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Maintaining the network

Whether it is through new automation improved reliability or better maintenance utilities are all looking for better ways to keep the grid humming

See sections on Automation, Asset Maintenance and Protection and Control

and...

The "Green Grid"

Selling new distribution corridors with an environmentally friendly tag

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MAKING NEW TRANSMISSION PALATABLE THROUGH THE ‘GREEN GRID’

Don Horne

The Grand Coulee Dam, located on the Columbia river in central Washington, holds the largest hydroelectric generator in the world (825 megawatts). The mechanical energy of water flowing through its floodgates turns turbines connected to generators, which produce electricity.

Greater interties of the grid and interconnectivity is always on the table to help improve the electrical grid across North America.

In Canada, Ontario has been pushing for greater east-west connections with hydro-rich Quebec, hoping to trade their wind farm generation for consistent hydro-electric generation.

Although no one is eager to have major new AC or DC electrical corridors be constructed through their backyards, there is one grid - the Green Grid - that is gaining modest acceptance.

Predicated on wind and hydro power

generation, this Green Grid is receiving tentative support from the provincial ministers, aboriginal leaders, environmental organizations and the various executives from the electrical infrastructure and financing sectors.

The joint statement, issued appropriately enough from the old national railway headquarters in Ottawa (now the Goverment Conference Centre), sets out an initial framework of principles for a cross-Canada Green Power Corridor transmission grid:

"We agree that the supply of Canada's clean energy future lies beyond our current grid structure, and are committed to realizing the potential of a Green Power Corridor that battles climate change by enabling vast new supplies of clean, secure energy to come on line, enhances economic opportunities for Aboriginal peoples and other local communities, and helps to protect ecological integrity by establishing valid conservation first principles."

The Minister of Energy and Chair of Cabinet for Ontario, the Honourable Dwight Duncan, underlined the flavour of the moment:

"The green power corridor is the railway of the 21st century. Building an inter-provincial green power corridor is as important to Canada today as was the building of the railway in the 19th century by the founders of our country."

The potential viable green power that could be accessed through an enhanced grid structure is estimated at 163,173 MW of hydro power and 175,000 MW of wind power.

The lion's share of the hydro power comes from Quebec (44,100 megawatts), as well as the majority of the wind power potential (101,000 MW), with Ontario coming in at a distant 38,979 MW.

To be fair, the data on viable wind power potential for most provinces isn't available; but in simple terms of increasing east-west connections, the potential for easing peak grid problems in Ontario becomes clear when Quebec's abundant hydro and wind power reserves are made available.

Looking south, July's Transmission & Distribution Automation Symposium in San Antonio, Texas will be taking an overall look at the emerging trends in T&D automation by maximizing performance and reliability, establishing and maintaining effective communications to help support the automation process and anticipating the upcoming reliability and regulatory standards as mandated by eveyrone's favourite acronyms FERC and NERC vs. ERCOT.

Along with the normal topics of automation (advanced metering and infrastructure and substation operations), the symposium takes a look at the wider issues facing all North American utilities: integrating greater automation and wireless systems into their existing infrastructures.

For Texans, the concept of an east-west Green Grid (like the one in Canada) to increase neighbouring state interties would be a welcome one.

The growing resistance to coal generation and rising fossil fuel prices has placed Texas power companies in the unfamiliar position of having to look outside state borders to find less expensive generation sources. Although greater automation and smart metering initiatives can control electricity demand, a more flexible grid is the long-term solution.

The Green Grid is a tip of the hat to the environmental lobby that, from a generation perspective, would like to see everyone beat their swords (nuclear, coal

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UTILITY DESIGN FOR RELIABILITY: OPTIMIZATION WITH SIX SIGMA TOOLS

By Robert P. Laudati, Marketing Program Manager, Electric T&D, GE Energy

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.

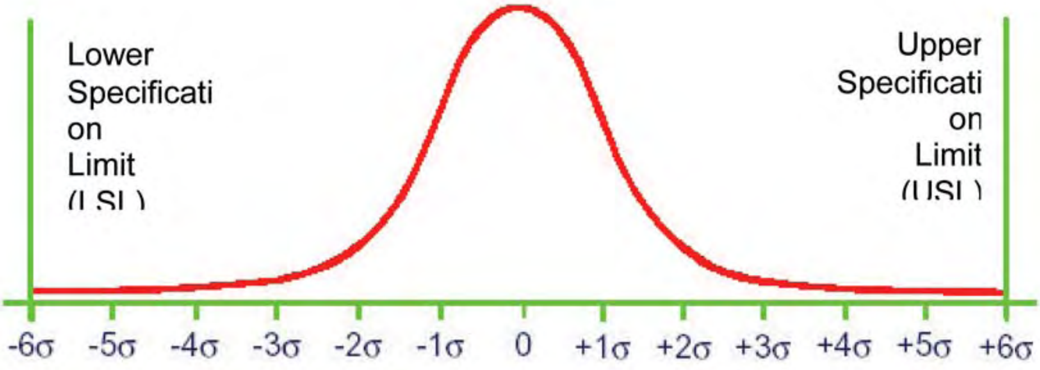

Figure 1. Normal distribution showing the area under the curve inside the specification limits. At Six Sigma, 99.9999998% of the variability of the characteristic is inside the limits, meaning it is outside (a defect) only 3.4 times per million opportunities.

The 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,

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Green Grid

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and natural gas) into ploughshares (wind and solar).

The massive 40-megawatt solar farm project that has been given the go-ahead in Sarnia, Ontario is a classic example of a government attempting to assuage the Green lobby with new non-polluting generation.

Yes, it will power anywhere from 10,000 to 15,000 homes on a sunny day - but the cost will be four or five times that of a typical 40 megawatt system.

Perhaps the best dose of reality comes from across the Pacific, from the solitary island of Taiwan.

A spokesman for the Chung-hua Instituion for Economic Research and advisor to the Taiwanese government warns that the ban on new nuclear plants and delays on current projects could bring power outages to that country as soon as 2010.

For Taiwan, a country that prides itself on hi-tech manufacturing industries, the potential disruption of a continuous supply of clean power might be the signal for future investors to locate elsewhere.

Liang Chi-yuan, another government advisor and economist, states it plainly: “Renewables can’t make up for the loss of nuclear power.”

Even Canada has had to dish out a small dose of reality to the public, announcing that they will be backing away from their Kyoto Protocol commitments insofar as greenhouse gas reduction targets are concerned.

> The green power corridor is the railway of the 21st century. Building an inter-provincial green power corridor is as important to Canada today as was the building of the railway in the 19th century by the founders of our country.

Environment Minister Rona Ambrose, who had led the Canadian delegation to the UN climate conference in Kenya recently, said the government must be “realistic” in what goals can and cannot be achieved.

Although the Bush administration never ratified the Kyoto Protocol, several states have proceeded independently by enacting their own tougher emission legislation.

Which brings us back to the Green Grid.

Certainly the concept of Canada’s Green Grid will be embraced by those U.S. states with grid ties across the border, and will be given lip service to curry favour with voters. But budgets are finite and deficits are large, so a good dose of reality should be handed out along with all the smiles and sunshine of solar power and wind farm projects.

Because in the still of the night, it will be the nuclear and coal plants that keep the nations of North America running.

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INSPECTION ROBOT CAPABLE OF CLEARING OBSTACLES WHILE OPERATING ON A LIVE LINE

By Serge Montambault and Nicolas Pouliot, Hydro-Québec

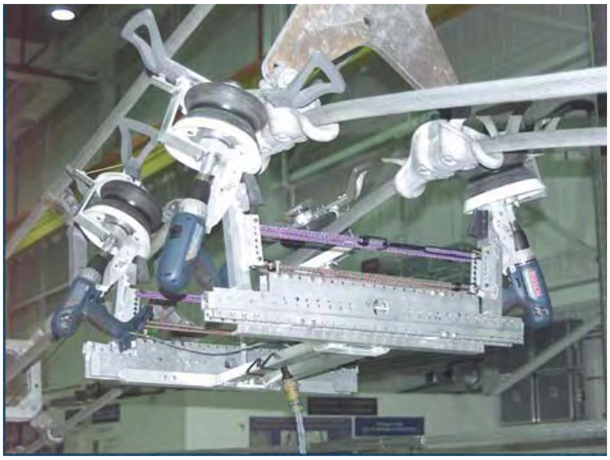

Figure 1: Hydro-Québec's RST-2X Technology

Robotic systems are used in a range of applications to carry out inspection and repair tasks in hostile environments and in otherwise inaccessible locations. Applied robotics has found several niche applications in Hydro-Québec operations. One example of a recently developed robotic solution for power line applications is the LineROVer Technology.

The LineScout robot developed meets this requirement and can clear obstacles as it travels down a line. It can move along several axes, allowing it to adjust its shape in real time to various line configurations and to a wide range of obstacles while remaining as light and compact as possible. The robot's geometry was engineered to give it at least six possible obstacle-clearing sequences, making it versatile in unforeseen situations. The robot can operate on an energized line, has one-day battery life and can be remotely controlled 5 km away. The control approach and electronics allow intuitive human operation of the robot. Moreover, it can operate semi-autonomously, learning to clear obstacles by means of automated sequences.

LINESCOUT TECHNOLOGY: DEVELOPMENT CONTEXT

Robotic technology has been used by electric utilities in many areas (production, transmission and distribution).

