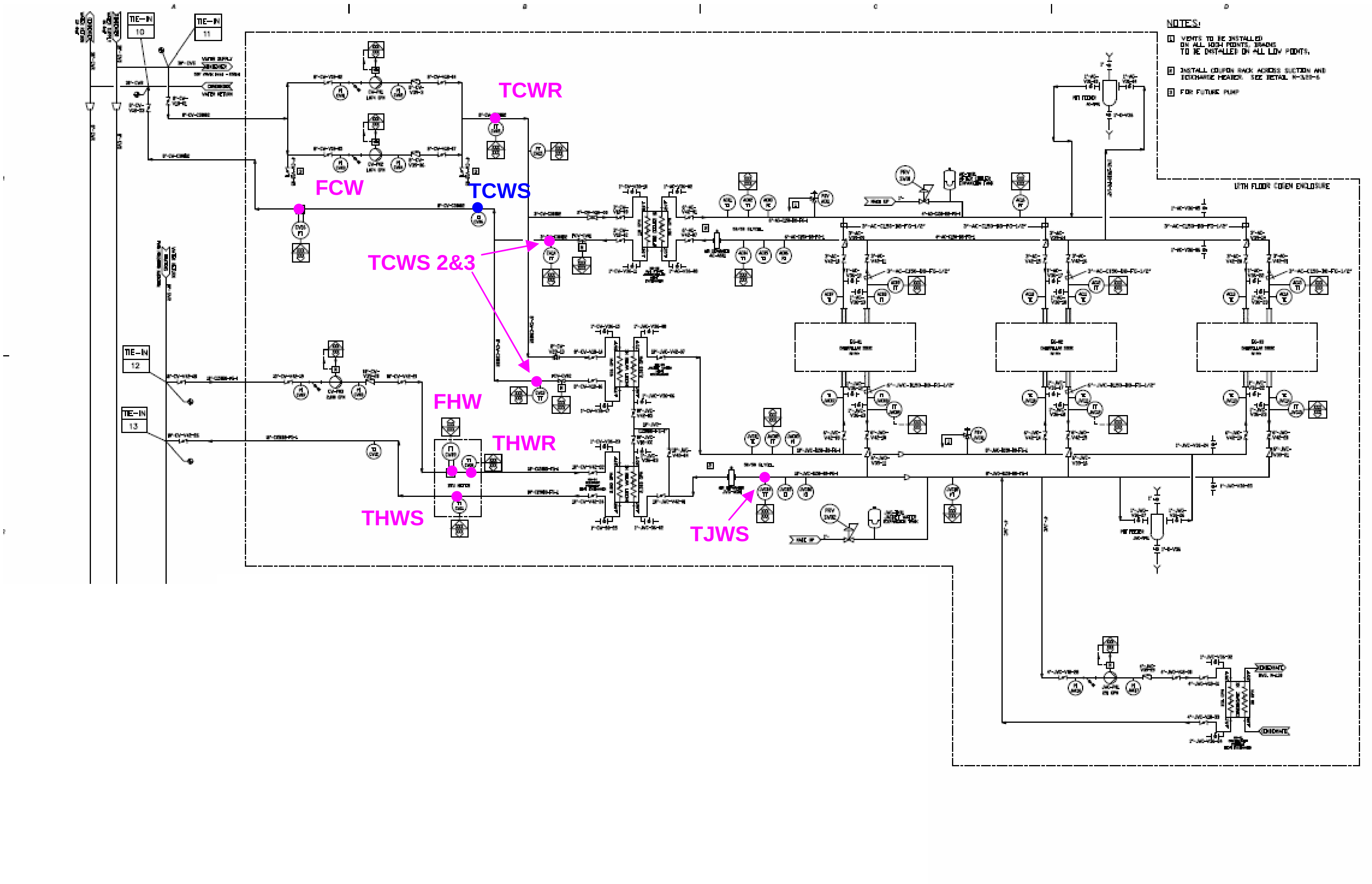


Figure 1. Schematic of HOT WATER Side of CHP System with Monitored Data Points Shown (blue points may be added in the future)

