Distributed Generation
Combined Heat and Power
Long Term Monitoring Protocols

Version: Interim

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Prepared for

Association of State Energy Research and Technology Transfer Institutions
Collaborative National Program for the Development and
Performance Testing of Distributed Power Technologies

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Foreword

Distributed generation (DG) technologies are emerging as a viable supplement to centralized power production. Independent evaluations of DG technologies are required to assess performance of systems, and, ultimately, the applicability and efficacy of a specific technology at any given site. A current barrier to the acceptance of DG technologies is the lack of credible and uniform information regarding system performance. Therefore, as new DG technologies are developed and introduced to the marketplace, methods of credibly evaluating the performance of a DG system are needed. This protocol was developed to meet that need.

This interim protocol describes the procedure for long term monitoring of the performance of microturbine generators (MTG), reciprocating internal-combustion engine (IC) generators, and small turbine generators in an actual or field setting. It also provides information for transmitting the monitoring data to a national database at the National Renewable Energy Laboratory (NREL). The protocol is applicable to systems with and without combined heat and power (CHP). The monitoring protocol is designed to report data on the electrical, thermal (if applicable), emissions, and operational performance of DG/CHP systems. Application of this protocol will provide uniform data of known quality that are obtained in a consistent manner. Therefore, this protocol will allow for comparisons of the performance of different systems, facilitating purchase and applicability decisions. In addition to this protocol, there are parallel interim protocols for:

- laboratory testing of these systems (Gas Technology Institute)
- field testing of these systems (Southern Research Institute)
- case studies of these systems in commercial applications (University of Illinois-Energy Research Center)

The performance results of DG systems tested and/or monitored with the protocols will be housed in a free searchable database managed by NREL. A list of meta-data is included in an appendix. The list defines the database structure to support the searchable database.

The long term monitoring protocol is intended for use by those evaluating new technologies (research organizations, technology demonstration programs, testing organizations), those purchasing DG equipment (facility operators, end users), and manufacturers. It is intended solely to provide consistent, credible performance data. It is not intended to be used for certification, regulatory compliance, or equipment acceptance testing.

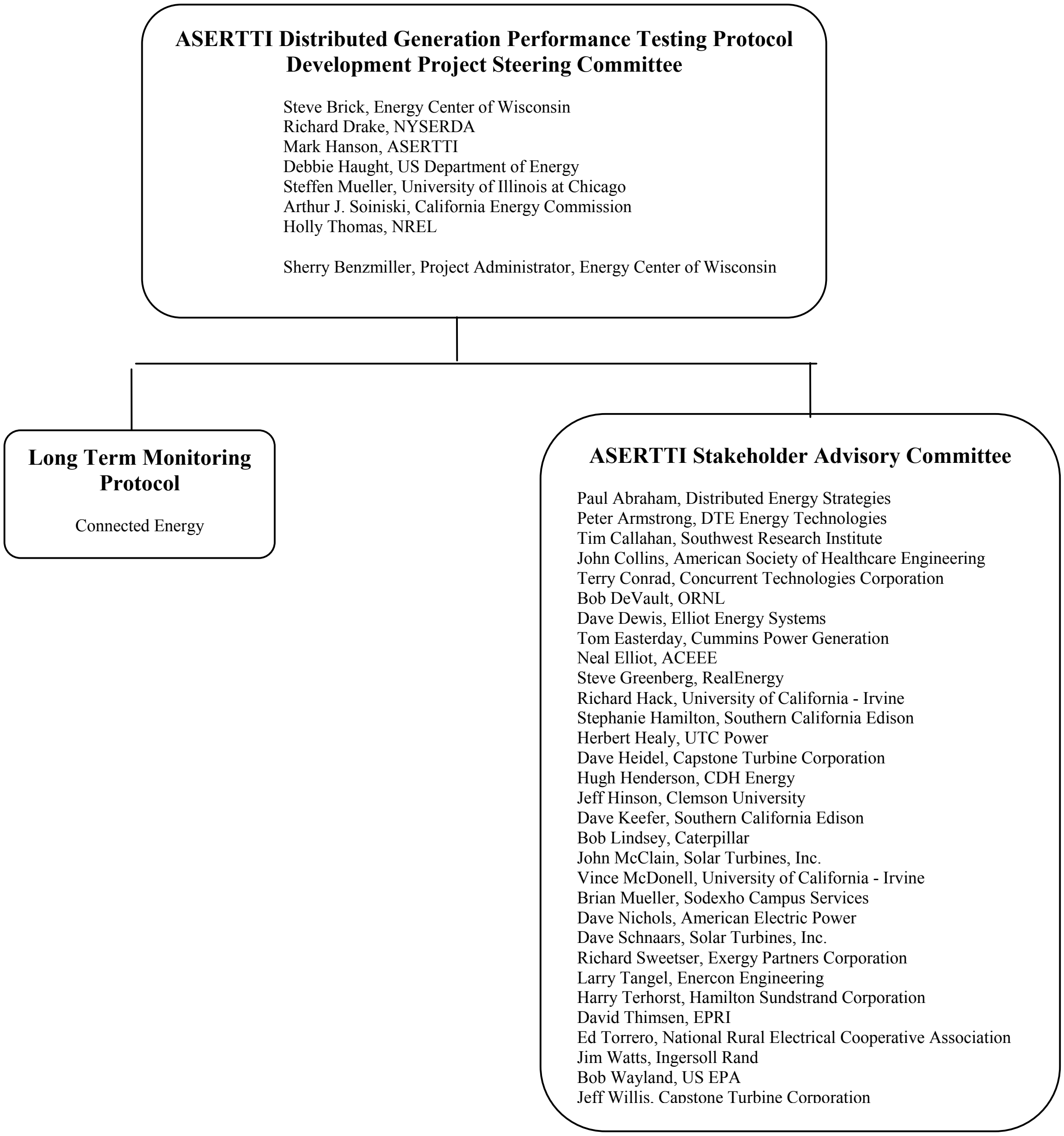
The Gas Technology Institute (GTI) and Underwriters Laboratory (UL) have initiated an effort through UL's Standards Process to offer a certification service that allows testing at any qualified laboratory. UL is adopting the laboratory performance protocol as part of its certification development process.

This protocol was developed as part of the Collaborative National Program for the Development and Performance Testing of Distributed Power Technologies with Emphasis on Combined Heat and Power Applications, co-sponsored by the U.S. Department of Energy and members of the Association of State Energy Research and Technology Transfer Institutions (ASERTTI). The ASERTTI sponsoring members are the California Energy Commission, the Energy Center of Wisconsin, the New York State Energy Research and Development Authority, and the University of Illinois-Chicago. Other sponsors are the Illinois Department of Commerce and

Economic Opportunity and the U.S. Environmental Protection Agency Office of Research and Development. The program is managed by ASERTTI.

The protocol development program was directed by several guiding principles specified by the ASERTTI Steering Committee:

- The development of protocols uses a stakeholder-driven process.
- The protocols use existing standards and protocols wherever possible.
- The protocols are cost-effective and user-friendly, and provide credible, quality data without excessive implementation costs.
- The interim protocols will become final protocols after review of validation efforts and other experience gained in the use of the interim protocols.



ASERTTI Distributed Generation Performance Testing Protocol Development Project Steering Committee

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Long Term Monitoring Protocol

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Figure 1. Long Term Monitoring Protocol Development Contributors

The long term monitoring protocol was developed based on input and guidance provided by the ASERTTI Stakeholder Advisory Committee (SAC). The SAC consisted of 27 stakeholders representing manufacturers, end-users, research agencies, regulators, and demonstrators.

The ASERTTI Steering Committee directed the project and provided review and final approval of this protocol. Figure 1 shows the program management structure and the individuals that were involved in the protocol development.

The protocol development process consisted of several steps following ASERTTI's guiding principles. First, a list of performance parameters for which laboratory and field testing protocols should be written was completed. The parameters selected provide performance data for electrical generation, electrical efficiency, thermal efficiency, atmospheric emissions, acoustic emissions, and operational performance.

The laboratory, field, long term monitoring and case study protocols' development was based on existing standards, protocols, and the experience of the committees. Existing standards and protocols potentially applicable to DG systems were reviewed and evaluated. The existing standards and protocols form the basis for instrument specifications, acceptable test methods, QA/QC procedures, calculations, and other requirements of this protocol. The laboratory protocol allows for the controlled evaluation of the effects of several parameters on performance of the unit that can not be reasonably verified in field testing. Laboratory testing also allows testers to determine performance under conditions that can not be practically controlled in a field setting, such as ambient conditions, response to upsets, and grid isolated (stand alone) operation for determining transient response characteristics.

Reasonable compromises were sought to provide a balance between the requirement for credible, quality data, and requirements that these protocols be user-friendly and result in minimizing cost to implement testing, such that they can be widely and consistently implemented and reported on the Search Database at NREL.

This protocol is an interim protocol. A final protocol will be issued in 2006 with any revisions based on feedback from various users and stakeholders. This feedback and results of the validation process will be reviewed by the SAC, and forwarded to the Steering Committee for approval of a final protocol.

The ASERTTI Steering Committee provided final approval of this interim protocol on September 30, 2004. For additional information regarding this protocol and the associated DG performance evaluation program, please contact the following:

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1. Introduction

The purpose of the Long Term Monitoring Protocol (the "Protocol") is to specify the data collection objective, data collection location, data collection procedure, data validation, and data formatting for continuously operated distributed generation (DG) sites. The Protocol is intended to provide data on the electrical, thermal (if applicable), operational and environmental (optional) performance of DG systems. Application of the Protocol will provide uniform data of known quality, which is obtained in a consistent manner for all DG systems under long term monitoring. Subscribing to the Protocol will allow for performance comparisons of different DG systems facilitating purchase and application decisions.

1.1 Monitoring Objectives

DG systems are installed at diverse sites delivering electrical and thermal energy for use in a range of applications. Interpreting the performance of the DG system at each site, in a consistent and complete fashion, will serve to further the general understanding of selecting, installing, operating and maintaining DG systems. The purpose of long term monitoring is to capture data relevant to qualifying the performance of the DG system in terms of the following parameters:

- electrical generation performance;
- electrical efficiency;
- thermal generation performance (if applicable);
- combined electrical and thermal efficiency (if applicable);
- operational performance;
- site impact;
- atmospheric emission performance (optional)*;

*The same atmospheric emission dataset identified in the ASERTTI Field Testing Protocol is recommended in this Protocol. It is recognized that atmospheric emission performance is a complex and expensive dataset to monitor on a continuous basis. Consequently it is classified as an optional dataset.

