MONITORING AND DATA COLLECTION STANDARD

FOR

DISTRIBUTED GENERATION/COMBINED HEAT AND POWER (DG/CHP) SYSTEMS

December 29, 2004

Revised

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GLOSSARY

DG/CHP System. The units, components, equipment and subsystems that make up the Distributed Generation/Combined Heat and Power system at a facility.

Data Acquisition System (DAS). The controllers, instrumentation and other equipment at the site to measure and record data related to the facility or DG/CHP system. Can be a dedicated data logger, a direct digital control (DDC) system for controlling facility operation, an industrial control system, or an on-board controller for the DG/CHP equipment. Generally, the DAS is located on-site near the DG/CHP System.

Data Collection, Logging, or Recording Interval. The time interval at which data are recorded or saved into memory in the on-site DAS.

Data Retrieval Interval. The time interval at which data are transferred from the on-site DAS to an off-site computer system for storage and analysis.

Data Point. The measured value or reading provided by a sensor or instrument installed as part of the on-site DAS or from other handheld instruments.

Demonstration Site. A facility or building where a DG/CHP system has been installed with financial support from NYSERDA.

Displaced Fuel Use. The natural gas or other fuels that would have been consumed if the DG/CHP system had not been installed/operating at the site.

Load. The equipment and systems in a facility or building that consume or use heat, power, or cooling that is produced by a DG/CHP system. In the absence of the DG/CHP equipment, the thermal load would be met with boilers, furnaces, chillers, or other fuel consuming equipment at the site. The electric load would have been met by the local electric utility.

Log or Logfile. The file or memory locations where control systems save or record time stamped data. This term is commonly used by building direct digital control systems.

Monitoring Plan. A document describing the sensors and equipment to be installed as part of the DAS. The plan explains the purpose and use of each sensor or data point.

Monitoring System. Same as Data Acquisition System (DAS).

Parasitic Power. Electric power consumed by the DG/CHP system. Can be power use internal to the DG/CHP unit (internal parasitics) or power use by pumps, fans, compressors and other components that are required to deliver heat, power or cooling to the load (external parasitics).

Scan or Sampling Interval. The time interval at which each sensor or instrument is read by the on-site DAS.

Introduction

This document describes the requirements and desirable attributes of an automated data collection system designed to monitor the performance of a distributed generation/combined heat and power (DG/CHP) system. This standard is intended to provide guidance to demonstration sites that are part of NYSERDA's DG/CHP program. Specifically, this document seeks to guide demonstration sites through the process of developing a monitoring system and preparing a Monitoring Plan for their DG/CHP site.

DG/CHP demonstration sites that receive funding from NYSERDA are generally required to collect key performance data at 15-minute intervals over the first year of operation. The monitored data are intended to quantify facility load profiles, generator power output, fuel consumption, useful thermal outputs, parasitic loads and equipment runtimes. These data provide the means to confirm electrical and CHP efficiencies over the year, determine equipment availability, and verify system economics.

The sections that follow discuss the types of on-site measurements that are required or recommended to meet the goals and monitoring requirements. First, this document describes the need to fully document the salient details of the DG/CHP system and to develop a simple system schematic. Next, the process of setting monitoring objectives and goals for a CHP project are described. Then, the process of selecting monitoring hardware and instrumentation to meet the project goals is demonstrated by an example. Finally, the advantages and disadvantages of various communications and web presentation options are compared.

Documenting System Details

The first step in developing a monitoring plan is to define the key components and equipment as well as to provide the basic layout of the components in the DG/CHP system. This step is critical because it helps to determine the data points and measured parameters that must be monitored to quantify system operation.

Describing DG\CHP Equipment

At a minimum, the monitoring plan should include the basic equipment and system details listed in Table 1.

Table 1. Documenting DG/CHP Equipment and Site Details

System overview	• Generator size and type • Is power exported to the grid? • standby power functionality • heat recovery used to meet facility loads; describe loads and displaced fuels
Power generating equipment	• Nameplate data such as output, operating voltage, generator type, fuel input • Basic nameplate data on standby power/auto transfer components • protective relay functions and settings
Heat recovery system and displaced thermal equipment	• Rated performance and corresponding operating temperatures of heating/ cooling systems • Size and Nameplate data on boilers, chillers and other equipment that are displaced by (or provide backup for) heat recovery operation
Facility load details	• Facility size, use, and other application details • Electric utility details: number of meters, original and current electric and gas tariff info

System Schematic

An important step to describing and understanding a DG/CHP system is to develop a simple schematic representation of the system. Unlike detailed engineering drawings that show the physical layout of all components in a system, a simple schematic conveys the functional layout of the system in order to understand the energy flows and thermodynamic boundaries. The key concepts conveyed by the schematic are the flow of fuel, electricity, and thermal energy between the DG/CHP system and the facility. The number of heat exchange steps, the direction of fluid flow, the operating temperature of each loop, the net power supplied to the building, and exported power are all shown.