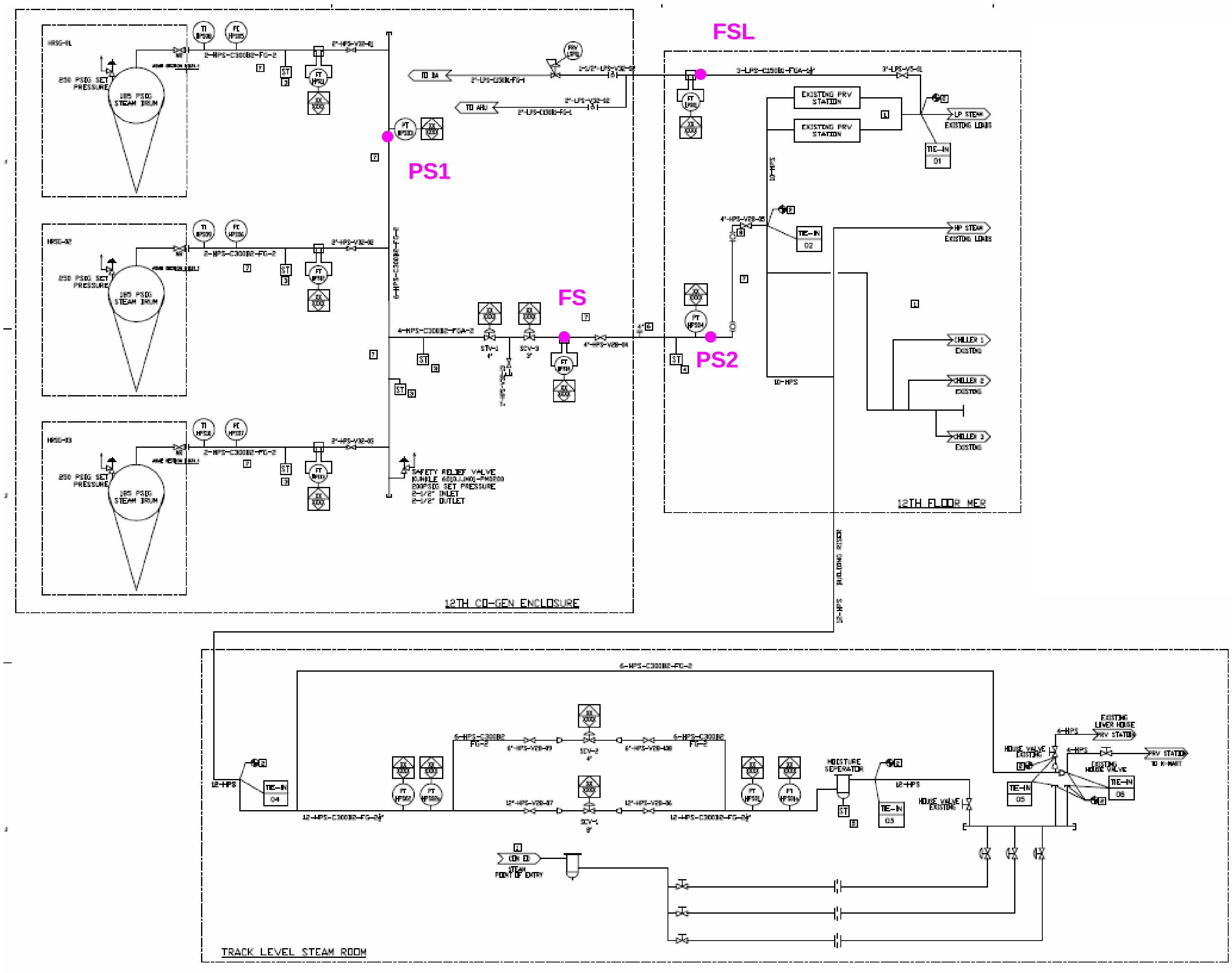


Figure 2. Schematic of STEAM Side of CHP System with Monitored Data Points Shown

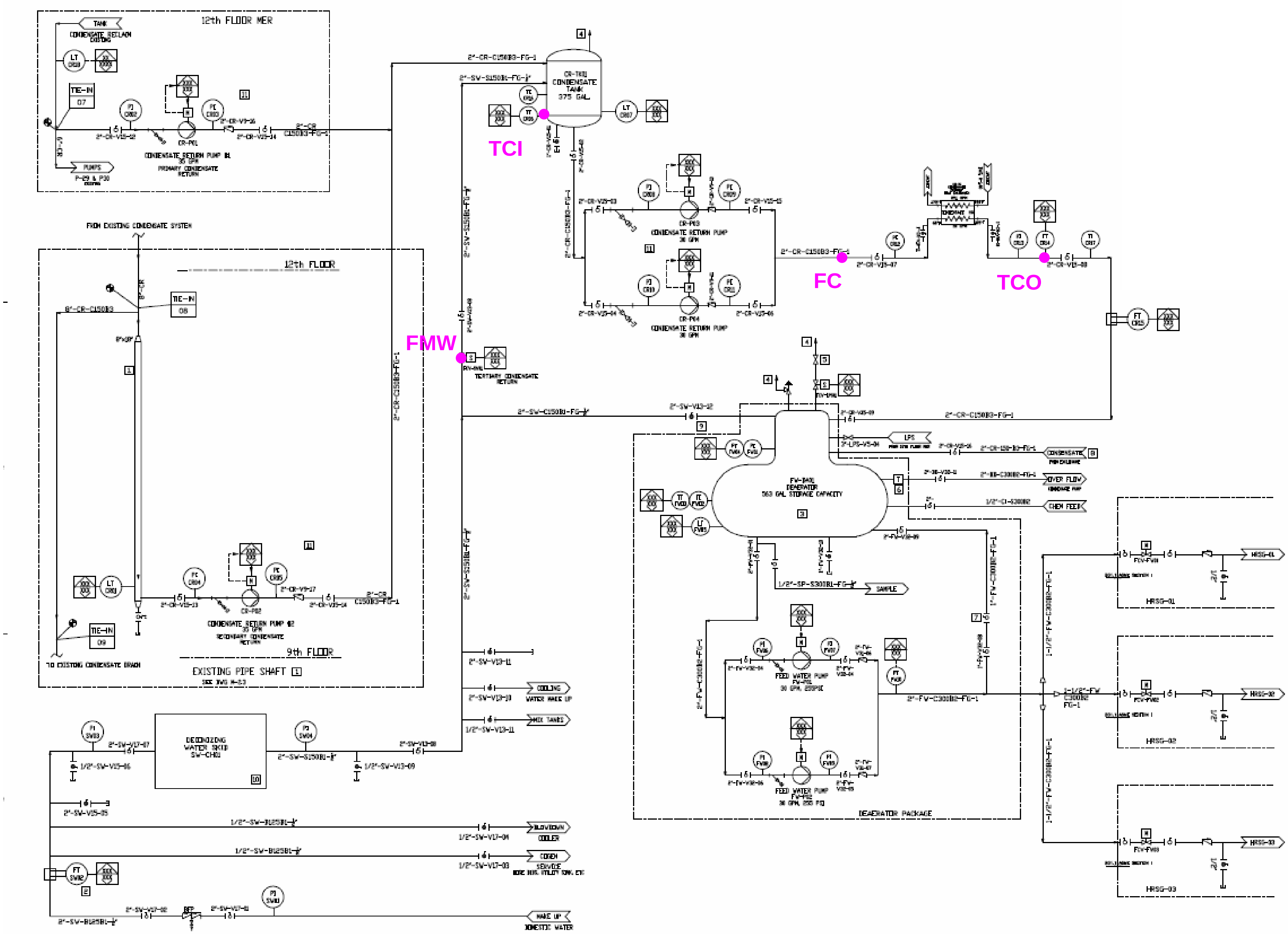


Figure 3. Schematic of CONDENSATE System with Monitored Data Points Shown

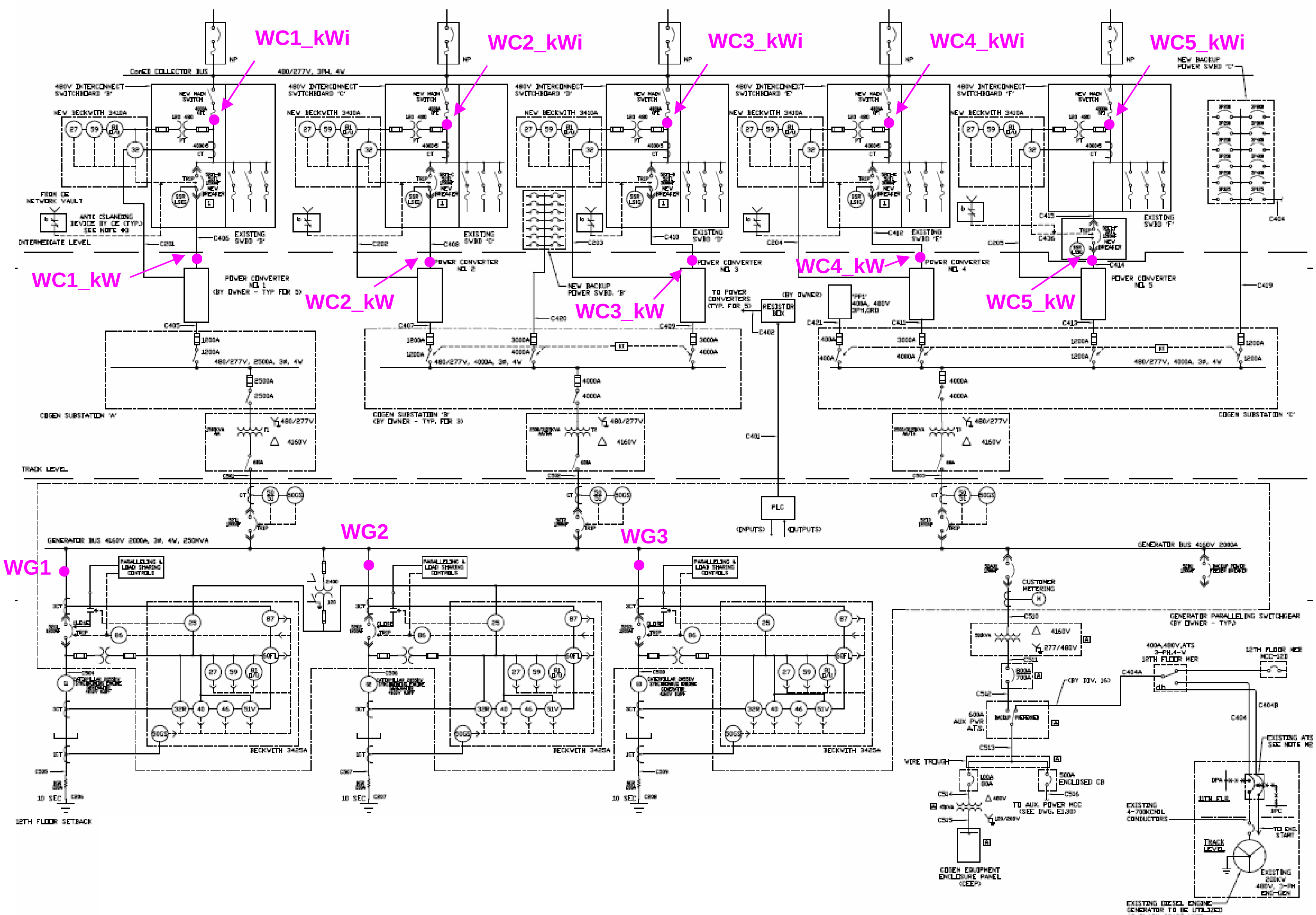


Figure 4. Schematic of ELECTRICAL Side of CHP System with Monitored Data Points Shown

Table 1. Monitored Data Points Required to Quantify Performance

Data Label	DCS Tag	DCS Point Description	DCS Subsystem	Eng Units
PSH2	PIC-HPS-04	HPS TO REDUCING STATIONS	STEAM	psig
PSH1	PI-HPS-03	HRSG STEAM HEADER	STEAM	psig
FSL	FI-LPS-01	LP STEAM TO AHUs	STEAM	lb/h
FS	FI-HPS-14	STEAM FROM HRSG'S	STEAM	lb/h
WC5_KWi	JI-PC-5-GRID-KW	PWR CNVTR 5 GRID PWR IMPORT	PWR_CNV_5/PCNV-5-SCDA-IN	kW
WC5_KW	JI-PC-5-KW	PWR CNVTR 5 ACTIVE PWR OUT	PWR_CNV_5/PCNV-5-SCDA-IN	kW
WC5	JQI-PC-5-KWH	PWR CVTR 5 KWH INJECTED AT OUTPUT	PWR_CNV_5/PCNV-5-SCDA-IN	kWh/int
WC4	JQI-PC-4-KWH	PWR CVTR 4 KWH INJECTED AT OUTPUT	PWR_CNV_4/PCNV-4-SCDA-IN	kWh/int
WC4_KW	JI-PC-4-KW	PWR CNVTR 4 ACTIVE PWR OUT	PWR_CNV_4/PCNV-4-SCDA-IN	kW
WC4_KWi	JI-PC-4-GRID-KW	PWR CNVTR 4 GRID PWR IMPORT	PWR_CNV_4/PCNV-4-SCDA-IN	kW
WC3	JQI-PC-3-KWH	PWR CVTR 3 KWH INJECTED AT OUTPUT	PWR_CNV_3/PCNV-3-SCDA-IN	kWh/int
WC3_KW	JI-PC-3-KW	PWR CNVTR 3 ACTIVE PWR OUT	PWR_CNV_3/PCNV-3-SCDA-IN	kW
WC3_KWi	JI-PC-3-GRID-KW	PWR CNVTR 3 GRID PWR IMPORT	PWR_CNV_3/PCNV-3-SCDA-IN	kW
WC2	JQI-PC-2-KWH	PWR CVTR 2 KWH INJECTED AT OUTPUT	PWR_CNV_2/PCNV-2-SCDA-IN	kWh/int
WC2_KW	JI-PC-2-KW	PWR CNVTR 2 ACTIVE PWR OUT	PWR_CNV_2/PCNV-2-SCDA-IN	kW
WC2_KWi	JI-PC-2-GRID-KW	PWR CNVTR 2 GRID PWR IMPORT	PWR_CNV_2/PCNV-2-SCDA-IN	kW
WC1	JQI-PC-1-KWH	PWR CVTR 1 KWH INJECTED AT OUTPUT	PWR_CNV_1/PCNV-1-SCDA-IN	kWh/int
