ENERGY AND ENVIRONMENTAL ANALYSIS, INC.

Executive Summary Report:

Distributed Generation Operational Reliability and Availability Database

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EXECUTIVE SUMMARY

This report summarizes the results of the project, "Distributed Generation Market Transformation Tools: Distributed Generation Reliability and Availability Database," sponsored by Oak Ridge National Laboratory (ORNL), Energy Solutions Center (ESC), New York State Energy Research and Development Authority (NYSERDA), and Gas Technology Institute (GTI).

Using operations and maintenance field data provided by distributed generation (DG)/combined heat and power (CHP) project operators, owners, and developers, the project team analyzed the operational reliability (OR) performance of various onsite generation technologies. OR generally refers to the reliability, availability, and maintainability attributes of a process system and its components. Specifically, the project team analyzed event histories for 121 DG/CHP units over a two-year time period. These 121 units represented 731 MW of installed capacity and operated for 1,669,411 service hours. Data concerning 2,991 outage events were collected. A data collection and management process was developed as well as a database. Each event was described using a consistent equipment taxonomy and outage codes consistent with IEEE Standard 762. The primary sources of data included O&M log books, outage summary reports, and contractor service reports. This project represented the first attempt to establish a baseline operating and reliability database for DG/CHP systems in more than a decade.

The methodology and OR measures used in this project are consistent with established industry standards. Measures include availability factor, forced outage rate, scheduled outage factor, service factor, mean time between forced outage, and mean down time. The results of this project provide insights into the actual OR performance of onsite power generation systems. This data base provides a solid foundation upon which additional units can be added or periodic annual updating of data can be performed in the future.

Objectives

The increased deployment of Distributed Generation (DG)/Combined Heat and Power (CHP) has been identified as a means to enhance both individual customer reliability and electric transmission and distribution system reliability. DG/CHP reliability and availability performance relates to several significant issues affecting market development. The reliability/availability profiles for DG/CHP systems can affect electric standby charges and back-up rates, the value of ancillary services offered to Independent Transmission System Operators (ISO), local grid stability and reliability, customer power delivery system reliability, and customer economics. Interest in power reliability has heightened in recent years in light of high-profile system.

Specific objectives of this project were to:

- Establish baseline operating and reliability data for distributed generation systems
- Identify and classify DG/CHP system failures and outages
- Determine failure modes and causes of outages
- Quantify system downtime for planned and unplanned maintenance
- Identify follow-on research and/or activities that can improve the understanding of reliability of DG/CHP technologies.

The primary deliverables of the project is a database framework populated with 121 DG/CHP units which is used to estimate the operational reliability (OR) of various DG/CHP technologies. From the data, key operational reliability (OR) measures were calculated. These objectives were accomplished with the valued participation of actual DG/CHP users and access to their operations and maintenance data.

Technical Approach

The methodology for assessing the operational reliability of DG systems was to establish baseline operating and reliability data for DG/CHP systems through an exhaustive collection of data from a sample of operating facilities. Data was collected from user maintenance logs, operation records, manufacturers' data, and other available sources. The project team calculated key operational reliability indices. We then identified and classified DG system failures and outages for various types of technologies and applications. Finally, the project team assessed forced outage causes and quantified system downtimes for planned and unplanned maintenance. The final work product was a database framework of operational reliability data for DG/CHP systems that characterizes unit reliability over a two year period. This database can be augmented with additional sites in the future or be improved to allow for additional operating data to be added on a regular basis, e.g., monthly.

The technical approach used was based on the following guidelines:

- Operational reliability data should address a diverse set of prime mover technologies and applications
- Data collection process will have to rely heavily on user participation and their records
- Procedures for collecting, processing, and analyzing data must be tightly controlled.

The scope of work consited of the following tasks:

- Review of Prior Work
- Identify and Select Candidate Sites
- Collect Operating Data
- Reduce and Analyze Data
- Assess Reliability
- Perform Forced Outage Cause Assessment

The project team conducted an exhaustive review of public and private databases to screen potential sites to populate the database. Two databases in particular that were used extensively are the PA Consulting/Hagler-Bailly and Energy Information Administration databases of non-utility power plants. In a parallel effort to screen sites, the project team utilized its network of contacts at manufacturers, developers, gas utilities, associations, and packaged cogeneration players. As the databases of existing facilities become less accurate for sites less than 1 MW in size, these personal contacts were important in identifying the smaller sized sites. In addition, we mailed letters to various stakeholders.