Innovation in transmission line maintenance was the subject of an extensive review of the literature in 2003. Innovations include a few robots designed to cross obstacles while operating on a transmission line: the TVA Line Rover, NSI Power Line Inspection System and Sawada's Mobile Robot for Inspection of Power Transmission Lines. A few other university and industrial designs were developed but never got beyond prototyping.

Since early 2002, a team at Hydro-Québec's research institute, IREQ, collaborating closely with Hydro-Québec TransÉnergie's personnel, has been developing two prototype robots for transmission line inspection that are able to move over obstacles while operating on a power line.

RST-2X Technology (Figure 1) is a demonstration prototype with a very simple design that has proven its ability to cross suspension insulator strings and spacer dampers on a four-conductor bundle. A patent is pending for that robot. The second robot, the LineScout Technology, has the more complex but far more versatile design described below.

The Pros and Cons of a Span-by-Span Approach

Since 2000, the LineROVer Technology has proven its worth and efficiency for live-line inspection on transmission networks. Its light weight, from 25 to 35 kg, depending on its configuration, allows it to move along ground wires and conductors of any gauge. The whole system is compact enough to be quickly and easily transported by helicopter to remote areas. Since the technology is fairly simple, no extensive training is needed to make an operator comfortable with its control.

TRANSMISSION NETWORKS: TARGET CAPABILITIES

The first thing to do in developing a technology like the LineScout is to target the part of the network where robotics applications are potentially useful: spans with many obstacles, river/road/distribution-line crossing and all parts of the network with conductor bundles. This means that the technology must work on live lines up to 735 kV. It is also imperative that the LineScout operate on ground wires.

That being settled, the obstacles the robot must be able to cross have to be chosen, weighing the inspection tasks desired against the increased robot complexity, weight and size entailed. Warning spheres (0.76-m diameter) provide a good example of a trade-off decision. However, the decision was taken to clear them given how highly valuable this is for transmission line inspections.

An extensive review was conducted of transmission line components and circuit configurations (bundles, vertical/horizontal circuits, single/double insulator strings). This review is summarized in Figure 2, which shows obstacles classified according to the continuous length to be crossed. For example, two vibration dampers could be seen as one or two obstacles, depending on the distance between them. Since that distance may vary, the robotic platform must have a flexible enough design to suit most situations encountered (Figure 3).

LINESCOUT TECHNOLOGY: THE PLATFORM

A team from IREQ developed the LineScout Technology to meet the objectives above. The name evokes its predecessor, the LineROVer, but also the new possibilities that arise by sending this

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GE
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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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Line Robot
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moving platform equipped with various tools farther along power lines to gather information and collect data. This section presents specifics about platform technology.

Crossing Approach

In order to move efficiently and fairly quickly along parts of spans with no obstacles, a two-wheel design was chosen for the vehicle. Furthermore, having natural rubber wheels of adequate size allows the LineScout to simply roll over simple obstacles such as splices, dampers and various types of clamps.

To clear other types of obstacles, the LineScout uses the sequence schematized in Figure 4. It must first be understood that the LineScout is built around three independent frames: the “Wheel Frame” (dark), the “Arm Frame” (light) and the “Center Frame” (white circle), which links the first two frames together.

In step 1, the LineScout stops in front of the obstacle to clear. Between the wheels but very close to them, are two sets of “Safety Rollers” (two small rectangles), which clamp firmly onto the conductors from below to secure the vehicle.

In step 2, the Arm Frame and Center Frame slide forward and pivot so that the two “Auxiliary Arms” (two vertical rectangles with “Gripper” tips) are located to either side of the obstacle. Note that since the Center Frame supports a fair fraction of the overall weight (e.g., onboard electronics and battery) LineScout’s center of gravity is still very close to one of the supporting wheels.

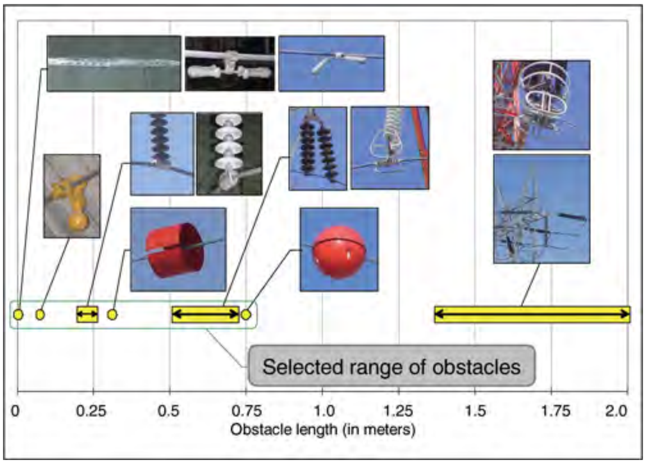

Figure 2: Obstacles classified by length

Figure 3: Sequence of obstacles

Table 1: Design technical specifications

Specification	Value
Line components and environment	
Conductor diameter	12 – 60 mm
Splice diameter	25 – 85 mm
Maximum obstacle length	0.76 m
Maximum conductor temperature	95.0°C
Number of conductor	1 – 4
Maximum slope in span	30°
Ambient operating temperature	0°C – 40°C
Platform	
Weight	100 kg
Length	1.37 m
Height	0.75 m
Traction force	500 N
Linear speed	1.0 m/s
Battery life	5.0 hours
Telecommunication signal range	5.0 km
EMI robustness	735 kV – 1000 A

This minimizes the cantilevered distances, reducing the size of the structure required.

Step 3 shows the platform configuration after two subsequent movements. First, the Auxiliary Arms rise up to the conductor and their Grippers clamp onto it, providing a new set of supports for the vehicle. Then, the Safety Rollers open and a mechanism flips the wheels down below the Wheel Frame.

By again sliding and pivoting beneath the obstacle, the Wheel Frame and the Center Frame now cross to the opposite side, as shown in step 4.

In step 5, as in step 3, the flipping mechanism brings the wheels back onto the conductor, allowing the Safety Rollers to secure their grasp again so that the Auxiliary Arm Grippers can be opened safely. The Auxiliary Arms then return to their initial lowered position.

Step 6 shows the LineScout once the Arm Frame and Center Frame have returned to their initial position. The entire sequence lasts about two minutes. The vehicle is now ready to continue rolling down the line.

One of the main advantages to this approach is the resulting compactness: a vehicle with an overall length of only 1.37 m is able to clear obstacles 0.76 m in diameter. This design still allows a relatively long (0.79-m) wheelbase making the vehicle very stable and able to carry a larger payload. Another key advantage of this approach is that it is neither limited to a specific size of obstacle nor to a specific distance between adjacent obstacles.

For example, Figure 3 shows a set of two torsion dampers followed by an insulators string. It is unlikely that such a set would always have the exact same spacing between obstacles. It was thus deemed necessary that the operator could adjust any crossing sequence to the actual configuration encountered. The numerous, somewhat redundant, degrees of movement are what make such adjustments possible.

Technology Overview

Once the approach was defined, the actual design could start, driven by the goal of obtaining a robust, reliable and fairly lightweight prototype. Time was also a tight constraint since only nine months were allotted before the first functioning prototype had to be demonstrated.

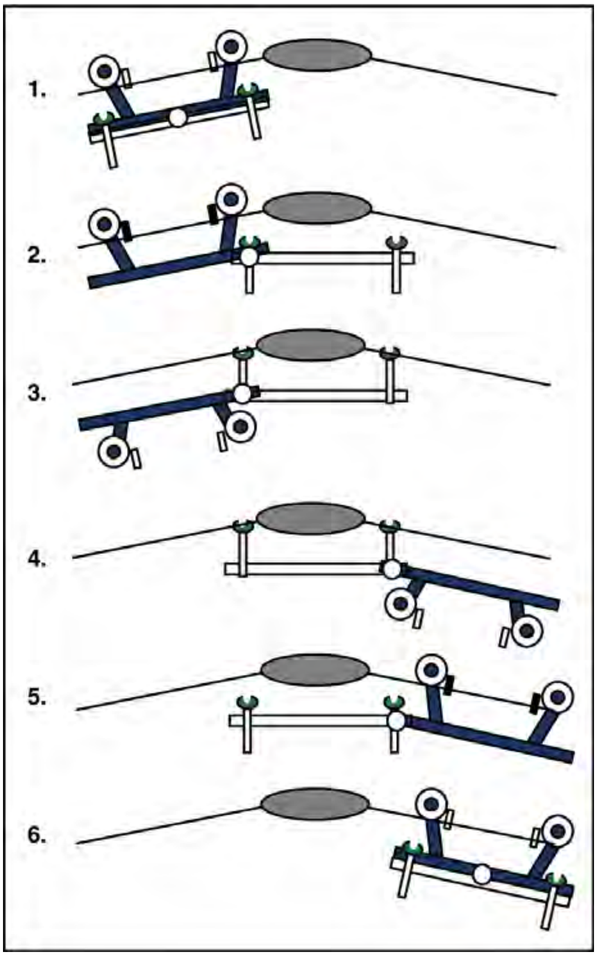

Figure 4: The LineScout obstacle clearing sequence

Mechanical Design

The LineScout 3D modeling, kinematics simulations and finite element analysis of critical components were performed using a CAD system. Most of the mechanical parts are machined from aluminum, others from magnesium. Whenever possible, high-quality commercial components were used to reduce development time and cost, and to maximize reliability. Since the robot has to work on energized circuits, the entire structure must conduct electricity to minimize any difference in potential developed across components.

