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Impact of Distributed Energy Resources on the Reliability of Critical Telecommunications Facilities

Preprint

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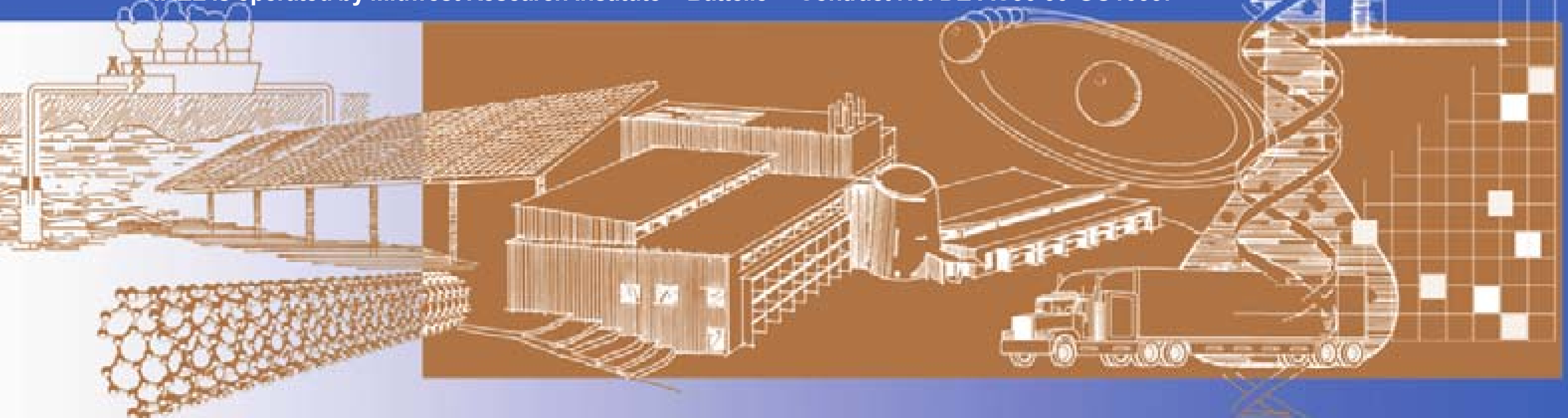
To be presented at INTELEC 2006 (International Telecommunications Energy Conference)
Providence, Rhode Island
September 10–14, 2006

Conference Paper
NREL/CP-620-40220
June 2006

NREL is operated by Midwest Research Institute ● Battelle Contract No. DE-AC36-99-GO10337



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***Abstract* - This paper documents a probabilistic risk assessment of existing and alternative power supply systems at a large telecommunications office. The analysis characterizes the increase in the reliability of power supply through the use of two alternative power configurations. Failures in the power systems supporting major telecommunications service nodes are a main contributor to significant telecommunications outages. A logical approach to improving the robustness of telecommunication facilities is to increase the depth and breadth of technologies available to restore power during power outages. Distributed energy resources such as fuel cells and gas turbines could provide additional on-site electric power sources to provide backup power, if batteries and diesel generators fail. The analysis is based on a hierarchical Bayesian approach and focuses on the failure probability associated with each of three possible facility configurations, along with assessment of the uncertainty or confidence level in the probability of failure. A risk-based characterization of final best configuration is presented.**

I. BACKGROUND

Telecommunications has been identified by the Department of Homeland Security as a critical infrastructure for the United States. Failures in the power systems supporting major telecommunications service nodes are a main contributor to major telecommunications outages, as documented by analyses of Federal Communications Commission (FCC) outage reports by the National Reliability Steering Committee (under auspices of the Alliance for Telecommunications Industry Solutions). There are two major issues that have increasing impact on the sensitivity of the power distribution to telecommunication facilities: deregulation of the power industry and changing weather patterns.

There is no incentive for the power utilities to make their systems more robust to these disturbances; rather, the industry has moved to change the reliability-reporting requirements to avoid financial penalties [1]. As noted by Sandia researchers in 2000, telecommunication companies, emergency services, etc. – which are dependent on a reliable source of power – need to be prepared for increased uncertainty in the operation of the national electrical infrastructure [2].

One approach toward improving the robustness of the power systems supporting telecommunications offices is to improve the reliability of the necessary supply of power. Current best practices involve a combination of on-site battery backup (for short, intermittent power interruptions) and diesel generators (for longer-term interruptions). Occasionally, universal power system (UPS) technologies are also used for specific data communications equipment backup.

A logical approach to improving reliability would be to increase the depth and breadth of technologies available to restore power in the face of power outages. Distributed energy resources such as photovoltaic (solar) cells, wind generators, fuel cells, and gas turbines could provide an additional on-site electric power source for backup power, if batteries and diesel generators fail. But does the diversity in power sources actually increase the reliability of offered power to the office equipment, or does the complexity of installing and managing the extended power system induce more potential faults and higher failure rates?