The project team collected raw data for 121 DG/CHP units. The breakdown of the 121 units is shown Figures 1 and 2.

Figure.1 - Distribution of Sample by Technology by Units (n=121)

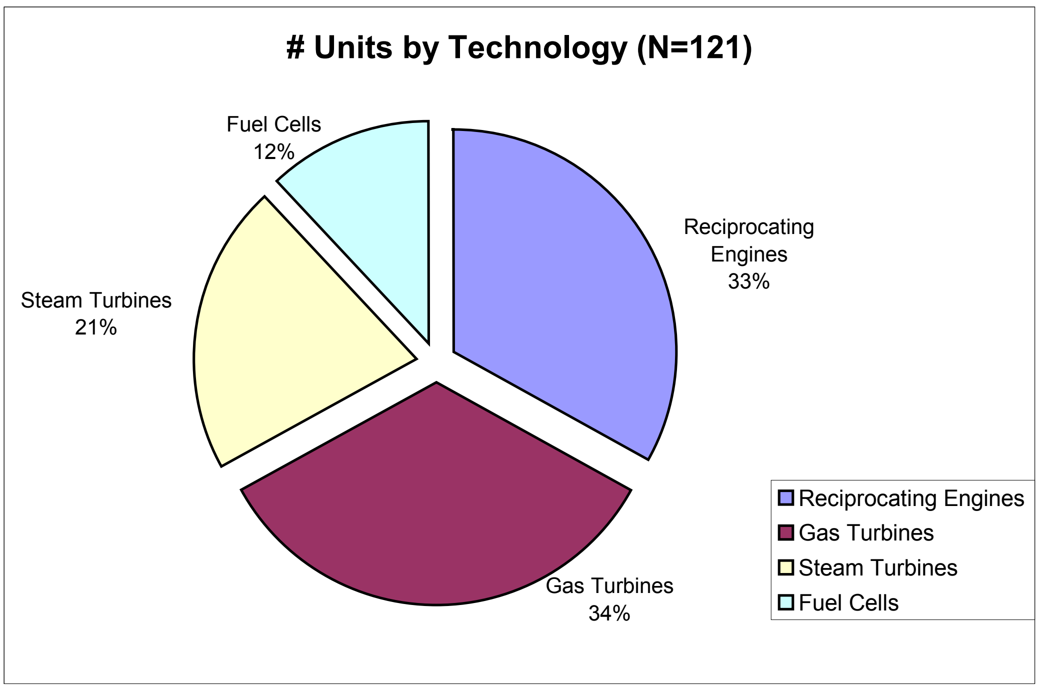
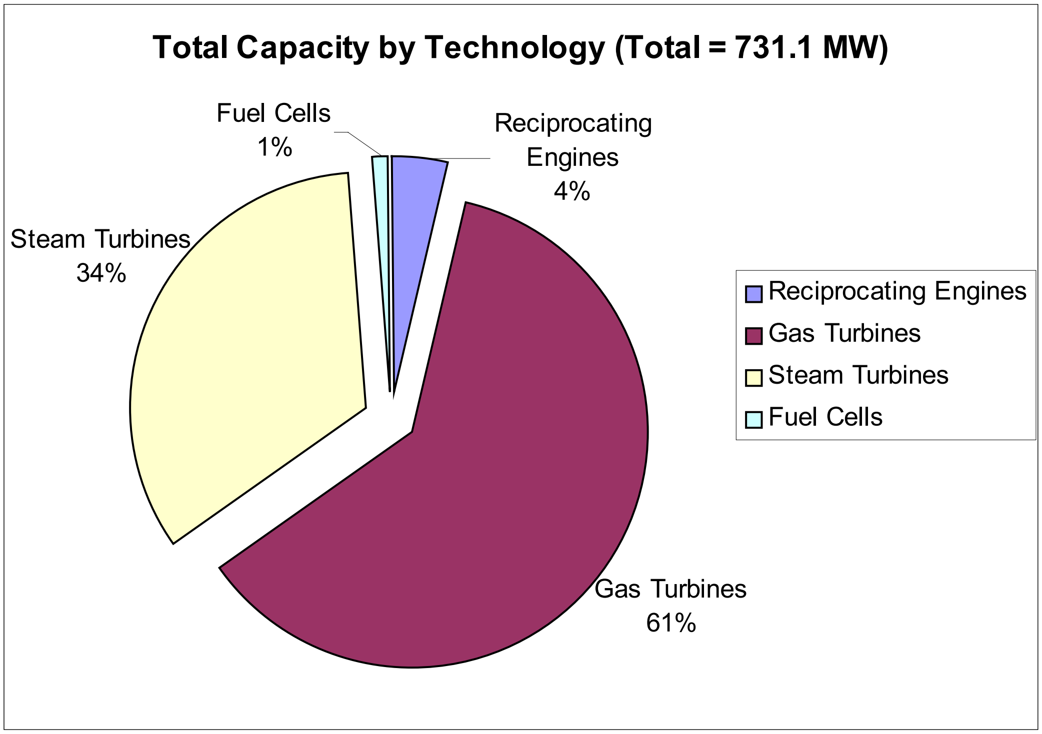