Aluminum and magnesium are good conductors by nature but the traction wheels had to be made out of a conductive natural rubber specially developed and moulded for this application. All other components in contact with circuit components, such as the Safety Rollers and Grippers, were covered by a protective sleeve made of soft conductive nylon that does not scar or dent to conductors.

A brushless motor coupled to a harmonic gearbox powers each LineScout's traction wheel. Lightweight yet powerful DC motors drive all nine other degrees of movement.

All these motors and their encoders and brakes, plus all cameras and sensors (see next section) are linked to the central electronics cabinet by a total of 30 m of double-shielded cables and securely coupled by military-type connectors. All these cables must be cleverly routed into and around the vehicle structure to avoid any risk of interference or jamming.

Onboard Electronics

The LineScout is equipped with a complete 19-inch rack-mount-type cabinet of circuit cards. Figure 5 shows the aluminum cabinet as circuit cards are inserted.

The energy source is a rechargeable voltage-regulated lithium-ion battery that can provide the power peaks required by the most demanding tasks and sufficient energy for a full day of operation. The battery itself has its fair share of electronics for monitoring charge/discharge rate, temperature and remaining energy level.

The LineScout transmits and receives data and video through two distinct radio-frequency transceivers with an effective range of 5 km. Note that the two transceivers are shown as a single antenna box in the upper left corner of Figure 7. Also note that the only elements that actually have to extend outside the EMI/RFI shielding (fine dotted line) are the antennas. For that reason, dedicated electronic protection was installed on each antenna circuit.

There are currently three video cameras on the LineScout platform and the images they transmit are the most important feedback used on the ground to drive the different axes of movement. Two wide-angle miniature cameras are rigidly mounted on the Auxiliary Arms, close to the Grippers. The other camera is mounted between the wheels on a pan-and-tilt unit to provide an adjustable point of view.

The onboard video card can receive signals from up to four cameras and transmits a combination of any two images, either in "picture on picture mode" or "split screen mode". The latter is especially useful when combining the two wide-angle camera images since it allows viewing the Grippers on both side of the obstacle simultaneously.

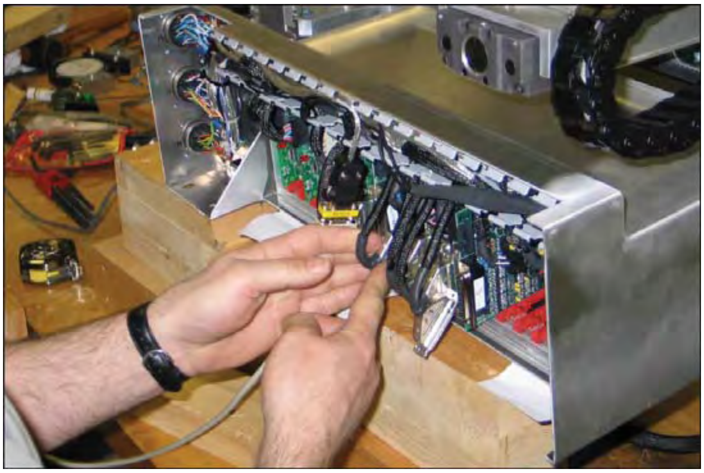
Figure 5: Onboard electronics cabinet

Various other sensors feed the circuit boards. The speed-based closed-loop control of most DC motors uses feedback from an optical encoder while that of other motors uses a potentiometer to get a sufficiently precise position estimate. Two distinct two-axis inclinometers return the absolute value of different angles, e.g., conductor slope. The temperature inside the electronics cabinet is kept at an adequate level by two EMI/RFI-shielded fans controlled by thermal switches. An infrared thermometer monitors conductor temperature. Should the need arise in the future, sufficient room is available to add such sensors as a GPS antenna, extra cameras, laser obstacle detector or force sensors.

The other important function of the onboard electronics is to manage the inspection tools that make the LineScout platform useful. For added flexibility, the strategy adopted is to supply one or two “Tool Lines”, carrying solely DC power and data signals to the moving frames. This will allow several tools to be used concurrently.

An even more important function of the onboard electronics is to provide the LineScout with a central safety system, including a watchdog that reduces power to the motors automatically if unexpected commands are received or loss of transmission suddenly occurs.

Control system

Even though the LineScout vehicle is fairly complex, it was important to keep its control system as simple, intuitive and ergonomic as possible. The ground control station was designed with that objective in mind. This portable system is shown in Figure 6.

The station consists of a stable tripod that supports the video and data transceivers, one case that contains a high-quality sun-readable video monitor and digital VCR, and another case whose lid unfolds into a table with adjustable length legs. The second case contains a military-type field tablet PC with a sun-readable touch screen and two industrial three-degree-of-movement joysticks. If required, a four-stroke gas generator provides electrical power for the entire station.

The heart of the control station is, however, the digital interface programmed using LabView. This approach was far more flexible for development than building a physical control panel with switches and buttons. It allowed several quick iterations to achieve an intuitive, informative interface. Moreover, it is extendable so new tools can be introduced.

The LabView interface translates human operator commands, mainly inputted via the two joysticks, into velocity commands. This was found to be a very intuitive way of controlling the robot.

From the operator's perspective, the farther he pushes one of the joysticks along an axis, the faster the same LineScout axis of movement will react. However, this holds true only if none of the built-in safety rules, called "interlocks", is limiting that axis of movement.

One simple interlock implemented is the monitoring of stroke limits for each axis of movement. For example, if the sliding frame is getting close to its physical stoppers while the human driver keeps the joystick input at its maximum setting, the software will override the command and send a slower setting. Eventually, once the limit is reached, this interlock prevents any displacement in that direction.

Such interlocks and various other safety rules significantly protect the LineScout Technology against human error.
Another good example is that it is impossible for the operator to open the Grippers unless several conditions check out, including that the wheels are back on the conductor.

Figure 6: Ground control station

Another challenge is providing a simple, intuitive way of controlling 11 different motors. The interface software achieves this by introducing the concept of "Function Modes". Most of the time, only a small number of motors need to move simultaneously. Therefore, different Function Modes can be selected by the operator as the obstacle-clearing sequence progresses.

This selection will map to a predetermined set of motors on each of the axes of the right joystick. For example, one Function Mode, referred as the "Displacement Mode", is used to travel down the conductor and only allows the traction wheel motors to be driven. At all times, the left joystick can thus be dedicated to controlling the video functions, either the fixed cameras or pan-and-tilt mount camera.

The interface software is useful for customizing information, provided to the operator in the form of data panels. The main control panel gives essential information such as battery level, Function Mode selected, interlock warning messages, error messages, etc.

Dedicated panels can also be generated by pressing the appropriate button on the touch screen. The example given in Figure 7 is a pictorial representation of the LineScout's attitude and configuration, updated in real time. Other useful data panels are dedicated to specific tools installed on the LineScout, since they could serve as a template to generate inspection reports.

It can be imagined that such a control interface, and the computer power behind it, have a great potential for evolving and automating tasks to various degrees. To demonstrate this, a semi-automated obstacle-clearing sequence was implemented where the operator only had to confirm completion of certain subtasks. This feature performed reasonably well but it was decided that, for the time being, the operator should maintain full control over the LineScout platform.

Prototype Testing

At the time this article was written, the LineScout platform was already a mature prototype, which has undergone several months of extensive testing, reliability analysis, problem solving and optimization.

The initial phase of testing was conducted in laboratories. The objective at that point was to demonstrate that the mechanical design had the potential to meet objectives. Antennas, battery and EMI/RFI shielding had yet to be incorporated. This first prototype ran on an indoor full-scale 315-kV model circuit.

The second phase was also lab testing but now of a complete prototype. The objectives were primarily to validate specific choices and gather data to determine the size of future components. For example, traction tests were conducted to help size traction wheel motors and evaluate power consumption at various levels of work.

A stability test was also performed by having the LineScout roll over different types of obstacles at different speeds while pulling it sideways to simulate the effect of strong lateral winds. These tests also helped validate the final wheel profile.