The goal of this research was to perform probabilistic risk assessments (PRAs) on an existing power configuration for a large telecommunications center with diesel generator and battery backup, and for two alternative power configurations adding natural gas turbines as a primary power source. The product from the study was an analysis of probability of failure associated with each of the three facility configurations, along with an assessment of the uncertainty or confidence level in the failure probability estimate.

II. Operational Scenario

The location of interest for this effort was assumed to be a remote switch facility with limited physical access via roads. The utility power at this location is particularly unreliable – in the most recent four-year period, there were 35 utility outages (compared with a national average of approximately three outages per year for 2001 and 2002).

The telecommunication center consists of a main facility supported by two switch bays. Power is supplied to the facility primarily through a traditional utility drop. In the event that utility power is lost, at least two of the three on-location 1.5MW diesel generators must function. In addition to the two generators, the battery system must be available to provide minimal support for an additional 4 hours in the event that the generators fail.

For this analysis, an (almost) worst-case scenario was assumed. This scenario represents a documented situation that will likely exist after a severe-weather event. If utility power is lost, restoration of power will not occur within a time period that will have a significant impact. Similarly, if a diesel generator or gas turbine fails, minor repair is possible, but replacement of the entire generator (or turbine) is not an option. The only available fuel for the generators is what is currently stored on-site (assumed to be 72 hours worth for each generator); fuel lost through consumption or contamination cannot be replaced within 4 hours. The 4hour limit is used because the batteries are required to provide minimum support for the plants for an additional 4 hours, in the event that power is lost from the generators.

Figure 1 depicts the time line of events for the Base Case scenario: utility power fails, generators start with some probability, fail with some likelihood, and run out of fuel after 72 hours. Batteries provide backup emergency power for a maximum of 4 hours (or until they fail during operation).

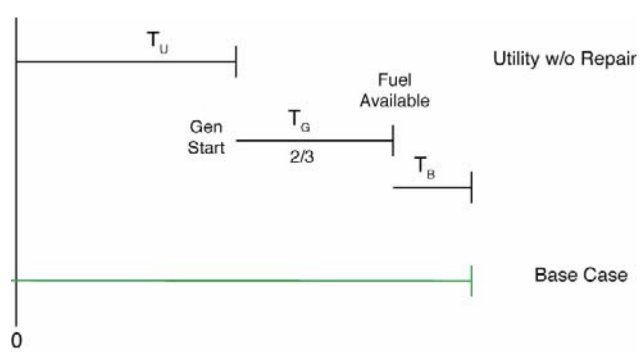

Figure 1. Base Case Time Line of Events. The figure shows the event sequence that is analyzed for the Base Case, where the x-axis is time.

III. Analysis Approach

The standard methods and data used to estimate the reliability of power systems are documented in the IEEE Standard 493-1997 IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems [3]. However, a traditional approach is not applied because of the sequential, time-dependent nature of how the system is operated.

Figure 1 depicts a typical sequence of events where the x-axis is a timeline. Each event logically follows at the conclusion of the previous event. For example, for the Base Case, the time that the utility is available T_U is a random variable described by an exponential distribution conditioned on the rate of utility power failure: $f(T \mid \lambda_U) = \exp[-\lambda_U t]$. The rate at which the utility power fails, λ_U, is not known with certainty; therefore this parameter is characterized as a random variable: $\lambda \sim g(\lambda \mid \alpha, \theta)$. Because of the conditional structure of the distributions for T and λ_U Gibbs, sampling must be used when simulating the power availability. The WinBugs computer software was used for all simulations conducted in this report [4]

Similar to the utility reliability, values for diesel generator operation reliability, T_G, and battery reliability, T_B, are simulated. The values are then combined to get the time until system failure, $T_{base}=T_U+T_G+T_B$. Figure 1 depicts the typical time line of events associated with what is referred to in the following discussion as the Base Case.

The following sections address each of the elements of the various scenarios. The Base Case is a function of the availability of power from the utility, the backup diesel generators, and the batteries. The additional alternatives explored include the addition of natural gas turbines from Capstone and Kawasaki as described in more detail below.

IV. Analysis Elements

The following sub-analyses are based on actual data related to characteristics of the individual elements.

A. *Utility Reliability*

As suggested earlier, it is assumed that the length of time that a utility power is up/operating, T_U, is an exponentially distributed random variable with parameter λ_U: $f(T \mid \lambda_U) = \exp[-\lambda_U t]$. The parameter λ_U represents the number of utility interruptions per year. However, the estimate $\hat{\lambda} = 8.75$ represents a simple average rate at which events occurred during the four years; in reality, there will be a great deal of variation or uncertainty about the rate, λ_U, at which events might occur each year.

Fitting a distribution to utility interruption rates resulted in λ_U being a gamma distributed random variable: $f(\lambda_U \mid \alpha, \beta) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \lambda_U^{\alpha-1} \exp\left[-\frac{\lambda_U}{\beta}\right]$ with parameters $\alpha = 19.14$ and $\beta = 0.457$. The resulting probability density function (PDF), describing the uncertainty in the number of utility outages each year, is presented in Figure 2.

