




Valuing Energy Security: Customer Damage Function Methodology and Case Studies at DoD Installations

J. Giraldez, S. Booth, K. Anderson, and K. Massey

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October 2012

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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, Colorado 80401
303-275-3000 • www.nrel.gov

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List of Acronyms and Abbreviations

ASAI	average system availability index
CAISO	California Independent System Operator
CDF	customer damage function
CPUC	California Public Utility Commission
DoD	Department of Defense
FY	fiscal year
GDP	gross domestic product
GNP	gross national product
ISO	independent system operator
kW	kilowatt
kWh	kilowatt-hour
MCAS	Marine Corps Air Station
NREL	National Renewable Energy Laboratory
NVESD	Night Vision and Electronic Systems Directorate
PUC	public utility commission
SAIDI	system average interruption duration index
SAIFI	system average interruption frequency index
SDG&E	San Diego Gas and Electric
VEES	value of electrical energy security

Executive Summary

This report describes a methodology to value non-energy savings that can be attributed to energy security projects. The methodology is based on: (1) completing a site survey to collect data on two hypothetical outage scenarios lasting for different durations to compute a customer damage function (CDF), which represents interruption costs as a function of the outage duration; (2) characterizing the reliability of the commercial power supply at the site; and (3) estimating the value of electrical energy security (VEES), which is a metric that characterizes on an annual basis the cost of utility outages. The avoided cost of commercial power outages can be used as ancillary non-energy savings to increase the return on investment of energy security projects.

For the purposes of this report, the general reach of energy security is focused on electrical energy security concerns, in particular, to the provision of electrical power during commercial electric power outages. Valuing energy security is an increasingly important component for financing energy projects. In the military sector, the ability to assess the value of energy security will play a critical role in prioritizing mission critical energy projects.

The CDF concept and energy security valuation have a variety of applications. An established CDF military function could be used as a tool when making investment decisions regarding energy security projects. It will assist with justifying project financing and/or comparing the relative benefits of several projects. As an example, the VEES, which is the annual avoided cost of commercial power outages, can be included as “non-energy” savings in the solicitation for Energy Conservation Investment Program funds, and used to prioritize investment and tradeoffs of energy security projects at installations with critical missions. Additionally, the process of working with the CDF questionnaire and establishing all of the assumptions necessary to develop the CDF curve can expose critical vulnerabilities at an installation that might otherwise only be detected through an outage.

The CDF function has direct applications for the Department of Defense (DoD). The National Renewable Energy Laboratory’s proposed energy security evaluation process is relatively easy to populate and could be adopted as a standard against which current and future installation energy security projects are prioritized. The methodology also could be developed into a tool for facility and regional energy managers, and/or DoD portfolio and enterprise managers to inform their decisions related to energy security projects.

The methodology presented in this paper can and will continue to evolve as lessons are learned from its application. Some of the next steps needed to refine and improve this methodology for application in the DoD would be to: (1) develop further processing of the surveyed data to refine both probabilities of events occurring and their associated cost with DoD personnel; (2) complete an extensive survey in strategically selected military installations; and (3) create a tool to compute the potential annual savings from increasing energy security, including survey processing capabilities, and CDF curve and commercial power reliability databases.

Summary of Results

The survey and CDF methodology were completed at two DoD installations: Marine Corps Air Station (MCAS) Miramar in San Diego, California, and the 300 Compound Area at Fort Belvoir (Army), Virginia . The VEES value was calculated using equation (ES.1) below:

$$VEES = Annual\ \#\ outages * CDF(Duration)\left[\frac{\$}{kWpeak}\right] * Peak[kW] \qquad \text{(ES.1)}$$

Where *Annual # outages* is the annual number of outages, *CDF(Duration)* is the value in $/kilowatt (kW) peak of an outage cost obtained from the CDF curve for a specified *Duration* of the interruption, and *peak* is the peak-demand of the installation.

The CDF for MCAS Miramar is shown in Figure ES-1. Table ES-1 below shows a range of VEES numbers at MCAS Miramar using Scenario A that could be used to support an energy security project.

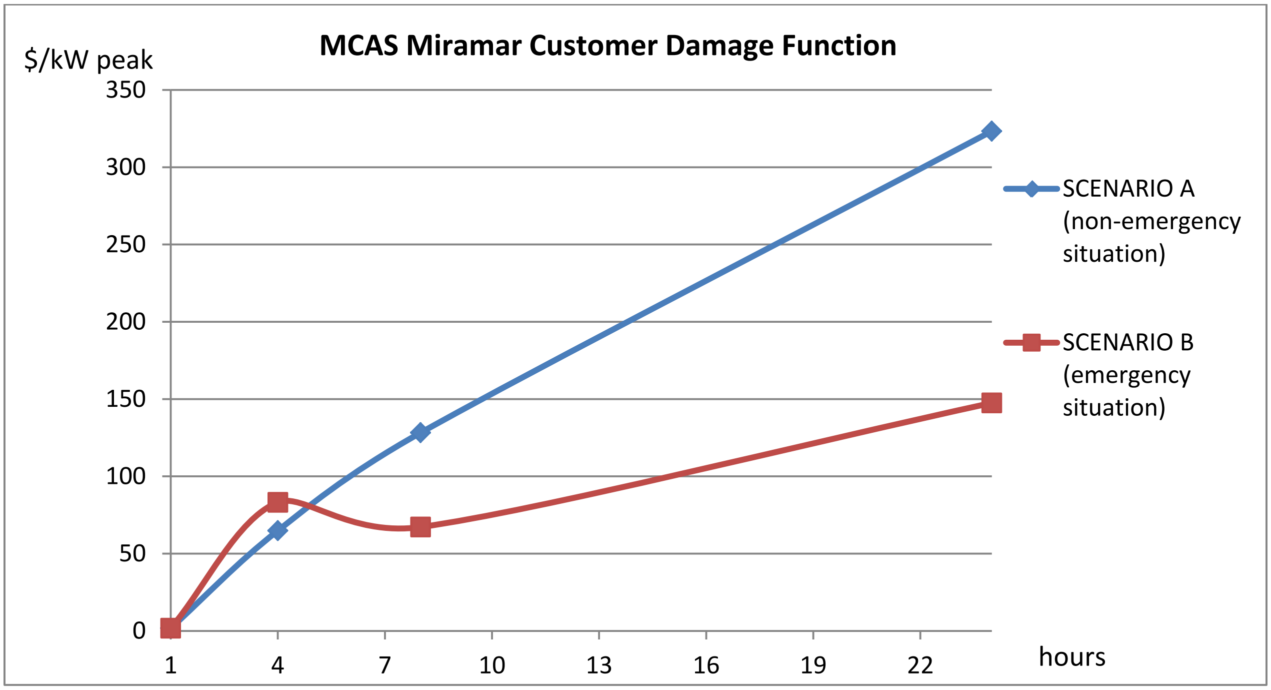

Figure ES-1. CDF for MCAS Miramar

Table ES-1. Annual VEES Values at MCAS Miramar Under a Non-Emergency Scenario

Case number	Annual number of outages	Annual outage duration	VEES in $/year
1. SDG&E 10 year average SAIFI and SAIDI	0.75	2.6 hours	$ 390,000
2. SDGE 2011 SAIFI and SAIDI	1.5	9.5 hours	$ 2,925,000
3. MCAS Miramar experiencing a 5 hour outage every 2 years	0.5	5 hours	$ 487,500

The first case uses the average SAIDI and SAIFI values over the last ten years, Case 2 uses SAIDI and SAIFI values in 2011, and finally the third case is calculated assuming that the base experiences a large 5 hour outage every two years. The annual losses due to outages at MCAS Miramar depending on the number and duration of outages range from $390,000 to $2.92 million.

The survey was also completed at the 300 Compound Area of the Fort Belvoir Army base, and the data were processed to compute the CDF shown in Figure ES-2. Table ES-2 shows annual VEES numbers at the 300 Compound Area.

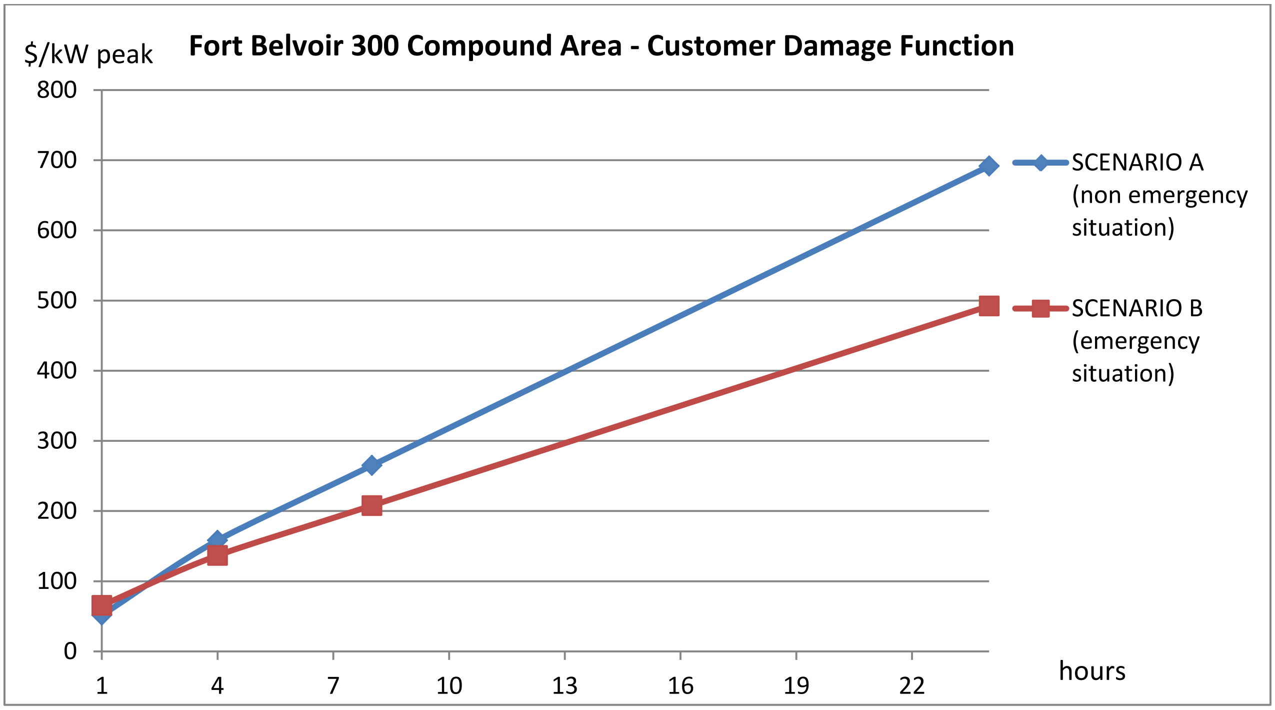

Figure ES-2. CDF for the 300 Compound Area, Fort Belvoir, Virginia

Table ES-2. Annual VEES Values at 300 Compound Area (Fort Belvoir) Under a Non-Emergency Scenario

Case number	Annual number of outages	Annual outage duration	VEES in $/year
1. Dominion Virginia Power 10 year average SAIFI and SAIDI	2.2	6.6 hours	$2,227,500
2. Dominion Virginia Power 2011 SAIFI and SAIDI	2.4	24.8 hours	$7,560,000
3. 300 Compound Area actual number and duration of outages in 2010	8	2 hours	$3,960,000

Using the CDF function in Figure ES-2 and utility 10 year average metrics in Case 1, the expected annual losses are approximately $2.23 million per year. In case 2, Dominion Virginia Power 2011 reliability metrics are used and the annual losses add up to $7.56 million. Finally, in Case 3, the actual number and duration of outages are used at the 300 Compound Area, from reference [26] and assuming that in 2010 the installation experienced eight 2-hour long outages, the annual losses for FY 2010 were $3.96 million.