1.2 Synergy with Lab, Field and Use Case Protocols

While part of a suite of ASERTTI DG/CHP performance testing protocols, the Long Term Monitoring Protocol is designed to be applied as a standalone protocol. Conversely, the four ASERTTI protocols (Lab, Field, Case Study, Long Term Monitoring) are also intended to address different test settings that correspond to different phases in the life cycle of the DG unit.

Conceptually, the intended uses for the four protocols are summarized below:

- Laboratory Testing Protocol - theoretical performance of the DG unit under a controlled laboratory environment.
- Field Testing Protocol - field performance of the DG unit, installed in the specific context of a real-world site.
- Long Term Monitoring Protocol - continuous performance of the DG unit and system, installed in the specific context of a real-world site.
- Case Study Protocol - financial and qualitative assessment in the effectiveness of the DG unit and system installed in a specific application and operational context of a real-world site.

The Lab Testing, Field Testing and Long Term Monitoring Protocols use a common system boundaries definition.

Unlike the other ASERTTI protocols, long term monitoring is expected to be in effect continuously without an explicit completion timeframe. Consequently, the Protocol is designed to be synergistic with and supportive of the ongoing operation and maintenance (O&M) of the DG system. The data set and instrumentation locations stipulated by the Protocol are intended to be a permanent part of the DG system. The dataset collected is intended to be useful to the operator of the DG system on an on-going basis. Cost to support the long term monitoring is to be minimized. Consequently, performance trending using relative measurements is deemed more important than the absolute accuracy, uncertainty and calibration assurance required by the Lab and Field Testing protocols. This is not to say data validation and quality are not important to the Protocol. Rather, the condition of long term monitoring demands the DG system's performance data be compared on a relative basis over the history of the system's operation.

In the case where the DG system was tested in accordance with the Field Testing Protocol, it is recommended that the readings from the permanently installed instrumentation for long term monitoring be compared to the baseline readings taken with field testing instrumentation, if it is not one and the same. This comparison should be reported at the start of the long term monitoring to establish a relative performance baseline for long term monitoring. Previous application of the Field Testing Protocol is not a prerequisite for the application of the Long Term Monitoring Protocol.

1.3 Scope

The Protocol was specifically developed to:

- establish performance parameters that offer meaningful insights into the electrical, thermal (if applicable), operational, and environmental (optional) performance of continuously operated DG units;
- specify the reporting data fields, frequency and formatting necessary to assure that the data gathered at the long term monitoring sites can be readily included in the National DG/CHP database hosted by the National Renewable Energy Laboratory (NREL).
- specify the Meta Data[1] fields to be used as search criteria to locate the long term monitored site and the associated DG system in the national DG/CHP database.
- identify attributes of the data collection and reporting system that are capable of delivering information to support the on-going operational performance of the DG system;

Long term monitoring is expected to be in continuous operation for the life of the DG system.

The Protocol is applicable for new sites in the planning stage, or it may be retrofitted to existing sites. Further, it is strongly recommended that the data acquisition process be automated to minimize the use of manual data collection techniques. However, not all the data stipulated in the Protocol need to be acquired automatically. A combination of manual and electronic data

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[1] Meta Data means "data about data."

collection is acceptable. For example, it is expected that maintenance staff are capturing the DG/CHP system O&M logs on paper.

1.4 Intended Users

The Protocol is intended for operators of DG systems. It is assumed the reader has a basic understanding of electric power parameters, electrical generation and heat recovery systems, as well as basic metering and instrumentation knowledge.

1.5 Monitoring System Boundaries

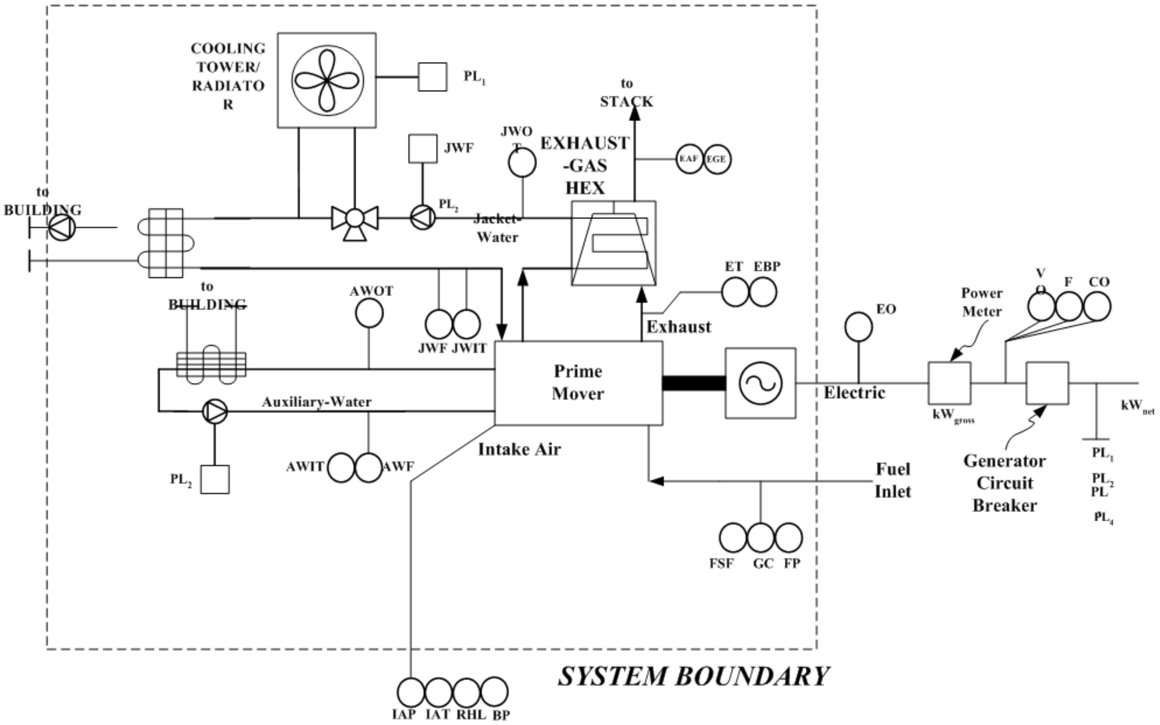
The purpose of defining system boundaries is to describe the elements of the installation that are within the scope of the long term monitoring. This Protocol subscribes to the same system boundaries defined in the Lab Testing and the Field Testing Protocols.

The boundaries are defined to provide an overall understanding of the DG system's impact on the host site in terms of benefits and shortcomings. The normative definition of the system boundaries for long term monitoring is:

"The system boundary includes the specific DG unit, associated heat recovery units (if a CHP application), internal parasitic loads, and essential auxiliary equipment (external parasitic loads), such as a fuel gas compressor or heat transfer fluid pump. Auxiliary equipment that serves multiple units in addition to the DG unit (such as large gas compressors) should be explicitly identified within the system boundary for the purpose of reporting. The system boundary should also include any thermal applications connected to the heat recovery unit (such as a chiller or hot water heater) to reflect overall benefits and shortcomings of the DG system."

Figure 2 below presents the system boundaries as a schematic diagram. This is the same diagram used to define system boundaries in the Lab Testing Protocol. Instrumentation points identified in the diagram are explained in the Lab Testing Protocol.

Figure 2: System boundary for Combined Heat and Power



2. DG System Performance Parameters

Measured system performance parameters must be sampled with a period no longer than five minutes. These samples can either be individually stored or averaged over 15-minute intervals and then stored. Calculated performance parameters must be calculated at least every 15 minutes. These measurement and calculation intervals should be considered recommended intervals. In instances where the data collection frequency is higher than the recommended frequency, the user may report the data at the higher frequency or average the data over 15-minute intervals. The timestamps associated with all data must include a time zone designation.

Some parameters are not measured or calculated according to the above frequencies:

- Operational performance parameters, rather than being sampled or averaged, must be recorded as discrete events. The timestamps must be recorded with a precision of one minute. The exception to this rule is Operation and Maintenance (O&M) hours and costs. The timestamps associated with these must be recorded with a precision of one day.
- Starting Reliability, which is a calculated parameter, must be calculated on at least a daily basis.
- The site elevation must only be determined once, at the time of commissioning.
- The specific heat and density of the heat transfer fluid is measured at the time of commissioning and then each time the fluid formula is altered.

The set of performance parameters for long term monitoring is listed in Section 2.2. Each data item is classified as a "required" or an "optional" item. Required items must be reported continuously for the duration of the DG System in accordance with the data capture frequencies described above. The optional items are parameters that users are encouraged to monitor and report on, in order to provide a comprehensive information base on the performance of the DG system. Due to additional instrumentation cost, users may choose to not monitor these optional items. Users are encouraged to report any of the optional data captured from accepted data sources in accordance with the specified data frequency.

2.1. Accepted Data Sources

This section provides a general description of the categories of data sources that are acceptable to the Protocol. An acceptable data source is a function of the parameter being measured. Data reporting must identify the following information for each data source:

- Manufacturer
- Model
- Accuracy Class
- Date Calibrated
- Calibration standard applied
- Signal Type (Pulse, 4-20mA, Serial Communication, etc.)
- Revenue Grade or Information Grade Meter (if applicable)

Acceptable data sources for reporting are:

- Revenue grade meter
    - These are meters deemed suitable for utility billing purposes. Examples are electricity power meters compliant with ANSI C12.1 or IEC 60687, 1.0 accuracy class or better. The accuracy class must be identified in the reports. Gas meters must be compensated for the actual fuel pressure and fuel temperature.
    - The revenue meters will need to be provisioned with an electronic output to automate data collection. Revenue meters can be ordered or retrofitted with pulse outputs (such as KYZ relay pulser). Meters are programmed with a pulse-ratio to correlate each pulse with a quantity of electric energy and gas volume. The pulses are accumulated to derive the kWh or scf measurements. Pulse frequency provides the rate readings such as kW or scf/minute. Revenue meters may also support electronic communication at an added cost.