Figure 1 shows a simple schematic of a CHP system that supplies heat recovery to a building via a hot water loop. Hot water from the CHP unit is supplied at 180°F. A heat exchanger (HX) is required to separate the building hot water loop from the CHP system loop. The extra heat exchange step lowers the fluid temperature that can be delivered to the load. A dump radiator rejects heat from the loop when it cannot be used to meet building thermal loads. The system supplies generated power into the main electric bus for the facility. This power is consumed internally (no power export to the utility). Some external parasitic power is required to run the pumps and dump radiator. The net purchases from the utility are also monitored at the main meter.

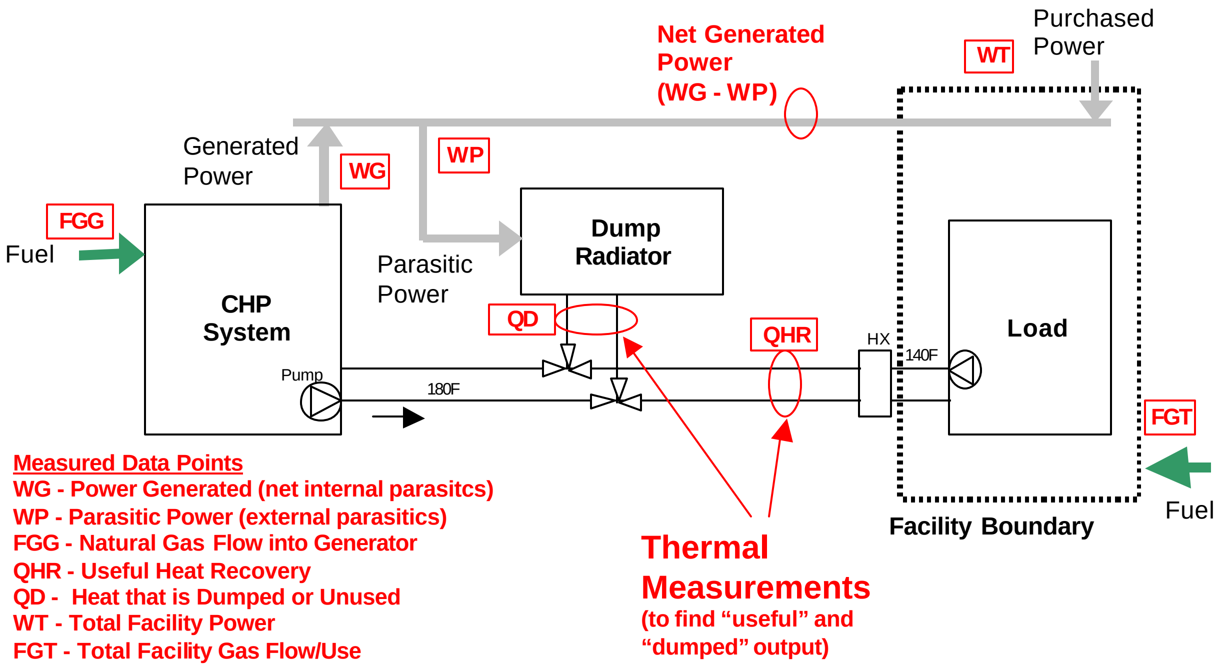

Figure 1. Simple Schematic CHP System

Figure 1 also shows the location of monitored data points that would be included to measure DG/CHP system performance. The data point name or tag corresponding to each sensor is shown as the red, box-enclosed text on the schematic[1]. A key purpose of the schematic is to show the location of each measured point in order to demonstrate that meaningful data are being collected. The next section talks about process and rationale for selecting these points.

Feasibility Study and Estimated Annual Performance

In most cases a DG/CHP System has installed and built after a detailed engineering feasibility study has been completed to evaluate the cost effectiveness of the system. Generally this study would have assumed or calculated sizes and performance characteristics for key equipment and predicted annual power production, daily or monthly load profiles, annual heat recovery savings, parasitic power use, etc. The key results of the feasibility study should be briefly summarized in the monitoring plan. The original feasibility study could also be attached as an appendix or provided as a reference.

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[1] Appendix A explains the naming convention that was used for selecting the data point names shown in Figure 1.

Data Collection and Monitoring

Monitoring Objectives

In order to select the necessary monitored data points the project objectives should first be clearly stated, since they drive the monitoring and data collection requirements. The primary monitoring objectives (listed in Table 2) are usually required for NYSERDA DG/CHP sites. Other optional objectives are listed in Table 3. The data points necessary to meet these objectives are listed in each table.