The VEES numbers in Table ES-1 and ES-2 represent the potential value of an energy security project that would provide 100% reliable power in case of commercial power interruption. A de-rating factor to the VEES number should be applied depending on the degree of reliability provided by the energy security project.

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1 Introduction

"Google the term 'energy security' and you'll get 92 million hits. Say energy security to five different people, and I bet you'll get 10 different answers," said Michael A. Aimone, director of Business Enterprise Integration, Office of the Deputy Undersecretary of Defense (Installations and Environment) in a blog post about energy security in March 2009. [1]

In the *2010 Quadrennial Defense Review Report,* there is a definition of energy security for the Department of Defense (DoD): "[Energy security] means having assured access to reliable supplies of energy and the ability to protect and deliver sufficient energy to meet operational needs." [2] However, this definition is very generic and does not define what "reliable supplies of energy" or "sufficient energy" means. Is a reliable supply of energy a power supply that can guarantee 100% delivery? Does 100% delivery assume a certain level of redundancy in power supply? Are operational needs defined in order to guarantee sufficient energy? Is sufficient energy expected to meet operational loads for an indefinite amount of time? These are just some of the questions that illustrate the complexity of defining energy security for DoD.

The Navy's definition of the term is "…having assured access to reliable and sustainable supplies of energy and the ability to protect and deliver sufficient energy to meet operational needs," [3] which is very similar to the definition included in the *2010 Quadrennial Defense Review Report*. The Army takes it to the next level in the *Army Energy Security Implementation Strategy* by defining more precisely the following three terms: sufficiency, surety, and sustainability:

> "Above all, energy security means having adequate power to conduct critical missions for the duration of that mission (sufficiency). Secondarily, and leading to sufficiency, is ensuring resilient and redundant energy supplies that are accessible when needed (surety). Finally, the energy supplies must present the lowest life cycle cost, while considering all statutory and executive order requirements, as well as the impact to mission, community, and environment (sustainability)." [4]

Here the definition of sufficiency includes the duration for which the reliable power supply is expected, and the definition of surety affirms that the reliability of the power supply is expected to be resilient and redundant.

For the purposes of this report, the general reach of energy security is focused on electrical energy security concerns, in particular, to the provision of electrical power during commercial electric power outages. One of the reasons to increase the sufficiency of energy security in DoD installations is that they are almost completely dependent upon the commercial power grid.

The report of the 2008 Defense Science Board Task Force on DoD Energy Strategy, *More Fight—Less Fuel*, [5] called on the department to initiate aggressive energy innovations aimed at reducing risk to soldiers and enhancing the military's long-term energy security. A key thread in the report was the vulnerability of the nation's electric power grid. At fixed installations in the United States, utility providers have become increasingly efficient following deregulation, in an attempt to lower costs, but also less resilient and more susceptible to outages. They are vulnerable to extreme weather, cyberattack, physical attack, and an aging infrastructure already operating beyond its design life. Large blackouts at a national level are growing in number and severity as shown in Figure 1.

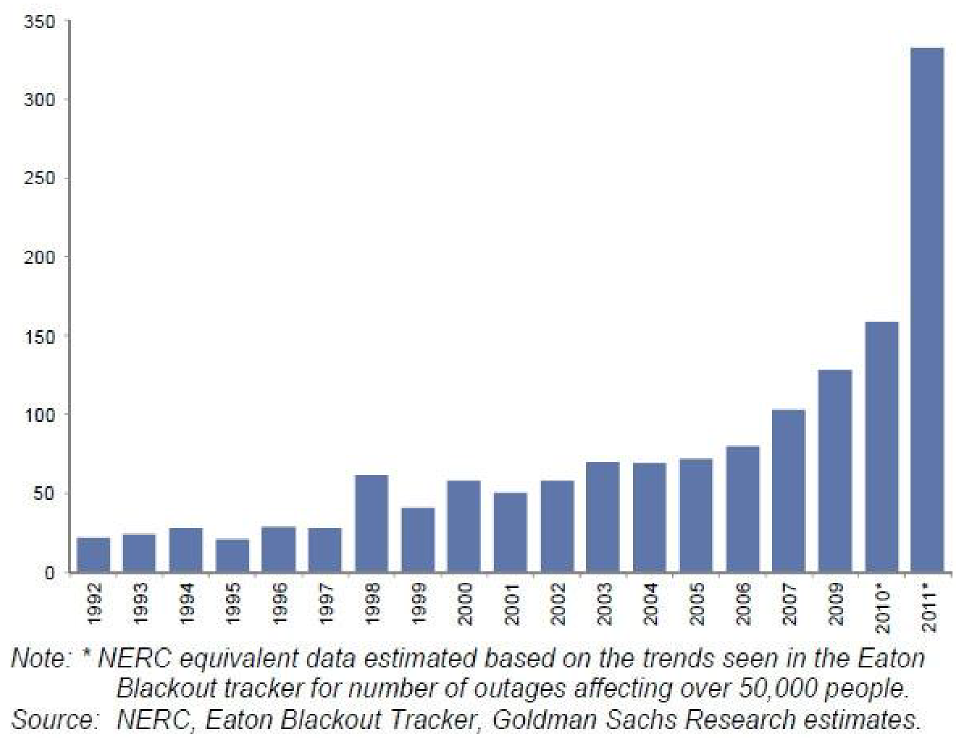

Figure 1. Major power disturbances in North America from 1992 to 2011

The number of outages affecting 50,000 or more people has risen from a total of 41 during 1991–1995 to 58 during 1996- 2000 to 92 during 2001–2005. The trend is similar for occurrences over 100 megawatts, going from 66 to 76 to 140 in the same time periods. [6] The latest data published in Eaton Corporation's *Blackout Tracker United States Annual Report for 2011* confirm an upward trend with the following results for a number of reported outages affecting 50,000 or more people: 42 outages in 2009, 52 outages in 2010, and 109 outages in 2011. [7] In all, 3,071 reported outages were tabulated and used as the basis for the 2011 report. The number of people affected by outages jumped from 17.5 million in 2010 to 41.8 million in 2011 due to multiple, massive power failures. Reliability metrics for individual utilities vary and are discussed more in section 4 of this report. In section 5 of this report, metrics from the utilities that serve the facilities discussed in the case studies are presented.

Solutions for backup power in DoD installations have not kept pace with the growing frequency and duration of commercial utility outages. [8] Most DoD installations have contingency plans in the event of a grid failure that can provide backup power to critical loads using, in most cases, diesel-powered building generators. However, the expected duration for these contingency plans is not well defined; diesel generators are not designed to run for weeks at a time, and fuel storage capacities vary widely. Additionally, the preventative maintenance for these diesel generators does not always prepare the generators for 100% availability; they have a low probability of 60% to start when needed. [9]

Microgrids are a primary solution to address the need for greater energy security in military installations. In a statement to Congress in March 2012, Dr. Dorothy Robyn, deputy undersecretary of Defense (Installations and Environment) states that:

> "[Microgrids]… will reduce installation energy costs on a day-to-day basis by allowing for load balancing and demand response—i.e., the ability to curtail load or increase on-site generation in response to a request from the grid operator. Most important, the combination of on-site energy and storage, together with the microgrid's ability to manage local energy supply and demand, will allow an installation to shed non-essential loads and maintain mission-critical loads if the grid goes down." [10]

Due to an increasingly stressed grid, ancillary services–such as operating and regulating reserves–are an essential component of grid reliability and stability. Operating reserves can be called upon quickly when a transmission line or generating station becomes unavailable or when local area distribution problems arise. Regulating reserves help balance the power system and maintain a steady frequency given the constant fluctuations in demand and intermittent generation sources. Due to the general decrease in reliability of the commercial power grid, it is expected that energy security projects at the customer level, such as a military installation, will benefit the local utility. In the new developing market systems, energy security projects such as microgrids can be paid for by providing demand-response services; and/or supplying a number of ancillary services or reliability services such as voltage regulation, reserve power, black start, controlled islanding, etc. Thus, it is expected that microgrids can both improve electrical energy security at DoD and provide increasingly highly valued reliability services to utilities and regional markets.

The scale and type of benefits created from microgrids will vary depending on customer and location-specific circumstances, including the thermal and electric demands of interconnected loads, the configuration of the local distribution system, the ability of existing legacy grid infrastructure to meet load growth, the local utility's generation mix, the retail cost of energy, and the energy market structure among others. The article "*Microgrids: An Assessment of the Value, Opprtunities and Barriers to Deploymnet in New York State*" [11] describes in depth the economic value streams of microgrids, which depend on the generating technologies deployed. Some of the benefits include:

- Reduced overall energy costs by reducing energy consumption and utility transmission and distribution services charges
- Exported power to the grid
- Participation in demand-response programs
- Participation in distribution and transmission ancillary services
- Greater use of renewable generation through the use of advanced control systems, demand response, and dispatchable generating sources
- Increased power quality
- Reduced power interruptions. [11]

Contingency plan expenditures traditionally have been reviewed and approved based solely on initial capital cost. However, efforts toward life cycle costing or performance parameters are now being discussed. Drexel Kleber, the director of the DoD Strategic Operations Power Surety Task Force, describes it in an article published in 2009:

> "Today, more than ever, the Department of Defense is learning to accept and create new business models, where fiscal decisions are made with a greater understanding of US national security vulnerabilities, mission requirements and long-term Energy security objectives. It is expected that some critical infrastructure investments will be made based on their contribution to DoD's Energy security objectives but which do not meet traditional life cycle cost analysis objectives or which don't provide a return on investment. This process will become easier with the development of an 'energy key performance parameter' as recommended by the Defense Science Board Task Force and metrics to quantify the 'fully burdened cost of fuel'." [8]

Although there are references to the need for metrics, as of today, the authors have not been able to find a metric that justifies the investment in energy projects that contribute to increased energy security. This paper uses the customer damage function (CDF) that has been used in non-military scenarios to develop a methodology to quantify the non-energy savings or avoided costs of energy security projects on DoD installations. Following this introduction, the paper is organized and presents information as follows:

- Section 2- Discusses methodologies for valuing energy
- Section 3- Describes CDF in detail
- Section 4- Discusses how to characterize the reliability of the commercial power grid
- Section 5- Presents two CDF case studies and the respective utility reliability metrics
- Section 6 –Presents conclusions and future work.