- Information grade meter
    - These are intelligent meters used for data collection but are not explicitly compliant with ANSI C12.1 or IEC 60687, 1.0 accuracy class.
    - Meters in this category usually provide a rich dataset such as 3-phase Voltage, 3-phase current, per phase power, per phase energy, per phase power factor, and so forth.

- DG System Controller (or Control System)
    - This is the electronic controller attached to the DG unit provided by the manufacturer of the DG unit, or by a 3rd party control vendor delivering to the installer of the DG unit. The function of the controller is to provide the real-time process control of the DG unit. Communications with the DG controller for the purpose of extracting data are usually through an explicitly designed communication port on the controller. Selecting a controller supporting standard communication protocols such as Modbus will simplify the effort required.
    - The DG system's internal sensors and meters, which are installed internal to the DG package for the purpose of process control, may be available through the communication interface. These internal sensors may be used in lieu of additional external sensors and meters for certain identified parameters. It is acceptable to report the data from these sensors and meters as information grade readings, if it is explicitly identified and used starting from the inception of the project.

- Calculated
    - These are data values calculated using values from other measured data points, using inputs from discrete sensors installed internal or external to the DG unit or heat recovery loop (if applicable).

- Utility bill
    - Monthly bills from the electric or gas utility summarizing the energy consumption profile.

- Logs
    - Manually recorded operation and maintenance data. It is common practice to maintain paper logs near the DG installation for the operators to record instrument

readings and events associated with the operation and maintenance of the DG unit and system. The entries from these logs may be used to report the operational performance of the DG system.

- 3rd Party Agent Reports
  - Reports generated by specialized testing agencies to validate the atmospheric emission performance of the DG installation.
- Geological elevation database
  - A nationally recognized reputable source for geological data specific to the installed site such as elevation (altitude) of the site. An example is the National Elevation Dataset hosted by US Geological Service (http://edcnts12.cr.usgs.gov/ned/).

2.2. Performance parameters summary

2.2.1. Required parameters:

Parameters	**Units**	**Acceptable Data Sources**	**Accuracy (±)**
Electrical Generation Performance Parameters			
Net real power delivered	kW	Revenue Grade Electric Meter	1% full scale
Net electrical energy delivered	kWh	Revenue Grade Electric Meter	0.25 kWh
Inlet air temperature	° F	RTD, other device meeting required accuracy, or DG System Controller	1 ° F
Elevation at installation (above sea level)	Feet	Geological database	1 foot
Electrical Efficiency Parameters			
Fuel consumption	scf/minute	Revenue Grade Gas Meter	1% full scale
Fuel lower heating value (LHV)	Btu/scf Btu/gal	Gas Utility	
Net electric efficiency delivered (LHV)	%	Calculated	3%
Gross electric efficiency delivered (LHV)	%	Calculated	3%
Thermal Generation Performance Parameters			
Thermal energy recovered	MBtu/hr	Revenue Grade BTU Meter	10% full scale

Parameters	Units	Acceptable Data Sources	Accuracy (±)
		or Calculated	
Thermal energy utilized	MBtu/hr	Revenue Grade BTU Meter or Calculated	10% full scale
Heat transfer fluid specific heat	Btu/Lb-° F	O&M Log	0.1%
Heat transfer fluid density	Lb/gal	O&M Log	0.2%
Combined Electrical and Thermal (CHP) Efficiency Parameters			
Net combined electric and thermal (CHP) efficiency	%	Calculated	6%
Operational Performance Parameters			
System Availability	%	Calculated	1%
Operating Hours	h	Calculated	0.25 h
O&M Hours	h	O&M Log	1 h
Total O&M Cost (parts and labor)	$ USD	O&M Log	$1
Site Impact Parameters			
Installation electric demand	kWh	Revenue Grade Electric Meter or Monthly Utility bill	

2.2.2. Optional parameters:

Parameters	Units	Acceptable Data Sources	Accuracy (±)
Electrical Generation Performance Parameters			
Voltage (per phase)	V	Information Grade Electric Meter	1% full scale
Current (per phase)	A	Information Grade Electric Meter	1% full scale
Power factor (per phase)		Information Grade Electric Meter	2%

Parameters	Units	Acceptable Data Sources	Accuracy (±)
Voltage Total Harmonic Distortion	%	Information Grade Electric Meter	2%
Current Total Harmonic Distortion	%	Information Grade Electric Meter	2%
Ambient air temperature	° F	RTD, other device meeting required accuracy, or DG System Controller	1 ° F
Electrical Efficiency Parameters			
Gross real power generated (per phase)	kW	Information Grade Electric Meter	1% full scale
Gross electric energy generated (per phase)	kWh	Information Grade Electric Meter	0.25 kWh
Fuel Pressure	psig	Pressure sensor	1% full scale
Gross reactive power generated	kVAR	Information Grade Electric Meter	1% full scale
Net reactive power delivered	kVAR	Information Grade Electric Meter	1% full scale
Parasitic power consumed (per phase)	kW	Calculated - can be based on one-time measurement	1% full scale
Parasitic energy consumed (per phase)	kWh	Calculated - can be based on one-time measurement	0.25 kWh
Fuel higher heating value (HHV)	Btu/scf Btu/gal	Gas Utility	
Net electric efficiency delivered (HHV)	%	Calculated	1%
Gross electric efficiency delivered (HHV)	%	Calculated	1%

Parameters	**Units**	**Acceptable Data Sources**	**Accuracy (±)**
Thermal Generation Performance Parameters			
Heat recovery loop flow rate (if applicable)	gph	Flow sensor	1% full scale
Heat recovery loop inlet temperature (if applicable)	° F	RTD or other device meeting required accuracy	1 ° F
Heat recovery loop outlet temperature (if applicable)	° F	RTD or other device meeting required accuracy	1 ° F
Combined Electrical and Thermal (CHP) Efficiency Parameters			
Gross combined electric and thermal (CHP) efficiency	%	O&M Log or Calculated	1%
Operational Performance Parameters			
Starting Reliability	%	Calculated	1%
Number of Start Attempts		O&M Log	0
Number of Successful Starts		O&M Log	0
Atmospheric Emissions		3rd Party Agent	

2.3. Electrical Generation performance

2.3.1. Instrumentation Locations:

Figures 3 and 4 are simplified schematics showing the recommended locations for installing instrumentation to measure the electrical generation performance.

Figure 3 shows a DG unit with all internal parasitic loads. An electric meter installed at the output of the DG unit at the location designated by JT-10 measures the net electric production delivered to the site's load. A revenue grade meter capable of reading power in kW and energy in kWh is recommended.

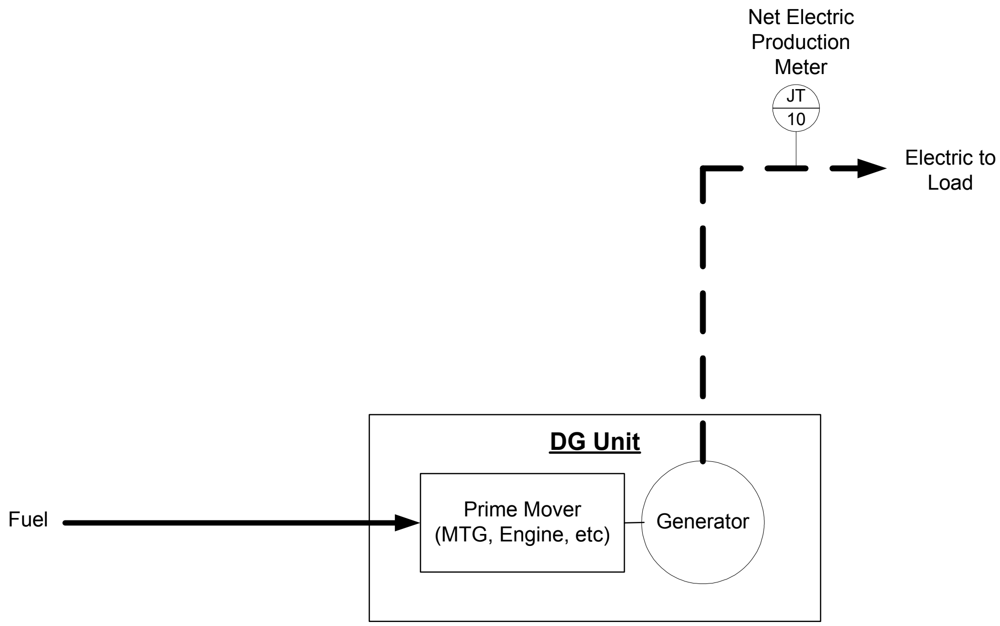


Figure 3: DG Unit with Internal Parasitic Loads

Figure 4 shows a DG unit with external parasitic loads. An electric meter (JT-11) is installed at the output of the DG unit and measures the gross electric production of the DG unit. A separate electric meter (JT-10) is installed after the parasitic loads and measures net electric production of the DG unit. A revenue grade meter capable of reading power in kW and energy in kWh is recommended for measuring the net electric production. An information grade meter capable of reading power in kW and energy in kWh is recommended for measuring the gross electric production.