WC1_KW	JI-PC-1-KW	PWR CNVTR 1 ACTIVE PWR OUT	PWR_CNV_1/PCNV-1-SCDA-IN	kW
WC1_KWi	JI-PC-1-GRID-KW	PWR CNVTR 1 GRID PWR IMPORT	PWR_CNV_1/PCNV-1-SCDA-IN	kW
WCTOT	JQI-PC-TOT-KWH	Sum of WC1…WC5	PWR_CNV_1/PCNV-1-SCDA-IN	kWh/int
WCTOT_KW	Sum	Sum of WC1_KW…WC5_KW		kW
WCTOT_KWi	Sum	Sum of WC1_KWi…WC5_KWi		kW
FG	Sum	GAS TO ENGINES	NG_FUEL	CF/h
WGTOT	JI-GEN-TOT-PWR	Total Power from Engines		kW
WG3	JI-GEN-3-PWR	GENERATOR 3 POWER	ENGINE_3/ENG3_SCADA	kW
FG3	FI-E3-156	ENG 1 Gas Fuel Flow	ENGINE_3/ENG3_SCADA	CF/h
WG2	JI-GEN-2-PWR	GENERATOR 2 POWER	ENGINE_2/ENG2_SCADA	kW
FG2	FI-E2-156	ENG 1 Gas Fuel Flow	ENGINE_2/ENG2_SCADA	CF/h
WG1	JI-GEN-1-PWR	GENERATOR 1 POWER	ENGINE_1/ENG1_SCADA	kW
FG1	FI-E1-156	ENG 1 Gas Fuel Flow	ENGINE_1/ENG1_SCADA	CF/h
TJWS	TIC-JWC-04	ENGINE JACKET COOLER OUT HDR TO HX-03_4	ENG_COLLECTIVE	ºF
TCWR	TI-CW06	Common Return Back to HX-02 & HX-03	Needs to be Added	ºF
TCWR3	TIC-CW-14	HX-02 COND WTR RETURN	ENG_COLLECTIVE	ºF
TCWR2	TIC-CW-13	HX-03 COND WTR RETURN	ENG_COLLECTIVE	ºF
THWS	TIC-CW-11	HEATING WTR FROM HX-04	ENG_COLLECTIVE	ºF
THWR	TI-CW-10	HEATING WTR TO HX-04	ENG_COLLECTIVE	ºF
TCWS	TI-CW-05	HX-02 COND WTR SUPLY	ENG_COLLECTIVE	ºF
FCW	FI-CW-16	COND WTR FROM HX-02 & HX-03	ENG_COLLECTIVE	gpm
FHW	FI-CW-09	HEATING WTR TO HX-04	ENG_COLLECTIVE	gpm
FMW	FI-SW-02	MAKE-UP WATER	DA	gpm
TCO	TI-CR-14	HX-01 OUTLET	CONDENSATE	ºF
TCI	TI-CR-06	COND RTN TK CR-01	CONDENSATE	ºF
TCS	TI-FW-03	Condensate Temperature out of DA	CONDENSATE	ºF
FC	FT-CR15	Condensate Flow Through HX-01	CONDENSATE	gpm
D_HRSG1	HRSG-1-DMPR-BYP	HRSG1 Bypass Damper Position	CAIN	%
D_HRSG2	HRSG-2-DMPR-BYP	HRSG2 Bypass Damper Position	CAIN	%
D_HRSG3	HRSG-3-DMPR-BYP	HRSG3 Bypass Damper Position	CAIN	%