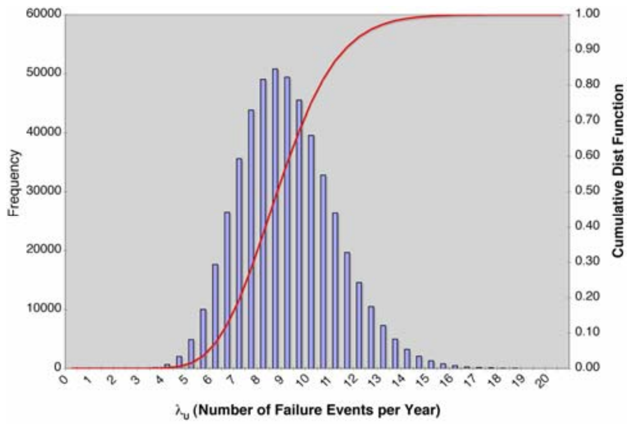

Figure 2. PDF (bars, left axis) and CDF (line, right axis) of the Number of Utility Outages per Year

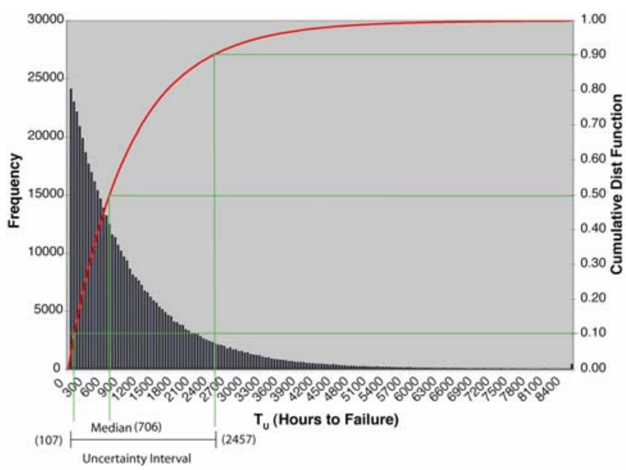

Figure 3. PDF (bars, left axis) and CDF (line, right axis) for Utility Reliability (T_U)

Figure 3. depicts the resulting PDF and cumulative distribution function (CDF) of the distribution for utility reliability.

B. Generator Reliability

Failure of a diesel generator is defined as a malfunction of the generator or associated support subsystems that prevent the generator from starting and running when a demand has occurred. Failures can occur in two modes:

- *Failure to start (FTS)* – A failure of the generator to either manually or automatically start on a bus under-voltage condition, reach rated voltage and speed, close the output breaker, or sequence safety-related electrical loads onto the respective safety-related bus.
- *Failure to run (FTR)* – A failure of the generator to continue to supply power to its respective safety-related electrical bus given the generator successfully started.

Using IEEE Std 493 [3], an estimated mean failure rate for diesel generators is 0.0001 failure/hour with a mean time to repair of 3.9 hours. However, the expected failure rate for diesel generators used in nuclear power plants is approximately 0.0223 failures/hour. In addition, for diesel generators at nuclear power plants the Pr{failure to start} = 0.0241 per demand [5,6].

Using the NUREG/CR-5500 data and the Gold Book as starting points, the uncertainty in the generator failure rate can be characterized.

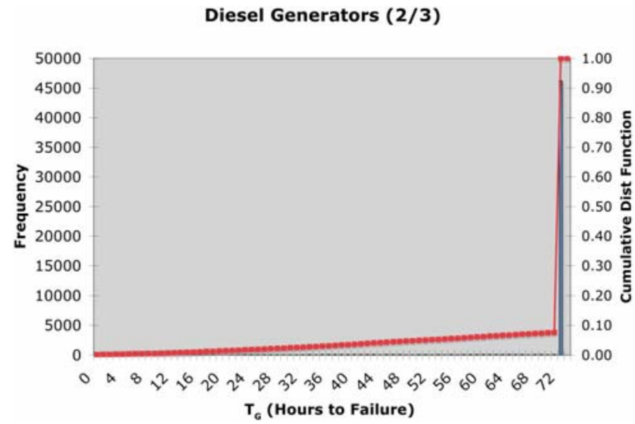

Figure 4. PDF (bars, left axis) and CDF (line, right axis) for Generator Reliability (T_G)