Table 2. Primary (NYSERDA Required) Monitoring Objectives

No	Objective	Data Necessary to Meet Objective
1	Quantify the variation of DG/CHP system power output, gas consumption, and efficiency over wide range of annual operating conditions.	WG[1], FGG, TAO
2.	Quantify external parasitic loads (e.g., gas compressors, pumps, dump radiators, etc.).	WP
3.	Quantify the daily, weekly monthly, and annual variation of total facility power use (or power purchased from the utility) so that actual utility costs can be determined.	WT
4.	Determine the thermal loads imposed on the CHP system by the facility (or the useful thermal output supplied to the facility) to measure the total CHP efficiency of the system on a daily, monthly and annual basis; quantify the variation of these loads with ambient conditions and operating schedules so the findings from this site can be extended to other climates.	QHR (or integrated flows & temperatures), TAO
5.	Quantify the displaced fuel use on auxiliary equipment and systems to confirm the benefit of heat recovery.	Boiler fuel use, total facility fuel use (FGT), chiller electric consumption
6.	Quantify the amount of available thermal energy that is unused or "dumped" by the CHP system in order to demonstrate a system heat balance.	QD (or integrated flows & temperatures)

1 - The data point names correspond to the points listed in Figure 1 and Appendix A

Table 3. Optional Monitoring Objectives

No	Objective	Data Necessary to Meet Objective
7.	Determine the impact of generator operation on power quality in the facility (power factor, kVAR, frequency, total harmonic distortion); measure at generator output and/or main service entrance.	Volts, amps, kVA, hz, THD, etc (total and/or per phase)
8.	Collect diagnostic data to confirm the DG/CHP system operates as expected and/or support of maintenance and operation activities.	Component statuses, intermediate temperatures, pressures
9.	Develop performance maps of CHP equipment and components to verify manufacturer specifications.	QHR, flows, temperatures, statuses, etc.
10.	Determine environmental emissions from DG/CHP equipment to quantify net emissions impacts of the system.	CO, NO_x, THC, etc

The primary objectives listed in Table 2 require the relatively small set of monitored data points shown on Figure 1. The optional objectives would require a more extensive monitoring system. Generally all these data would be captured and recorded at 15-minute intervals. Though in some cases one-time readings with handheld meters will sufficient to quantify operation (e.g., one time readings of parasitic power for a constantly operating pump; one-time flow readings for loop flow rates that are constant). Some data, such as local weather data, can also be purchased instead of measured (www.ncdc.noaa.gov).

In some cases it may be more convenient to measure power at different locations in the system. For instance:

- measure total facility power use instead of net utility purchases,
- separately measure generator gross output and internal parasitics instead of net busbar power output.

These variations are acceptable but must be documented in the monitoring plan tables and schematic. The Monitoring Plan must include equations defining how the values shown in Figure 1 can be calculated from the measured data.

Monitoring Hardware Issues

The necessary sensors and equipment are driven by monitoring objectives as well as the type of monitoring system hardware and software that will be used. For instance, if the monitoring system is capable of counting pulses, then a utility-grade KYZ (or Form C) output can often be added to main electric meter at a relatively low cost. Otherwise an additional power meter with a more compatible output (e.g., a 4-20 ma output proportional to kW) might have to be installed on the building main. Similar issues are true for the gas meter installed on the CHP unit.

Another monitoring system issue is the type of software used to sample, record, and save the monitored data. Building control systems have historically had the ability to sample data at specified interval and then save that information in a “log”. In contrast data loggers and other more flexible control systems can usually scan or read sensors at relatively fast interval (e.g., every few seconds) and then average or totalize the readings over the recording interval (e.g., every 15-minutes). This distinction can become very important when aggregating the data to daily, monthly, or annual values. The relative impact depends on how much the outputs, inputs, or loads fluctuate in time. Generally, monitoring systems than can average or totalize over the recording interval will provide more accurate and useful data.

Key examples are the electric power output from a generator or total power use of a facility. The goal is usually to determine the overall energy production (kWh) as well as the average demand (kW) for each recording interval (e.g., 15-minutes). With a pulse output meter, the total energy use (kWh) is explicitly determined. However, the average demand (kW) in time interval can also be determined if the pulse resolution is sufficiently small. In this case the average demand is:

KW_{avg} = (measured kWh per interval) / (time interval)

The other metering option would be to use a power meter that measures power (kW) and provides an analog output (e.g., 4-20 mA). This meter explicitly measures power demand. However, the overall energy use can also be inferred:

KWh_{total} = (measured kW) x (time interval)

For systems were the measured value changes faster than the time interval, the error in determining the inferred kWh value can be large. This is especially true for monitoring systems that only take one sample in the recording interval. Scanning and averaging the power transducer at a faster rate can generally alleviate these concerns.

Other more expensive types of power meters solve this problem by independently providing a kWh and kW reading via a serial connection (e.g., MODBUS) for each interval.

Generally we believe that priority should be on explicitly determining energy use (kWh) with a high-resolution, pulse-emitting meter since this reading is most important to overall economics. The average demand in any interval can be closely inferred by the method described above.

