UTILITY DESIGN FOR RELIABILITY: OPTIMIZATION WITH SIX SIGMA TOOLS

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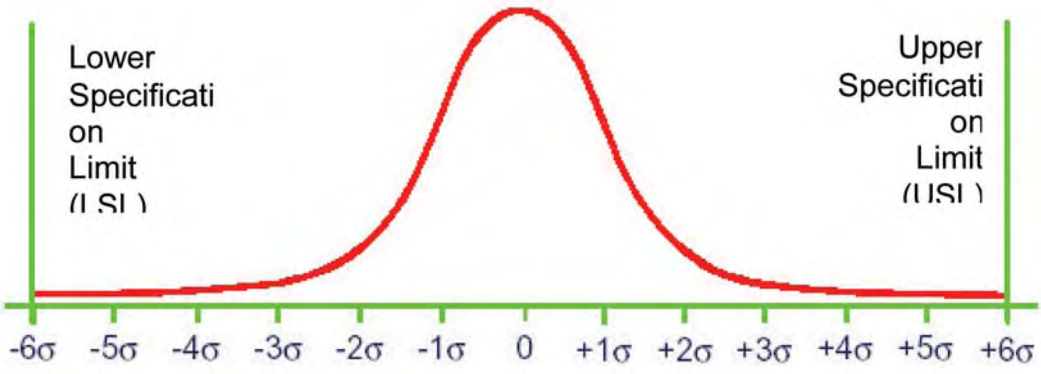

Figure 1. Normal distribution showing the area under the curve inside the specification limits. At Six Sigma, 99.9999998% of the variability of the characteristic is inside the limits, meaning it is outside (a defect) only 3.4 times per million opportunities.

The concurrence of the retirement of an aging utility workforce with the need to replace an outdated infrastructure calls for significant advances in the automation of designing utility networks.

Clearly a new paradigm is required.

Drawing from the "Design for Six Sigma" (DFSS) process, this paper explores the integration of engineering design, operations management, and enterprise asset management systems to give designers of any skill level robust tools to develop next generation utility infrastructures.

The DFSS methodology incorporates performance characteristics into design decisions by analyzing the effects of variation before construction begins, optimizing them to meet requirements using specific and quantifiable metrics.

By using reliability metrics from outage management systems as well as performance characteristics such as the probability of failure and mean time to repair from network asset management systems, a framework for leveraging DFSS in a utility design scenario can be developed. With this framework, other sources of potential reliability issues, including customer load profiles and environmental conditions, can be factored in as additional effects of variation.

INTRODUCTION

The concurrence of the retirement of an aging utility workforce with the need to replace an outdated infrastructure calls for significant advances in the automation of designing utility networks.

For example, in distribution systems, which are responsible for a large number of customer interruptions, decades old templates still often dictate design practices.

New reliability standards will mandate improved infrastructure, and the ability to design for reliability represents a new paradigm for utilities after decades of reactive maintenance programs.

This article explores the use of statistical quality control tools in conjunction with the integration of engineering design, operations management, and network asset management systems to give designers of any skill level robust tools to develop next generation utility infrastructures.

INDUSTRY TRENDS

First, a look at some of the drivers behind the need to design for reliability. Some of today's key industry trends that affect the engineering department include:

Aging Workforce

The typical demographic profile of employees at utilities in North America includes a majority of engineers in their 50s and 60s, a smaller band in their 40s, and an even smaller group in their 20s and 30s. At National Grid, one of the largest U.S. utilities, the average employee is 48 years old (Parson, 2006). At a recent GITA committee meeting, a Canadian utility employee estimated that the average age of their workforce using GIS was 57 years old. The aging utility workforce represents a huge burden, forcing companies to train a new employee base that in general has not been educated in power engineering or related disciplines.

Aging Infrastructure

The nation's utility systems were predominantly built in the 60's with a 30-40 year expected lifecycle. As a result, significant investment in infrastructure projects will be necessary over the next decade. Clearly, the entire grid cannot be rebuilt, so more sophisticated tools will be required to analyze and prioritize where investments should be made, and they must be accessible to a less skilled workforce.

Increased Regulatory Focus on Reliability

Recent legislative and regulatory initiatives (e.g., FERC,

Continued on Page 11

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Continued from Page 8

2006) are leading companies to put into practice and document reliability measures or face penalties. Performance-based ratemaking provides additional incentive to discover creative ways to improve reliability.

ENGINEERING APPLICATIONS

The engineering department has benefited from advances in technology, from system planning to actual design and construction. Many of the industry trends discussed above have been addressed by deploying systems that make the design process more efficient.