2 Methodologies for Valuing Energy Security

New efforts are underway to place a value on energy security as a way to justify any additional costs to enhancing energy security. Investments to enhance energy security should result in the reduction or elimination of outages. Outages have very real costs to DoD, both direct and indirect, so the avoided cost of outages can be viewed as a legitimate part of the return on those investments. There are two ways of quantifying outage costs described below: macroscopic and microscopic.

The macroscopic method to valuing energy security would use the costs of energy not supplied [$/kilowatt hour (kWh)] and/or a cost per interrupted power [$/kilowatt (kW)] as an adjustable measure for interruption severity. This approach attempts to relate the outage costs to a national level by estimating the total cost of outages over a long (i.e., annual) period of time. It is difficult to accurately assess the value of unserved energy for every customer due to the potentially large volume of data. The gross national product (GNP) and gross domestic product (GDP) estimation methods have been developed to approximate long-term outage costs. The GNP (or GDP) outage cost method is designed to estimate the outage cost based on the ratio of GNP (or GDP, respectively) to the total energy consumption. In a macroscopic approach, the outage cost is calculated using equation (1) by:

$$Outage\ Cost\ \left[\frac{\$}{kWh}\right] = \frac{GNP\ (or\ GDP) in\ \$}{Total\ Annual\ Energy\ Consumption\ in\ kWh} \qquad (1)$$

The macroscopic approach is based on economic productivity parameters and is particularly difficult to apply to a military installation whose primary function is national security rather than economic productivity.

A microscopic approach uses costs for the energy not supplied and requires a large-scale survey to collect the outage cost information. Interruption costs are a function of both the outage and user impacts, and can be presented as a function of outage duration. This approach is known as a CDF. Actual interruption damage may depend on the type of interrupted customers, duration of the power outage, and the situation in which the interruption occurs: day of week, time of day, customer's activity at the moment of interruption, etc. This microscopic approach is better suited to the mission of DoD and the actual impacts on an installation than the macroscopic approach.

The CDF is typically computed based on customer survey data. The survey must include direct and indirect losses to the customer. Direct impacts are those resulting directly from cessation of supply while indirect impacts result from a response to an interruption. Hence, direct economic impacts include loss of production, paid-for resources (material, labor, etc.), process restart costs, spoilage of raw material or food, equipment damaged as a direct result of the power outage, costs associated with human health and safety, etc. Direct social impacts include any inconvenience due to lack of transportation, and economic personal injury or fear. Indirect losses usually rise as consequences and may be difficult to categorize. Examples of such costs are civil disturbances or disobedience, failure in providing an essential service, etc.

Once the survey is completed, direct and indirect economic impact data are processed and transformed in order to create a CDF curve.

3 Customer Damage Function

CDF customer surveys can be found in the literature for industrial, commercial, and residential sectors of the economy. However, the authors found no published survey that addressed the impact of utility interruptions on DoD bases. A military base is a unique area that includes residential, commercial, and mission critical activities. The National Renewable Energy Laboratory (NREL) has prepared a survey specific to military bases, building on previous surveys with questions directed toward the military sector.

Surveys are associated with hypothetical scenarios that may vary in several ways (duration, time/type of day, season, etc.). For this survey, two hypothetical scenarios were developed that vary in duration and emergency level:

1. Scenario A- There is a power outage and the lack of power supply lasts for 1, 4, 8, or 24 hours. The base is not in an emergency situation.
2. Scenario B- There is an outage and a natural disaster, or a terrorist attack event is simultaneously going on in the area. The lack of power supply lasts for 1, 4, 8, or 24 hours, and the base is under an emergency situation and has to remain operational.[1]

Hypothetical scenarios can be further developed, and different outage duration times may be selected depending on the mission type of the installation. For instance, R&D installations may be severely affected by short outage durations (less than 1 hour) versus main operational bases that may be affected by longer outage durations (longer than 1 day).

The NREL-designed survey assesses direct and indirect costs of power failure due to:

- Suspended operations, personnel sent home from work, overtime for emergency workers
- Base security impacts and infrastructure impacts (heat, water, sewer, traffic lights)
- Curtailing commercial facility operating hours, food spoilage
- Delays or failures in backup generation, fuel for backup generators
- Equipment damage
- Human lives put in danger
- Residential impacts
- For disaster/attack, impact on relief and rescue missions.

Once the survey has been completed by a facility, the data are processed and dollar values are assigned to the items such as:

- Loss of productivity ($/hour/person)

[1] "Operational base" refers to DoD bases' mission to utilize an installation's military assets for protection, defense, or force projection. or for humanitarian relief and rescue missions using military assets as the central command and control hubs to coordinate the work of other deployed national resources; and as a source of skilled personnel to provide rescue, recovery, medical and other emergency services required by survivors.

- Cost of equipment damaged and repairs ($/equipment)
- Cost of restarting equipment ($/hour/person)
- Cost of human life/lives put to risk (probability x $/person) – mission critical
- Food spoilage [$/kilowatt (kW) peak]
- Backup generator fuel use ($/gallon)
- Loss of ability to communicate (probability x $).

The results of surveys completed at two DoD installations are described in section 5 of this report. A literature review was performed and used to create the plots in Figure 2. [12-18] The values from the research were converted to U.S. dollar values in 2010.[2] From the literature research, it can be observed that the cost ranges for each of the categories are very wide. An Electric Power Research Institute report also outlines "…the tremendous variability in costs across business establishments." [19] It is natural that not every sector has similar costs due to outage events; and within each sector, not every company, campus, or agency will have similar costs. However, the CDF methodology is based on customer surveys and hypothetical scenarios, and therefore is subjective. It is expected that the larger the database to create sector CDFs, the more accurate they will be.

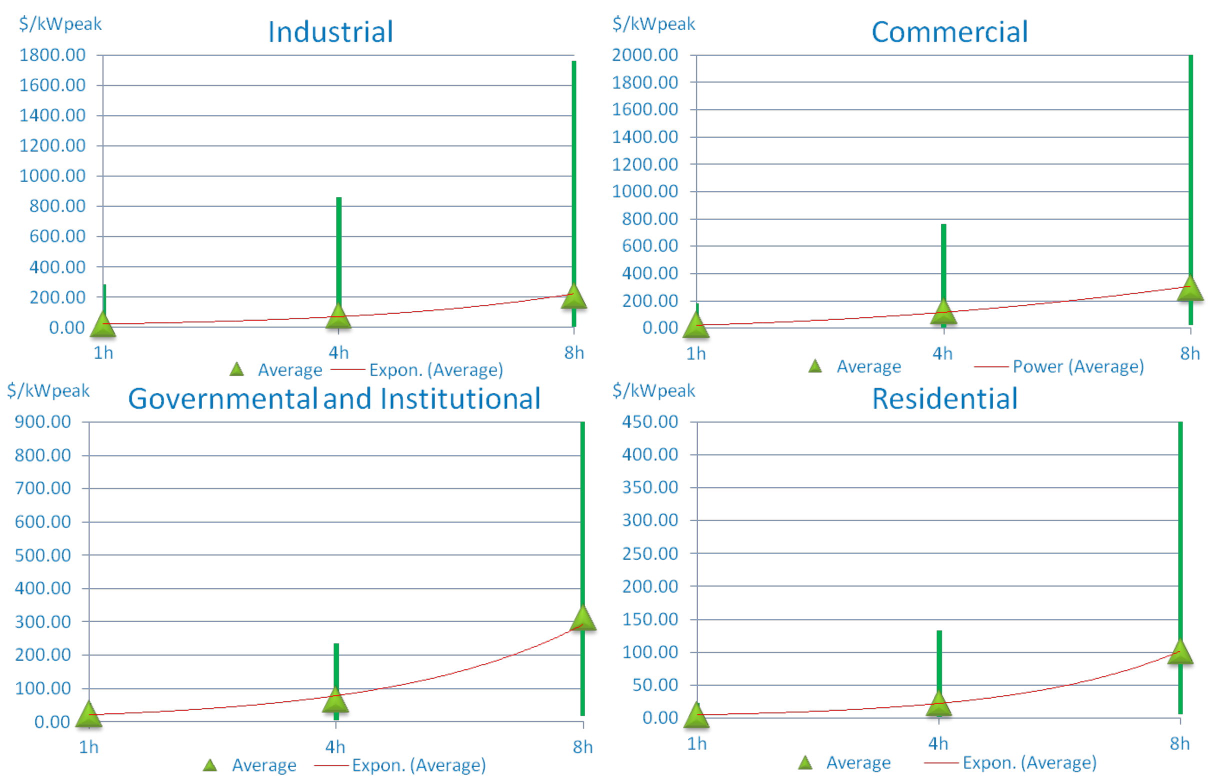

Figure 2. Literature research on cost of outages (in $/kWpeak) for four sectors: industrial, commercial, governmental and institutional and residential

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[2] The consumer price index annual average number published by the U.S. Department Of Labor Bureau of Labor Statistics, Washington, D.C, was used to compute the inflation rate factor.

For that reason, completing an extended outage survey at strategically selected military bases would be a logical next step. As more data are compiled, the following questions should be considered:

- Is there an intuitive form for an installation's CDF curve that varies by mission type?
- How should the military sector CDF curve compare with other sector CDF curves?

4 Reliability in Electric Systems

The utility reliability indices described in this section are consumer or end-user oriented indices, and depend to different degrees on the number of consumers affected, the total number of consumers, the average load connected, and the duration of interruption [20]. These values often depend on utility reporting procedures, such as how an end-user is defined, whether by a single physical location or the number of meters.

The three indices described here are the three most popular customer-oriented indices. The system average interruption duration index (SAIDI) is defined in equation (2) as the average interruption time per customer:

$$SAIDI = \frac{sum\ of\ customer\ interruption\ durations}{total\ number\ of\ customers} \tag{2}$$

The system average interruption frequency index (SAIFI) is defined in equation (3) similarly to SAIDI, but describes how often interruptions occur per customer, on average:

$$SAIFI = \frac{total\ number\ of\ customer\ interruptions}{total\ number\ of\ customers\ served} \tag{3}$$

The average system availability index (ASAI) is defined in equation (4) as the average system availability:

$$ASAI = \frac{customer\ hours\ of\ available\ service}{customer\ hours\ demanded} \tag{4}$$

The ASAI index describes the time, as a fraction of a year, for which the system is available for customer use.