Note: kWh/int = kWh per 15-minute interval
blue data points are not installed as of December 2010
The 2nd letter in the DCS Tag can be either "T" for transmitter or "I" for visual indicator. These codes are often interchanged

Data Collection Process

The Emerson DeltaV DCS has been installed by Control Associates. The DeltaV system has been programmed to record the data values listed in Table 1. These data points are automatically averaged and logged to a file at 15-minute intervals. Each 15-minute record is time and date stamped. The file is row-oriented ASCII, text, or comma separated values (CSV) file with sufficient resolution to accurately represent each reading. Once per day the file is automatically transferred to CDH Energy (the NYSERDA web site contractor) via Secure FTP to the CDH data server.

The DeltaV system has provisions to save the daily data files locally for up to several hundred days.

3. Data Analysis Procedures

The collected data will be used to determine quantities required for the NYSERDA CHP website and for the incentive calculations. The calculation procedures are listed in Table 2.

Table 2. Calculations to Determine the Quantities of Interest to NYSERDA

Parameter	**Required Calculations**
WNet: Net Power Output (kW & kWh/h) The smaller of the converter output OR 95% of the generator output	= **WC1_kW + WC2_kW + WC3_kW + WC4_kW + WC5_kW** OR = (**WG1 + WG2 + WG3) x 0.95**
FG: Engine Gas Consumption (CF/h)	**= (FG1 + FG2 + FG3) x 60**
QU: Useful Heat Recovery (Btu/h)	**= FS x Δh(PSH2, TCO)** **+ k_{hw} x FHW x (THWS-THWR)** **+ k_c x FC x (TCO – TCI)**
QR: Unused Heat Recovery (Btu/h)	**= k_{cw} x FCW x (TCWS-TCWR)**
Utility Power Consumption (kWh/h)	= **WC1_kWi + WC2_kWi + WC3_kWi + WC4_kWi + WC5_kWi**

Where the calculation parameters are defined as:

Δ**h** - energy content of steam (Btu/lb) at the operating pressure (e.g., **PSH2** for high pressure and **TCO** for entering condensate temperature; considers phase change and sensible heating)

k_{hw} - product of specific heat and density for hot water loop fluid at its operating temperature (typical average of **THWS** and **THWR**)

k_c - product of specific heat and density for condensate at its operating temperature (typical average of **TCO** and **TCI**)

k_{cw} - product of specific heat and density for cooling water loop at its operating temperature (typical average of **TCWS** and **TCWR**)

More detailed definitions of these terms are given in Appendix B. The other collected data from Table 1 will be used to independently confirm and check the calculations.

The net power output from the CHP system (**WNet**) is directly measured in this case by measuring the output from the five power converters. However, the power transducers in the power converters are not as accurate as the power transducers on the generators. Therefore we will use the smaller of the converter output or 95% of the generator output (this assumes 5% parasitic losses).

The fuel conversion efficiency of the CHP system, based on the lower heating value of the fuel, will be defined as:

$$FCE = \frac{QU + 3.412 \cdot (WNet)}{0.9 \cdot HHV_{gas} \cdot FG}$$

where:	**QU**	-	Useful heat recovery (Btu/h)
	WNet	-	Net generator output (kW)
	FG	-	Generator gas consumption (Std CF/h)
	HHV_{gas}	-	Higher heating value for natural gas (~1021 Btu per CF in NY for 2008). Where 0.9 is the conversion factor between HHV and LHV

The FCE can be calculated for any time interval. When converting to daily, monthly, or annual values, the each value is summed and then the formula is applied:

$$FCE = \frac{\sum^{N} QU + 3.412 \cdot \sum^{N} (WNet)}{0.9 \cdot HHV_{gas} \cdot \sum^{N} FG}$$

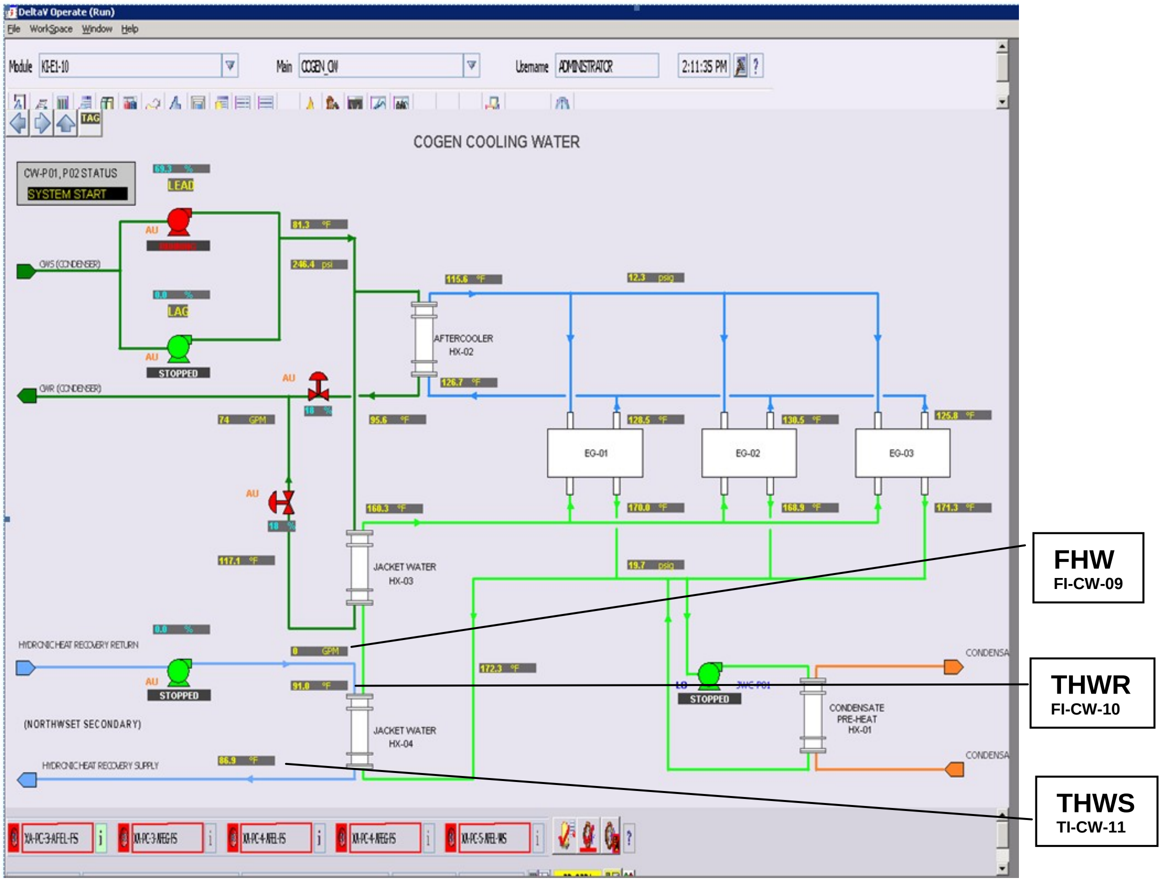
Where N is equal to the number of intervals in the period of interest.