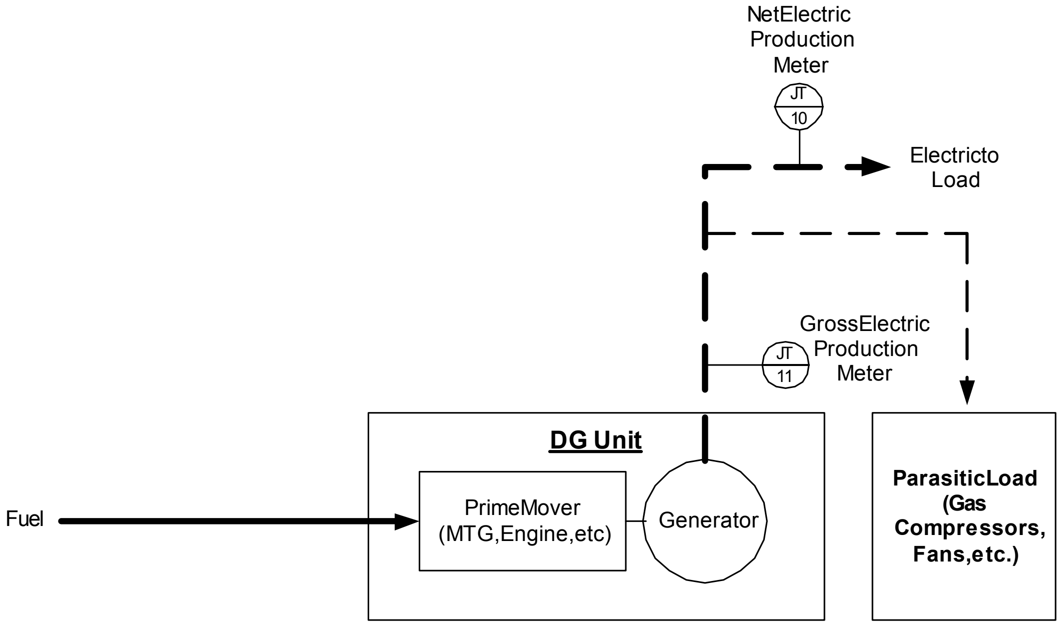


Figure 4: DG Unit with External Parasitic Loads

Alternatively the gross electric production values in kW and kWh provided by the DG unit's electronic controller or control panel may be used in lieu of a separate information grade meter, provided the data satisfies the data formatting specifications listed in 2.2.2.

Inlet air temperature should be measured at the inlet air intake of the prime mover, away from direct air flow and shielded from sunlight and other radiant sources that may alter the readings. When it is not possible to locate a permanently installed temperature sensor at the inlet location, it is acceptable to install a sensor near the DG system to capture and report the optional ambient air temperature in lieu of the inlet temperature. It is required to report the difference between the ambient and inlet temperature at the inception of the project using a hand-held thermometer to capture the inlet temperature. It is strongly recommended this difference reading be verified whenever air flow near the intake may be altered.

The optional per phase voltage, current, voltage harmonic, current harmonic, and power factor data may be reported using the Gross Electric Meter readings or the Net Electric Meter readings. The source meter must be identified and remain unchanged for the duration of the reporting period. Numerous information grade electronic meters convey these optional parameters in addition to the basic power and energy readings.

2.4. Electrical efficiency

2.4.1. Instrumentation Locations:

Figure 5 is a simplified schematic showing the recommended locations for installing instrumentation to measure the parameters necessary to calculate gross and net electrical efficiency.

Figure 5 shows a DG unit without heat recovery and with all external parasitic loads.

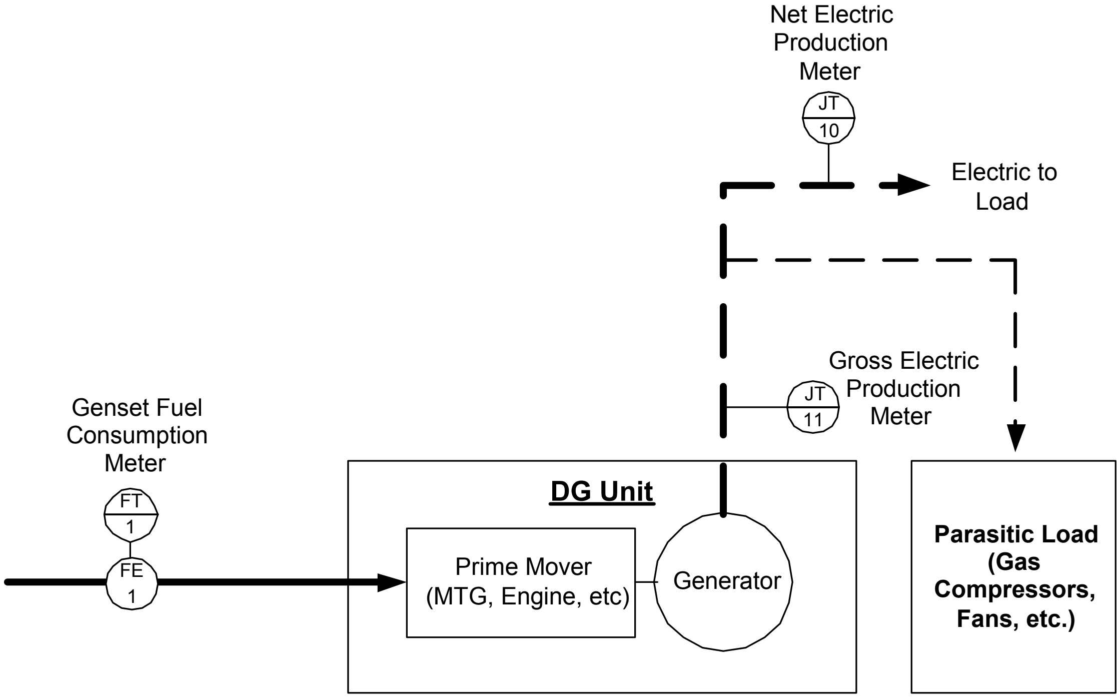


Figure 5: DG Unit With External Parasitic Loads and No Heat Recovery

An electric meter installed at the output of the DG unit at the location designated by JT-11 measures the gross electric production by the DG unit. A separate electric meter installed after the parasitic loads at the location designated by JT-10 measures net electric production of the DG unit. A revenue grade meter capable of reading power in kW and energy in kWh is recommended for measuring the net electric production. An information grade meter capable of reading power in kW and energy in kWh is recommended for measuring the gross electric production.

2.4.2. Measurement Procedures and Calculations:

The efficiency is calculated as a ratio of the output power and equivalent input power. Both net and gross output electric power are needed to calculate the required efficiency parameters. The net electric power is the reading provided by the net electric meter. The gross electric power is the reading provided by the gross electric meter.

Equation (1) specifies the formula for the calculation of net electric efficiency:

Equation 1: Net Electric Efficiency Calculation

$$n_{NET} = \frac{Net\ P_{REAL}(kW)}{FuelConsumption(\frac{Ft^3}{\min}) \times \frac{60\min}{hour} \times Fuel\ LHV(\frac{Btu}{Ft^3}) \times \frac{kWh}{3412Btu}} \times 100$$

where the denominator is the consumed fuel's equivalent electric power in kW:

$$P_{FUEL \cdot INPUT}(kW) = FuelConsumption(\frac{Ft^3}{\min}) \times \frac{60\min}{hour} \times Fuel\ LHV(\frac{Btu}{Ft^3}) \times \frac{kWh}{3412Btu}$$

Equation (2) specifies the formula for the calculation of gross electric efficiency:

Equation 2: Gross Electric Efficiency Calculation

$$n_{GROSS} = \frac{Gross\ P_{REAL}(kW)}{P_{FUEL \cdot INPUT}(kW)} \times 100$$

Equation (3) specifies the formula for the calculation of total parasitic kW:

Equation 3: Parasitic Power Calculation

$$P_{PARASITIC}(kW) = Gross\ P_{REAL}(kW) - Net\ P_{REAL}(kW)$$

Equation (4) specifies the formula for the calculation of total parasitic kWh:

Equation 4: Parasitic Energy Calculation

$$E_{PARASITIC}(kWh) = Gross\ E_{REAL}(kWh) - Net\ E_{REAL}(kWh)$$

The formal definition of electric power (P in kW) and electric energy (E in kWh) is provided in Section 2.2 of the Field Testing Protocol.

2.5. Thermal generation performance

2.5.1. Instrumentation Locations:

Figures 6 and 7 are simplified schematics showing the recommended locations for installing instrumentation to measure the parameters associated with the thermal generation performance.

The thermal generation performance refers to the useful heat recovered from the waste heat using the heat transfer fluid. Although other heat transfer schemes such as direct-exhaust are not directly specified in this protocol, the parameters should be reported based on the same principle stipulated in this protocol.

The thermal energy recovered is differentiated from the thermal energy utilized in installations where a bypass, dump cooler or separate radiator is used to remove from the heat recovery loop the excess heat not consumed by the site. Figure 6 illustrates a system where 100% of the heat recovered is consumed by the site. In this instance thermal energy recovered and thermal energy utilized are the same. Figure 7 illustrates a system where an external dump cooler/radiator is used to remove the heat (e.g. lower the heat exchanger's inlet temperature) not consumed by the site. In this instance the heat recovered is higher than the heat utilized.