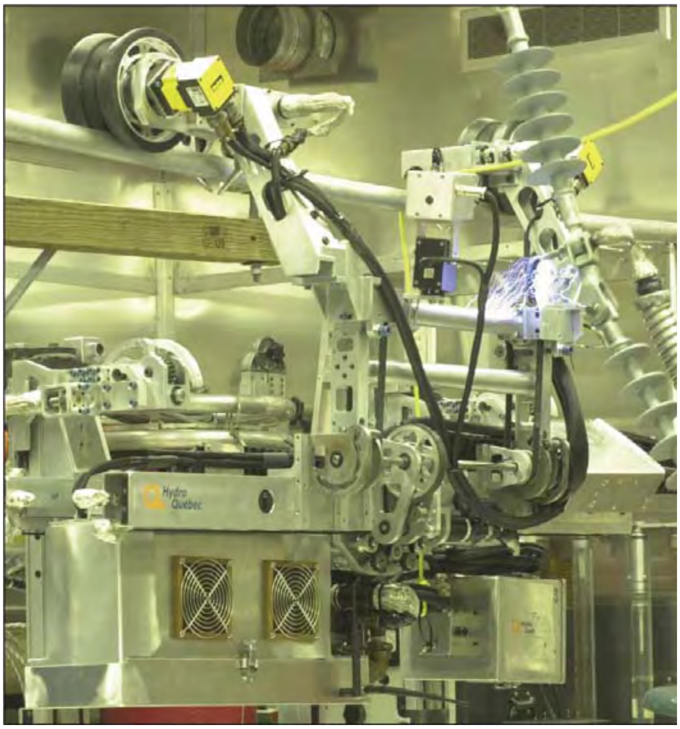

Figure 8: EMI/RFI shield testing in IREQ's lab

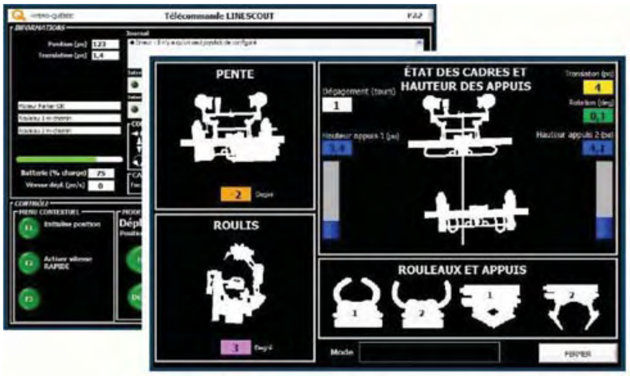

Figure 7: Data panels generated by the control interface

Among the most challenging tests was the EMI/RFI shield lab test. Figure 8 shows the LineScout supported by an insulated bar as a high-voltage conductor slowly approaches the prototype. At a certain distance, the high voltage creates an electric arc that discharges into the prototype's protective shielding and the metallic structure. The purpose of this test was to simulate the electric discharge on the robot as it approaches the conductor of a live line. The test setup simulated an electrical field up to an equivalent 315 kV with none of the components suffering any damage.

Sensitivity to a strong magnetic field was also tested successfully on an outdoor test rig by traveling along a conductor with a 1000 A load.

The next phase of testing took place outdoors on an experimental facility comprising six full-scale spans of de-energized transmission lines (single conductor and conductor bundle). This full-scale facility helped check that data and video signals were transmitted properly up to a distance of 5.0 km. Even more important, these tests confirmed that the LineScout was easy to operate and that its safety interlocks worked as the prototype cleared obstacles 30 m above the ground. Endurance testing was also performed since over 500 obstacles were crossed and the LineScout traveled along more than 50 km of conductor. The LineScout prototype was then successfully tested on an energized circuit at 315 kV (Figure 9).

Applications implemented

Visual inspection remains the type most widespread in many industries. Transmission line maintenance is no exception. Of the three cameras needed for the LineScout remote control, the pan-and-tilt mount one is also used for visual inspection. A fourth camera, also on a pan-and-tilt unit, can be mounted on the opposite frame to give a complementary point of view. Since it is located on one of the Auxiliary Arms, it provides a very flexible point of view. This module also allows visual inspection of the cylindrical warning markers often found on river-crossing spans. Lastly, the LineScout can inspect suspension clamps and insulator strings while crossing them.

Splice condition evaluation based on the measurement of the electrical resistance of the splice is another application where the LineROVer Technology has proven its worth and is one readily implemented using the LineScout Technology. Crossing obstacles allows a significant increase in productivity when inspecting splices on a circuit. Moreover, spans with obstacles can now be covered for that valuable application.

ON-GOING WORK

So far, most of the effort put into the development of the LineScout Technology was directed toward producing a high-performance, reliable robotic platform. It was a challenge to design a compact robot that could cross obstacles while operating on a live line.

However, the value of this technology resides in the tasks that it can perform. This means that application modules, such as the splice condition evaluation module, must also be developed. The value and relevance of the LineScout Technology for a particular application are driven by such factors as adapting to changes in how transmission networks are operated, making working methods more efficient than at present, and reducing risks to which workers are exposed.

While still assessing potential applications for the technology, on-going work includes the development of a module that will temporarily repair broken conductor and ground wire strands. In addition to visual inspection for better repair job planning, this module would then reduce the risk of further deterioration of the component.

Another high-value application for the LineScout Technology is visual inspection of line components that are found on conductor bundles: spacer dampers, insulator strings, suspension clamps and the conductors themselves near the clamps. The robotic arm or end effectors needed for this task would also allow splice condition evaluation and some live-line work.

The LineScout Technology was developed based on an open-ended design approach. Implementing automated sequences for crossing obstacles and inspecting components is also underway.

CONCLUSIONS

The LineScout Technology is able to cross most of the obstacles found on transmission networks at large, including those encountered on conductor bundles. Its adaptability to a large spectrum of line configurations makes it a versatile and efficient robotic platform.

Its versatility also stems from its open design, accommodating potential high-value applications. The control strategy was developed for remote operation in an intuitive way. Testing was successfully conducted on a 315-kV circuit. Future work includes testing the technology on 735-kV lines.

Figure 9: A successful test on an energized 315 kV circuit.

The LineScout Technology was used in pilot projects on Hydro-Quebec's transmission network throughout 2006. The LineScout Technology is a versatile moving platform that extends live-line inspection capabilities and lends itself to future power line repair work.

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Nicolas Pouliot has a B.S. degree in mechanical engineering and a master's degree from Laval University in Quebec City. Since 2002, he has worked as a researcher for Institut de Recherche d'Hydro-Québec (IREQ) in Québec, Canada in the Automation and Measurement Systems group.

PREDICTING FUTURE ASSET CONDITION BASED ON CURRENT HEALTH INDEX AND MAINTENANCE LEVELS

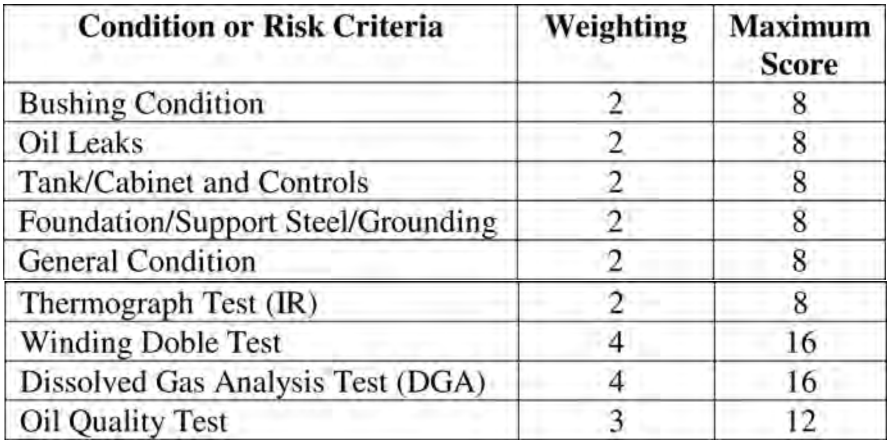
By Thor Hjartarson, Shawn Otal, Kinectrics Inc.

With restructuring of the electricity sector into profit oriented business models, an increasing number of electric utilities are adopting Health Indices to measure and monitor the condition of their assets.

The Health Indices represent a novel way for capturing and quantifying the results of operating observations, field inspections, in situ and laboratory testing into an objective and quantitative picture, providing the overall health of the assets. Asset Health Indices become a powerful tool in managing assets and identifying investment needs and prioritizing investments into capital and maintenance programs.

When appropriately developed, Health Indices provide an accurate indication of the probability of asset failures and associated risks. Having established the Asset Health Index under current conditions, Health Index values in future can be predicted by taking into account the impact of environmental and operating conditions along with the preventative maintenance practices. This article describes the techniques to account for impact of preventative maintenance on Health Indices and for predicting future asset condition based on the current Health Index and maintenance practices.

Table 1
Example of a Health Index for a Distribution Asset



Condition or Risk Criteria	Weighting	Maximum Score
Bushing Condition	2	8
Oil Leaks	2	8
Tank/Cabinet and Controls	2	8
Foundation/Support Steel/Grounding	2	8
General Condition	2	8
Thermograph Test (IR)	2	8
Winding Doble Test	4	16
Dissolved Gas Analysis Test (DGA)	4	16
Oil Quality Test	3	12

The techniques can be used for evaluating future risks associated with an asset or in selecting optimal maintenance levels that would provide the right balance between risk and investment costs.

ANALYSIS, STRATEGIC PLANNING, TRANSFORMERS

1. Introduction

Increased demands for improved financial and technical performance by electric power companies throughout the world are resulting in much closer scrutiny of capital investments.

There is also significant pressure to control operating and maintenance costs while maintaining or improving system performance. In order to achieve the optimal balance among capital investments, asset maintenance costs and operating performance, there is a need to provide economic and technical justifications for engineering decisions and spending plans. The analysis outlined in this paper specifically focuses on the technical justifications for proposed expenditures.