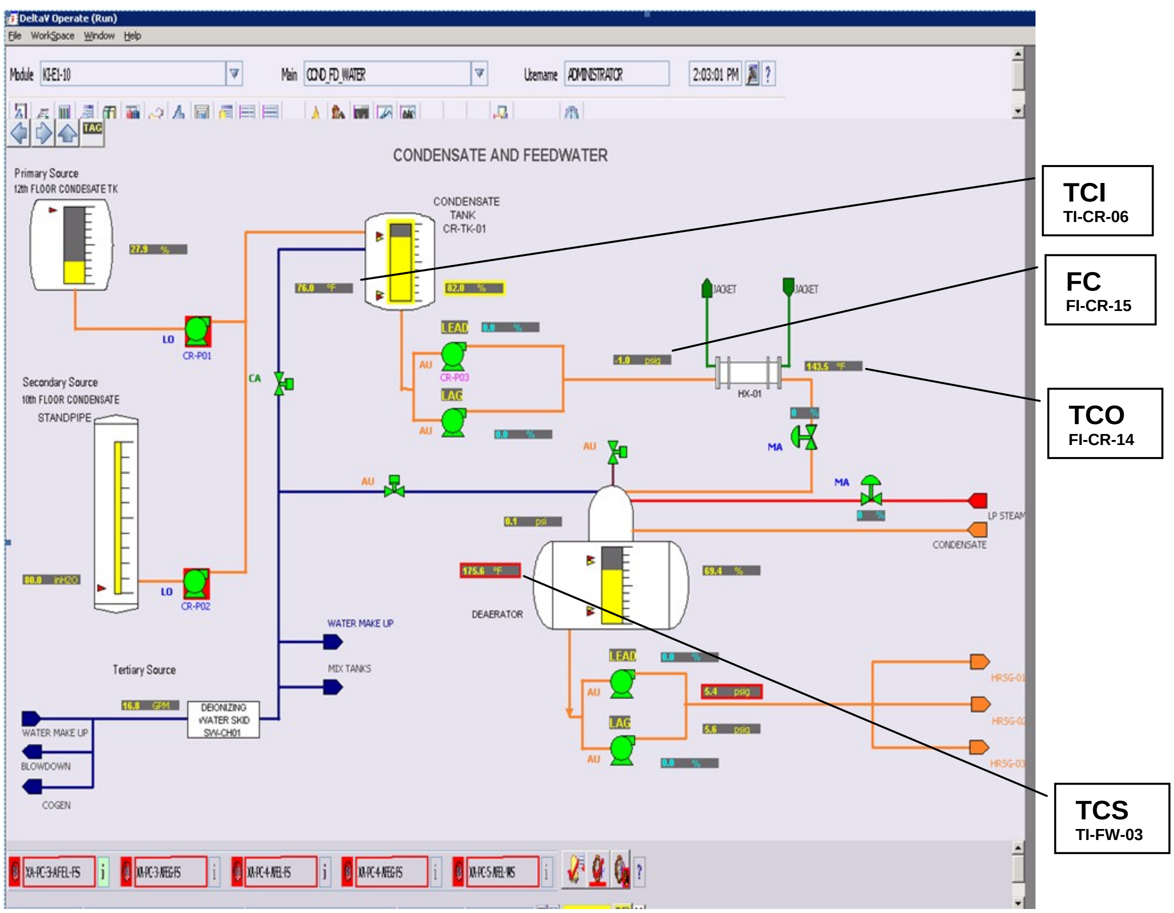
APPENDIX A

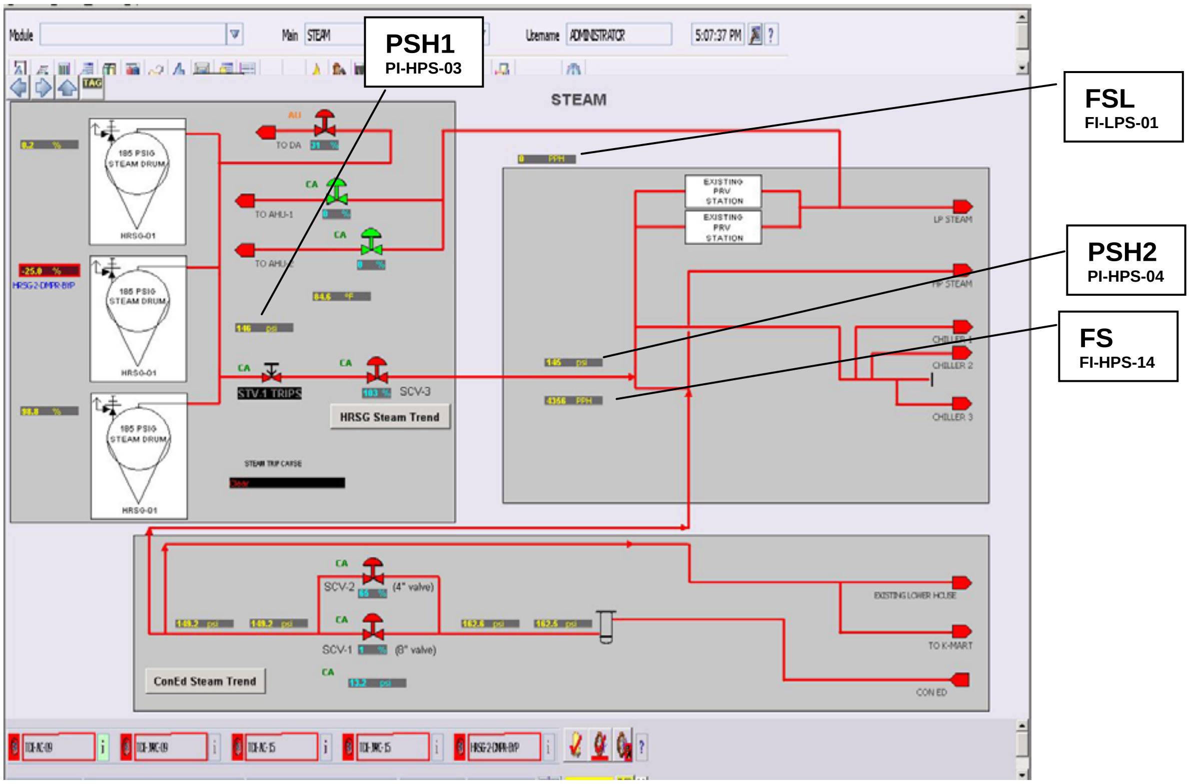
Annotated Photographs and Delta V (DCS) Screen Shots
One Penn Plaza