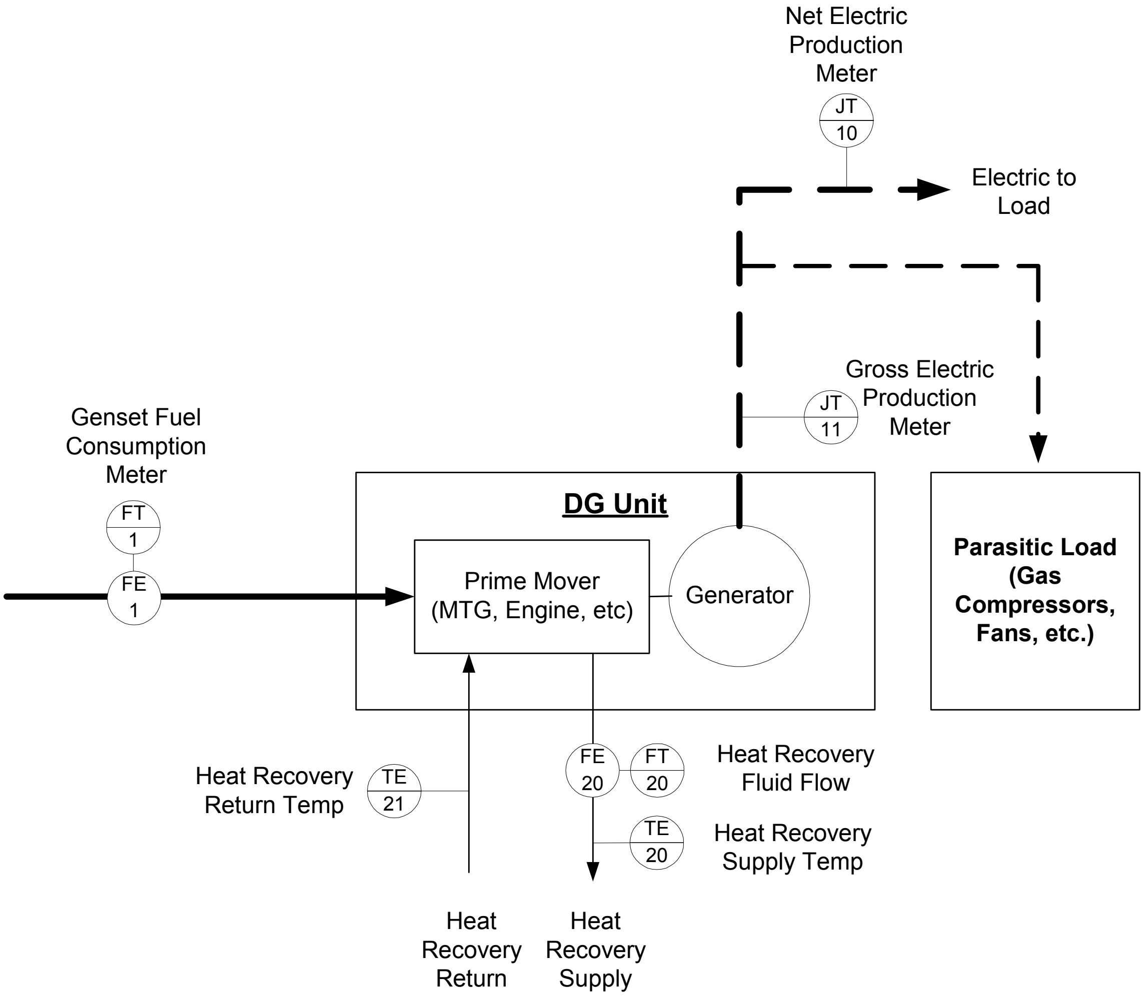


Figure 6: DG Unit with Heat Recovery, No External Dump, External Parasitic Load

2.5.2. Measurement Procedures and Calculations:

Thermal energy may be measured using a dedicated "BTU Meter" or calculated using separate temperature and flow rate parameters.

Equation (5) specifies the formula for the calculation of heat rate in MBtu/hour:

Equation 5: Heat rate calculation (MBtu/hour)

$$Q = \frac{T_{\Delta}(^{\circ}\mathrm{F}) \times Specific\ Heat(\frac{Btu}{Lb \cdot {}^{\circ}\mathrm{F}}) \times Flow(gph) \times Density(Lb/gallon)}{1000 \frac{Btu}{MBtu}}$$

where: $T_{\Delta}(^{\circ}\mathrm{F}) = Outlet\ Temperature(^{\circ}\mathrm{F}) - Inlet\ Temerature(^{\circ}\mathrm{F})$

For thermal energy recovered, the parameters for equation (5) are:

- Outlet Temperature: TE20
- Inlet Temperature: TE21
- Flow: FT20

For thermal energy dumped (not used by the site), the parameters for equation (5) are:

- Outlet Temperature: TE25
- Inlet Temperature: TE26
- Flow: FT25

Equation 6 specifies that the difference between thermal energy recovered and thermal energy dumped is equal to the thermal energy utilized by the site:

Equation 6: Thermal energy utilized calculation

$$Q_{UTIL} = ThermalEnergyUtilized(\frac{kBtu}{hour}) = Q_{REC} - Q_{DUMPED}$$
$$Q_{UTIL} = Thermal\ Energy\,\mathrm{Re}\,\mathrm{cov}\,ered - ThermalEnergy\ Dumped$$

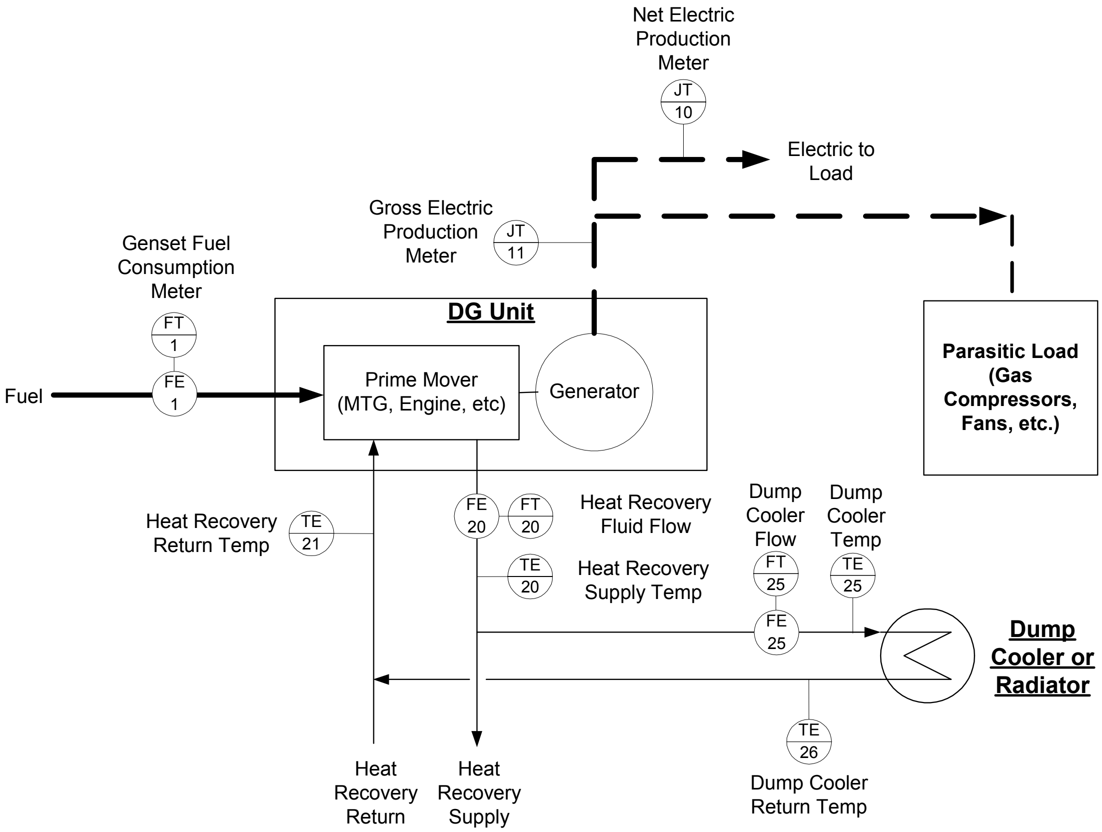


Figure 7: DG Unit with Heat Recovery, External Heat Dump, External Parasitic Load

2.6. Combined electrical and thermal efficiency

2.6.1. Instrumentation locations:

Figures 6 and 7 are simplified schematics showing the recommended locations for installing instrumentation to measure the parameters associated with the thermal generation performance.

2.6.2. Measurement Procedures and Calculations:

For Combined Heat and Power (CHP) systems, the combined electrical and thermal efficiency is calculated by adding the equivalent power of the heat generated/recovered to the electric power produced. Equation 7 specifies the conversion of heat rate in MBTU/Hr to equivalent real power in kW:

Equation 7: Heat equivalent power

$$P_{QGEN}(kW) = \frac{Q_{GEN}(MBtu/hour)}{3.412\frac{MBtu}{kWh}}$$

$$P_{QNET}(kW) = \frac{Q_{NET}(MBtu/hour)}{3.412\frac{MBtu}{kWh}}$$

Equations (8) and (9) specify the gross and net CHP efficiency:

Equation 8: Gross CHP Efficiency

$$n_{CHP\cdot GROSS} = \frac{Gross\ P_{REAL}(kW) + P_{QGEN}(kW)}{P_{FUEL\cdot INPUT}(kW)} \times 100$$

Equation 9: Net CHP Efficiency

$$n_{CHP \cdot NET} = \frac{NET\ P_{REAL}(kW) + P_{QNET}(kW)}{P_{FUEL \cdot INPUT}(kW)} \times 100$$

2.7. Operational Performance

2.7.1. Measurement Procedures and Calculations:

The following are the factors for calculating the system availability (%) of the system:

- *Total period hours* (PH) = total number of hours since system commissioning.
- *Scheduled outage hours* (SOH) = total number of scheduled outage hours since commissioning.
- *Forced outage hours* (FOH) = total number of unscheduled outage hours since commissioning.
- *Scheduled non-operating hours* (SNH) = total number of scheduled hours since commissioning the system is intentionally non-operating but not under a scheduled outage or a forced outage.
- *Scheduled unloaded hours (TUH)* = total number of hours when the system is running (e.g. prime mover is consuming fuel) but no electric or thermal output is produced by the system.

Here are further clarifications of operational performance parameters:

- O&M Hours = total number of hours where operations and maintenance was performed. O&M hours could occur during *Scheduled outage hours* and *Forced outage* hours.
- O&M cost = total cost for performing O&M service including labors and parts.

Equation (10) specifies the calculation of System Availability:

Equation 10: System Availability calculation

$$Availability(\%) = \frac{TVH * 100}{PH}$$

where:

- *Total system available hours (TVH) = Total period hours (PH) - Scheduled outage hours (SOH) – Forced outage hours (FOH)*

Equation 11 specifies the calculation of total operating hours:

Equation 11: Operating Hours Calculation

$$Operating\ Hours = TVH - TUH - SNH$$

Equation 12 specifies the calculation of starting reliability:

Equation 12: Starting Reliability (SR) Calculation

$$SR(\%) = \frac{Number\ of\ Successful\ Starts}{Number\ of\ Starting\ Attempts}$$

2.8. Site impacts

2.8.1. Measurement Procedures and Calculations:

The purpose for these data is to support the assessment in the benefits of the CHP System to the installation. These data are also useful for comparing different CHP installations in order to explain differences in performance characteristics between the two installations. The installation electric demand is the total electric demand of the site, building or location where the CHP System is principally interconnected.