Electric utility transmission and distribution systems are made up of a large number of individual system components with different characteristics and different importance. Assets such as transformers, circuit breakers, reclosers, overhead lines, underground cables, switches, rights-of-way, and civil works are a few typical examples of the type of components that make up the asset base of an electric transmission or distribution utility. Conventionally, in order to make decisions on the maintenance and replacement needs for such assets, relatively detailed information on each asset would be required. This immediately raises a very significant practical problem. Firstly, an attempt to gather detailed information on each individual asset would be both practically and economically infeasible. Secondly, there are no standard interpretations of the various tests and inspections that may be carried out on each asset, therefore, requiring reliance on engineering judgment, which may be difficult to apply uniformly over

Continued on Page 20

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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.

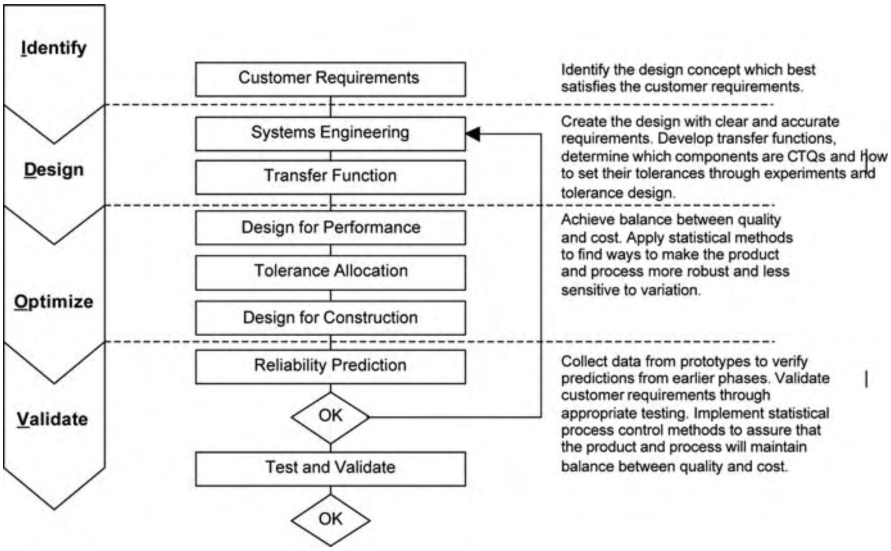

Figure 2. Example Design for Six Sigma (DFSS) roadmap illustrating the IDOV process. Modified from Kiemele, 2003.

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

Asset Condition

Continued from Page 18

an entire asset group or for different asset groups. In order to overcome these problems, a statistical sampling method can be used which would result in accurate evaluation of the overall asset class, providing a hierarchical approach to condition assessment.

2. Asset Degradation and Health Indices

It is important to understand the differences between defect management and reactive maintenance versus long-term asset degradation and asset condition assessment. Defects are usually well defined and associated with failed or defective components in the ancillary systems that affect operation and reliability of the asset well before its end-of-life. These defects do not normally affect the life of the asset itself, if detected early and corrected. Defects are routinely identified during inspection and dealt with by corrective maintenance activities to ensure continued operation of the asset.

Long-term degradation is generally less well defined and it is not easily determined by routine inspections. The purpose of asset condition assessment is to detect and quantify long-term degradation and to provide a means of quantifying remaining asset life. This includes identifying assets that are at or near end-of-life and assets that are at high risk of generalized failure that will require major capital expenditures to either refurbish or replace the assets.

A good understanding of the asset degradation and failure processes is vital if condition assessment procedures are to be effectively applied. It is important to identify the critical modes of degradation, the nature and consequences of asset failure, and, if possible, the time remaining until the asset is degraded to the point of failure. Unless there is a reasonable understanding of the degradation and failure processes, it is impossible to establish sensible assessment criteria or to define appropriate end-of-life criteria.

A composite Health Index is a very useful tool for repre-

Table 2
Design Criteria for Health Index Formulation

Health Index	Cond-ition	Probability of failure (pof)	Equivalent status on life curve	Requirements
85-100	Very Good	Low	First half of mean life expectancy (Green in Fig 2)	Normal maintenance
70-85	Good	Low but slightly increasing	Second one-third of mean life expectancy (Pale Blue in Fig 2)	Normal maintenance
50-70	Fair	Rapidly Increasing but lower than pof at mean age	Final one-third of mean life expectancy (Yellow in Fig 2)	Increase diagnostic testing, possible remedial work or replacement depending on criticality
30-50	Poor	Higher than pof at mean age and increasing	First one-third after the mean life expectancy (Brown in Fig 2)	Start planning process to replace or rebuild considering risk and consequences of failure
0-30	Very Poor	Very High, more than double the pof at mean age	Second one-third after the mean life expectancy (Red in Fig 2)	Immediately assess risk, replace or rebuild based on assessment

senting the overall health of a complex asset. Transmission and distribution assets are seldom characterized by a single subsystem with a single mode of degradation and failure. Rather, most assets are made up of multiple subsystems, and each subsystem may be characterized by multiple modes of degradation and failure. Depending on the nature of the asset, there may be one dominant mode of failure, or there may be several independent failure modes. In some cases, an asset may be considered to have reached its end-of-life only when several subsystems have reached a state of deterioration that precludes continued service. The composite Health Index combines all of these condition factors using a multi-criteria assessment approach into a single indicator of the health of the asset.

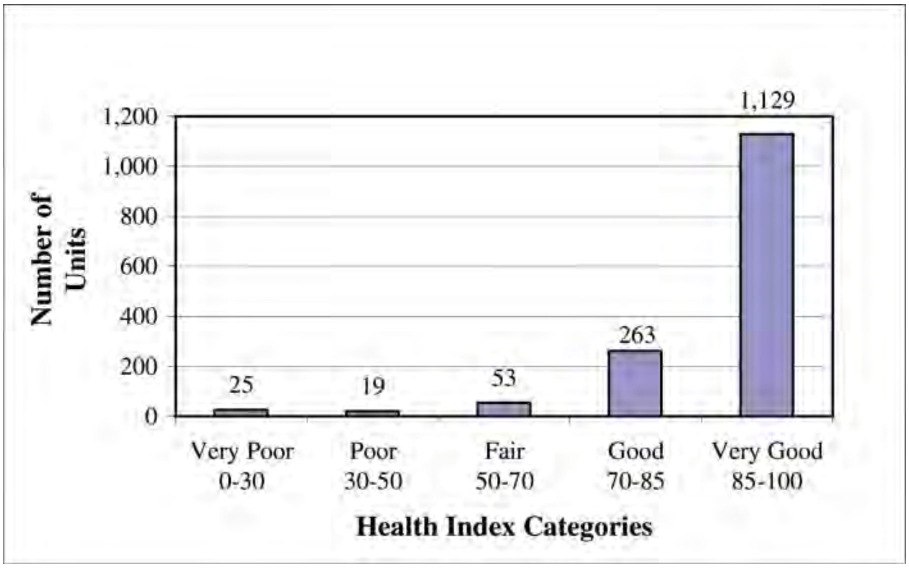

Figure 1
Actual Health Index Results for a Typical Distribution Asset

For a typical asset class, a wide range of diagnostic tests and visual inspections may be undertaken, either as part of the ongoing maintenance program or as special-purpose Asset Condition Assessment (ACA) surveys. In some cases, a poor condition rating value will represent a failure of a subsystem, which can be repaired through replacement of that subsystem, with no resultant impact on the serviceability of the overall asset. However, it should be recognized that generalized deterioration of many or all of the subsystems that make up an asset can also be a valid indication of the overall health of the asset. A composite Health Index captures generalized deterioration of asset subsystems, as well as fatal deterioration of a dominant subsystem.

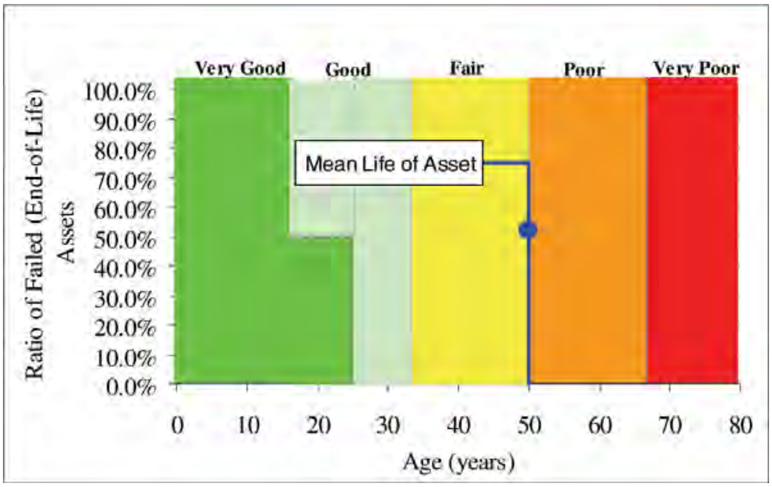

Figure 2
Health Index scaling categories as reflected to the age curve

In developing a composite Health Index for an asset, it is very important to understand the functionality of the asset, and the manner in which the various subsystems work together to perform the key asset functions. With a clear understanding of asset functionality, condition ratings of different asset components and subsystems can be combined to create a composite "score" for the asset, and the continuum of asset scores can be subdivided into ranges of scores that represent varying degrees of asset health.

The critical objectives in the formulation of a composite Health Index are:

- The index should be indicative of the suitability of the asset for continued service and representative of the overall asset health
- The index should contain objective and verifiable measures of asset condition, as opposed to subjective observations
- The index should be understandable and readily interpreted

Table 1 shows an example of a combined Health Index for Voltage Regulators (see previous page).