Today's Design Tools Automate the Data Capture Process

One of the easiest value propositions to justify is the automation of designs using geospatial technology. Current design tools automate the initial layout and make the approval process more efficient through integration with work management systems (WMS).

Analysis Tools Optimize Current Design Scenarios

Today, many utilities are taking advantage of analysis tools to provide their designers with more capabilities where previously only system engineers performed analysis. Challenges remain to insure that the design will be constructed as planned, as construction crews typically do not embrace a wide variety in construction work.

Determine How Design Decisions Impact the Future Network

As regulatory pressure increases, can better decisions be made during the design process? How would these decisions be measured? At this stage, performance characteristics of the network can be incorporated into design decisions by analyzing the effects of variation before construction begins, optimizing them to meet requirements using specific and quantifiable metrics.

SIX SIGMA TOOLS

In order to understand how design for reliability can be measured with Six Sigma tools, a brief review of the methodology is necessary.

Six Sigma

Six Sigma refers to a business initiative that improves the financial performance of a business through the improvement of quality and the elimination of waste.

Employees at Motorola developed the Six Sigma initiative in 1986 as a means to measure defect rates, and subsequently rolled it out through the organization with an emphasis on improving the manufacturing process. Other significant early adopters of Six Sigma methods include Allied Signal (now Honeywell) and GE. Today, more and more companies are using Six Sigma concepts, but not just for manufacturing; its uses now span the commercialization of new products and processes (Perry and Bacon 2007).

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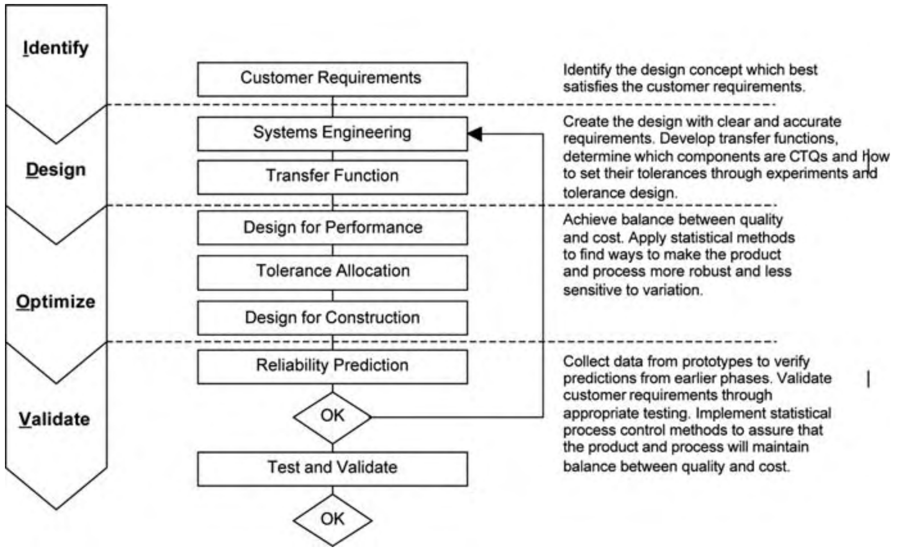

Figure 2. Example Design for Six Sigma (DFSS) roadmap illustrating the IDOV process. Modified from Kiemele, 2003.

The figure shown here illustrates the original meaning of Six Sigma as a statistical concept. Assume a process has a "characteristic" or output having an upper tolerance limit (UTL) and a lower tolerance limit (LTL). The bell-shaped curve represents the relative probabilities that this characteristic will have different values along the horizontal scale of the graph.

The s (sigma) represents one standard deviation that is a measure of how much this characteristic varies from unit to unit. In this case, the difference between the tolerance limits is 12s, which is ±6s on either side of the target value in the center. The process will almost never produce a characteristic with a value outside the tolerance limits.

Design For Six Sigma

Design for Six Sigma (DFSS) is a systematic methodology based on Six Sigma for designing or redesigning products, services, or processes to meet or exceed customer requirements and expectations. While Six Sigma focuses on improving existing processes, DFSS starts at the beginning of the project, in research, design, and development of products and services (Brue and Howes, 2006).

The DFSS methodology uses a "roadmap" to guide the progress through each project. One effective DFSS roadmap includes four phases: Identify, Design, Optimize, and Validate, or IDOV, as shown here:

DFSS provides a methodology for

Continued on Page 34

Continued from Page 19

quantifying the changes required in a design to meet the desired performance outcome. The next section discusses how Six Sigma and DFSS techniques might be applied to engineering design.