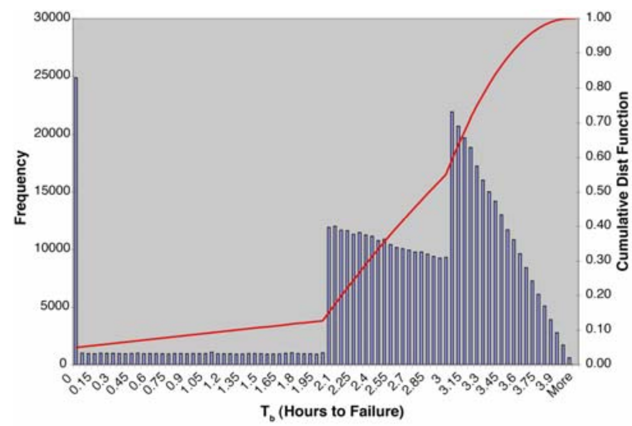

Figure 5. Battery Reliability Summary (T_B)

This can then be coupled with the failure-to-start likelihood and the probability of available fuel supply. Finally, considering that two of the three generators must be operational, a simulation was performed – the results are depicted in Figure 4. The sharp increase at 72 hours is due to the limited source of on-site fuel.

C. Battery Reliability

Battery backup consists of a bank of valve-regulated lead-acid (VRLA) batteries. VRLA batteries are a well-established technology used as a backup power source for short periods of time. The facility has two switch plants where Plant 1 has a 10,000 amp shunt and has 28 strings of C&D HD-1300; and Plant 2 has a 15,000 amp shunt and has 8 strings of C&D HD-1300 and 8 strings of East Penn AVR95-33.

A reliability assessment for the batteries was performed in a manner similar to that accomplished for the utility and generator reliability assessments. The results are depicted in Figure 5.

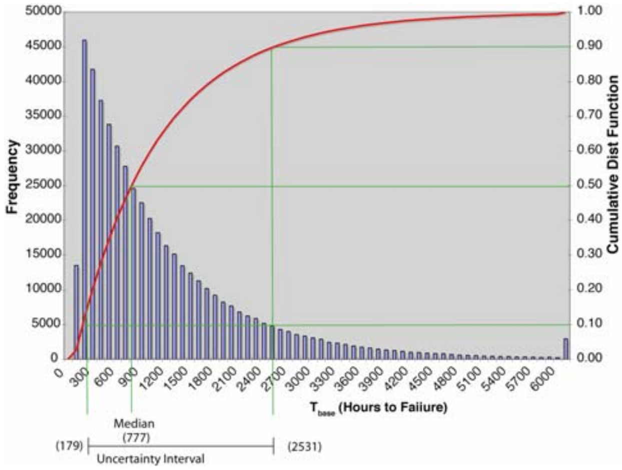

Figure 6. PDF (bars, left axis) and CDF (line, right axis) for Base Case

D. Base Case Summary

Table 1 summarizes the results for the Base Case configuration; recall that this represents a summary of the reliability characteristics of the current configuration at the telecommunications facility under the operational scenario assumed. Figure 6 depicts the results graphically.

III. DISTRIBUTED ENERGY RESOURCES

The following sections discuss the analysis of two alternatives to traditional utility power. These alternatives are based on the use of natural gas turbines to provide generation of on-site power at the telecommunications facility. Two configurations of interest were a single Kawasaki turbine and an arrangement of four pallets, each with six Capstone natural gas microturbines. Both of these configurations depend on a supply of natural gas; therefore, the reliable supply of the natural gas is critical. Section A addresses the supply of natural gas, and Sections B and C document research into the two turbine configurations.

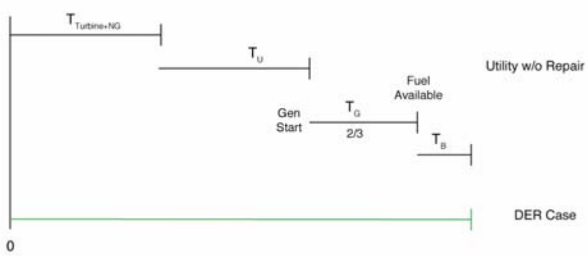

Figure 7. Time Line for DER Analyses

The analysis of the operational scenario proposed involves relying on the turbine as the primary facility power source and the use of the Base Case configuration as the backup power supply. This is depicted in Figure 7.

A. Natural Gas Pipeline Reliability

The Office of Pipeline Safety (OPS), within the U. S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration (PHMSA), has overall regulatory responsibility for hazardous liquid and gas pipelines under its jurisdiction in the United States. Federal safety standards are described in the U.S. Code of Federal Regulations (CFR), Title 49 Transportation, Parts 190 – 199. There are more than 2 million miles of pipelines that support the movement of hazardous liquids, natural gas, and propane. The two types of natural gas pipelines are transmission and distribution. The focus of this effort involves the 1.86 million miles of pipeline involved with distribution of natural gas.