Measures of reliability, such as the metrics described in equations (2)-(4), have been reported by electric utilities to public utility commissions (PUCs) for many years. In some cases, utilities also report on reliability metrics of the largest annual outage events (i.e., large as defined by number of customers affected, duration or both) and their cause, which raises the following questions:

- Do average metrics, such as SAIDI and SAIFI, capture key criteria for energy security planning at DoD installations?
- What is the risk that DoD wants to assume and plan for? (Section 5 in this report includes a review and analysis on reliability metrics for the utilities providing electrical power to the case study installations discussed in section 4 of this report.)]

An analytical approach could also be followed to characterize the reliability of an area's electric power system. This approach is more comprehensive and requires generation and load models to compute reliability metrics such as expected energy not supplied or loss of load probability. The generation model includes the capacities, forced outage rates, failure rates, and repair rates. The load model includes the probability of load changes and demand. This approach would require an extensive data gathering phase to model all the generators and loads in an area.

5 Case Studies: MCAS Miramar and 300 Compound Area at Fort Belvoir

The survey and CDF methodology were completed at two DoD installations: Marine Corps Air Station (MCAS) Miramar in San Diego, California, and the 300 Compound Area at Fort Belvoir(Army), Virginia. The two military installations have radically different missions and are served by different commercial electric utilities.

5.1 MCAS Miramar CDF and Grid Reliability

In this section, the results from the survey and the CDF for MCAS Miramar are presented first, followed by the analysis of its utility power supplier's reliability. It concludes by calculating the value of energy security for Miramar.

MCAS Miramar's mission is to maintain and operate facilities and provide services and material support to the 3rd Marine Aircraft Wing and other tenant organizations. [21] Miramar provides world-class facilities with operational and service support excellence to facilitate combat readiness and training objectives. Miramar's vision is that its strategic location in the southwestern United States and mission are essential elements in the preparation of Marines and sailors for combat.

5.1.1 MCAS Miramar CDF

The survey was completed at MCAS Miramar, and the data were processed to compute the CDF shown in Figure 3.

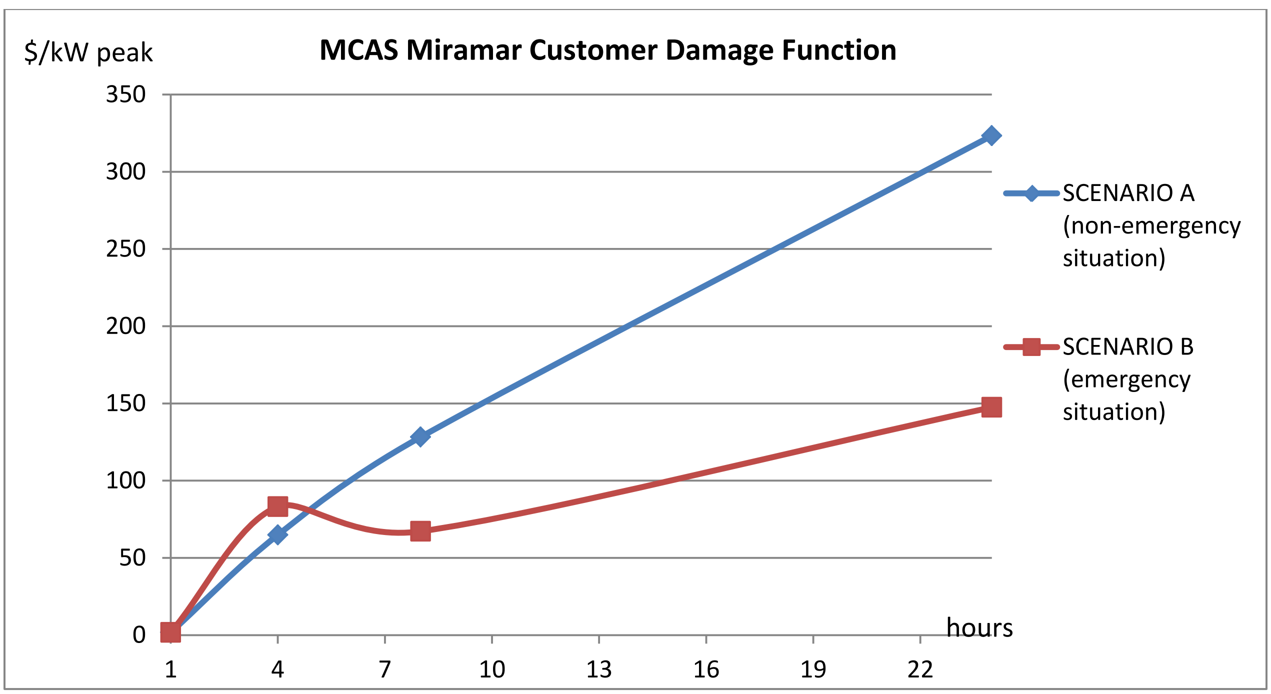

Figure 3. CDF for MCAS Miramar

The results may appear to be counterintuitive because the cost of an outage at MCAS Miramar is greater under nonemergency conditions, with the exception of an outage lasting 4 hours. As a matter of fact, the main driver of an outage cost is the loss of productivity at the base resulting from sending personnel home, and this happens to a greater extent under nonemergency conditions. In Scenario A, 80% of the personnel at the base are sent home if the outage lasts for more than 1 or 2 hours versus 30% sent home during emergency conditions in Scenario B.

The loss of productivity cost is shown in Figure 4. The cost corresponds to the product of the number of people sent home and the average federal salary per hour in San Diego ($25.5/hour-person pre-tax)[22] and the time of unproductiveness. The latter is obtained by calculating the probability that an outage occurs during working hours, which is 17%, 33%, and 100% for 4, 8, and 24 hours respectively. The probability of an outage occurring is multiplied by the duration of the outage, for outages lasting 4 and 8 hours, to obtain the unproductive time. For an outage lasting 24 hours, the probability is multiplied by 10 hours of working time because a long outage can cause delays and further complications.

The second driver and main difference in cost between scenarios A and B are the risks associated with the outage. The risk cost was calculated by estimating the probability of losing a human life times the cost associated with a human life. The probability of losing a human life is a subjective value determined by MCAS Miramar after several discussions with NREL and the flight-line operations team. The cost of a human life used in this study is $6.3 million and was taken from a report published by the Department of Transportation and used for statistical analysis of security measures. [23]

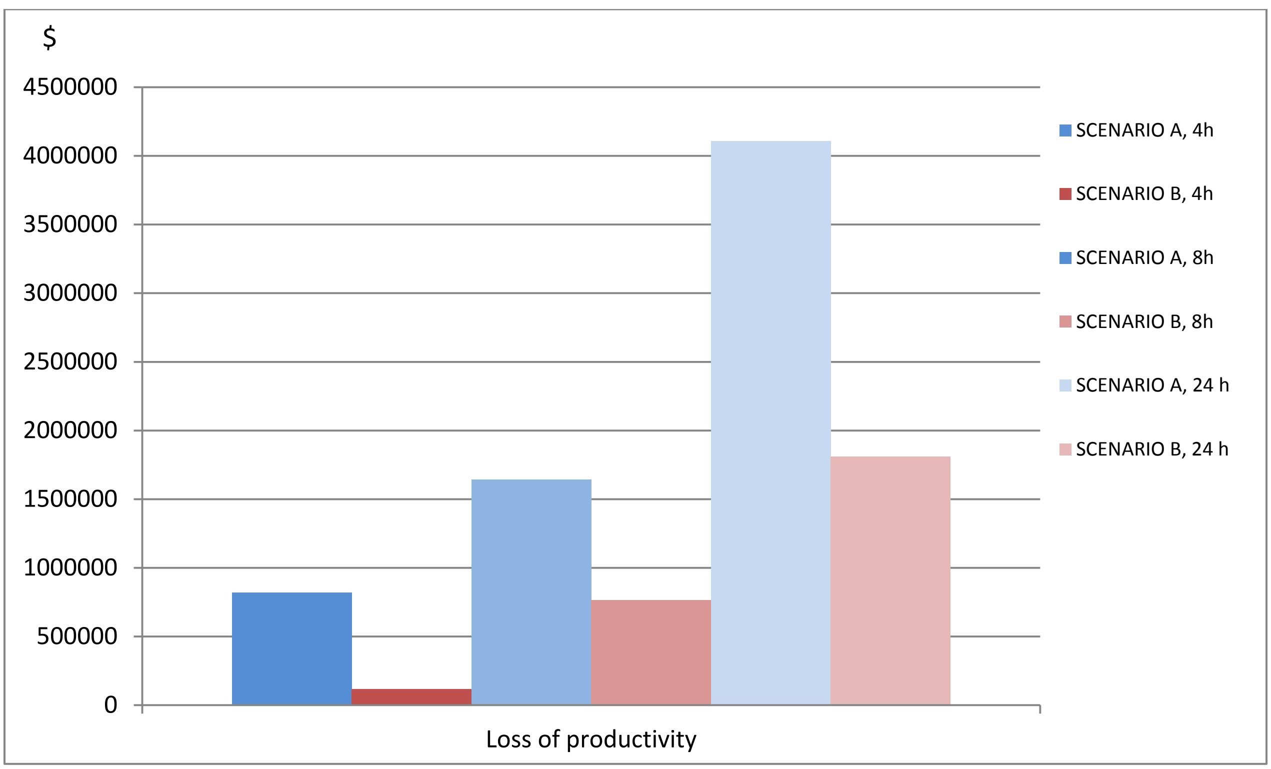

Figure 4. Loss of productivity in $ in Scenarios A and B for 4, 8, and 24 hours of lack of power supply

Figure 5 shows the final costs associated with the risks in scenarios A and B for different durations of the outage. The risk associated with an outage lasting 1 hour is the same in scenarios A and B under the assumption that in the first hour of an outage, there is the same lack of information and the probability of risk is relatively high (0.1% of losing a life). However, if the outage lasts for 4 hours, the risk increases in Scenario B due to the fact that the base is under an emergency condition (10% probability of losing a life). Chaos and riskier decisions can occur in the first 4 hours of an outage under a natural disaster or terrorist attack event in the proximities of the base. On the contrary, a nonemergency (Scenario A) outage lasting 4 hours would have decreased risk, as it is assumed that the base has had the time to resolve the situation (0.01% of losing a life). Finally, for outages longer than 4 hours, it is assumed that for both scenarios A and B, the probability of risk decreases when compared to the 4-hour outage because the base has had the time to get informed and lay out a plan of operation minimizing the risk. However, it is still considered that Scenario B will have a higher risk than Scenario A due to the fact that more people remain or have to evacuate the base under an emergency situation.