Determining the thermal outputs from a CHP system has similar issues. Determining the thermal output generally requires that the flow and delta temperature be measured. The product of flow and delta temperature must be integrated (or summed) to determine the energy content:

$q = k \cdot \Sigma\{gpm_i \cdot (Tin_i - Tout_i)\} \cdot (\text{time interval})$

Where i corresponds the readings at each scan interval. The factor “k” depends on the specific heat and density of the actual fluid at the site. The summation is completed for all the scans to find the total value “q” for the recording or logging interval (i.e., 15 minutes). The integration can be done by a control system/data logger or by using a dedicated electronic device known as a BTU Meter. If the flow is known to be constant throughout the year, then a one-time flow reading can be combined with continuous temperature measurements. In all cases, care should be taken to properly integrate the flow-temperature product at small intervals if the flow varies (or cycles on and off) to meet the needs of the load.

If a constant flow is assumed, then the Monitoring Plan must explicitly make the case that no pumps or valves in the loop will vary. At a minimum, a one-time flow measurement is required to verify the flow rate. Design flow values from drawings or engineering design calculations are not acceptable.

Monitored Data Points

The monitored data points that are ultimately selected need to specified in tabular and graphic form. The tabular summary needs to specify or provide:

- the data point name or tag
- a description of the measured value
- the engineering units of the measured/recorded value
- the type of sensor or transducer and key manufacturer information

Separate tables should be provided for continuous or automatically-collected data points and for measurements that a taken periodically or one-time with handheld or temporary meters.

The DG/CHP system schematic should be used to show the location of each data point in the system. The schematic must include sufficient detail to explain why and how the measurement location was selected.

Finally, the rationale and intended purpose for each data point should be described in the text. The description should explain how the measured point would be used to analyze and understand DG/CHP system performance. The description can be bulleted text or in narrative format. The next subsection shows an example of how the monitored data points could be presented and defined.

Selecting Monitoring Points for and EXAMPLE CHP SITE….

The continuously-monitored data points in Table 4 were selected to quantify the performance of the CHP system. Figure 2 shows the location of each monitored point in the system. The CHP system includes two 60 kW microturbines with integrated heat recovery. Hot water produced by the microturbines is used to provide space heating to the building. Hot water is also provided to an absorption chiller that can meet the space cooling loads in the summer. Heat recovery provided for space heating will displace boiler operation. Hear recovery used by the chiller will displace operation of the original electric chiller.

The monitoring system will use a Campbell Scientific CR-10x data logger that samples and integrates every 10 seconds and records data at 15-minute intervals.

Table 4. Continuous or Automatically Collected Monitoring Points for EXAMPLE CHP System

Channel Type	Data Pt Name	Description	Eng Units	Sensor Type
Analog-1		Thermocouple reference		
Analog-2	TAO	Ambient Temperature	F	type-T TC
Analog-3	TCHL	Chilled Water Supply - system	F	type-T TC
Analog-4	TCHE	Chilled Water Return - system	F	type-T TC
Analog-5	THXL	Hot Water from microturbines	F	type-T TC
Analog-6	THXE	Hot Water to microturbines	F	type-T TC
Analog-7	TBXL	Hot Water Supply on Boiler-Side of HX	F	type-T TC
Analog-8	TCWE	Cooling Water Entering Abs. Chiller	F	type-T TC
Analog-9				
Analog-10	FHW	Heat Recovery Flow	gpm	Onicon F-1110
Analog-11	FCH	Chilled Water Flow	gpm	Onicon F-1110
Analog-12	RHO	Ambient RH	%	Vaisala RH
Pulse-1	FGB	Building Gas Use	cu ft	Gas meter[1]
Pulse-2	FGT	Microturbine Gas Use	cu ft	Gas meter[1]
Pulse-3	WCH	Electric Chiller Power	kWh	Veris H-6010
Status-1	SCH	ABS Chiller Status	min	Veris 800
Status-2	SHV	Boiler/Abs CH Valve Status	min	Veris 800
Status-3	SCT	Cooling Tower Status	min	Veris 800
Status-4	SHP	Heat Exchanger Pump Status	min	Veris 800
MODBUS	WT1	Power Microturbine #1	kW/V/A	Veris Modbus
MODBUS	WT2	Power Microturbine #2	kW/V/A	Veris Modbus

Notes: 1- Gas meters are utility-grade, temperature- and pressure-compensated meters.