TABLE I.
BASE CASE RELIABILITY SUMMARY (T_G)

Time to Failure	μ	σ	10.00%	median	90.00%
Base Case Total $T_{base} = T_U + T_G + T_B$	1130	1119	178.8	776.9	2531
Utility Time to Failure - T_U	1058	1120	107	706.2	2457
Generator Failure to Start	0.02414	0.04833	2.03E-06	0.00343	0.07514
Diesel Generator - T_G	69.57	10.04	72	72	72
Battery (time) - T_B	2.625	0.9331	1.294	2.869	3.53

There are a number of failure modes for pipelines, most of which are unique to the area where the pipeline is located – including corrosion, external forces (such as excavation or natural forces), and material failure. Characterization of the probability of failure of a particular distribution line can be extremely complicated. For example, failure due to corrosion is dependent on factors such as the type and condition of the pipe's coating, the effectiveness of corrosion control equipment, and the soil conditions surrounding the pipe. Alternatively, the probability of pipeline damage as the result of third-party damage depends on, for example, the extent and type of excavation or agricultural activity along the pipeline right-of-way and the depth of cover over the pipeline.

According to industry input, natural gas distribution system pipeline could be extended about 4 miles (6.437 km), utilizing a 4" (101.6 mm) diameter feeder line connected to an on-site turbine compressor station, with direct connection to the power systems.

Historically, the dominant failure mode for natural gas distribution pipeline is a result of external factors involving third parties, e.g., excavation. The rate at which these failures occur are a function of the buried depth, how well the pipeline is marked, the density of the population, and the land use of the area of interest. The factors can be used to augment the basic failure rate established for pipes of a particular diameter [7].

Contribution of external factors to the failure rate of the pipeline: $\lambda_{Ext} = \lambda_d K_{dc} K_{wt} K_{pd} K_{pm} d$ where λ_d is the basic failure rate for pipes of diameter *d*, and the correction factors $K_{dc}, K_{wt}, K_{pd}, K_{pm}$ account for failure due to third-party activities: buried depth, wall thickness, population density, and prevention method. Assuming a distribution pipe diameter of 102 mm, an estimate of the basic failure rate is $\lambda_d = 0.218$ failures/1,000 km-year (Table 2, [7]).

It is assumed that, for the facility in question, the area is rural; $K_{pd} = 0.81$ and best protection method is employed and the length of pipe is 6.44 km. Estimates of the failure rates are from [8] and [7].

Specifically, the following assumptions are made in the analysis:

- K_{dc} - worst case is to assume depth of cover is less than 0.91 m: $K_{dc} = 2.54$; best case is to assume that depth of cover is greater than 1.22 m: $K_{dc} = 0.54$.
- K_{wt} - worst case is to presume that the wall thickness of pipe will be no more than the minimum of 4.8 mm: $K_{wt} = 1.0$; and best case assumes that the thickness is greater than 4.8 mm: $K_{wt} = 0.2$
- K_{pd} - the location of the telecommunication center appears to be rather remote (7 miles of dirt road). Assume that the area is rural (best case): $K_{pd} = 0.81$; and the worst-case assumption is that the distribution pipe is laid through a densely populated area: $K_{pd} = 18.77$.
- K_{pm} - worst- case situation implies that there are only marker posts to delineate the location of the distribution line: $K_{pm} = 1.03$; while for best- case, additional methods are used: $K_{pm} = 0.91$.

Best/worst case (failures/year):

$$\lambda_{best} = \lambda_d K_{dc} K_{wt} K_{pd} K_{pm} d$$
$$= (0.000218)(0.54)(0.2)(0.81)(6.44)(6.44)$$
$$= 0.000112$$
$$\lambda_{worst} = \lambda_d K_{dc} K_{wt} K_{pd} K_{pm} d$$
$$= (0.000218)(2.54)(1.0)(18.77)(1.03)(6.44)$$
$$= 0.0.06894$$

The probability of failure in one year is then assumed to be in the range:

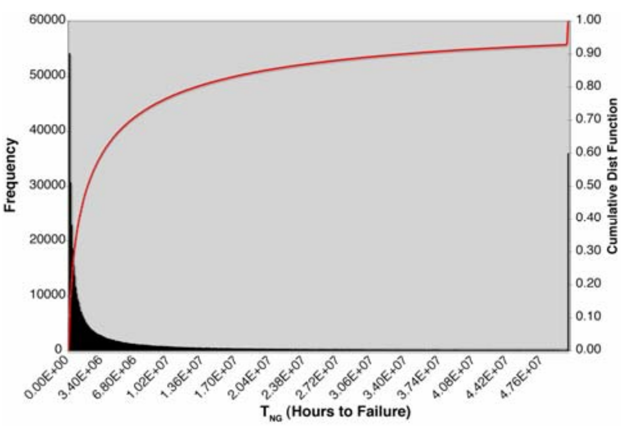

Figure 8. PDF (bars, left axis) and CDF (line, right axis) for Natural Gas Time to Failure (T_{NG})

$$F_{ng} = \{1 - \exp[-0.000112] = 0.00012,$$
$$1 - \exp[-0.068984] = 0.06662\}$$

The failure rate of pipeline is assumed to be a random variable, characterized by a lognormal distribution, with a 5% lower limit of 0.000112 and an upper 95% limit of 0.06894. Figure 8 depicts the final distribution for the time to failure of the natural gas pipeline. As with other elements in the system, the time to failure for the pipeline is assumed to be an exponentially distributed random variable: $T_{NG} \sim \exp[-\lambda_{NG} t]$, where λ_{NG} represents the rate at which pipeline failures occur.