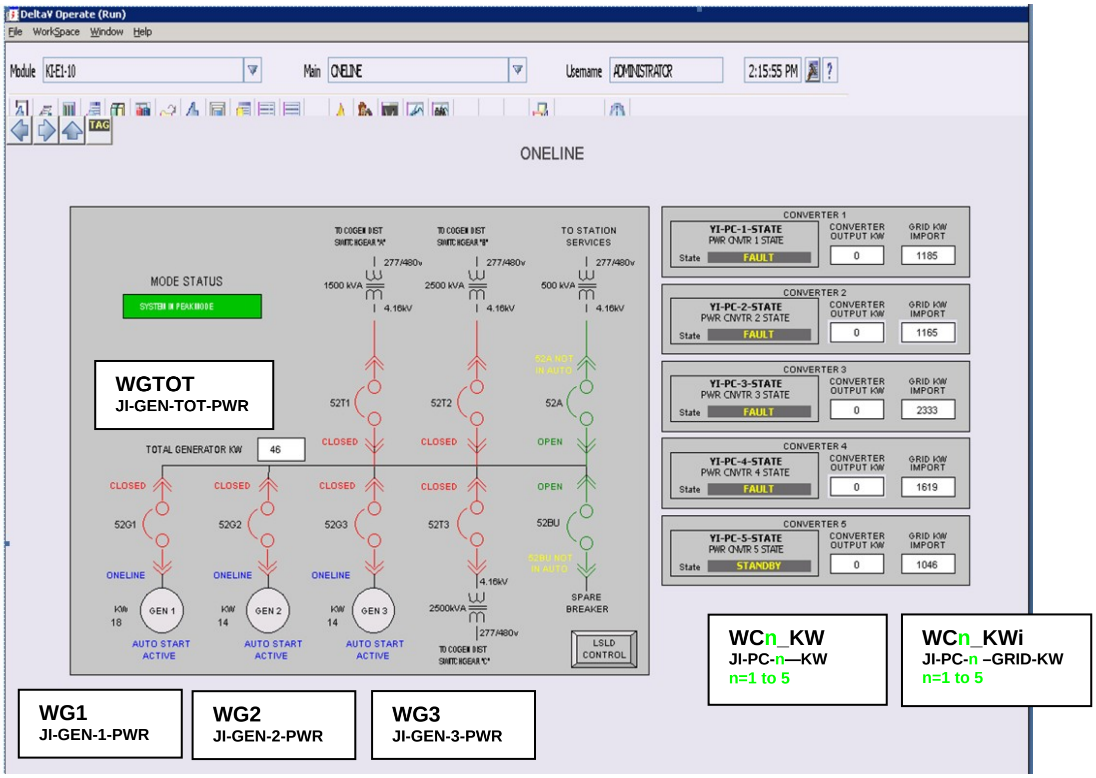
Engine Locations and Serial Numbers

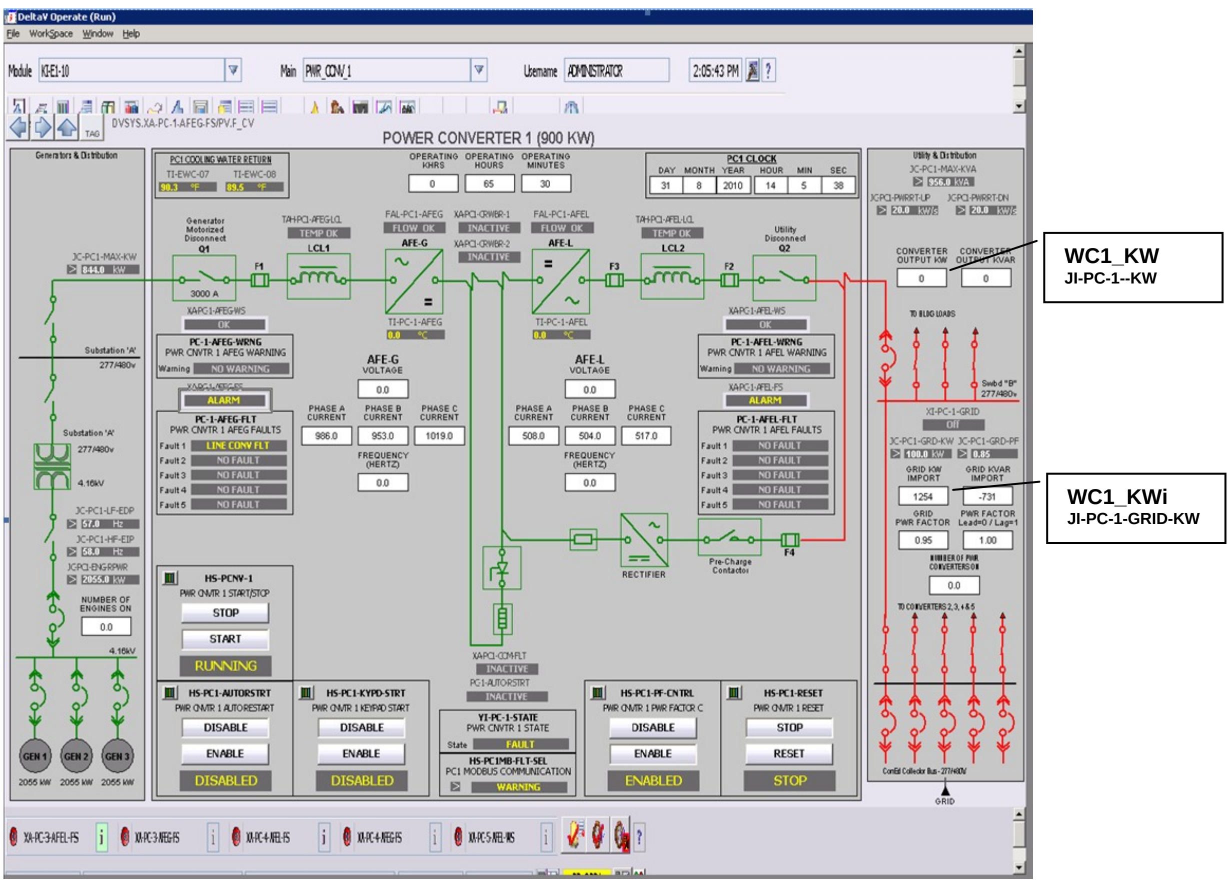
Engine Number	Location	Serial Number
1	Farthest from Tower	----207
2	Middle	----205
3	Closest to Tower	----206