3. Data Collection and Reporting

3.1. Data Validation

Data accuracy is critical to deliver the intended value of long term monitoring. Good data are necessary to enable the presentation of useful information that can lead to beneficial operational decisions and actions. They are also necessary to instill confidence in the system users so that these users will view the system as a useful tool and continue to use it and derive benefit from it. Data *validation*, which allows for the detection and correction of data errors, is the tool used to ensure data accuracy. Recommended practices and procedures to validate the data identified in this protocol can be found in Appendix C.

3.2. Automated Data Collection

The Protocol recognizes that typically the recommended data collection frequency for electrical, thermal and efficiency parameters may only be practically realized with an automated data collection system. The cost of such a system may be minimized when long term monitoring is included during the engineering design stage of the planning process.

Examples of planning steps to facilitate long term monitoring are

- requesting KXY relay outputs be provisioned with the electric and gas meters from utilities;
- installation of thermal temperature sensors at the heat exchanger's inlet from the manufacturer;
- specifying an additional electric meter to differentiate between gross and net electric production;
- specifying additional thermal and flow sensors for the heating loops;
- requesting electrical and thermal demand profiles at the installation for the assessment of site impact;
- specifying a thermal sensor for ambient temperature in lieu of inlet air intake temperature;
- requesting parameters for long term monitoring be provided by the control system vendor;

It is also recommended that the monitoring equipment be installed and operational prior to the CHP System start-up. This will allow a baseline of electric and thermal demands to be established prior to operating the CHP System. These data shall serve to compare the performance of the new CHP System with the pre-CHP state.

3.3. Data Frequency

The recommended data collection frequencies need to be rationalized with respect to the specific application of the CHP system under monitoring. The frequencies specify the sampling rate of the data. They are specified conservatively to assure capturing any variations that could provide insight into the performance of the CHP system and allow different CHP systems to be meaningfully compared. In instances where a higher data-sampling rate is used, the reader may average the data into 15-minute periods.

Appendix A: Acronyms and Abbreviations

A	ampere
acfh	actual cubic feet per hour
ASERTTI	Association of State Energy Research and Technology Transfer Institutions
ASTM	American Society for Testing and Materials
Btu	British thermal unit
Btu/h	Btu per hour
Btu/kWh	Btu per kiloWatt-hour
Btu/lb	Btu per pound
Btu/scf	Btu per standard cubic foot
BoP	balance of plant
c_p	specific heat (constant pressure)
CARB	California Air Resources Board
CEC	California Energy Commission
CH_4	methane
CHP	combined heat and power
cm	centimeter
CO	carbon monoxide
CO_2	carbon dioxide
CoP	coefficient of performance
CSV	comma-separated value
CT	current transformer
dB	decibel
DG	distributed generation
DOE	US Department of Energy
DUT	device under test
DVM	digital volt meter
dscfh	dry standard cubic feet per hour
ECW	Energy Center of Wisconsin
EPA	US Environmental Protection Agency
EPS	electric power system
ETV	Environmental Technology Verification
FID	flame ionization detector
FS	full scale
GC/FID	gas chromatography with flame ionization detector
GHG	greenhouse gas
gph	gallons per hour
gpm	gallons per minute
gr/dscf	grains per dry standard cubic foot
GTI	Gas Technology Institute
h	hour
HHV	higher heating value
Hz	Hertz
IC	reciprocating internal-combustion engine
ID	induced draft
ISO	International Organization for Standardization
kAIC	kiloampere interrupt current
kVA	kilovolt-ampere (apparent power)
kVAR	kilovolt-ampere reactive (reactive power)
kW	kilowatt (real power)
kWh	kilowatt-hour
LHV	lower heating value
lb	pound
lb/gal	lb per gallon
lb/h	lb per hour
lb/kWh	lb per kWh
lb/lb.mol	lb per lb-mole
M	motor
mA	milliamp
ml	milliliter
mph	miles per hour
m/s	meters per second
MTG	microturbine generator
MTG-CHP	MTG with CHP
NDIR	non-dispersive infra-red
NIST	National Institute of Standards and Technology
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
O_2	oxygen
PC	personal computer

PCC	point of common coupling
PF	power factor
PG	propylene glycol
ppm	parts per million
ppmv	ppm, volume basis
psia	pounds per square inch, absolute
psig	pounds per square inch, gage
PT	potential transformer
QA/QC	quality assurance / quality control
rms	root-mean-square
RT	refrigeration ton
SAC	Stakeholder Advisory Committee
scf	standard cubic feet
scfh	scf per hour
SO_2	sulfur dioxide
SUT	system under test
THC	total hydrocarbons
THD	total harmonic distortion
THCD	total harmonic current distortion
THVD	total harmonic voltage distortion
TPM	total particulate matter
UIC	University of Illinois at Chicago
V	volt
VA	volt-ampere (apparent power)
VAR	volt-ampere reactive (reactive power)
w	Watt
^{o}C	degree Centigrade
^{o}F	degree Fahrenheit
^{o}R	degree Rankine, absolute
ΔT	absolute temperature difference, ^{o}R or ^{o}F
η	efficiency, percent
ρ	density, lb/gal

Notation for References, Tables etc.

All figures and tables in the Protocol document are numbered using the Section number followed by a sequential digit. Appendices replace the Section number with the Appendix letter. Example references within the test are:

Figure 3-2	The second figure in Section 3
Table 6-1	The first table in Section 6
Eqn. D18	The 18th equation occurring in Appendix D

References within the main text appear as a sequential number within square brackets, or [4] (fourth reference in the document) and may be found at the back of the document. References within the appendices appear as[D4] (fourth reference in Appendix D) and may be found at the back of the indicated appendix.

Appendix B – Meta-data List

The purpose of Meta Data is to provide a set of concise descriptors for the long term monitored sites that are logical for users to use as search criteria to locate the site and the associated DG system in the national DG/CHP database. The Meta Data also provides the Users a snapshot of the performance for the DG systems organized by technology, application, location, etc. A common list of Meta Data will be used for all four ASERTTI Testing Protocols.

Meta Data	Definition	Domain	Applicable Test Types
Site Data			
Organization Name	Name of the organization (company, test site) where DG system was installed and tested. This name must also identify the system if the site has tested more than 1 system, as lab test sites might (e.g., DG Testing Laboratory - Westinghouse Unit 234).		All
City	City in which the test was performed		All
State	State in which the test was performed		All
Description	Type of facility in which distributed energy system was installed; select 1	Agriculture, Commercial - hotel, Commercial - ice arena, Commercial - office-high rise, Commercial - office-low rise, Commercial - refrigerated warehouse, Commercial - restaurant, Commercial - retail store, Commercial - supermarket, Commercial - theater, Commercial - other, Industrial - food processing, Industrial - plastics processing, Industrial - wood/wood products, Industrial - other, Institutional - hospital/healthcare, Institutional - school/university, Institutional - nursing home, Institutional - other, Residential - multifamily-single building, Residential - multifamily–multibuilding, Residential - single family, Testing Laboratory, Water Utility, Other Utility, Other	All
Altitude - feet	Altitude of site, in feet		All

Meta Data	**Definition**	**Domain**	**Applicable Test Types**
System Data			
DG System Enclosure	Describes whether/how the system is enclosed; select 1	Indoor (I), Dedicated Shelter (DS), Outdoor (O)	All
System Application	Defines whether the distributed generation system is used to produce power only or for combined heat and power; select 1	Electric Power Only (E), Combined Heat and Power (C)	All
Number of prime movers	Number of prime movers for generating electricity in the distributed energy system		All
Stand-alone Capability	Ability of system to operate in stand-alone mode and type of transfer between stand alone and grid connected mode; select 1	No (N), Seamless Transfer (YS), Manual Transfer (YM), Auto Transfer <=10sec Delay (YAL), Auto Transfer >10sec Delay (YAM)	All
Power Rating - kW	Power generation rating of the system, in kW (total combined rating if the distributed energy system has more than one prime mover)		All
Nominal Voltage - V	Voltage output normally generated, in Volts		All
Heat Recovery - BTU	If applicable, heat recovery rating, in BTU/hr; (total combined heat recovery rating if multiple units)		All
Cooling Capacity - RT	If applicable, total rated cooling capacity in refrigeration tons		All
Component Integration	Party responsible for integrating system components; select 1	Factory Integrated (F), Customer Assembled (C)	Field, Long-term, Case Study
Controller	Origin of equipment controller; select 1	Manufacturer Integrated (M), Third Party Off-the-shelf (OTS), Third Party Custom (CUST)	All
System Installer	General contractor for the installation of the distributed energy system		Field, Long-term, Case Study

Meta Data	Definition	Domain	Applicable Test Types
Point of Contact Data			
Name	Name of the individual responsible for meta data and test report, and point of contact for the quality checking process.		All
Organization	Organization with which the POC is affiliated		All
Email	Email address of the individual responsible for meta data and test report		All
Telephone	Telephone number of the individual responsible for meta data and test report		All
Prime Movers (may be more than 1 per site; include only distinct units)			
Technology Type	Type of prime mover technology; select 1	Internal Combustion Engine (ICE), Microturbine (MT), Gas Turbine (GT)	All
Manufacturer Name	Company that manufactured the prime mover		All
Model Number	Model number assigned by the manufacturer to the prime mover		All
Inverter-Synchronous-Induction	select 1	Inverter (INV), Synchronous Generator (SG), Induction Generator (IG)	All
Rated Power - kW	Power output rating of the prime mover, in kW		All
Heat Recovery Equipment (may be none, one or more than one per site; include only distinct units)			
Technology Application	Type of heat recovery technology	Domestic Hot Water/Space Heating/HVAC Reheat (DHW), Cooling/Dehumidification (CD), Process Heat (PH), Combustion Air Preheat (CAP), Other (O)	All