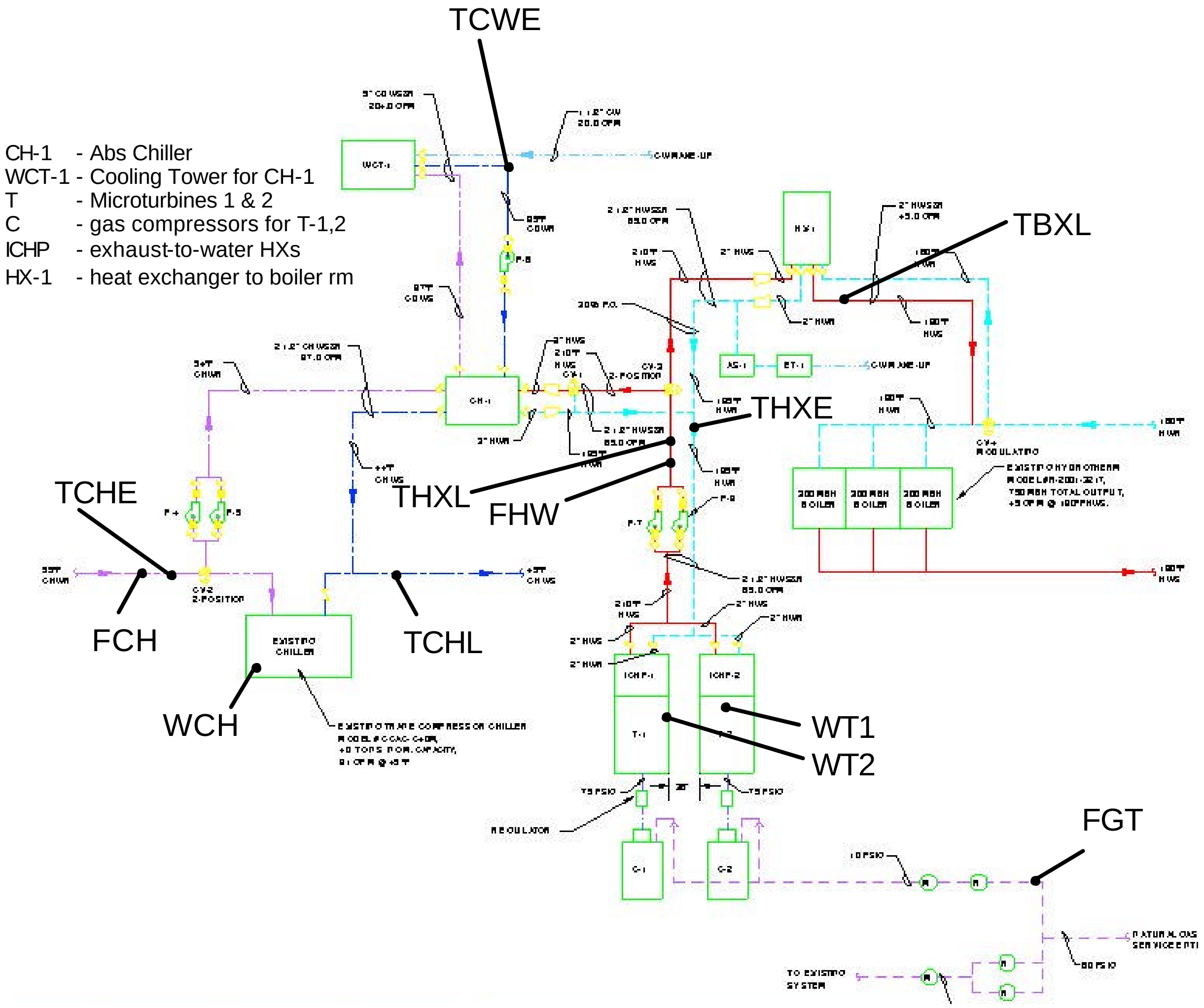


Figure 2. System Schematic Showing Sensor Locations in EXAMPLE CHP System

The electrical output of the microturbines (**WT1 & WT2**) will be measured with a MODBUS power transducer than can also measure volts, amps and true power for each phase (Objectives 1 & 7). The gas input to the turbines (**FGT**) will be measured by a single gas meter with pulse output (supplied by local utility) (Objective 1). The parasitic power use of the DC-powered gas compressors will be captured in the turbine power (so a separate power transducer is no longer needed) (Objective 2). A valve status sensor (**SHV**) will determine when the heat recovery output is going to the boiler load or to the chiller (Objectives 4, 6 & 8). The runtimes of the absorption chiller, constant-speed tower fans, and heat recovery pump will also be monitored (**SCH, SCT, SHP**) (Objectives 2 & 8).

The thermal output from the heat recovery unit will be determined from the flow and temperature difference (**FHW, THXL, THXE**) (Objectives 4 & 9). The data logger will integrate these readings every 10 seconds to determine the thermal output. We will also measure the temperature of the hot water supplied to the boiler loop after the boiler HX (**TBXL**) to determine how effectively the heat is being transferred into the boiler loop (Objective 8 & 9). Total gas use for the building (**FGB**) will be continuously monitored to provide an indication of how much boiler gas use is displaced by heat recovery (Objective 5).