DeltaV Operate (Run)
COGEN COOLING WATER
CW-P01, P02 STATUS
SYSTEM START
LEAD
LAG
STOPPED
AFTERCOOLER
HX-02
JACKET WATER
HX-03
JACKET WATER
HX-04
EG-01
EG-02
EG-03
HYDRONIC HEAT RECOVERY RETURN
HYDRONIC HEAT RECOVERY SUPPLY
(NORTHWSET SECONDARY)
CONDENSATE
PRE-HEAT
HX-01
FHW
FI-CW-09
THWR
FI-CW-10
THWS
TI-CW-11


DeltaV Operate (Run)
CONDENSATE AND FEEDWATER
Primary Source
12th FLOOR CONDESATE TK
CONDENSATE
TANK
CR-TK-01
CR-P01
Secondary Source
10th FLOOR CONDENSATE
STANDPIPE
CR-P02
CR-P03
LEAD
LAG
HX-01
JACKET
LP STEAM
CONDENSATE
DEAERATOR
WATER MAKE UP
MIX TANKS
Tertiary Source
DEIONIZING
WATER SKID
SW-CH01
BLOWDOWN
COGEN
TCI
TI-CR-06
FC
FI-CR-15
TCO
FI-CR-14
TCS
TI-FW-03

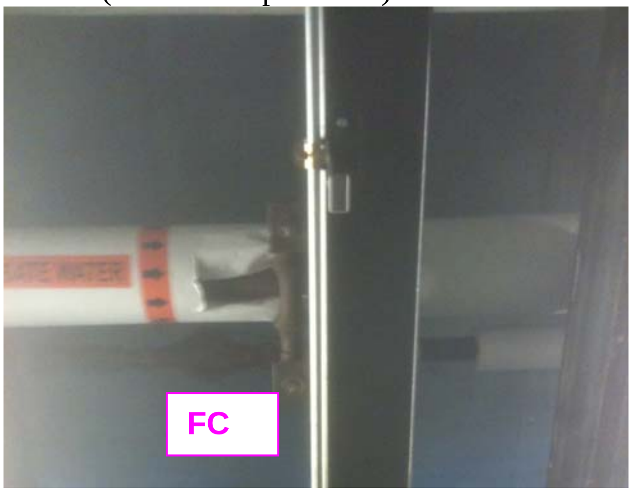

PSH1
PI-HPS-03
FSL
FI-LPS-01
PSH2
PI-HPS-04
FS
FI-HPS-14
STEAM
TO DA
TO AHU-1
SCV-3
HRSG Steam Trend
LP STEAM
CHILLER 3
SCV-2
(4" valve)
SCV-1
(8" valve)
ConEd Steam Trend
TO K-MART
CON ED


DeltaV Operate (Run)
ONELINE
WGTOT
JI-GEN-TOT-PWR
WCn_KW
JI-PC-n—KW
n=1 to 5
WCn_KWi
JI-PC-n –GRID-KW
n=1 to 5
WG1
JI-GEN-1-PWR
WG2
JI-GEN-2-PWR
WG3
JI-GEN-3-PWR

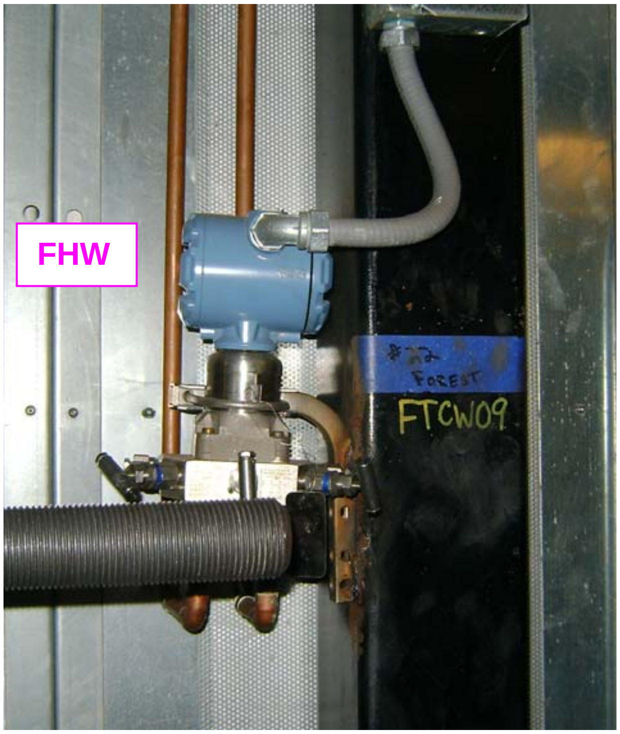

DeltaV Operate (Run)
POWER CONVERTER 1 (900 KW)
WC1_KW
JI-PC-1--KW
WC1_KWi
JI-PC-1-GRID-KW

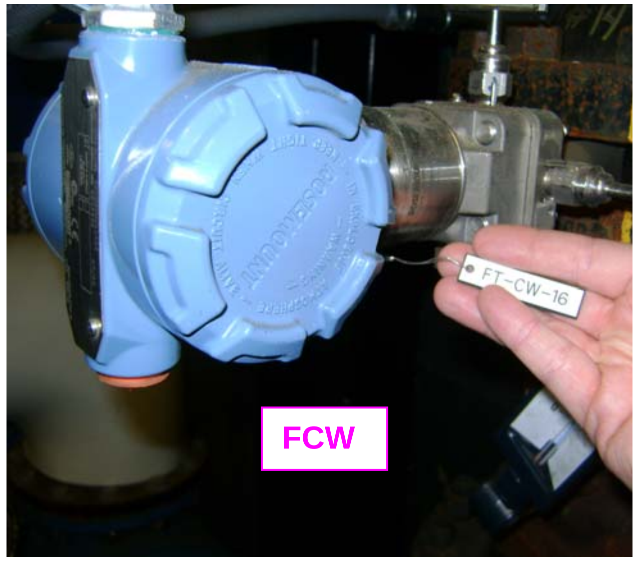
HX-01 (condensate preheater)