In this example, the maximum score is 92; Health Index is therefore (Total Score/92) X 100 (0-100) and provides a measure of the level and extent of degradation of the asset components.

Finally assets with a health index within a specific range can be assigned appropriate rankings (i.e. poor, fair, good etc., as shown in Figure 1).

3. Relationship among Health Index, Asset Condition and Probability of Failure

The targeted design criteria for assigning asset condition to a health index range and relating it to the failure probability of an asset is shown in Table 2 and illustrated in Figure 2 and Figure 3. This asset is assumed to have a median life expectancy of 50 years. The life expectancy curves for the asset are initially developed through careful evaluation of the design and manufacturing standards for the asset, results of accelerating aging tests where available and utilizing industry's collective experience with historic performance and failure rates through expert judgment. By applying actual condition data to a large enough population and studying failure rates over a period of time, the initial formulation can be revisited and, if necessary, adjusted towards the design criteria.

The asset health scaling categories would correspond to probability of failure rates on the asset life expectancy curve as illustrated in Figure 2 and can be utilized to assess effective age of the asset based upon its condition. Similarly, Figure 3 illustrates the probabilities of failure for these health scaling categories.

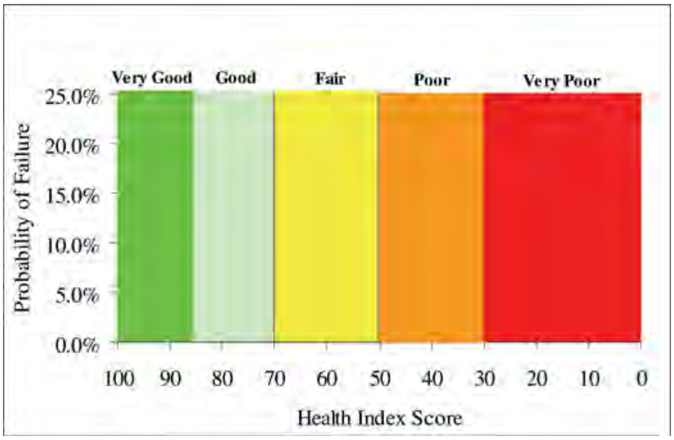

Figure 3
Health Index scaling categories and probabilities of failure

Based on these results, decisions for this particular asset can now be made on the most appropriate level of investments into maintenance, refurbishment or replacement over a defined time period. As such, the Health Index can be considered a key performance indicator (KPI) in a corporate performance management and decision making setting where its interpretation takes into account the nature of the asset being rated; e.g., end-of-life has a different meaning for a substation drainage system than for an distribution wood pole.

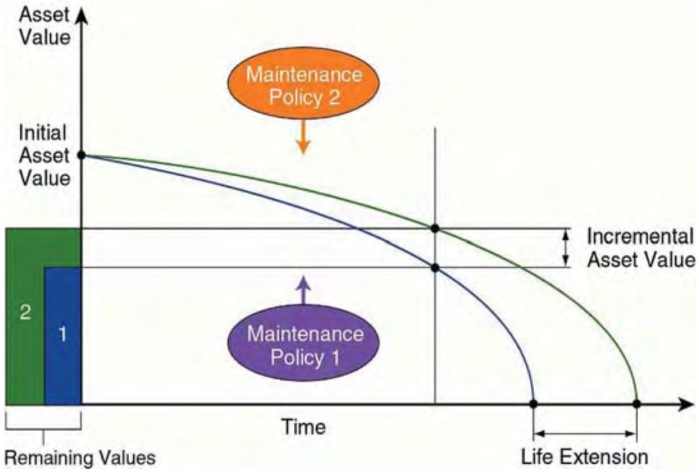

Figure 4
Two life curves for the same equipment under two different maintenance scenarios (Operating conditions are assumed to be the same)

4. Future Asset Health Condition and Effect of Maintenance

The scope and frequency of asset maintenance activities significantly impact asset life expectancy and asset health at any time during asset's lifespan. Different types of assets require different preventative maintenance routines, which have varying levels of impact on asset health and condition and probability of failure.

Figure 4 shows an example of two life curves for the same type of equipment under two different maintenance scenarios. If a comprehensive scope of maintenance activities is selected and these maintenance activities are carried out with greater frequency, as indicated by "Policy 2" in Figure 4, it would result in an increase in asset's life expectancy and the health index at any particular time (represented as asset value in the graph) will be higher. On the other hand, if maintenance policy 1 selected, which consists of fewer maintenance activities and carried out less frequently, it would result in shorter asset life expectancy and a lower value of health index at any time during asset's life. We can observe that the life curves in Figure 4 are equivalent to those in Figure 2.

The time period over which a certain maintenance policy is applied is, of course, of equal importance. For example, if the comprehensive maintenance policy 2 is applied from the beginning, the life expectancy would be significantly extended. However, if Policy 2 is applied late in the asset life cycle, the life extension may be minimal.

While the curves in Figure 3 allow derivation of the current effective age of an asset based on the present health index, Figure 4 provides means of taking into account the effect of the current maintenance policy and predicting expected aging and deterioration of the asset in future years. Thus, future asset health and condition can be predicted. Similarly, a change in the maintenance policy can be evaluated and its effect on the overall asset's life assessed.

It is important to note that accurate depiction of maintenance impacts on health and condition of assets and development of curves indicated in Figure 4, is not a trivial task, but requires extensive experience and knowledge in maintaining and operating assets to determine accurate cause-and-effect algorithms which are used in deriving these curves.

5. Conclusion

Health Indices provide a basis for assessing the overall health of an asset and risk of failure and are, therefore, a key performance indicator (KPI) on the asset condition. Health Indices are based on aging and degradation modes of assets and their subsystems under different environmental and operating conditions.

Use of health indices in establishing the level of investment levels into capital and maintenance activities allows the selection of optimal risk mitigation initiatives for implementation. A key factor in such integration is using the information available to assess the expected asset failure rates and the corresponding remaining life. This can be done by utilizing demographic, performance and condition information through health index analysis.

The effect of different maintenance options can then be analyzed for the optimal life extension of the assets.

ENERGY CONSERVATION IS CRUCIAL NO MATTER WHAT THE COST

By Clinton Roeder, Senior Vice President, Direct Energy

The Ontario Energy Board (OEB) recently announced a reduction in the regulated rate that the province's consumers will be charged for the electricity they use over the next six months. This may seem like good news in the short term, but the government-controlled price for electricity is very much at odds with some of today's most important priorities for consumers.

While the Ontario government has taken the lead on a number of initiatives to reduce greenhouse gases in response to the threat of climate change, keeping electricity prices artificially low continues to encourage the wrong type of behavior. The structure of the regulated electricity rate in Ontario provides little incentive to conserve energy, and discourages investment in new and much needed electricity generation.

The reality is that the regulated price of electricity in Ontario is distorted. The process used to set the rate every six months relies heavily on adjustments and "true ups" from prior periods, which means that at any time the price signal includes costs that are out of date. The resulting effect is to shield people from the true cost of electricity and from a major incentive to conserve.

People react to signals that affect their wallets. If con-

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REDUNDANCY IN SUBSTATION LANS WITH A RAPID SPANNING TREE PROTOCOL

By Michael Galea, Marzio Pozzuoli, RuggedCom Inc. - Industrial Strength Networks

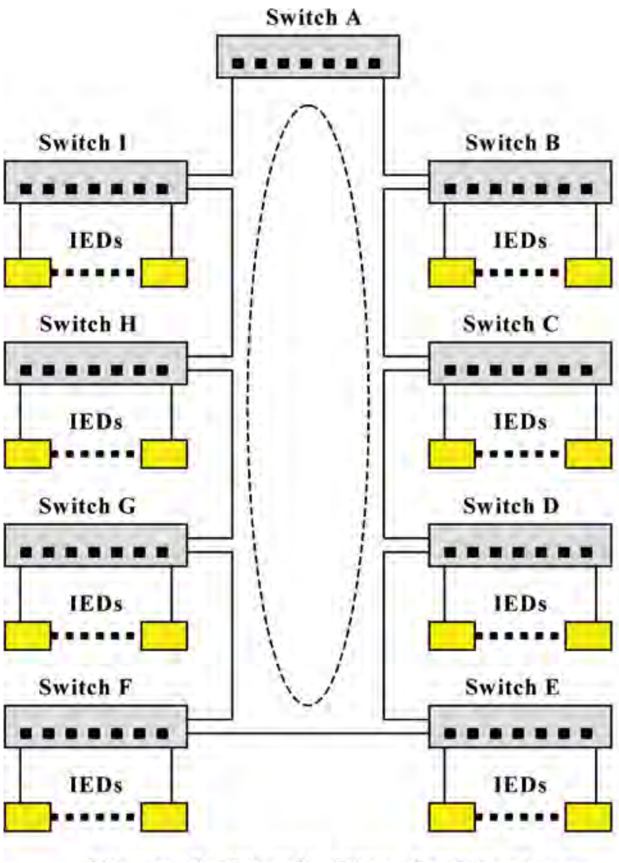

Figure 1: Simple Ring Architecture

INTRODUCTION

Ethernet local area networks (LANs) are steadily gaining more acceptance in substation automation applications where the LAN has become an integral part of the protection and control system. Most protective relaying manufacturers now offer Ethernet ports on their relays in both fiber optical and copper media.