The output of the total chiller system (electric and absorption) will be measured (**FCH, TCHL, TCHE**) along with the condenser water temperature (**TCWE**) entering the absorption chiller (Objectives 4, 5 & 9). This data will allow us to confirm that the COP and capacity of the chiller is consistent with the manufacturer's performance specifications. Absorption chiller and cooling tower parasitic power will also be determined by combining one-time power measurements (**WABS, WCTF, WCTP**) with the continuously recorded component runtimes (**SCH, SCT, SHP**) (Objective 2). The total power for the electric chiller (**WCH**) will be continuously monitored with a power transducer (Objective 5).

Table 5. One-Time Measured Data Collected for EXAMPLE CHP System

Name	Description	Eng Units	Sensor Type
WCH	ABS Chiller Parasitic Power	kWh	Handheld Pwr Meter
SCT	Cooling Tower Fan Power	kWh	Handheld Pwr Meter
SHP	Heat Exchanger Pump Power	kWh	Handheld Pwr Meter

Communications, Data Retrieval Procedures, and Web Presentation

Communications with the monitoring system can range from manual data retrieval to fully automated broadband connections that allow for real-time (or near real-time) display of measured values on a web page. The type of communication link needed for a project depends on:

- the type of DG/CHP equipment,
- how the system is operated, maintained, or dispatched, and
- the reporting needs for monitoring.

Strictly speaking, it might be fully rational to provide a complex monitoring system with no communications capability if on-site staff are available to operate/maintain the system and to periodically transfer monitored data from a computer to a CD or memory stick. Conversely, a very simple monitoring system may require a direct broadband connection if system operation were critical and responsible personnel were remotely located. NYSERDA's DG/CHP sites are generally encouraged to have some form of communication connection so that system status and periodic reporting can be provided on the web.

Table 6. Communications Options for Data Retrieval and Monitoring

Type of Communications for Data Collection	Description / Example
None / Manual download	Data is manually downloaded or transferred to a CD or memory stick on a periodic basis (monthly, weekly, daily).
Phone	Data are automatically (or manually) retrieved via phone-modem link using dedicated software. Data retrieval rates can be hourly, daily, weekly or monthly.
Broadband	A DSL or Ethernet connection allows continuous automated data retrieval. The operating state and performance of the DG/CHP system can be displayed in real or near-real time. A web connection can be established directly with the unit controller or via an intermediate server capable of aggregating data from many sites.

The system that displays DG/CHP operating data and performance history on the web can be implemented with a variety of communications options. The key question is whether the web site is intended to present a real time snapshot of system operation (such as Figure 3 and Figure 4) or present a higher-level summary of recent and historic performance (Figure 5). Real time control and monitoring of the DG/CHP system clearly require a DSL or Ethernet connection (though an phone-modem connection polled hourly can approach real time functionality). Requirements for monitoring alone can be less stringent so that a phone-modem connection is sufficient. The choice of the communications option is often driven by the cost or difficulty of providing either a phone or broadband connection in the facility.