B. Capstone Microturbine Analysis

The Capstone microturbines were investigated as one possible alternative-power generation source. Emissions are low: approximately 2.3 parts per million on dry volume basis (ppmvd) NOx per generator for 75% loading, and about 2.0 ppmvd NOx for 100% loading.

The configuration of Capstone turbines consisted of four pallets of six turbines for a total of 24 turbines. Each turbine is capable of 60 kW of output; and, for efficiency purposes, the turbines are exercised at 90% of their capacity. The total available power is then 1.296 MW. The current maximum demand is approximately 1.1 MW, leaving an excess capacity of 196 kW. At the peak level of loading, only 21 of the 24 Capstone turbines are needed to supply power for the facility. The facility can be supported at a minimum level, if even if seven of the microturbines were unavailable.

According to Capstone engineers, these turbines are currently in-place at a variety of locations and have attained 95% availability. The overall design life is 40,000 hours, and Capstone engineers have estimated the mean time to failure for an individual microturbine to be 8,000 hours and noted – that they expect this to double over during the next few years. Scheduled maintenance activities are recommended at 8,000 and 20,000 hours. The 8,000-hour maintenance is to change air and some other filters, and for replacing the igniter. The downtime for this service is 3 hours. The 20,000- hour service includes the 8,000- hour actions, plus changing of fuel injectors. The downtime for this service is 12 hours.

To characterize the uncertainty in the failure rate for a single Capstone microturbine, it was assumed that there was a

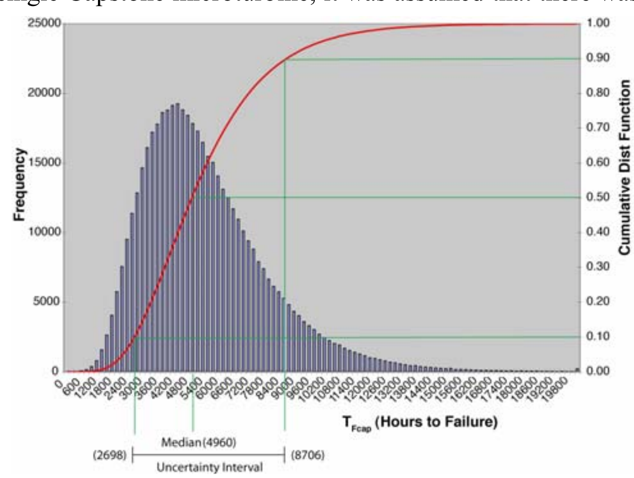

Figure 9. PDF (bars, left axis) and CDF (line, right axis) for alternative configuration w/Capstone Configuration

20% chance that the failure rate would be greater than $\lambda = 1/8000$. Further, it was assumed that there was a 90% probability that the failure rate would be less than $\lambda = 1/16000$. Failure probability of the Capstone microturbine is assumed to be an exponentially distributed random variable: $T_{C1} \sim \exp[-\lambda_{C1} t]$, where λ_{C1} represents the rate at which turbine failures occur.

Using this information and the operational configuration of the microturbine array, a cumulative distribution function was constructed assuming the Capstone microturbine configuration above. Note that these results are sensitive to the operation and maintenance philosophy adopted; it is possible that more reliable configurations could have been found with proper application of optimization algorithms.

C. Kawasaki Turbine Analysis

A second power-system configuration involved the use of a single Kawasaki natural gas turbine. A typical turbine for this application is the GPB 15X 1.5 MW turbine. With the addition of a combustion/catalyst system, the emissions of the Kawasaki turbine are low: approximately 3 ppmvd NO_x (15% O_2) over a broad range of power.

Kawasaki provided a mean time to failure (MTTF) = 200,974 hours; and a mean time to repair (MTTR) = 3.1 hours; based on a sample of 150 installed units. To characterize the uncertainty in the failure rate for a Kawasaki turbine, it is assumed that there was a 10% chance that the failure rate would be greater than $\lambda_K = 1/200974$. This number is exceptionally high, and to be conservative it is assumed that the median failure rate was twice the value reported by Kawasaki. This implies that there is a 50% chance that the failure rate might be as high as $2 \times \lambda_K$

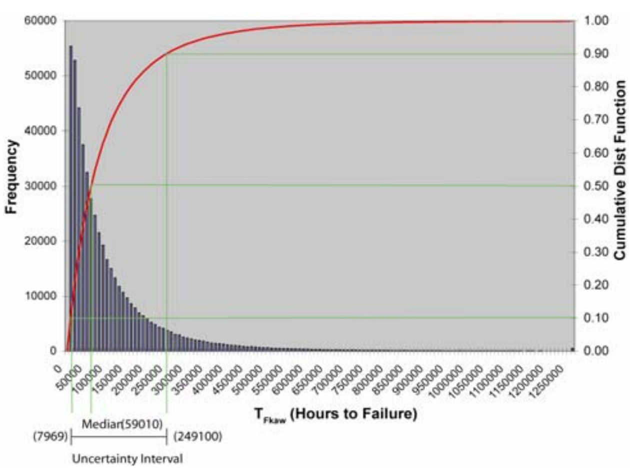

Figure 10. PDF (bars, left axis) and CDF (line, right axis) for the alternative power system configuration with a Kawaski Turbine.