Meta Data	**Definition**	**Domain**	**Applicable Test Types**
Manufacturer Name	Company that manufactured the heat recovery unit		All
Model Number	Model number assigned by the manufacturer to the heat recovery unit		All
Heat Recovery Rating	Heat recovery rating of the unit, in BTU/hr		All
System Operation			
URL	Internet address of the detailed long-term monitoring data		Long-term
Test Type	The type of test or study that was performed; select 1	Lab (LT), Field (FT), Long-term (LTM), Case Study (CS)	All
Start Date	Date on which data collection was begun		All
Testing/Monitoring Termination Date	Date on which data collection on the DG system was terminated		All
Fuel	Fuel used during the test/study period; select 1 or more	Natural Gas (NG), Biogas (BG), Propane (P), Diesel (D), Biodiesel (BD), Other (O)	All
Primary Power Application	Primary use of generated power; select 1	Base Load (BL), Peak Shaving (PS), Backup (BU), VAR Support (VAR), Other (O)	Field, Long-term, Case Study
Secondary Power Application	If applicable, secondary use of the generated power; select 1	Base Load (BL), Peak Shaving (PS), Backup (BU), VAR Support (VAR), None (N), Other (O)	Field, Long-term, Case Study
Primary Heat/Cooling Application	Primary use of recovered heat; ie, end use to which the highest amount of recovered energy is directed; select 1	Space Heat and/or Cooling (SHC), Process Heat and/or Cooling (PHC), Domestic Hot Water (DHW), Refrigeration (R), None (N), Other (O)	Field, Long-term, Case Study
Secondary Heat/Cooling Application	If applicable, secondary use of the recovered heat; ie, end use to which the second highest amount of recovered energy is directed; select 1	Space Heat and/or Cooling (SHC), Process Heat and/or Cooling (PHC), Domestic Hot Water (DHW), Refrigeration (R), None (N), Other (O)	Field, Long-term, Case Study
Average Fuel HHV	Average Higher Heating Value of the fuel(s) used during the testing/monitoring period**. This is optional.**		All

Meta Data	**Definition**	**Domain**	**Applicable Test Types**
Average Fuel LHV	Average Lower Heating Value of the fuel(s) used during the testing/monitoring period		All
Heating Value Units	Units in which heating values are presented; select 1	BTU/std cu ft (BTU_per_SCF), BTU/gal (BTU_per_Gal)	All
Highest Combustion Intake Air Temp - F	Highest temperature of the combustion intake air during the testing or monitoring period; degrees F		Field, Long-term, Case Study
Lowest Combustion Intake Air Temp - F	Lowest temperature of the combustion intake air during the testing or monitoring period; degrees F		Field, Long-term, Case Study
NOx Emissions Data Available	Does the report include NOx emissions data?	Y/N	Field, Long-term, Case Study
CO Emissions Data Available	Does the report include CO emissions data?	Y/N	Field, Long-term, Case Study
Capacity Factor	The ratio of the gross electricity generated, for the period of time considered, to the energy that could have been generated at continuous full-power operation during the same period (the testing or monitoring period); a fraction between 0 and 1. **This is optional.**		Long-term, Case Study
Availability	The number of hours in a given time period that the unit was in the available state (the state in which a unit is capable of providing service at any capacity, whether or not it actually is in service), divided by the total number of possible operating hours in that time period (the testing or monitoring period); a percent between 0 and 100%. **This is optional.**		Long-term, Case Study
Electrical Efficiency - HHV	Average net electrical efficiency over the testing or monitoring period and over all load levels; based on fuel higher heating value; calculated as 100 x kWh net electrical output / kWh fuel input. A percent between 0 and 100%. **This is optional.**		All

Meta Data	**Definition**	**Domain**	**Applicable Test Types**
Electrical Efficiency - LHV	Average net electrical efficiency over the testing or monitoring period and all load levels based on fuel lower heating value; calculated as 100 x kWh electrical output / kWh fuel input. A percent between 1 and 100%.		All
Run Hours	Total hours of operation since testing or monitoring was begun, in hours		Long-term, Case Study
12-Month Energy Savings	If available, value of energy saved during most recent 12-month period due to the distributed energy system, in $		Case Study
DG System Cost	Total installed first cost of the distributed energy system, in $		Case Study

Appendix C: Recommended Data Validation and Quality Assurance Practices

1. Introduction

This set of practices was developed by Connected Energy Corp. as part of the ASERTTI (Association of State Energy Research and Technology Transfer Institutions) project to develop standardized testing and comparison methods to facilitate the adoption of distributed generation (DG), including combined heat and power (CHP), technology. The program includes the development of four protocols: a laboratory test protocol, a field test protocol, a case study protocol, and a long-term monitoring protocol. The data validation practices attempt to ensure that the performance data from these four protocols are accurate and valid so that they present a true picture of the equipment's performance. Although the practices can be applied to data obtained from any of the four protocols, they are most relevant to the long-term monitoring protocol. Much of the data validation in the lab and field test protocols is accomplished through the definition and use of the measurement uncertainties described in those protocols. These uncertainties may also be used as input when defining the parameters for the techniques described in this document. Once the data from the four protocols are validated, they may be used for performance analysis of the DG/CHP systems and for other data mining purposes to extract useful information that will further the understanding of the DG/CHP systems or components.

Data accuracy is an important component of any remote monitoring system. Good data are necessary to enable the presentation of useful information that can lead to beneficial operational decisions and actions. They are also necessary to instill confidence in the system users so that these users will view the system as a useful tool and continue to use it and derive benefit from it. Data *validation*, which allows for the detection and correction of data errors, is the tool used to ensure data accuracy.

This Data Validation Protocol is divided into four (4) sections describing the following areas:

1. The types of data errors and their associated causes
2. The available methods to detect data errors
3. Proposed corrective actions
4. Data validation procedures.

2. Types and Causes of Data Error

In Connected Energy's experience most data errors can be traced to the following root causes (Figure 1):

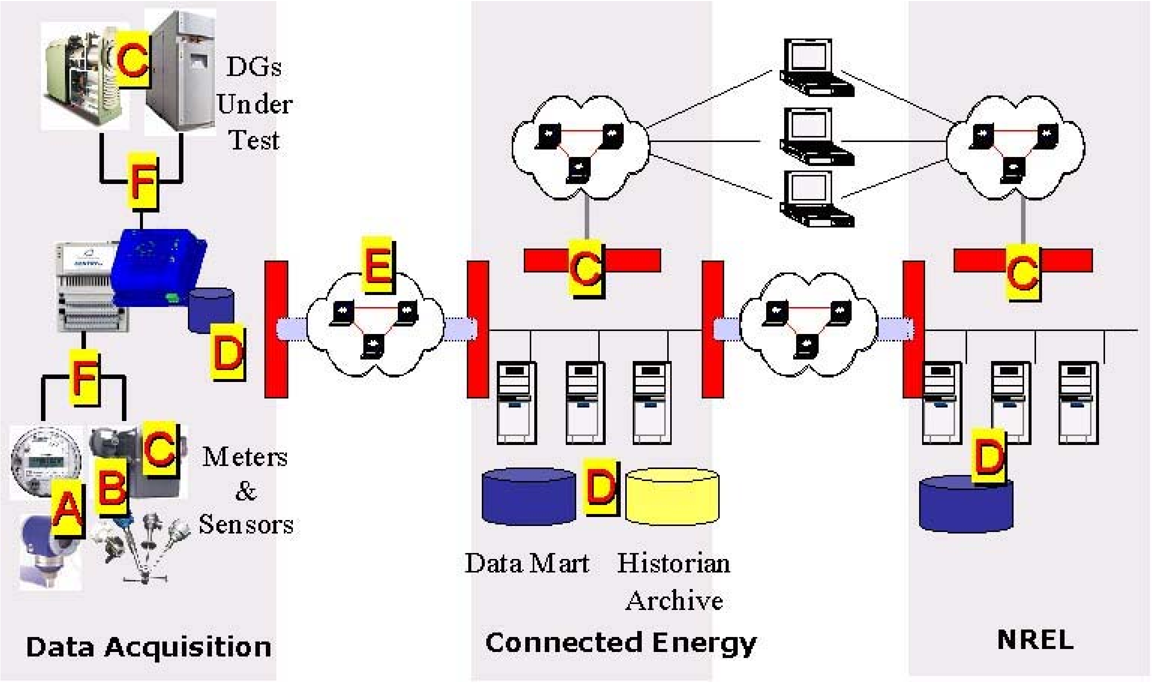
A. Malfunctioning meters and sensors.
B. Miscalibrated, inaccurate, or drifting meters and sensors.
C. Misunderstanding or misuse of the data.
D. Improper configuration of the data storage system.

Communication problems:

E. between the data collection device and remote data storage.
F. between the meters/sensors and the data collection device.

Figure 1 below illustrates the sources of data error in the data path for the DG/CHP performance database:

Figure 1



These root causes can manifest themselves in several types of data error. Recognizing the error types is a prerequisite to error detection.

2.1. Out-Of-Range Data

The most common manifestations of a malfunctioning or inaccurate meter are **out-of-range** data and **totalizer resets**. Out-of-range data often occur when equipment is shutdown. For example, a kW reading may display a very large or very small value instead of going to zero. Totalizer resets occur when counters that measure quantities such as total equipment running hours or generated kWh reset to zero in an undesirable fashion. This may happen when the value becomes sufficiently large or after some type of maintenance is performed on the meter causing the totalized value to reset. Another example is totalizers that are designed to measure monthly totals not resetting exactly at the beginning of a new month.

2.2. Biased Data

Another manifestation of an inaccurate meter is **data bias** or **random error**. Data bias is indicated by measurements that are consistently too high or too low; random error shows no obvious pattern. These errors are within the acceptable measurement range but are nonetheless inaccurate. They are therefore less noticeable than out-of-range data but may become readily apparent once calculations are performed on the data. For example, a relatively small error in a fuel flow or power output reading may lead to a calculated efficiency greater than 100 percent.

Data bias may be caused by installation errors or by spatial variations. Spatial variations can be remedied by adjusting the sensor location or by using multiple probes. Other causes of data bias can usually be corrected by calibration of the measurement device.

2.3. Misapplied Data

Misunderstanding the discreet nature of certain data or attempting to obtain real-time measurements from these data can result in **data spikes**. For example, at many DG/CHP sites, real-time fuel flow readings are captured from KXY relay pulse-type meters. These meters rely on the measurement of a given flow volume to produce an output signal pulse. Therefore, when they are used to produce *real-time* fuel flow and efficiency measurements, the quantization errors during the accumulation intervals can lead to spikes in the calculated values.

Similar behavior can also be observed when performing calculations using inputs with different scan rates. This is especially noticeable under transient conditions such as during system start-up or shutdown.