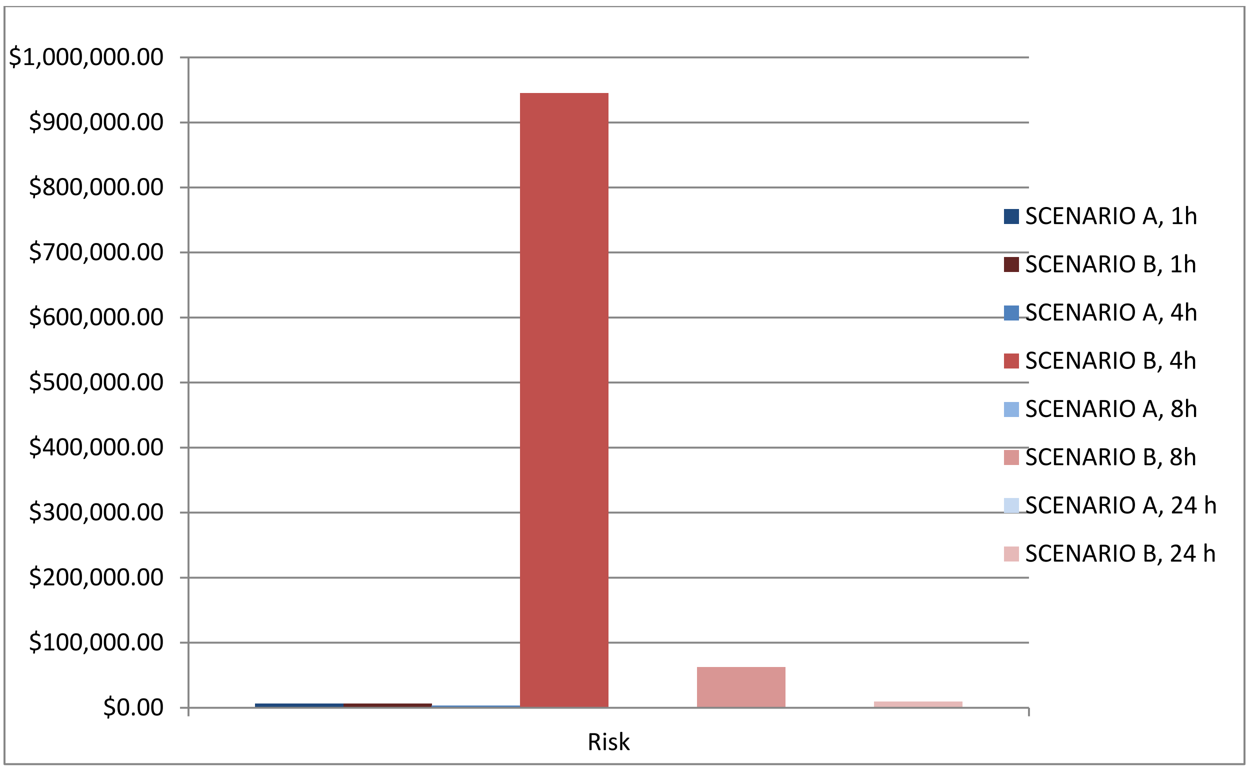

Figure 5. Cost of risk associated to an outage in Scenarios A and B and lasting for 1, 4, 8 and 24 hours

5.1.2 Reliability of Miramar's Electric Utility (San Diego Gas & Electric)

An overview and analysis of reliability metrics and utility outage events for San Diego Gas & Electric (SDG&E) are discussed next to characterize the reliability of commercial power supply at MCAS Miramar.

The *SDG&E Electric System Reliability Annual Report* for 2011 was prepared in response to California PUC (CPUC) Decision 96-09-045. [24] The CPUC decision established additional reliability recording, calculation, and reporting requirements for SDG&E. All statistics and calculations include forced transmission, substation, and distribution outages, and exclude planned outages. Forced outages are those that are not prearranged, and sustained outages are those outages that lasted 5 minutes or more in duration, while momentary outages are those outages that lasted less than 5 minutes in duration.

The measurement of each reliability performance indicator excludes CPUC major events and events that are the direct result of failures in the independent system operator (ISO)-controlled bulk power market, or non-SDG&E owned transmission and distribution facilities. A major event is defined in CPUC Decision 96-09-045 as an event that meets at least one of the following criteria:

- The event is caused by earthquake, fire, or storms of sufficient intensity to give rise to a state of emergency being declared by the government.
- Any other disaster not in the previous bullet that affects more than 15% of the system facilities or 10% of the utility's customers, whichever is less for each event.

A summary of 2011 performance is presented in Table 1, where SAIDI is given in minutes and SAIFI in customer interruptions, both per customer per year. [24] Including major events, in 2011, the average annual outage interruption per customer is approximately 9 hours and 28 minutes, and the average annual number of interruptions per customer is 1.5. The 10-year average reliability metrics, including major events, is 2 hours and 35 minutes for outage interruption per customer (SAIDI) and 0.75 for the number of interruptions per customer (SAIFI).

Table 1. SDG&E Reliability Indices in 2011

CRITERIA	SAIDI	SAIFI
Including CPUC Major Events (2011)	567.59	1.472
Excluding CPUC Major Events (2011)	54.14	0.473
10-Year Average (2002-2011) Including CPUC Major Events	155.49	0.751
10-Year Average (2002-2011) Excluding CPUC Major Events	64.22	0.580

Figure 6 shows SDG&E's SAIDI and SAIFI values from 2000 to 2011 and shows that there is no trend in values increasing or decreasing over time. Note that the 2003 and 2007 peaks in SAIDI values correspond to the firestorms that occurred in the state of California, and the peak in 2011 corresponds to the Pacific southwest electrical outage of September 8. The average number of customers affected and average duration of interruption of the annual 10 largest annual events from 2001 to 2010 are shown in Figure 7; and once more, the data show no clear trend in the number of customers affected or duration of the outages in the last 10 years to conclude that the numbers are increasing or decreasing over time. However, the data show that large events can last between 10 and 90 hours.

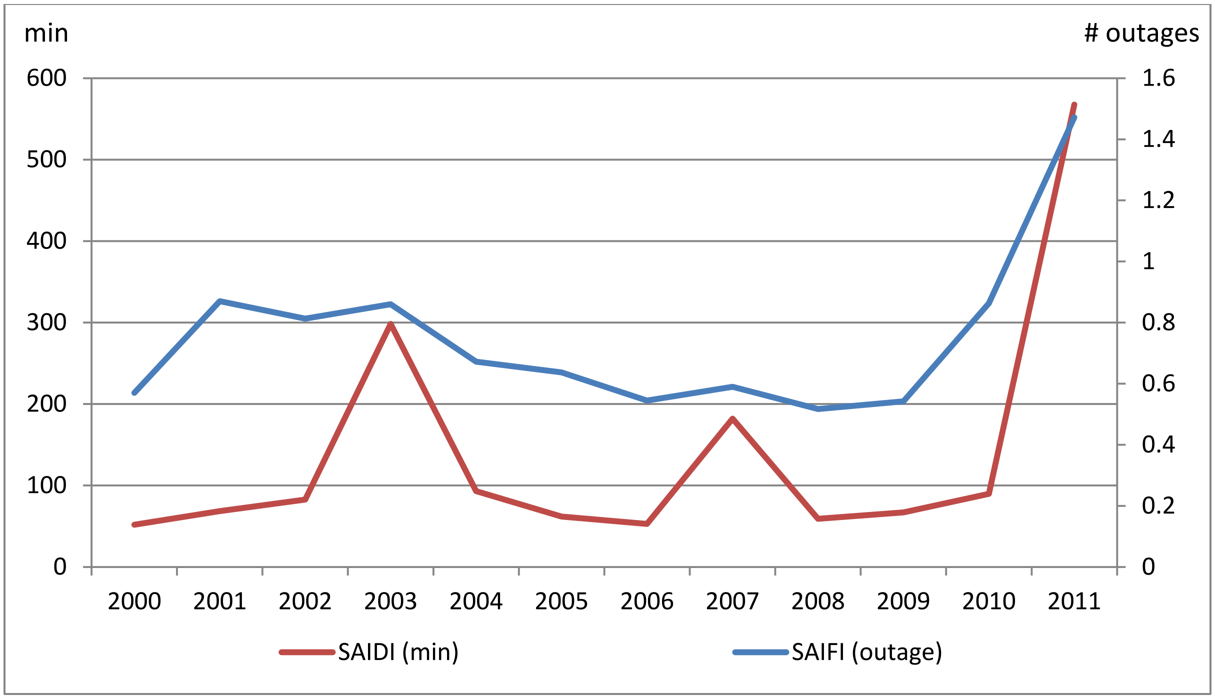

Figure 6. SDG&E's SAIDI and SAIFI values from 2000 to 2011

Average metrics, such as SAIDI and SAIFI, may not capture key criteria for energy security planning in DoD installations and the question becomes: what is the risk that DoD installations want to assume? Figure 8 shows the statistical frequency distribution of the duration of the 100 largest events over the past 10 years and could help an installation assess its energy security requirements. For example, is a 5% chance of having an outage event that lasts for 90 hours acceptable? Is more than a 40% chance of having an outage event lasting between 10 and 20 hours acceptable? Other historical data that would help answer these questions would include the number of large outage events that an installation experiences a year. This information could be used to compute a facility's probability of experiencing a large outage event. Unfortunately, military installations typically do not keep records of outage events.

Ten years of data for the 10 largest outages per year by cause are summarized in Figure 9. The statistics show that the average interruptions by cause are, in a 10-year average, six interruptions per year due to non-utility causes and three interruptions per year due to utility-related events. Non-utility causes include weather related issues such as rain, wind, and lightning storms; external factors causing equipment failures such as vehicle, vegetation, or animal contact; and California ISO (CAISO) related issues including load curtailment and increases in peak load that are expected to keep occurring in following years. These causes do not entirely depend on the utility's reliability of power supply. Utility-related events include SDG&E equipment failure outage events that might be prevented or mitigated by increasing preventive maintenance on utility-owned equipment.