As with the Capstone microturbine, the failure rate is assumed to be a random variable characterized with a lognormal distribution, and this distribution is fully characterized by the two failure rates assumed above. Finally, the time to failure for a single Kawasaki turbine is assumed to be an exponentially distributed random variable: $T_K \sim \exp[-\lambda_K t]$, where λ_K represents the rate at which turbine failures occur.

Figure 10 depicts the time to failure of the facility, given the installation of a single Kawasaki natural gas turbine.

VI. Results

Figure 11 summarizes the results of the three analyses: Base Case, alternative configurations that included the Capstone microturbine array, and the single Kawasaki turbine. The overlay provides the capability to make a risk-based decision of the relative reliability benefits of the three alternatives through a comparison of the credibility limits for each alternative.

Since there is no overlap between the credibility limits, a comparison is relatively straightforward. Consider a comparison between the reliability of the current power supply (i.e. Base Case) and the array configuration of Capstone microturbines investigated. There is a 90% chance that the utility power will fail before 2,529 hours, while there is a 90% chance that the Capstone array will provide power for at least 2,698 hours.

Finally, consider that there is a 90% probability that the Capstone array will fail to provide power for less than approximately 8,706 hours, while there is a 90% probability that the single Kawasaki turbine will provide power for at least 9,048 hours.

A significant, but not decisive, element in the lower reliability estimate for the Capstone was the configuration and operational plan investigated. Other configurations could have quite different reliability characteristics and warrant further investigation. However, installation issues associated with the Capstone, e.g. special enclosure, could be a factor in the final decision.

Not considered in the analysis for either the Kawasaki or Capstone configurations is the probability that the turbines will fail to start. Just as with the diesel generators, the Capstone microturbines can be characterized by a probability to start from a cold-standby. This is less of a consideration for the Kawasaki since this turbine would be operating 24/7. Also not considered in the analyses is consideration of the differences in the control systems for the two turbines.

In conclusion, probabilistic risk assessments (PRAs) on alternative-power configurations have been shown to be an informative approach to evaluating risk mitigation for power disruption. Methodologies have been developed and applied to a case study for a large telecom site. For the case-study configurations and operating assumptions, a PRA indicates that significant increased reliability can be achieved – including likelihood of natural gas delivery failure – by incorporating a natural gas turbine as primary power with utility grid, diesel, and batteries as the backup systems.

VII. Acknowledgments

This project was funded by the U.S. Department of Energy through the Office of Planning, Budget, and Analysis. The DOE Project Manager is Dr. Allan Hoffman.

Sandia is a multiprogram laboratory operated by Sandia Corporation (a Lockheed Martin Company) for the United States Department of Energy's National Nuclear Security Administration, under Contract DE-AC04-94-AL85000.

NREL is operated for the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, by Midwest Research Institute and Battelle, under Contract No. DE-AC36-99-GO103