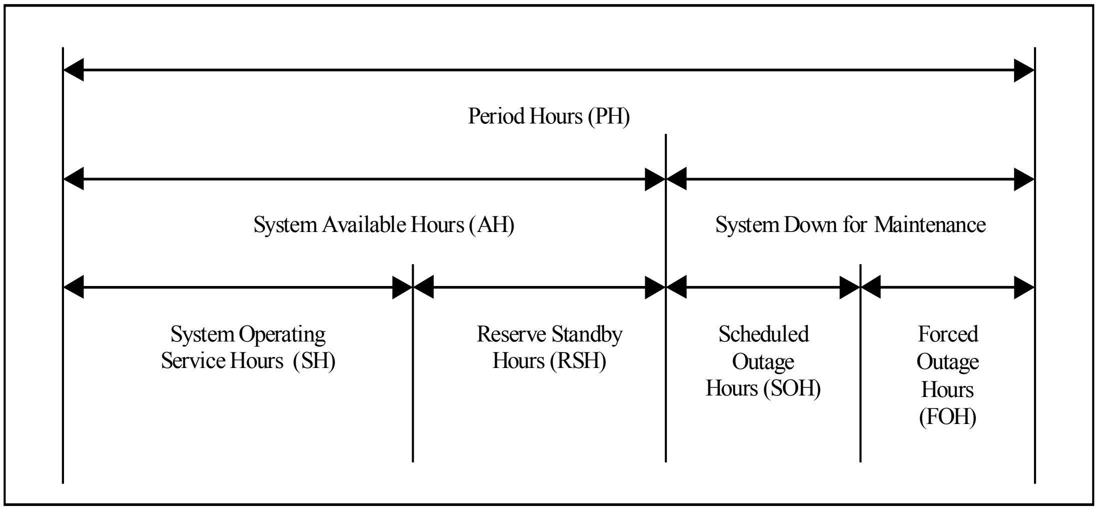
Figure 2 - Distribution of Sample by Technology by Capacity



These 121 units represented 731.MW of installed capacity and operated for 1,669,411 service hours. Data concerning 2,991 outage events were collected. Each event was described using a consistent equipment taxonomy and outage codes consistent with ANSI/IEEE Standard 762 *Standard Definitions for Use in Reporting Electrical Generating Unit Reliability, Availability, and Productivity*. IEEE Standard 762 contains 66 reliability related terms and 25 OR performance indices (none of which is explicitly named "reliability"). The primary sources of data included O&M log books, outage summary reports, and contractor service reports.

The project team developed a data collection plan that addressed the framework and procedures used to screen potential participants, enter data and analyze OR performance. The project team calculated OR measures consistent with industry practices. Measures include availability factor, forced outage rate, scheduled outage factor, service factor, mean time between forced outage, and mean down time. The OR measures calculated are shown in Figure 3 and are consistent with ANSI/IEEE 762.