To make matters worse, CAISO plans to take the San Onofre nuclear power plant generating units offline for maintenance, which, according to the current planning standards, would put the San Diego area at risk of outages. [25]

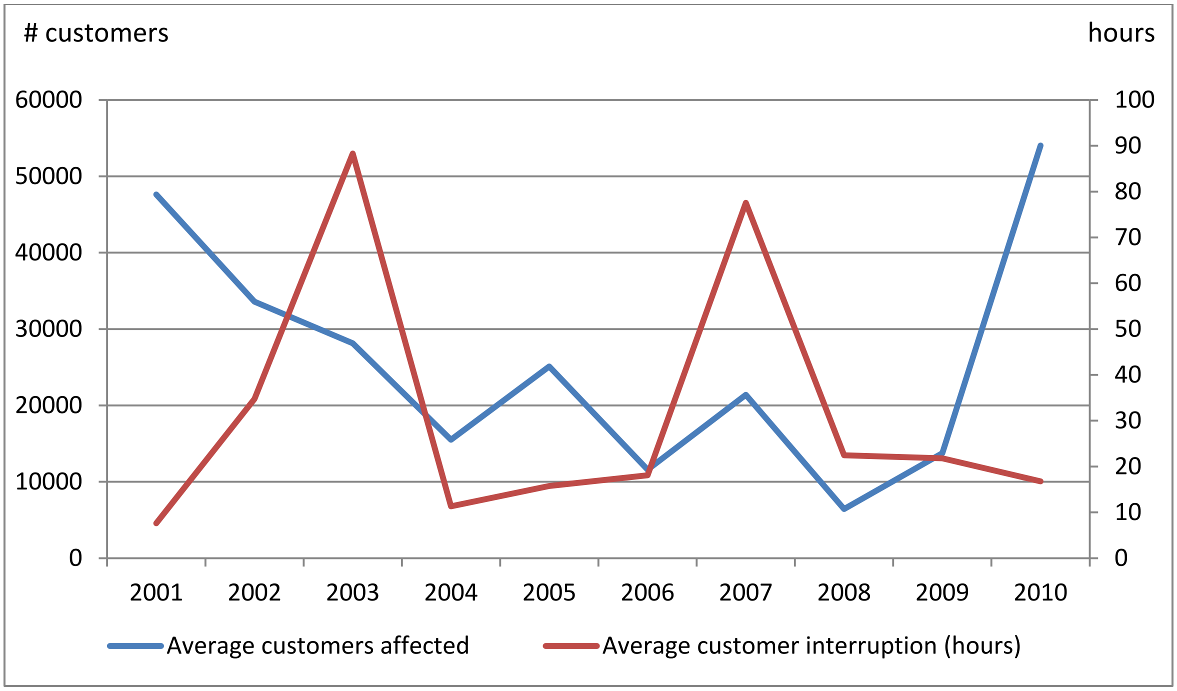

Figure 7. Average customers affected and duration of interruption of the largest annual 10 events from 2001 to 2010

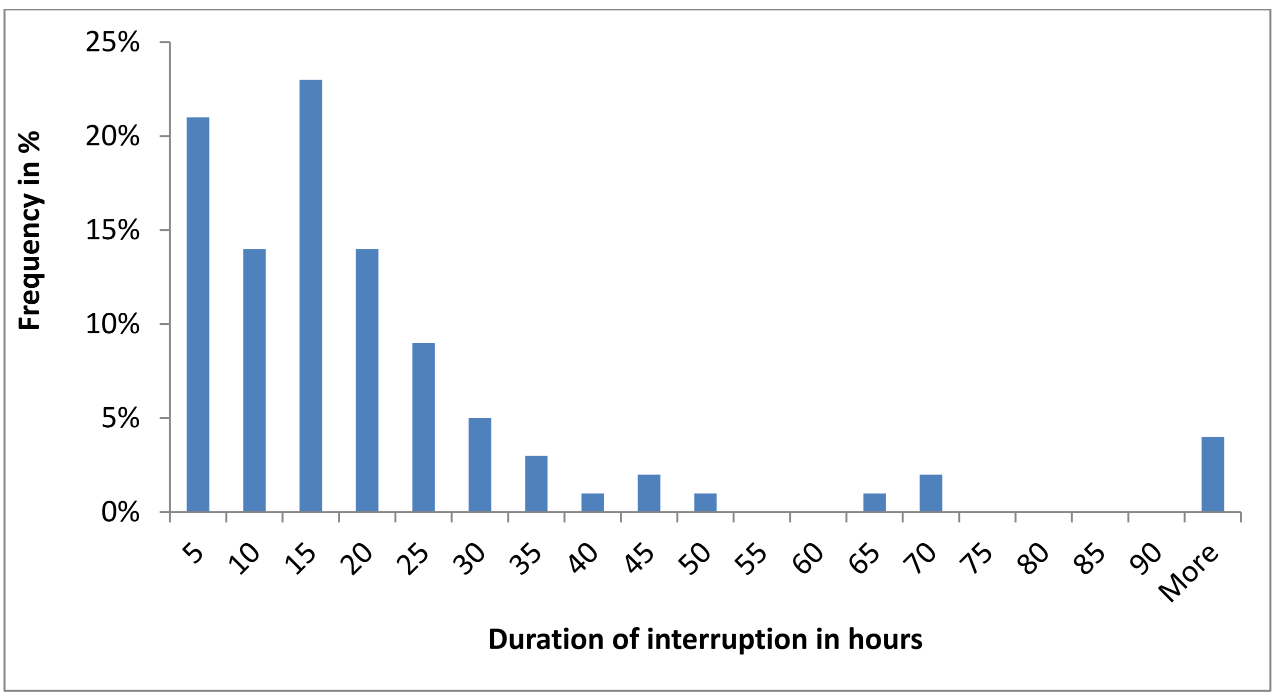

Figure 8. Frequency distribution of outage duration of 100 largest events from 2001 to 2010

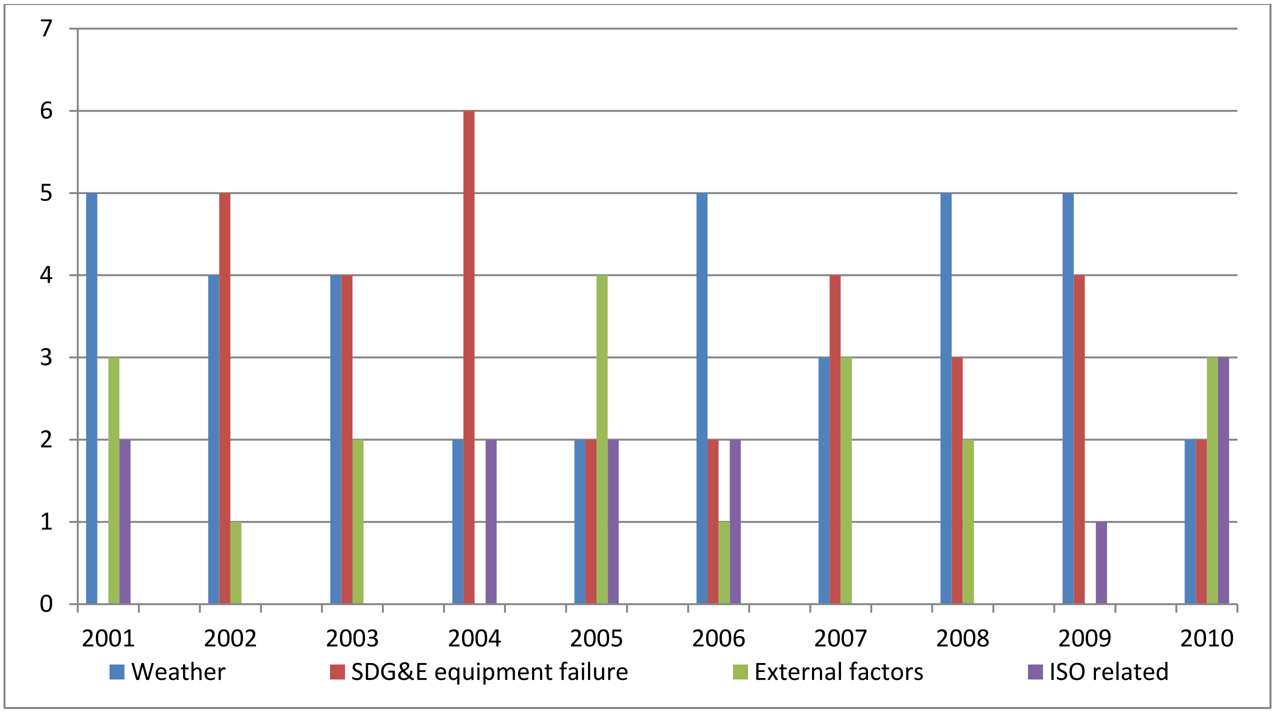

Figure 9. Number of 10 largest outage events by cause

5.1.3 CDF to Support Financing Energy Security Projects at MCAS Miramar

The previous discussion on utility reliability metrics and outage events is useful to come up with a representative annual outage duration to be used to compute "energy savings" from increasing the energy security at MCAS Miramar. The Value of Electrical Energy Security (VEES) values are obtained as follows in equation (5) below:

$$VEES = Annual\ \#\ outages * CDF(Duration)\left[\frac{\$}{kWpeak}\right] * Peak[kW] \qquad (5)$$

Where *Annual # outages* is the annual number of outages, *CDF(Duration)* is the value in $/kWpeak of an outage cost obtained from the CDF curve for a specified *Duration* of the interruption, and *Peak* is the peak-demand of the installation.

Table 2 below shows annual VEES values at MCAS Miramar using Scenario A in the CDF curve in Figure 3 that could be used to support an energy security project depending on the annual number and duration of outages. The first case uses the average SAIDI and SAIFI values over the last ten years, Case 2 uses SAIDI and SAIFI values in 2011, and finally the third case is calculated assuming that the base experiences a large 5 hour outage every two years. An example of using equation (5) to obtain the VEES value in Case 3 in Table 2 is shown in equation (6) below:

$$0.5 * 75\left[\frac{\$}{kWpeak}\right] * 13000[kW] = \$487{,}500 \qquad (6)$$

Table 2. Annual VEES Values at MCAS Miramar Under a Non-Emergency Scenario

Case number	Annual number of outages	Annual outage duration	VEES in $/year
1. SDG&E 10 year average SAIFI and SAIDI	0.75	2.6 hours	$ 390,000
2. SDGE 2011 SAIFI and SAIDI	1.5	9.5 hours	$ 2,925,000
3. MCAS Miramar experiencing a 5 hour outage every 2 years	0.5	5 hours	$ 487,500

The VEES numbers above in Table 2 represent the potential value of an energy security project that would provide 100% reliable power in case of commercial power interruption. A de-rating factor to the VEES number should be applied depending on the degree of reliability provided by the energy security project.

Note that in the computation of the CDF, microgrid capabilities are not taken into consideration. For instance, if MCAS would have the capability to island during a commercial power outage, the installation could become a secure regional operational center for the Marine Corps. The value to an energy security project under that assumption would increase considerably, particularly under an emergency situation (Scenario B). The final decision on the value of energy security needs to come from MCAS Miramar. It needs to set its acceptable level of reliability. The statistics show that outage events can be long in duration, and the base needs to assess acceptable risk.