Condensate Tank

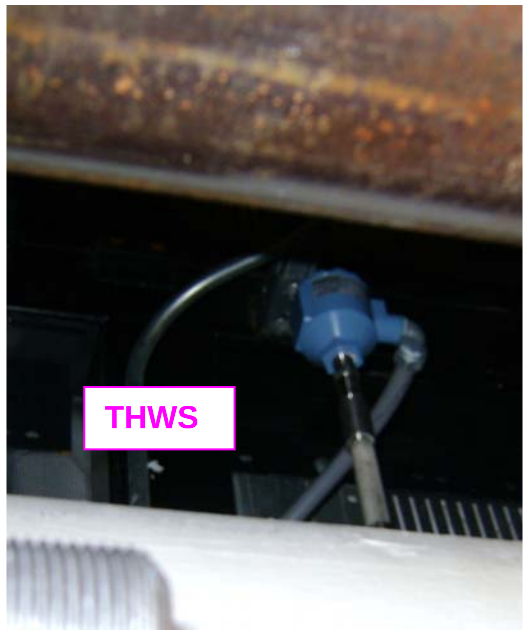


Condensate Flow Meter


FHW
#22
FOREST
FTCW09

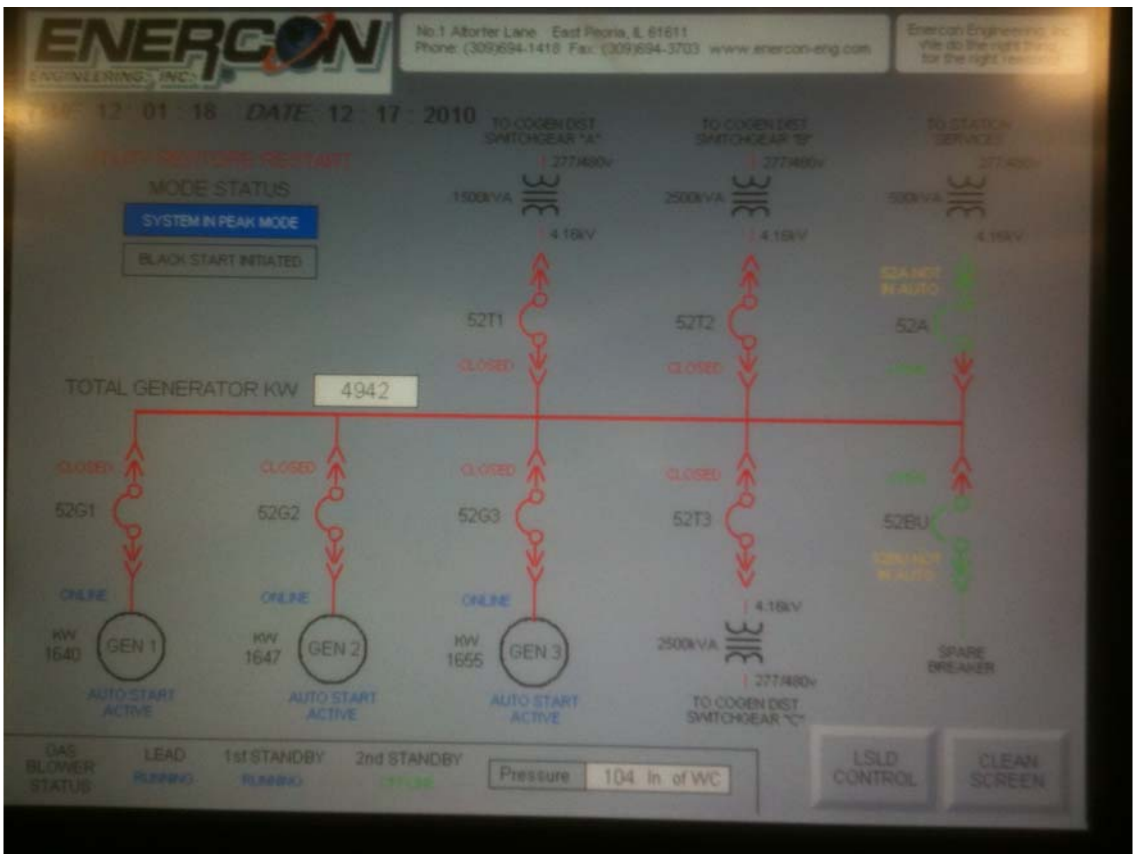

FT-CW-16
FCW


FSL


THWS

Power Converter Power Output

Grid Import Meter



Enercon One-Line Screen

Connections to Cogen Enclosure (HW supply & return; CW supply & return; HP Steam out; LP Stean input; Condensate return; Makeup water)

Cain Heat Recovery Steam Generator (1 of 3)

HX-04 (serves Perimeter Heating Loop)

APPENDIX B
Assumptions and Calculation Procedures for One Penn CHP System Analysis

19-Dec-10

Steam Calculations

			Sat Temp Coefs						
PSH2 Steam Pressure (psig)	110.0	inputs	212.7075	3.071716	-0.04885	0.000605	-4.36E-06	1.62E-08	-2.39E-11
TCO Ent Condensate Temp (F)	200.0		HFG Coefs						
Saturated Temperature (F)	344.5		970.1283	-2.08599	0.034617	-0.00047	3.56E-06	-1.37E-08	2.05E-11
Steam Hfg (Btu/lb)	875.0								
Condensate delta-h (Btu/lb)	144.5	assumes cp is 1 Btu/lb-F	assumes steam at saturation (no superheat)						
Total Steam delta-h (Btu/lb)	1,019.5								

Qsteam = FS x delta-h

Jacket Heat Transfer (HX04)

K-factor	487.8	Fluid = Pure Water @ 180F
THWR (F)	160	The perimeter loop is just water
THWS (F)	200	
FHW (gpm)	100	
QHW (Btu/h)	1,951,200	

Condensate Heating (HX01)

K-factor	487.8	Fluid = Pure Water @ 180F
TCI (F)	160	
TCO (F)	200	
FC (gpm)	10	divide by 15 to get gpm
QC (Btu/h)	195,120	

Natural Gas Input

Energy Content - HHV (Btu / std CF)	1,021.0	from EIA "Heat Content" data for NY, 2008
Energy Content - LHV (Btu / std CF)	918.9	(National number is 1027 Btu/CF)

Efficiency Calcs (used for the interval of interest)

Gas Input (CF/h)	66,000	sum of 3 engines
Electric NET Output (kW)	6,000	NET is sum of converter outputs (may need to derate by parasitics)
Total Thermal Output (Btu/h)	17,000,000	Qsteam + QHW + QC
Fuel Conversion Efficiency	62%	
Electrical Efficiency	34%	

Notes:

Power readings are kWh per interval	multiply by 4 to get average kW
Gas readings are CF per interval	multiply by 4 to get average CF/h
Condensate flow (FC) is lb per interval	multiply by 4 to get average lb/h

Thermal outputs (Btu/h) must be calculated for each 15-minute interval and then summed or averaged