DFSS APPLICATIONS TO ENGINEERING DESIGN

The fundamental use of Six Sigma tools to describe and improve the reliability of an electric distribution system is illustrated by Sutherland (2001), who explains how Six Sigma can be applied to a distribution system to reduce the failure rate and improve reliability. He notes that a typical distribution system has a sigma of approximately 3.5, and through a variety of improvements and changes to the network, a sigma level of 4 to 5 can be achieved. Using Six Sigma techniques can help determine what changes to the network will result in the highest improvement for the lowest cost.

While there are many benefits in using Six Sigma to measure and improve reliability of existing networks, another application of this methodology is in new engineering where DFSS techniques become important. Although DFSS is designed to help with the design of new products and services, the engineering design process can be thought of as a new product, and therefore DFSS may be well suited to optimizing this process. Specific areas that may be applicable to DFSS methodology include:

- System planning and layout
- Network design and construction
- Replacement and relocation activities

In these applications, the “Identify” step in the IDOV model is fulfilled by identifying the customer requirements that may come from a residential developer who needs power to a new subdivision, or from internal utility requirements to add redundancy to an existing circui t to support a key customer.

“DESIGNING” THE DESIGN

The next step in the DFSS IDOV process is the design phase, and in order to measure and validate the results of the design, measurement criteria must be defined. In order to measure the opportunity to improve the network, Sutherland (2001) and, more recently, Yeddanapudi (2005) suggest that network outage information is the “Critical to Quality” (CTQ) variable that can be measured and improved, providing benefits such as increased production time, reduction of downtime due to outages, reduced repair and rework costs, and reduced damage to equipment.

Although over 40 different values are mentioned in the literature for measuring outage characteristics, Morris (1999) suggests that the four most commonly used indices are SAIFI, SAIDI, CAIDI, and ASAI, as described on this page:

- SAIDI - System Average Interruption **Duration** Index : $\frac{\text{Total Duration of Customer Interruptions}}{\text{Total Number of Customers}}$
- SAIFI - System Average Interruption **Frequency** Index : $\frac{\text{Total Number of Customer Interruptions}}{\text{Total Number of Customers}}$
- CAIDI - Customer Average Interruption **Duration** Index : $\frac{\text{Total Duration of Customer Interruptions}}{\text{Total Number of Customer Interruptions}}$
- ASAI – Average Service **Availability** Index : $\frac{\text{Customer Hours of Available Service}}{\text{Customer Hours Demanded}}$

Utilities typically record outage and failure information and include details of the outages that occur in the network. These data are used to compute historical reliability indices and they can also form the basis for the development of statistical models used to predict the failure characteristics of distribution equipment and to ultimately evaluate the effects of engineering design decisions.

The historical reliability measures also form the basis for modeling various distribution components used in predictive reliability studies. To achieve this predictive capability, parameters must be calculated for various distribution devices including (Yeddanapudi, 2005):

- Overhead and underground line segments
  - Permanent Failure Rate
  - Temporary Failure Rate
  - Mean Time to Repair

- Protective and Switching Devices (e.g., reclosers, switches, fuses, breakers, etc.)
  - Probability of Failure
  - Protection Reliability
  - Recloser Reliability
  - Mean Time to Repair
  - Switching Reliability
  - Mean Time to Switch

Since the unit of measure, or CTQ, is based on outages and not the failure of specific devices, Sutherland (2001) explains that only failures that result in an outage are of interest for this type of study. However, the number of opportunities for a failure to occur is based on the number of devices serving a particular customer and, therefore, the exposure of individual devices over a period of time is considered to be an opportunity. For linear devices, exposure to failure depends on the length of the line or cable and it is standard practice to define a linear component of 1000 feet of conductor length.

Yeddanapudi (2005) summarizes the methods available for calculating reliability using these variables, including analytical methods such as Markov methods, network reduction, and fault-tree analysis, as well as simulations such as Monte-Carlo analysis. While it is beyond the scope of this article to discuss the merits of these techniques, the ability to analyze a proposed network configuration is essential to be able to apply the DFSS methodology.

OPTIMIZING DESIGN DECISIONS

Armed with historical outage data, opportunities for failure, and predicted failure rates, the DFSS methodology can be used to analyze the design decisions and optimize for future reliability before construction begins. One of the most critical aspects to this process is the creation of transfer functions that incorporate the allowed tolerances for each characteristic (Y) in the design. For each characteristic, tolerances represent the extreme values that are tolerable for an individual device in the design. Since tolerance design enables engineers to predict and optimize the statistical characteristics of products and processes before building any prototypes, it is a vital part of the Design For Six Sigma (DFSS) methodology. Successful tolerance design satisfies the customer's quality and performance requirements including least product cost, shortest construction time, and highest reliability. In addition to a tolerance for a design characteristic Y, tolerance design requires a transfer function of the form Y=f(X).