Figure 3 – Operational Reliability Measures and Definitions



Reliability Performance Indices	Formula
Period of Demand (POD): Measures the time the unit was planned to operate.	POD = PH - RSH- SOH
Availability Factor (AF, %): Measures, on a percent basis, the unit's "could run" capability. Impacted by planned and unplanned maintenance.	$AF = \frac{(PH - SOH - FOH) * 100}{PH}$
Forced Outage Rate (FOR, %): Measures portion of downtime due to unplanned factors.	$FOR = \frac{FOH * 100}{(SH + FOH)}$
Scheduled Outage Factor (SOF, %): Measures percent of time set aside for planned maintenance.	$SOF = \frac{SOH * 100}{PH}$
Service Factor (SF, %): Percent of total period hours the unit is on-line – varies due to site-related or economic factors.	$SF = \frac{SH * 100}{PH}$
Mean Time Between Forced Outages (MTBFO): Measures the nominal time between unscheduled forced outages.	$MTBFO = \frac{SH}{\# \text{Forced Outages}}$
Mean Down Time (MDT): Measures the nominal duration the unit is down during maintenance events.	$MDT = \frac{SOH + FOH}{\# \text{Forced Outages} + \# \text{Plant Outages}}$

Results

The entire project methodology was based heavily on the involvement of DG/CHP users. Data (maintenance logs, operation records, and other available sources) and results came directly from actual customer operating data and experience. This required an extremely labor-intensive effort on the part of both project participants and the project team. The voluntary cooperation of participating facilities and time assembling data and being interviewed was greatly appreciated. While time-intensive, the involvement of users created better understanding of actual operations.

The OR performance of a unit is affected by many factors including technology and operations and maintenance practices. When compared to electric utility units reported by the North American Electric Reliability Council Generating Availability Data System (NERC GADS), most DG/CHP units reviewed in this project demonstrated comparable to superior OR performance. OR statistics for units are shown tables 1 through 4.

Table 1 – Summary Statistics for Reciprocating Engine Systems

Reciprocating Engines	<100kW			100-800 kW			800-3000 kW		
Number Sampled		14			8			18	
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Availability (%)	96.27	97.93	99.00	84.55	95.99	99.93	91.14	98.22	100.00
Forced Outage Rate (%)	0.86	1.76	3.07	0.00	1.98	5.05	0.00	0.85	6.63
Scheduled Outage Factor (%)	0.26	0.73	1.33	0.07	2.47	14.22	0.00	1.12	3.42
Service Factor (%)	68.20	75.11	79.60	2.06	51.76	95.43	1.50	40.59	91.39
Mean Time Between Forced Outages (hrs)	505.96	784.75	1376.60	361.18	1352.26	4058.71	263.00	3582.77	14755.30
Mean Down Time (hrs)	7.29	13.71	24.21	12.50	50.66	173.05	0.00	27.06	91.91

Table 2 – Summary Statistics for Gas Turbine Systems

Gas Turbines	0.5-3 MW			3-20 MW			20-100 MW		
Number Sampled		11			21			9	
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Availability (%)	88.88	97.13	100.00	88.56	94.97	99.60	86.33	93.53	99.45
Forced Outage Rate (%)	0.00	2.89	18.84	0.00	2.88	9.07	0.00	1.37	6.63
Scheduled Outage Factor (%)	0.00	0.99	4.57	0.00	2.39	11.44	0.00	5.14	13.50
Service Factor (%)	5.33	57.93	97.27	6.26	82.24	99.01	70.27	88.74	99.45
Mean Time Between Forced Outages (hrs)	765.62	2219.72	4318.00	216.77	1956.46	15298.00	536.00	3604.62	17424.00
Mean Down Time (hrs)	0.17	65.38	325.09	2.77	68.63	501.75	21.29	75.30	288.50

Table 3 – Summary Statistics: Fuel Cells and Steam Turbines

Other Technologies	Fuel Cells <200kW			Steam Turbines <25MW		
Number Sampled		15			25	
	Min.	Avg.	Max.	Min.	Avg.	Max.
Availability (%)	42.31	76.84	95.04	72.37	92.02	99.82
Forced Outage Rate (%)	4.31	22.94	57.51	0.00	2.34	16.41
Scheduled Outage Factor (%)	0.48	0.92	1.23	0.00	6.01	27.63
Service Factor (%)	42.27	74.01	92.21	3.37	81.12	99.65
Mean Time Between Forced Outages (hrs)	1416.71	2004.47	2696.33	120.18	5317.73	29585.00
Mean Down Time (hrs)	66.92	369.24	1686.83	5.51	292.06	4848.00