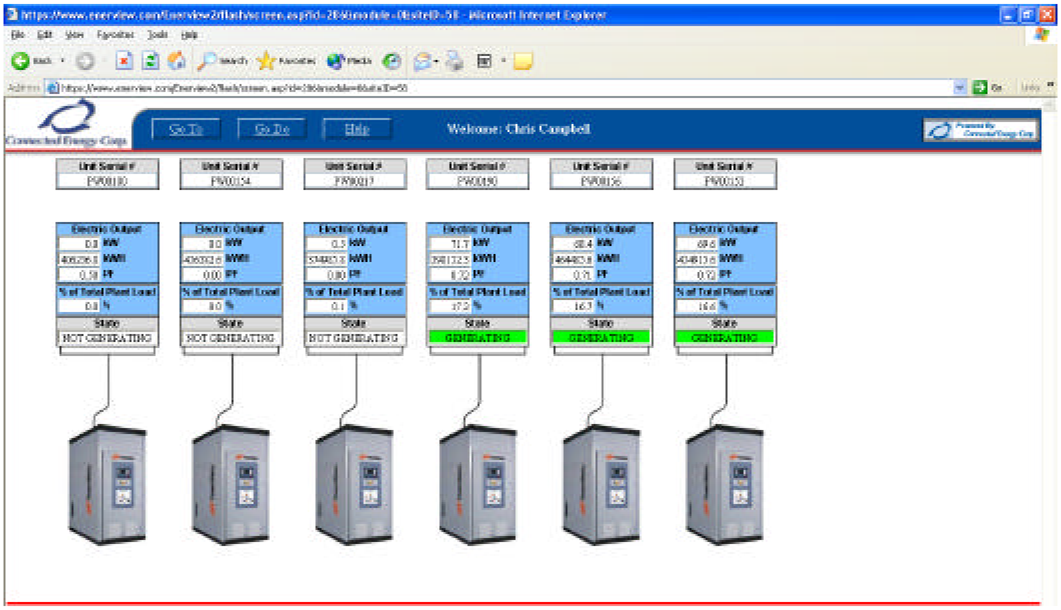
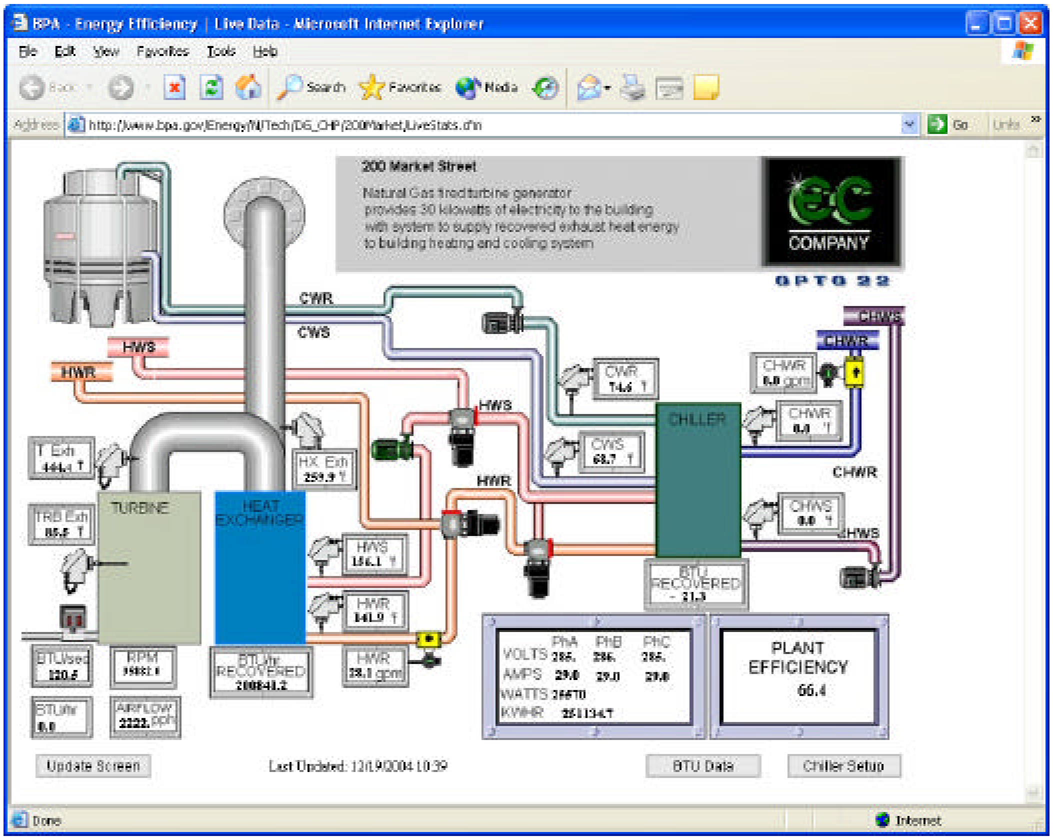


Figure 3. Example of a Real time Web Page Showing System Status (Served from Intermediate Site)