The transfer function computes design characteristics Y from lower level characteristics X.

In an engineering design scenario, an example might be a 25Kva transformer (the X) placed in a residential design. What is the likelihood of continuous service (the Y) given various loading characteristics ranging from 50% to 120%? In general, the analysis for each X and Y in the design would include the following steps (Sleeper, 2006):

· Define the tolerance for each Y. This may come from individual customers through Service Level Agreements (SLA) or perhaps from regulatory requirements.

· Develop the transfer function Y=f(X) from historical and predictive values. This is the step where methods such as Markov methods, network reduction, and fault-tree analysis, as well as simulations such as Monte-Carlo analysis are critical.

· Compile variation data on each X. The method of tolerance analysis determines which specific information is required for each X, and then estimates of the statistical information are unavailable, assumptions may replace them.

· Predict the variation of Y. In this step, tolerance analysis predicts the variation of Y, but the nature of this prediction depends on the tolerance analysis tool. After performing either statistical method, process capability and defect rates may be predicted.

· Optimize the design to balance quality and cost. This process requires additional loops through the process. If the predicted capability of Y is not acceptable, adjusting nominal or tolerance values for X may improve it.

The determination of customer requirements (commercial, residential, etc.), generating the preliminary design, optimizing the alternatives for the various components while trying to minimize the expected outages as well as cost, and validating the decision made are the essence of the DFSS methodology. The key issue is developing the appropriate transfer functions to establish the relationship between the design components and historical and predictive data (the Xs) in order to maximize the expected reliability levels (the Ys).

Once the preliminary design assessment is performed, design alternatives can be created and tested with the aid of feedback from variations on the transfer function Xs. In the example above, different transformers can be selected to test the overall design response.

When an optimal design is selected, sensitivity analysis is performed to test and validate the selection. It is worth remembering that many design scenarios are generally similar, e.g., residential class 3 design or light commercial. Even when incorporating additional design criteria such as weather or vegetation (discussed below), the characteristics will generally be the same.

Therefore, these studies could be done once for various design classes and then used as templates for actual engineering designs.

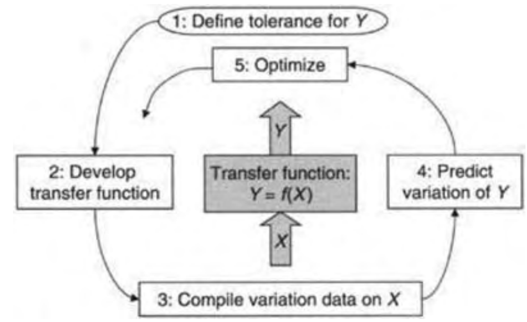

Figure 3: Example process flow for tolerance design, with a focus on the transfer function. From Sleeper, 2006.

DESIGNING FOR THE FUTURE

With a DFSS framework in place, it becomes possible to consider the development of a forward-looking system that consistently anticipates the optimum network configuration. By developing DFSS-based optimization tools, a transition from a cost-based, historical analysis methodology to one based on more rigorous predictive analysis can be achieved.

Furthermore, the optimization routines can be made more sophisticated by adding additional constraints. Additional system characteristics can be treated in the same way by developing transfer functions that test the sensitivity of each component. Some examples include:

· Increased network loading/activity. Increased customer demand during peak summer months can result in increased loading on network devices. This increases the operating temperatures of distribution transformers, for example, making them more susceptible to failure.

· Environmental/weather conditions. Another important factor that influences the useful life of a device is the environment. Dusty and moist climates in general increase the tendency to fail. Adverse weather conditions like lightning and windstorms also increase the chances of device failure.

· Vegetation management. Trees are one of the largest contributors to failures in distribution networks due to parts of trees touching the lines. Thus, it is increasingly important that utilities maintain clearance in the right of way.

SUMMARY

In this article, the concept of "design for reliability" based on Six Sigma DFSS methodology is introduced. Based on proven Six Sigma tools, DFSS can be applied to the engineering design process, giving designers tools to select optimum designs that meet reliability standards in addition to cost and availability criteria.

Using a DFSS approach may help utilities to meet long-term reliability regulations and decrease overall network maintenance costs by having the ability to look over the entire device lifecycle. Sutherland (1999) states that design changes or incremental improvements will only result in incremental changes in Sigma, but even a slight change in Sigma can mean a large reduction in overall outages, and therefore a significant improvement in distribution network quality and reliability.