The North American Reliability Council Generating Availability Data Service (NERC GADS) was created to provide utilities with information on OR perfomance of electric generating units and their related equipment. One of the primary reports that NERC GADS produces is the *Generating Availability Report* (GAR). The GAR reports OR data over a cumulative five years, annually. The statistics in the GAR are calculated from data that electric utilities report voluntarily to (NERC GADS). Operating histories for more than 4,400 electric generating units reside in GADS. Data are reported by 178 utilities in the United States and Canada, representing investor-owned, municipal, state, cooperative, provincial, and federal segments of the industry. NERC aggregates these data and presents the results annually in its GAR. Table 4 shows 1997-2001 OR performance data for five central station technologies. Data on onsite generation technologies assessed for this project are comparable or better than the most recent NERC GAR OR data on central station technologies.

Table 4 - NERC GAR 1997-2001 Summary OR Statistics

OR Measure	Fossil (Boiler)	Nuclear	Gas Turbine	Combined Cycle	Hydro
# of Units	1524	128	887	80	823
Availability Factor (%)	86.66	82.87	90.31	85.85	90.62
Forced Outage Rate (%)	5.16	7.83	41.40	3.24	4.68
Scheduled Outage Factor (%)	9.59	10.09	6.36	7.64	6.53
Service Factor (%)	68.98	82.85	4.72	61.36	57.95

Table 5 summarizes the OR statistics calculated from the database by technology group. The technology groups were defined as:

Reciprocating Engines
Group 1: <100 kW
Group 2: 100 - 800 kW
Group 3: 800 kW – 3 MW
Fuel Cells
Group 4: <200 kW
Gas Turbines
Group 5: 500 kW – 3 MW
Group 6: 3 MW – 20 MW
Group 7: 20 – 100 MW
Microturbines
Group 8: <100 kW
Steam Turbines
Group 9: <25 MW

With the exception of Technology Group 4 (fuel cells), all technology groups demonstrated acceptable to very good OR performance. Good performance is generally considered to be 90% availability factor or higher. Fuel cell OR performance was greatly affected by downtime associated with unusually long delays and not related to typical operation. Waiting time for service or replacement parts can have a serious effect. For example, several multi-month outages due to delays in service created an inaccurate representation of fuel cell OR performance. In those specific cases the availability calculated can become more a measure of the service system than the inherent disposition of the equipment to perform. It should also be noted that single units in both the 0.5-3000 MW and 3-20 MW gas turbine groups (groups 5 and 6) accounted for a disproportionate amount of forced outage time.

The project team included units in all technology groups with the exception of Group 8, microturbines. This is due to the fact that units installed and operating by January 2000, the cut-off date for the required two years of operation to be included in this project were either pre-commercial or first generation microturbines. Developers and users would have had to provide data and characterize operational reliability of this class of technology based on units that would not be representative of the products that would ultimately be used in the market. They were justifiably reluctant to participate on this basis. In fact, this effect was seen in the fuel cell data collected and analyzed for this project. The decision was made not to include microturbine data at this time but to structure the database to accommodate the addition of microturbine data at a later date if so desired.

Table 5 - Summary Operational Reliability Statistics by Technology Group

Technology Group	n	Availability (%) Avg.	Outage Rate (%)	Outage Factor (%)	Factor (%) Avg.	Between Forced	Mean Down Time (hrs)
1	14	97.93	1.76	0.73	75.11	784.75	13.71
2	8	95.99	1.98	2.47	51.76	1,352.26	50.66
3	18	98.22	0.85	1.12	40.59	3,582.77	27.06
4	15	76.84	22.94	0.92	74.01	2,004.47	369.24
5	11	97.13	2.89	0.99	57.93	2,219.72	65.38
6	21	94.97	2.88	2.39	82.24	1,956.46	68.63
7	9	93.53	1.37	5.14	88.74	3,604.62	75.30
9	25	92.02	2.34	6.01	81.12	5,317.73	292.06
Entire Sample	121	93.09	4.65	2.66	70.23	2,869.83	138.53