Information models and exchange methods currently being defined as part of the IEC 61850 standard allow for real-time control (e.g. Trip/Block) messages to be sent across the LAN between relays or other intelligent electronic devices (IEDs).

Furthermore, there is a trend towards multicasting sampled data of current and voltage parameters over a 100Mbps Ethernet LAN as defined in IEC 61850-9-2 (Process Bus). With Ethernet LANs playing such a critical role in protection and control systems, new standards such as IEEE 802.1W Rapid Spanning Tree Protocol which are used to implement network redundancy and ring architectures are of critical importance.

BACKGROUND

Ethernet switches operate by forwarding traffic between their ports. The switch examines each Ethernet frame and records (learns) its MAC address and the port upon which it resides. When a frame arrives for a given MAC address, the switch "knows" on which outgoing port to send it. If a frame arrives and its destination MAC address is unknown, the switch will "flood" the frame out all of its ports.

If switches in the network are connected in a loop a ‘broadcast storm’ will result where a single broadcast frame will circulate endlessly. This condition consumes all available bandwidth on the loop, making the network unusable. The Spanning Tree Protocol is used to prevent this situation.

BRIEF HISTORY OF SPANNING TREE PROTOCOL (STP) AND RAPID STP (RSTP)

The Spanning Tree Protocol (IEEE 802.1D) was designed to solve the fundamental problem of traffic loops. The key idea in STP is to prune (looping) links in order to reduce the network topology to that of a tree. The resulting tree "spans" (i.e. connects) all switches, but eliminates loops. The steps in order to best accomplish this process are:

1. Allow all switches to send messages to each other that convey their identity and link "cost".
2. Elect a single switch among all the switches in the network to be a "root", or central switch.
3. Let all other switches calculate the direction and cost of the shortest path back to the root using messages received from switches closer to the root.

Each switch must have only one "best" way to forward frames to the root.

4. If two switches servicing the same LAN exchange messages with each other, the one with the lowest cost to the root will service the LAN. The other switch will discard all frames received from that LAN, thus opening the link and blocking a traffic loop.

The STP protocol has proved to be the tried and tested method for providing path redundancy while eliminating loops. The STP protocol does suffer from a number of drawbacks that limit its applicability, namely:

- STP has lengthy failover and recovery times. When a link fails in STP, a backup link to the root requires at least 30 seconds to recognize that it is the best (or only) path to the root and become usable.
- When a failed link returns to service, information about the "better" route will instantly cause a backup link to start blocking. But the portion of the network below the link that is returning to service will be isolated (for about 30 seconds) until that link becomes forwarding.
- Another problem with STP is that it requires that all links must pass through a lengthy period of address learning, even if the link is a point-to-point link to a device such as an IED (e.g. Relay, RTU, PLC).

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Rapid Spanning Tree

Continued from Page 24

ENTER RSTP (IEEE 802.1W)

RSTP solves STP's problem with failover time by a number of means. Whereas STP switches store only the best path to the root switch, RSTP switches store all potential paths. When links fail, RSTP has pre-calculated routes to fall back upon. Additionally, unlike STP switches, an RSTP switch will respond to another switch that advertises an inferior or incorrect route to the root switch. This information allows the switch with incorrect information to be rapidly trained.

RSTP solves STP's problem with lengthy recovery time by introducing a new procedure called proposing-agreeing. Proposing and agreeing works after a better path to the root is restored by "shuffling" the restored part of the network one hop at a time towards the network edge. This method also enables the network to come up quickly at inception.

RSTP also introduces a method for quickly bringing up ports at the edge of the network, while still protecting them against loops. If the port is designated as an "edge" type of port, RSTP will continue to send configuration messages out the port (in order to detect loops) but will allow traffic to flow as soon as the port rises. In the event of a loop, some looped traffic may flow before RSTP quickly seals the network. PCs, IEDs and RTUs connected via edge ports can send traffic without the extensive delays imposed by RSTP.

RINGS

A ring topology offers built-in redundancy and is often the most economical in terms of interconnection costs. Two popular methods of implementing rings are collapsed backbone and distributed switch. The distributed switch method, or simple ring (See Figure 1), is employed when network connected IEDs are geographically distributed.

The IEDs at each location are aggregated onto switches,which are organized into a ring. The connections between switches in the ring may be made using dual redundant links to obviate the possibility of failure at a fiber, connector or port level. The collapsed backbone method (See Figure 2) is usually employed when a large number of network connected IEDs are located in close proximity to one another. The IEDs are aggregated onto switches, the switches organized into a number of rings and all rings terminated in a common root node. Quite often, the network topology is a mixture of both methods, such as a ring of rings. Traffic in a ring tends to be balanced. The ring will open itself with an equal number of switches on either side of the root switch given an odd number of switches in the ring.

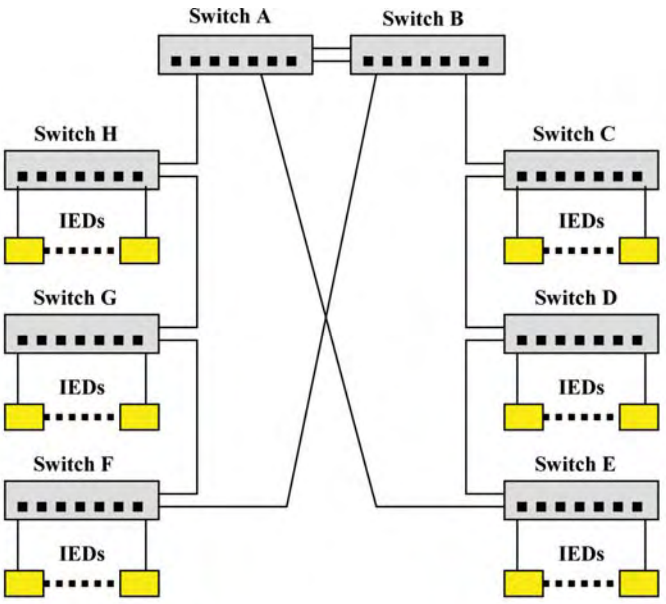


Figure 2: Collapsed Backbone Ring Architecture

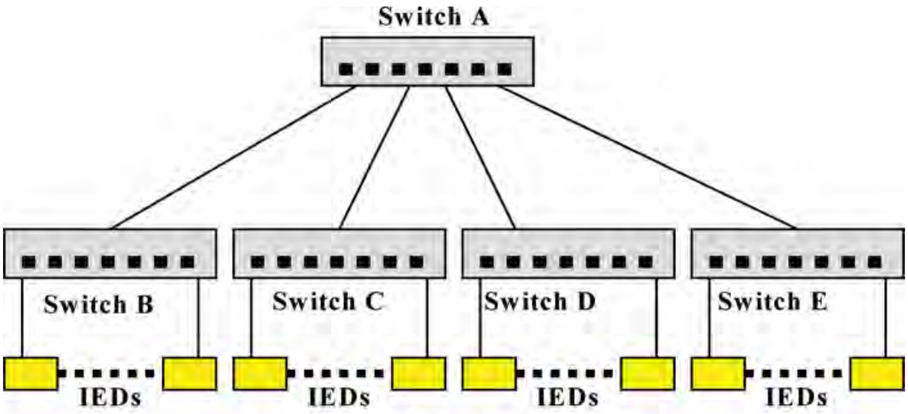


Figure 3: Tree Architecture

Latency in ring networks tends to be greater than in tree networks (See Figure 3) as there are usually more hops to pass through in order to go anywhere useful.

The worst case occurs when switches on either end of the blocked link at the “bottom” of the ring need to forward to each other. In this case, traffic must flow through every switch in the ring.

Ring networks offer only slightly slower failover and recovery times than tree networks. The worst case link failure in ring networks occurs on a port at the root. In this failure case, half of the switches in the ring must retrain themselves to face their root port in a completely opposite direction after a link failure or recovery. The other half of the network must reverse the direction of transmission to switches in the failing half.

The size of the ring is, in theory, limited by the RSTP switch diameter which assumes a pessimistic transit delay of one second per switch. In practice, the maximum number of switches in an optimized ring occurs when the number of priority switch levels has been exhausted. This limits the size of the ring to 31 switches. Rings of more than 31 switches are still possible but will failover and recover in a slower fashion.

FAILOVER AND RECOVERY PERFORMANCE IN RINGS

Figure 4 presents a network of nine RuggedCom RuggedSwitch Ethernet switches organized in a ring topology. The figure details the sequence of steps to heal the ring after the link between switches A and B fails.

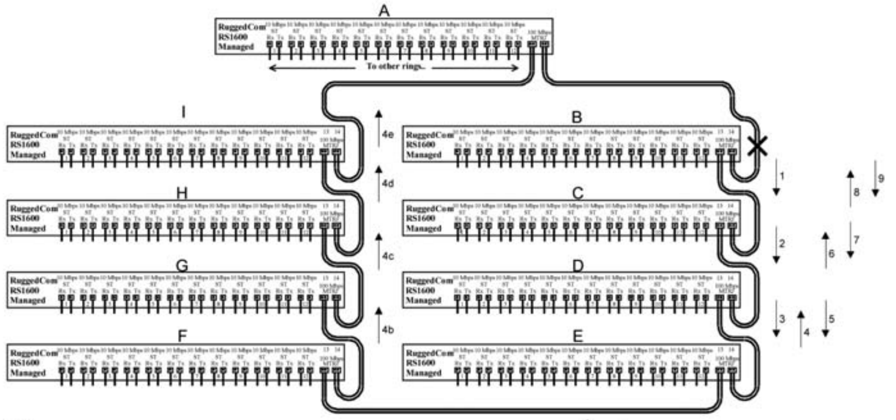
Initially, switch B has information

only about root switch A. All information about the root switch flows towards the break between switch E and F. After link AB fails, switch B recognizes the failure and must conclude that it is the root switch, propagating the information towards C.