Misunderstanding data can also lead to apparently erroneous **unequal values**. For example, one may expect a measurement of a DG unit's running hours to match the number of hours that the kW output was greater than zero. However, if the kW reading does not drop to zero at the exact time the running hours cease accumulating, the two approaches will not yield matching results. If the equipment is frequently started and stopped, measurements of the monthly running hours can differ significantly.

Differing results can also occur due to measurement uncertainty. Performing calculations using data from different meters or sensors may magnify the underlying uncertainty leading to calculated values that are significantly different.

2.4. Problems with Data Communication

Communication problems and data storage configuration problems most frequently manifest themselves as **data gaps** and **uncorrelated data**. Data gaps are simply "holes" in the data. The data are missing from the database either because a lack of physical connectivity prevented the data from being acquired or transmitted to the data center or because the database was improperly configured and rejected the data. Uncorrelated data describe an incongruous situation that could not possibly exist in reality. For example, a disconnected fuel flow sensor may result in a zero fuel flow measurement while the power output sensor shows power being generated.

3. Detecting Data Errors

Experience shows most data errors occur at the beginning of a DG/CHP project when meters and sensors are being installed, the system is being commissioned, and users are learning the meaning of the data and deciding how they should be displayed and reported. Most of the errors that occur at this time can be identified upon manual inspection of the data. Other errors become apparent once calculations such as efficiency calculations are performed on the data. However, manual inspection is error prone and slows the commissioning process when a large volume of data is involved. Automating the inspection process while allowing manual intervention when needed can result in higher data quality. This is the recommended approach for data acquired from DG/CHP sites under long-term monitoring.

Once the DG/CHP system has been in continuous operation, experience shows data errors are usually associated with communication problems or with maintenance actions performed on the DG/CHP unit. More subtle errors, such as data bias, may also become apparent during this time. These errors are much more easily detected by an automated process.

3.1. Employing a Staging Environment

Since invalid data can corrupt a database and lead to inappropriate user actions, every effort should be made to ensure a system is configured properly and functioning correctly before it is declared operational. The preferred method of doing this is to use a "staging" environment at the beginning of a monitoring project, when the likelihood of error occurrence is the highest, so that invalid data will be prevented from entering the production performance database. The staging environment has the same configuration as the production environment. When a long-term test DG/CHP system is initially commissioned, the data are first collected, stored and processed in the staging server. The Stakeholders verify that the meters, sensors, and DG/CHP system are connected and functioning properly. This is the initial level of validation of the data and the techniques used to detect invalid data. Online reports should be verified for accuracy at this time since errors not apparent in the real-time data often become apparent in summarized reports. For example, power output and fuel consumption measurements may look correct until they are used in an efficiency calculation resulting in efficiency greater than 100 percent.

Once the system operation is validated, data collection, processing and storage are switched to the production environment. The data that were posted to staging are discarded. This helps minimize the amount of invalid and potentially corrupting data posted to the production system at a time when the probability of data corruption is at its highest.

Even with the use of a staging environment, data errors will still occur in the *production* environment. The error detection techniques described in the following sections can help minimize their impact. These techniques are the same ones that were used to validate the initial data in the staging environment, but additional errors become apparent when data is analyzed over longer periods.

3.2. Out-of-Range Data

The performance database system must allow for the definition of minimum and maximum valid values for each measurement. These defined values must be the maximum and minimum values that may be encountered under *any* operating conditions. If a datum falling outside this range is posted to the database, it is automatically flagged with a status of "Under Range" or "Over Range." Data with a status other than "Good" are displayed neither on the real-time display screens nor on the historical plots, and they should be disregarded in all reports. Calculated points that depend on points flagged in such a manner should also be flagged and ignored.

Frequent flagging of data in the above manner leads to gaps in the data. Therefore, the root cause of out-of-range data must be addressed. Experience shows that the most frequent source of such data during normal operations is a meter that displays a very large or very small value when the actual value is zero. For example, certain power meters display a very large number when the generator is powered down. Using a "calculated point" to translate the erroneous values to zero can be used to combat this phenomenon.

Calculated points can be used to filter out undesirable values. For example, a calculated point could be defined for power output. When the fuel flow is above a certain small value x, the value of the calculated point is just the value of the power output. However, when the fuel flow is below x, the value of the calculated point is zero. In this manner, the fuel flow is used to detect when the generator is off so that the power output reading can be forced to zero. If a reliable real-time fuel flow measurement cannot be obtained, then other parameters could be used.

3.3. Data Gaps

Data gaps are most often caused by communication problems. Two locations where communication can fail are

- between the meters/sensors and the data collection device
- between the data collection device and the data center.

In the first case, the data are simply lost and cannot be recovered – there is no way to reconstruct a physical process that happened in the past unless the meter logs the data. In the second scenario, the data are recoverable. It is recommended that a data collection device automatically save data for a certain number of days (depending on the volume of data), and when the connection is restored, these data can be posted.

In the first two scenarios, where a loss of connection means a loss of data, the only remedial action is to produce alarms as quickly as possible to minimize data loss. It is recommended that an alarm be generated by the data collection device when it cannot communicate with its data source. In the event of a connection loss between the data collection device and the data center, the system at the data center should produce alarms if the data have not been updated for a specified period. The length of the period depends on the data scan rate and frequency of data submission to the performance database. These alarms can be displayed at the data center operator's interface or generate a notification message to an operator so that remedial action can be taken. In any real-time data display, it is also useful to display a timestamp indicating when the data was last updated. This allows the user to know the currency of the data.

3.4. Deadband Filtering

The output of a measurement device is not constant even when a variable being measured is not changing sufficiently to be of interest. That is, although two successive measurements may not be numerically equal, they are statistically equivalent within the accuracy limitations of the measurement process. Slight variation in the physical process itself may also produce small data fluctuations. For example, the power output of a fuel cell may vary slightly around 80 kW, but the variations may be too small to be of interest.

"Deadbands" may be used as a simple method to eliminate insignificant variations. This means that a new datum is recorded only if it has changed by a predefined amount from the previous datum. This reduces data storage requirements, improves the efficiency of the system, and reduces confusion by eliminating insignificant data.

Setting deadband values is a trade-off between capturing only meaningful data changes and losing valid data fluctuations. It is recommended the allowable uncertainties defined in the Laboratory Test and Field Test protocols be used as input when defining the size of the deadbands.

3.5. Notification

Once erroneous or suspicious data have been identified, someone must be notified so that action may be taken. Defining alarms for each individual data series is cumbersome and consumes valuable resources, so it is suggested that a logging architecture be developed. The data validation modules would write to this log indicating information such as the questionable data and the perceived problem with the data. Notifications could be sent to an administrator at pre-defined intervals if the log has changed, and the administrator could check the log and take the necessary actions.

4. Correcting Data

Once a bad datum has been identified and the administrator notified, the administrator must be able to take some sort of action. The four basic actions that he should be able to take are

- Change the datum.
- Delete the datum.
- Accept the datum as good.
- Accept the datum and flag it as bad.

An interface must be developed to allow the administrator to take these actions. Ideally, this interface would include the ability to plot the data series and analyze it further using various techniques. It would then allow these four actions to be performed. The interface should also allow the administrator to initiate the recalculation of reports when he changes data.

5. Data Quality Assurance Procedure

This section consolidates the above methods in a list of steps to validate a set of DG/CHP monitoring data. The particular tools used to do the validation depend on the system under investigation.

For each data point that is to be validated, define the following:

1. A maximum valid value
2. A minimum valid value
3. Alternate measurement sources for the same physical quantity
4. Other points with which this point must correlate
5. Equations in which the point participates
6. A textual description of the expected graph pattern
7. If there are other units with an identical configuration at the same site operating at the same setpoint, then define the allowable variation for the point value across equipment.

After these items have been defined, use the available tools to check the point's data against each one. If no advanced tools are available, then use simple query tools or visual inspection. The checks corresponding to each item are as follows:

1. Verify that the maximum recorded value is not larger than the defined maximum value.
2. Verify that the minimum recorded value is not smaller than the defined minimum value.
3. Verify that all measurements of the same physical quantity at the same point in time are equal within the uncertainty limits of the measurement devices.
4. Verify that the point shows the expected degree of correlation with other points. For example, under normal circumstances, energy output should rise when fuel consumption rises.
5. Verify that expressions in which the point participates yield reasonable results. For example, when validating fuel consumption data, use the fuel consumption values and the power output values, along with other applicable values such as heat recovery, to calculate the efficiency. The efficiency should be within the expected range. If measurements are available for both sides of the equation – in this case if the equipment provided its own efficiency measurement – then verify that equality holds.
6. Produce a graph of the data and verify that there are no holes, spikes, or other unusual patterns. Verify that the data changes at the expected rate.
7. Verify that all equipment at the site with identical configurations produce data that match within the allowable variation.

Use the available data correction tools to correct, delete, or flag any invalid data.

The use of reports can greatly facilitate this procedure. Whenever possible, reports should be defined that automatically perform the necessary checks and highlight any invalid or possibly invalid data.

6. Summary

The typical causes of data error are

- malfunctioning or inaccurate meters
- misunderstanding or misuse of data
- communication problems
- and data storage configuration errors.

These causes generally result in the following types of errors:

- out-of-range data, totalizer resets, biased data, and random error
- data spikes and apparently erroneous unequal measurements
- data gaps and uncorrelated data

By following the recommended data validation methods, the bulk of these errors can be caught during acceptance testing when data are posted to the staging environment. Errors can be prevented by the use of appropriate sensors and meters and their proper installation, orientation, configuration, and calibration. However, inevitably, errors will occur in production. The most common problems are communication problems, which are detected using alarms. Other errors can be detected using reports that employ equations, trends, and other such techniques to locate invalid data. Automated methods can be augmented by visual inspection.

Once errors have been detected, they should be written to a log, and an administrator should be notified. That administrator should have the ability, through a graphical user interface, to further analyze the data and either

- change the data
- delete the data
- accept the data as good
- or accept the data and flag them as bad.

When data are changed, the administrator should be able to initiate the recalculation of reports, including any archived reports affected by the faulty data.

Once the data has been validated, the end user will be able to trust the data and use them as the basis for sound operational and strategic decisions. This should serve to increase the success of DG/CHP systems.