Table 6 summarizes the OR statistics calculated from the database by duty cycle. Cycling average data is less impressive than the other duty cycles. This is primarily due to the fact that a number of fuel cell systems fall into this category. With regard to very low service factor units (e.g., standby units with service factor 3 %), an additional future analysis based on starting reliability may provide improved insights. These units are characterized by approximately 100-300 hours of annual operation and service hours that range from 100 to 200 hours of maintenance and service. They have a very large percentage of their time in the state of reserve standby during which the unit is fully available but not operating. Using the same OR measures as higher service factor may not represent their reliability accurately.

Table 6 – Summary Operational Reliability Statistics by Duty Cycle

Duty Cycle	Service Factor Range	N	Availability (%) Avg.	Forced Outage Rate (%) Avg.	Scheduled Outage Factor (%) Avg.	Service Factor (%) Avg.	Mean Time Between Forced Outages (hrs)	Mean Down Time (hrs)
Peak	1-10%	14	99.42	0.02	0.58	2.60	456.80	22.21
Cycling	10-70%	26	88.76	10.15	2.16	54.03	2,339.48	383.19
Baseload	>70%	81	93.39	3.69	3.18	87.11	3,457.13	80.10
Entire Sample	0-100%	121	92.62	6.48	1.59	36.86	1,659.54	250.93

During the time period unit operations were assessed, specific units were observed to exhibit both very good to poor OR performance. In almost all technology groups, subsystems other than the prime movers themselves contributed more significantly to the occurrence of forced outage events. Many events that occur are the result of random equipment failures expected of any complex power system. Other events may be nonrandom in nature, indicating problems that may relate to issues pertaining to the unit design or installation. This project did not result in the identification of any such systemic problems. Most failures within technology groups appear to be random occurrences of short duration.

It is noteworthy that OR performance of established commercial technologies (i.e., reciprocating engines and gas turbines) was significantly better than the sample of emerging technologies (fuel cells) included in the project. The OR performance of emerging technologies and early commercial products need to be compared separately. Established products have the benefit of millions of hours of operation from which to develop operations and maintenance best practices. Their observed performance in this project and prior work bears this out. As time passes and more experience is gained from the operation of emerging technologies, it is likely their demonstrated OR performance will improve to the level of the other technologies. Fuel cell operational reliability indices calculated were significantly lower than all other technology groups and what fuel cell manufacturers typically quote. Availability, forced outage rate and mean down time was greatly affected by downtime associated with unusually long delays (e.g., maintenance personnel response, availability of replacement parts, site operations) and not related to typical operation. Waiting time for service or replacement parts can have a serious effect. For example, several multi-month outages due to delays in service created an inaccurate representation of fuel cell OR performance. In those specific cases the availability calculated can become more a measure of the service system than the inherent disposition of the equipment to perform.

Conclusions and Recommendations

The database is intended to establish a baseline of OR data on DG/CHP and allow current and potential users to benchmark reliability. The methodology and framework for recording and analyzing data is straight forward, repeatable and consistent with industry standards. It should be noted that the data reviewed for this project is only for 2000-2002 time period. The database does not include very large samples in all technology groups. It is structured to accommodate more units and technology groups in a follow-on effort. Future periodic updating and maintenance on a regular basis will ensure continued usefulness and increase the confidence in the measures calculated.

The first version of the DG/CHP Reliability and Availability Database provides a general framework for recording operating data and analyzing OR performance. It provides a solid foundation for future improvements and enhancements. Recommended improvements to the database framework include:

- Add additional units in under-represented technology groups to improve the robustness of the data
- Update data on an annual basis to include years of operation beyond the original time period
- Include microturbines with at least two years of operations (not including R&D demonstration) along with fuel cells with similar operating history in a separate database pertaining to emerging DG/CHP technologies

Any follow-up effort needs an efficient site identification and data collection process. For example, monthly data submission by site operators with secure web-based data entry system would reduce the labor costs associated with data collection substantially.