5.2 300 Compound Area – Fort Belvoir – CDF and Grid Reliability

The 300 Compound Area in Fort Belvoir is mainly dedicated to research and development. Due to the sensitivity of its testing equipment, the Night Vision & Electronic Sensors Directorate (NVESD) is particularly impacted by power outages. Any electrical disturbance can destroy sensitive testing equipment, nullify tests being performed over long periods, and/or substantially delay the deployment of new technology to the warfighter. In addition to the NVESD facilities, there are tenants in the 300 Compound Area that directly support the warfighter and for which power outages can cause a risk to critical operations.

5.2.1 300 Compound Area CDF

The survey was also completed at the 300 Compound Area of the Army base of Fort Belvoir, and the data were processed to compute the CDF shown in Figure 10. Once again, the results may appear to be counterintuitive because the cost of an outage is greater under nonemergency conditions, with the exception of an outage lasting less than 3 hours. The main driver of an outage cost is the loss of productivity at the base based on personnel being sent home. Under non-emergency conditions in Scenario A, almost 100% of the personnel at the base are sent home if the outage lasts for more than 1 or 2 hours versus 67% in Scenario B.

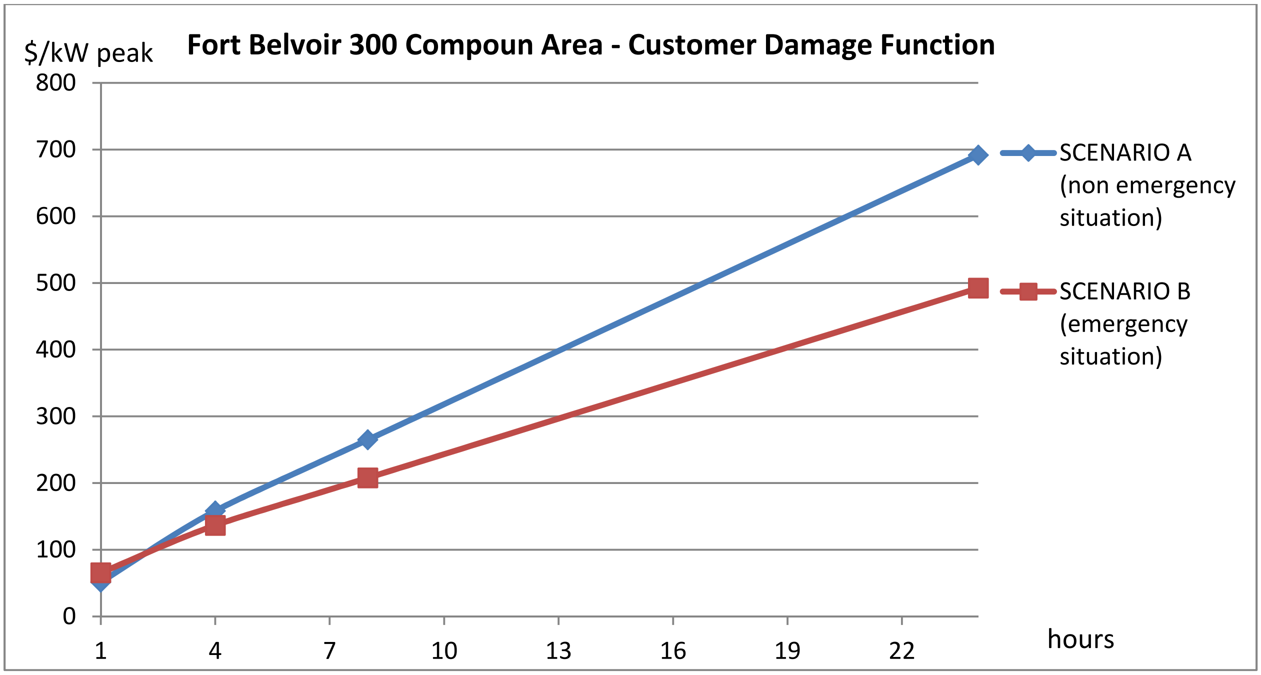

Figure 10. CDF for the 300 Compound Area, Fort Belvoir, Virginia

Among the main items contributing to the cost of an outage at the NVESD facilities is the probability of interrupting experiments in their state-of-the-art laboratories. For example, experiments requiring the vacuum chamber in operation are interrupted by the loss of commercial power supply, and the time wasted to restart the process, as well as data losses, has a substantial adverse impact on the tenants.

The loss of productivity cost is a product of the number of people sent home, their average hourly salary (300 Compound Area- $80/hour-person[3]), and the time they are unproductive. The latter is obtained by calculating the probability that an outage occurs during working hours, which is 17%, 33%, and 100% for 4, 8, and 24 hours respectively. The probability of an outage occurring is multiplied by the duration of the outage—for outages lasting 4 and 8 hours—to obtain the unproductive time. For an outage lasting 24 hours, the probability is multiplied by 10 hours of working time because a long outage can cause delays and further complications. In addition, there is an added cost due to the time wasted to restart the process as well as data losses for the tenants of the NVESD. It was estimated that on average, an outage would interrupt an experiment equivalent to 1 month of five researchers' time.

The difference between scenarios A and B is due to fewer personnel sent home in Scenario A and a higher risk of putting a human life in danger in Scenario B. The risk in the 300 Compound Area is increased because the tenants support critical life action overseas, and an outage may compromise critical missions due to disrupted communications.

5.2.2 Reliability of Fort Belvoir's Utility (Dominion Virginia Power)

An overview and analysis of reliability metrics and utility outage events for Dominion Virginia Power are discussed next. The reliability metrics and data presented were provided by the

[3] Fully burdened federal cost of employment after-tax

Division of Energy Regulation of the Virginia Commonwealth State Corporation Commission. Customer interruptions include all service interruptions greater than 2 minutes, and momentary outages are not included.

Figure 11 shows Dominion Virginia Power SAIDI and SAIFI values from 2000 to 2011 including major storms. SAIFI values on range from 1.5 to 3.7 outages per customer. As seen in Figure 11, SAIFI has no clear tendency to increase or decrease over time. (The major blackout in 2003 shows a large aberration to this trend line.) The average value of approximately two outages per customer for this metric is considered a high value when compared to other utilities. With regards to SAIDI, the average duration of outages per customer range from 180 minutes to 1,500 minutes, with an average over the last ten years of 4 hours and 48 minutes excluding the spike in 2011 and 6 hours and 33 minutes including the spike in 2011. Note that the dramatic increase in SAIDI in 2011 may be due to the outage cause by Hurricane Irene.

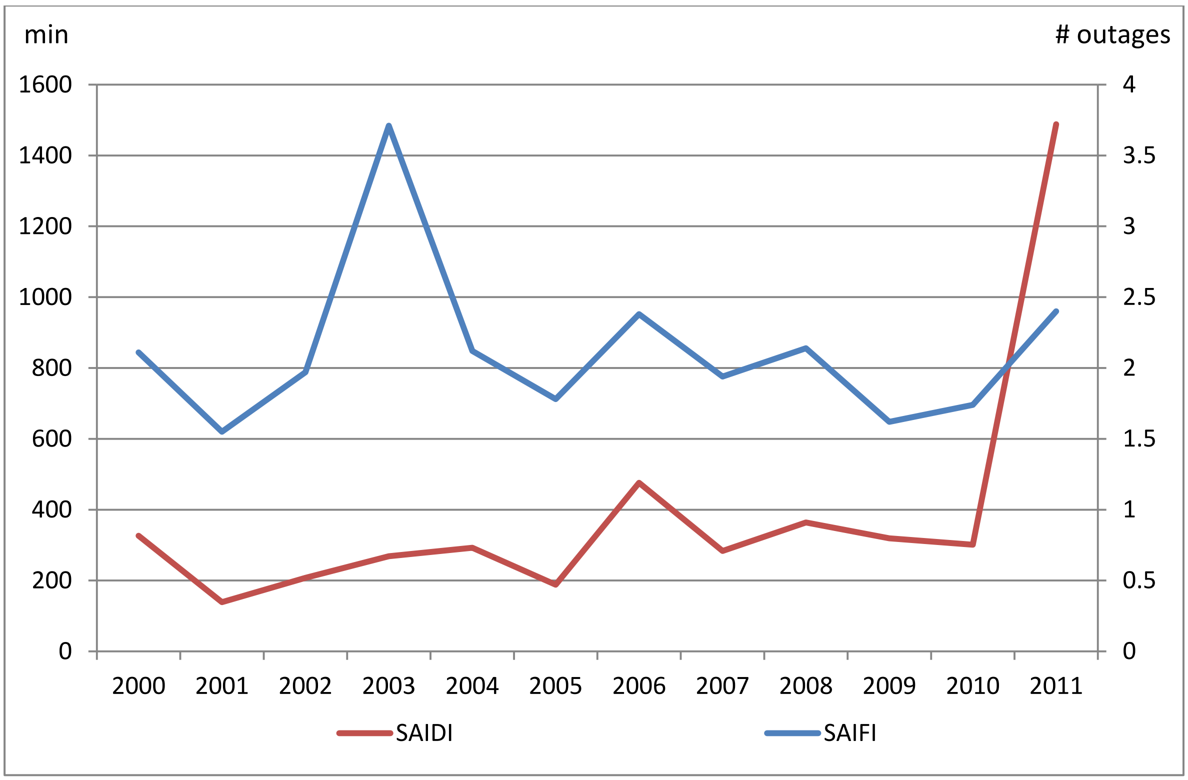

Figure 11. Dominion Virginia Power SAIDI and SAIFI values from 2000 to 2011

Figure 12 shows the percentage of customers affected by number of outages. The percentage of customers affected by more than 10 outages is very low, between 0.1% and 0.4 %. The percentage of customers affected becomes more significant within four-to six outages, and noticeably increases for customers affected between one to three outages per year. Figure 13 shows the percentage of customers affected by outage cause.