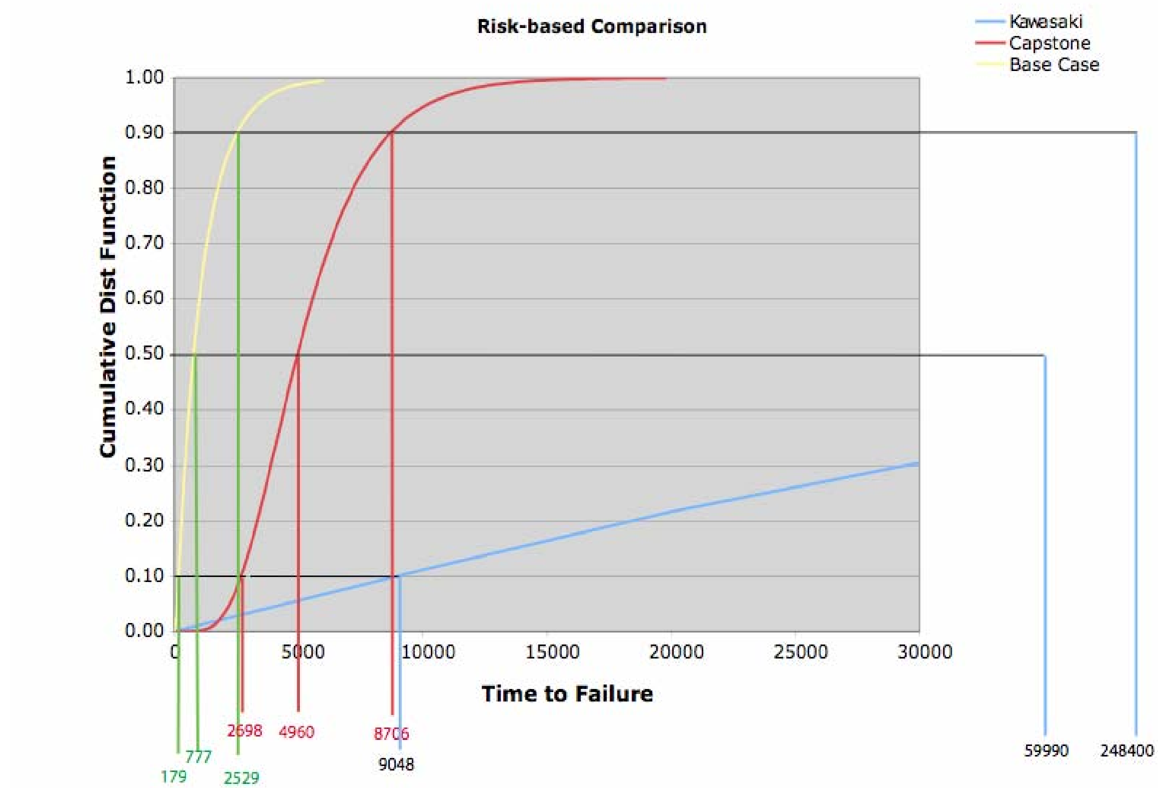

Figure 11. Comparison CDFs for the three system configurations with 10%, median, and 90% probability points delineated for comparison.

VIII. REFERENCES

1. C. Warren, J. Bouford, "Classification of Major Event Days," Transactions IEEE T&D Conference, IEEE Working Group on System Design , 2003.
2. M. Ivey, A. Ahkil, D. Robinson, K. Stamber, J. Stamp, and K. Chu, "Accomadating Uncertainty in the Planning and Operations of Electric Power Systems," Sandia National Laboratories, Albuquerque, NM SAND2000-1681, July 2000.
3. IEEE recommended practice for the design of reliable industrial and commercial power systems. 1998, USA : 1998.
4. D. Spiegelhalter, A. Thomas, and N. Best, "WinBUGS Version 1.4 " 2006.
5. G. Grant, J. Poloski, A. Luptak, C. Gentillon, and W. Galyean, "Emergency Diesel Generator Power System (1987-1993)," U.S. Nuclear Regulatory Commission NUREG/CR-5500, 1996.
6. G. Grant, J. Poloski, A. Luptak, C. Gentillon, and W. Galyean, "Emergency Diesel Generator Power System (1997-2003)," U.S. Nuclear Regulatory Commission NUREG/CR-5500U, 2005.
7. Y. D. Jo and B. J. Ahn, "A method of quantitative risk assessment for transmission pipeline carrying natural gas," *Journal of Hazardous Materials*, vol. 123, pp. 1-12, 2005.
8. G. A. Papadakis, "Major hazard pipelines: a comparative study of onshore transmission accidents," *Journal of Loss Prevention in the Process Industries*, vol. 12, pp. 91-107, 1999.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*
June 2006

2. REPORT TYPE
Conference Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Impact of Distributed Energy Resources on the Reliability of Critical Telecommunications Facilities: Preprint

5a. CONTRACT NUMBER
DE-AC36-99-GO10337

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
D.G. Robinson, D.J. Arent, and L. Johnson

5d. PROJECT NUMBER
NREL/CP-620-40220

5e. TASK NUMBER
SAO1.0100

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401-3393

8. PERFORMING ORGANIZATION REPORT NUMBER
NREL/CP-620-40220

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
NREL

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*
This paper documents a probabilistic risk assessment of existing and alternative power supply systems at a large telecommunications office. The analysis characterizes the increase in the reliability of power supply through the use of two alternative power configurations. Failures in the power systems supporting major telecommunications service nodes are a main contributor to significant telecommunications outages. A logical approach to improving the robustness of telecommunication facilities is to increase the depth and breadth of technologies available to restore power during power outages. Distributed energy resources such as fuel cells and gas turbines could provide additional on-site electric power sources to provide backup power, if batteries and diesel generators fail. The analysis is based on a hierarchical Bayesian approach and focuses on the failure probability associated with each of three possible facility configurations, along with assessment of the uncertainty or confidence level in the probability of failure. A risk-based characterization of final best configuration is presented.

15. SUBJECT TERMS
Distributed energy resources; telecommunications facilities; telecommunications; Federal Communications Commission; FCC; universal power systems; electrical infrastructure; power systems; National Renewable Energy Laboratory; Doug Arent; Sandia National Laboratory; David Robinson; Sprint Power Standards; Larry Johnson

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
Unclassified	Unclassified	Unclassified	UL		19b. TELEPHONE NUMBER *(Include area code)*