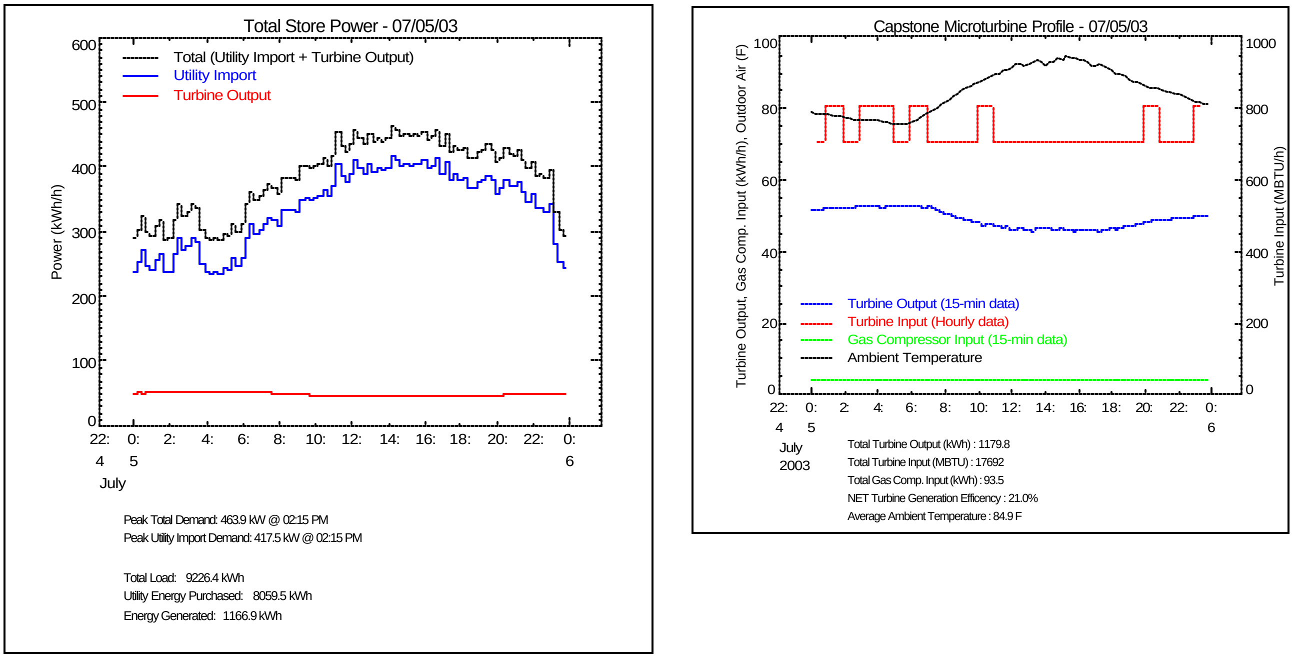


200 Market Street

Natural Gas fired turbine generator provides 30 kilowatts of electricity to the building with system to supply recovered exhaust heat energy to building heating and cooling system

Last Updated: 12/19/2004 10:39

Figure 4. Example of a Real time Web Page Showing System Status (Served by Site-level PLC/computer)



Peak Total Demand: 463.9 kW @ 02:15 PM
Peak Utility Import Demand: 417.5 kW @ 02:15 PM

Total Load: 9226.4 kWh
Utility Energy Purchased: 8059.5 kWh
Energy Generated: 1166.9 kWh

Total Turbine Output (kWh) : 1179.8
Total Turbine Input (MBTU) : 17692
Total Gas Comp. Input (kWh) : 93.5
NET Turbine Generation Efficency : 21.0%
Average Ambient Temperature : 84.9 F

Figure 5. Example of a Web Page Showing Recent System Performance (Served from an Intermediate Site)

The frequency of data retrieval from a monitoring system can vary based on the project needs. For monitoring systems with a broadband connection, data retrieval rates can take place every few seconds. For phone-modem systems, data retrieval can take place as quickly as once every hour.

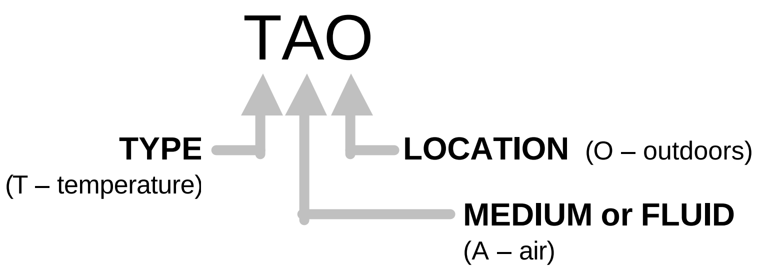
Even more important than the rate of data retrieval is the need for a robust system for archiving and capturing all the data regardless of the communications status. Data loggers generally are most robust at this task since data logging and recording is the highest priority function (i.e., data logging continues even when communications with the remote host are taking place). Even if the communication connection is lost, the on-board memory can continue to record data for several days or weeks until communications are reestablished. PLCs (programmable logic controllers) are at the other end of the spectrum since they can only save the most recent readings and a loss of communications typically results in a loss of data.

A robust monitoring system must place as much emphasis on reliably storing the collected data in the local controller as it does on the real time display of those values.

APPENDIX A
Suggested Convention for Naming Data Points or Tags in a Monitoring System

An important but often overlooked aspect of developing a monitoring system is to select rational and easily-understood naming conventions for each data point. Consistent naming helps communications within the project team as well as with outside entities. The following is one possible convention.

Each data point should be named according a hierarchy, for instance:



Suggested designations for the type, medium, or location are given in the table below. One or more letters can be used for each designation. The actual letter designations can change based on project needs and preferences. The important aspect is the hierarchy of the naming convention. Each site or monitoring entity is encouraged to develop and use their own consistent naming conventions.

Data Point "TYPE"	Data Point "MEDIUM"	Data Point "LOCATION"
T – temperature P – pressure RH – relative humidity W – Power (watts/watt-hr) F – flow S – status/runtime V – volts I – current/amps HZ - frequency	A – air G – gas (natural) CH – chilled water CW – cooling water HW – hot water CT – cooling tower B – boiler	O – outdoor I – indoor E – entering L – leaving

Examples

TCHL: temperature – chilled water – leaving
TBXL: temperature – boiler heat exchanger – leaving
WT1: watts/power – turbine #1
FGT: flow – gas – turbines
FCH: flow – chilled water
VAT1: volts – phase A – turbine 1