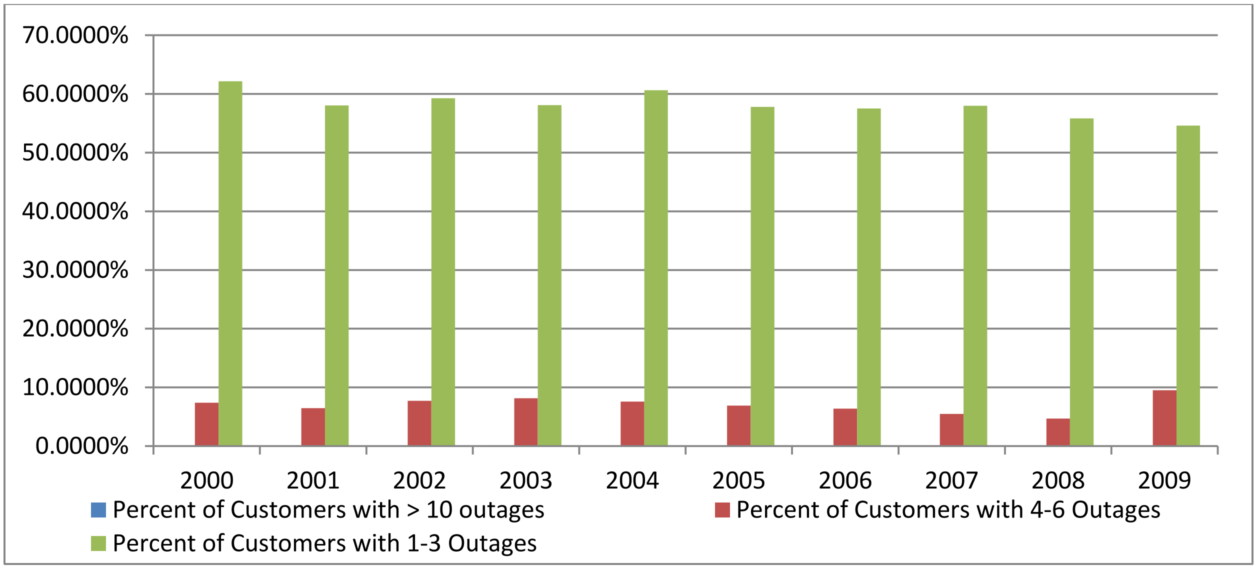

Figure 12. Percentage of customers affected by more than 10, 4-6, and 1-3 outages

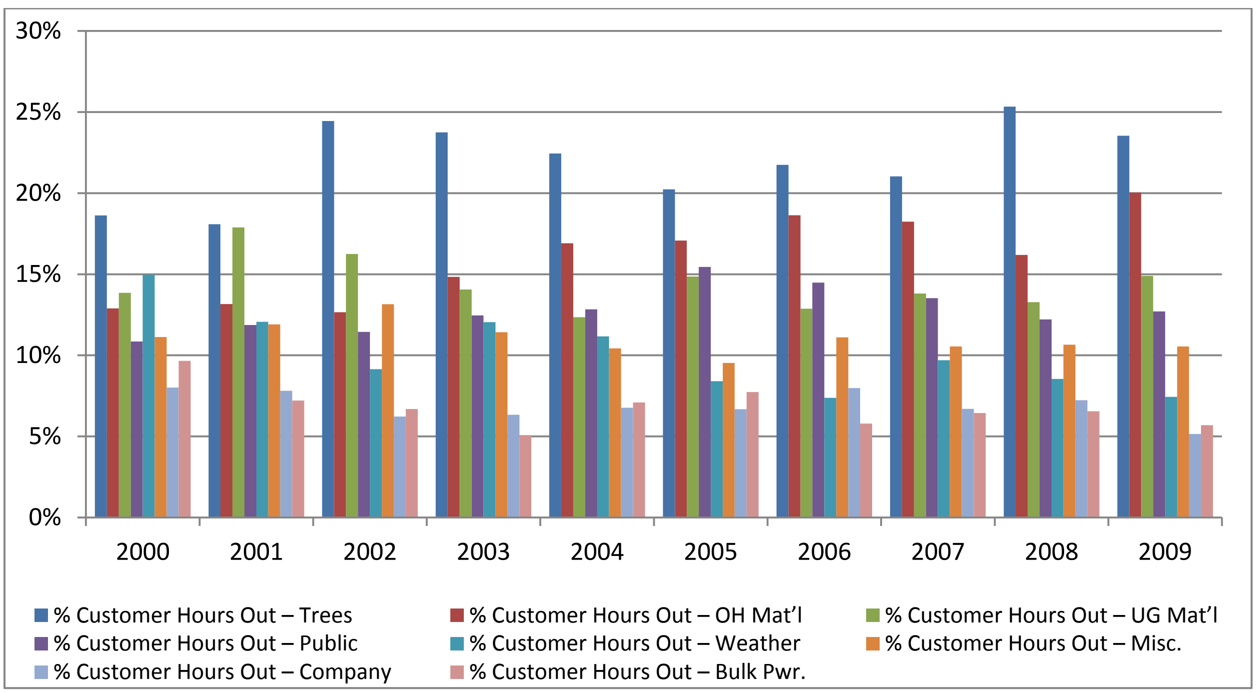

Figure 13. Percentage customers by outage cause

5.2.3 CDF to Support Financing Energy Security Projects at the 300 Compound Area

Average metrics in this case show the unreliability of commercial power supply to the 300 Compound Area in Fort Belvoir. In a report, "*Achieving Energy Security Utilizing a Microgrid in Tri-generation Mode at Fort Belvoir 300 Area Compound*" [26], the U.S. Army Research Development and Engineering Command's Communications-Electronics Research, documents the ongoing disruptions in electricity supply in the 300 Compound Area. From 2006 to 2010, the 300 Compound Area has experienced 37 electrical outage events between 6 a.m. and 6 p.m., lasting a total of 115 hours. In addition, there were 34 outages totaling 152 hours between 6 p.m. and 6 a.m. The financial impact in "*Achieving Energy Security Utilizing a Microgrid in Tri-generation Mode at Fort Belvoir 300 Area Compound*" was calculated based on the cost of all employees and contractors in the 300 Compound Area during the time of the outages. [26] The calculation takes into account that a certain percentage (20%) of all personnel would be offsite during any outage and reduces the calculation accordingly.

Table 3 shows annual values of energy security at the 300 Compound Area. Using the CDF function in Figure 10 and utility 10 year average metrics in Case 1, the expected annual losses are approximately $2.23 million per year. In Case 2, Dominion Virginia Power 2011 reliability metrics are used and the annual losses add up to $7.56 million. Finally, in Case 3, the actual number and duration of outages are used at the 300 Compound Area, from "*Achieving Energy Security Utilizing a Microgrid in Tri-generation Mode at Fort Belvoir 300 Area Compound,*" [26] and assuming that in 2010 the installation experienced eight 2-hour long outages, the annual losses for FY 2010 are $3.96 million.

An example of using equation (5) to obtain the VEES value in Case 1 is shown below in equation (7):

$$2.2 * 225[\frac{\$}{kWpeak}] * 4500[kW] = \$2{,}227{,}500 \qquad (7)$$

Table 3. Annual VEES Values at 300 Compound Area (Fort Belvoir) Under a Non-Emergency Scenario

Case number	Annual number of outages	Annual outage duration	VEES in $/year
1. Dominion Virginia Power 10 year average SAIFI and SAIDI	2.2	6.6 hours	$2,227,500
2. Dominion Virginia Power 2011 SAIFI and SAIDI	2.4	24.8 hours	$7,560,000
3. 300 Compound Area actual number and duration of outages in 2010	8	2 hours	$3,960,000

Once again, a de-rating factor to the VEES number should be applied depending on the degree of reliability provided by the energy security project. The final decision on the value of energy security needs to come from the installation itself. It needs to set an acceptable level of reliability. The statistics show that outage events can be long in duration, and the base should assess if it would be acceptable to be exposed to such risk.

5.3 Comparison of the Two Case Studies' CDF Curves

Below is a comparison of MCAS Miramar's CDF with the 300 Compound Area's CDF:

- Outage cost:
  - Scenario A– The outage cost in $/kW peak is higher for the 300 Compound Area at Fort Belvoir than for MCAS Miramar. The main driver of the outage cost for both sites is the loss of productivity. The average salary used at the 300 Compound Area is higher than the average government salary in San Diego used at MCAS Miramar. Secondly, the fully burdened federal cost of employment after tax was used at the 300 Compound Area versus the pre-tax wage employment cost at MCAS Miramar. In addition, the 300 Compound Area is a smaller site than MCAS Miramar, and experiences utility outages regularly, making data collection an easier task. The personnel at the 300 Compound Area had more detailed data on utility outage costs.
  - Scenario B – The outage cost in $/kW peak is higher for the 300 Compound Area at Fort Belvoir than for MCAS Miramar. Once more, the loss of productivity cost used for the 300 Compound Area is higher than for MCAS Miramar.
- CDF form:
  - Scenario A – The cost of a 1 hour or less outage at MCAS Miramar has little economic impact versus at the 300 Compound Area where a short interruption of power causes significant power losses. The outage cost for both sites trend to be linear with respect the duration of the outage.
  - Scenario B – The form of the MCAS Miramar CDF curve is different from the linear trend of the 300 Compound Area CDF curve. Under an emergency situation at MCAS Miramar, critical personnel and aircraft would be evacuated to an alternate base. For that, it was assumed that the risk increases in the first 4 hours of an outage when the chaos and lack of information types of situation may affect the safety of the evacuation procedure of the base. After 8 hours, it is assumed that MCAS Miramar personnel and operations would have been evacuated.

6 Conclusion and Future Work

This paper describes a methodology to identify and value non-energy savings from energy security projects. The methodology is based on: (1) completing a site survey to collect data on two hypothetical outage scenarios lasting for different durations to compute a CDF, (2) characterizing the reliability of the commercial power supply at the site, and (3) estimating on an annual basis the cost of utility outages. The annual cost of a commercial power supply that has low reliability can be used as non-energy savings provided by energy security projects to increase the return on investment of energy security projects such as microgrids.

Valuing energy security is an increasingly important component for financing energy projects. In the military sector, the ability to assess the value of energy security could play a critical role in prioritizing mission critical energy projects. The CDF concept and energy security valuation have a variety of applications. An established CDF military function could be used as a tool when making investment decisions regarding energy security projects. It might assist with justifying project financing, and/or comparing the relative benefits of several projects. Additionally, the process of working with the CDF questionnaire and establishing all of the assumptions necessary to develop the CDF curve can expose critical vulnerabilities at an installation that might otherwise only be detected through an outage.

Should the CDF military function be of interest to the DoD, NREL's proposed energy security evaluation process could be refined and adopted as a method to value energy security. The methodology also could be developed into a tool for facility and regional energy managers, DoD portfolio and enterprise managers, or both to inform their decisions related to energy security projects.

The methodology presented in this paper will continue to evolve as there are lessons learned from its application. It is recommended that military installations consistently record outage events and their consequences to the mission. The next steps needed to refine and improve this methodology for application in the DoD would be to:

- Develop further processing of the survey data to refine probabilities of events occurring and their associated cost with DoD personnel
- Extensively survey in strategically selected bases and analyze, compare CDF curves and adjustment
- Create a tool to compute the potential annual savings from increasing energy security. The tool would include survey processing capabilities, a CDF curve database, and a utility and regional reliability database among others.
- Explore further methodologies, such as the probabilistic risk assessment used by the U.S. Nuclear Regulatory Commission, to estimate risk by computing real numbers to determine what can go wrong, how likely is it, and what are its consequences.
- Work with DoD, the Office of Management and Budget, and the National Institute of Standards and Technology to address how energy security valuation techniques could ultimately be used for the economic justification of energy security projects, both government funded and third-party financed.

- Research the added value of site-specific energy security projects to the surrounding community such as other DoD installations and/or critical civilian sites.

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