The information will continue to propagate around the ring until it reaches the portion of the network that is still aware a path to switch A exists (i.e. switch E).

Switch E propagates correct information towards switches D, C and B. Since these switches are changing the identity of their root ports, they must use the proposal-agreement process to achieve rapid forwarding.

Typically, each step in the process involves a protocol “think time” and a frame transmission time, the sum of which is less than about 3 milliseconds. This leads to a total failover time for the ring of about 27 milliseconds. There is also the time required to signal topology change to switches F-A. In this example the topology change time is interleaved with the failover process and does not contribute to the failover time.



Notes

Before the link between A and B fails, Switch A is the root and the link between E and F is blocking. All ports that face in the direction of Switch A are root ports and all ports that face away from A are designated ports.

1) Switch B detects a failure of the link to switch A. It propagates information about a new root (itself) to C.
2) Switch C propagates information about the new root to D.
3) Switch D propagates information about the new root to E.
4) Switch E knows that root switch A is still alive. It discards D’s BPDU and sends it a BPDU with a port role of designated and the proposal flag set.
4a) Switch E takes the link to F out of blocking and signals a topology change to F. Bridge F, G, H and I propagate the change upward.
Any frames sent by these switches are now flooded in both directions around the ring.
5) Switch D blocks the link to C and moves its root port to E by sending it a BPDU with a port role of root and the agreement flag set.
6) Switch D sends a BPDU to C with a port role of designated and the proposal flag set.
7) Switch C blocks the link to B and moves its root port to D by sending it a BPDU with a port role of root and the agreement flag set.
8) Switch C sends a BPDU to B with a port role of designated and the proposal flag set.
9) Switch B converts its link to C from a designated port to root port by sending C a BPDU with the agreement flag.

The ring is now healed.

Figure 4: Failover in Ring Architecture

The recovery process for this example is quite straightforward. When link AB is restored, switch A will transmit a BPDU down it. Switch B will change its root port towards A, and then signal a topology change. Switch B will propagate the new root information towards switch C. Switch C will change its root port and will train switch D. Switch D will train switch E. Switch E will attempt to train switch F but switch F will see a lower path cost from switch G and will discard the BPDU from E. At this point the network will be healed.

When switch A receives the topology change from B, it propagates the topology change towards switches I-F. During the recovery process, switch A will continue to forward a number of frames for switches B-E in the direction of switch I. At some point these frames will encounter a newly blocked link on switch C-E.

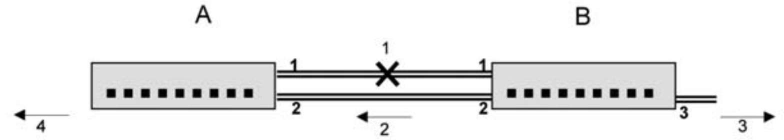
Fortunately, switch A will use the

topology change to start flooding frames, as will switches I through F. Switch A will lose about 2 milliseconds worth of frames, switch I, 4 milliseconds, switch H, 6 milliseconds, switch G, 8 milliseconds and switch F, 10 milliseconds worth of frames.

DUAL LINK ARRANGEMENT

Figure 5 presents two switches protected by a dual link arrangement, and the series of events that occur after a link failure.

Both switches detect failure of link 1 simultaneously and immediately age out the learned MAC address entries for these ports.



Notes

Before the link between A and B fails, Switch A is the root and link 2 is blocking at B. Both of A's ports are designated. Port 1 of Switch B is root and port 2 is an alternate.

1) The link fails.
2) Switch B transmits a BPDU to A on link 2 signifying it has changed it's port role from Alternate to Root. Switch B places the link in the forwarding state. At this point connectivity is restored. The BPDU also has the topology change bit set.
3) Switch B issues BPDUs with the topology change bit set to any of its designated ports.
4) Switch A issues BPDUs with the topology change bit set to any of its designated ports.

Figure 5: Dual Link Failover

Switch B has been receiving periodic transmissions of Bridge Protocol Data Units (BPDUs)1 on link 2. This information allows it to evaluate link 2 as its best path to the root switch. Switch B immediately sets its root port to 2.

RSTP procedure requires a topology change when adding a path to the topology. Switch B “sees” the new root port as an added path and floods topology changes out its ports. Though not strictly necessary in this case, they cause no ill effects. Including the time to recognize the link failure (a process that takes less than a millisecond), the switches failover to link 2 in less than 5 milliseconds.

The recovery process for this example is quite straightforward. When link 1 is restored, switches A and B will transmit BPDUs on it. Switch A will ignore the BPDU from switch B. Switch B will use the switch A BPDU to place its link 2 in blocking and then change its root port towards A. Afterwards, switch B will signal a topology change to switch A. At this point, the network will be healed. The recovery process introduces an outage of less than 5 milliseconds.

CONCLUSIONS

- RSTP may be employed effectively in tree type or ring type network architectures to provide redundancy and fault-tolerance.
- Practical rings should be limited to 31 switches. (RuggedCom’s RuggedSwitch has enhanced RSTP technology to support rings with up to 80 switches).
- A useful rule of thumb is to budget 5 milliseconds of recovery time for every switch in the ring (based on RuggedCom’s RuggedSwitch enhanced RSTP performance).
- Dual link arrangements (where one link serves as a hot standby for another) provide rapid failure recovery, typically in less than 5 milliseconds.

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Marzio Pozzuoli is the founder and president of RuggedCom Inc. Prior to founding RuggedCom, Mr. Pozzuoli developed advanced numerical protective relaying systems and substation automation technology. He is also an active member of the IEEE and is involved in standards work as a member of the IEEE Power Engineering Society Substations Committee task force C2TF1 working on developing a standard for communications networking devices in substations.


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ATTAINING "ZERO-PACKET-LOSS" IN THE SUBSTATION

By Marzio P. Pozzuoli, RuggedCom Inc. – Industrial Strength Networks

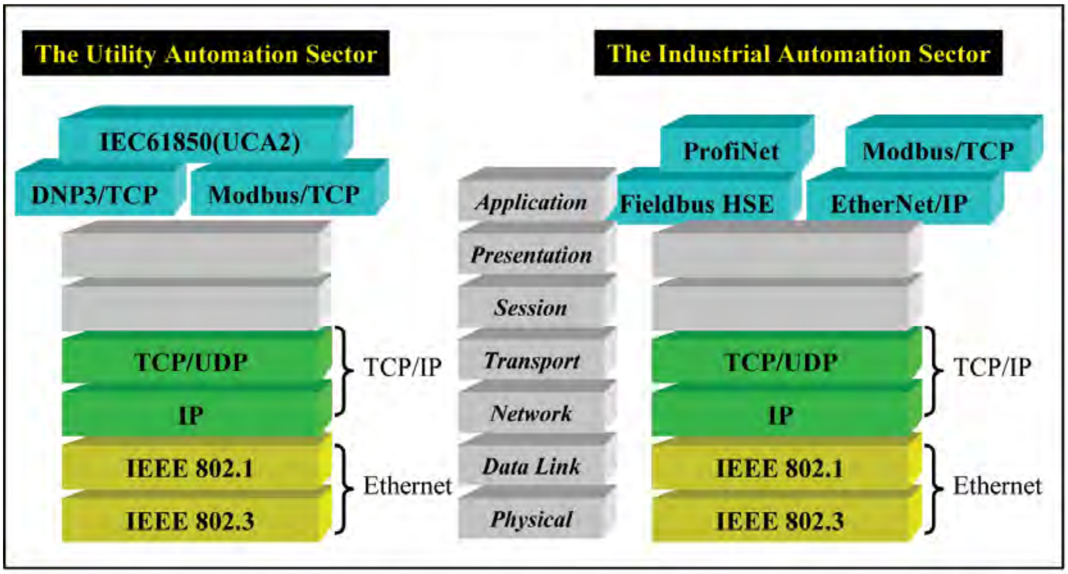


Figure 1: Ethernet based communications profiles in the Utility and Industrial Sectors

INTRODUCTION

The proliferation of Ethernet networking technology from the office environment to the substation environment for use in real-time mission critical control applications has resulted in both the IEC and IEEE developing new standards addressing networking equipment in substations. In both cases, the standards define conditions that require the networking equipment operate without any loss or interruption of communications during the application of a variety of destructive EMI immunity type tests.

These type tests are essentially the same type tests applied to protective relaying devices and utilize essentially the same test levels. Since the protective relaying devices are required to pass these type tests without 'misoperation' or damage, the equivalent is also required of the networking equipment to which these devices are being connected. Zero-Packet-Loss under EMI stress is the networking equivalent of no 'misoperation' under EMI stress for protection relays.

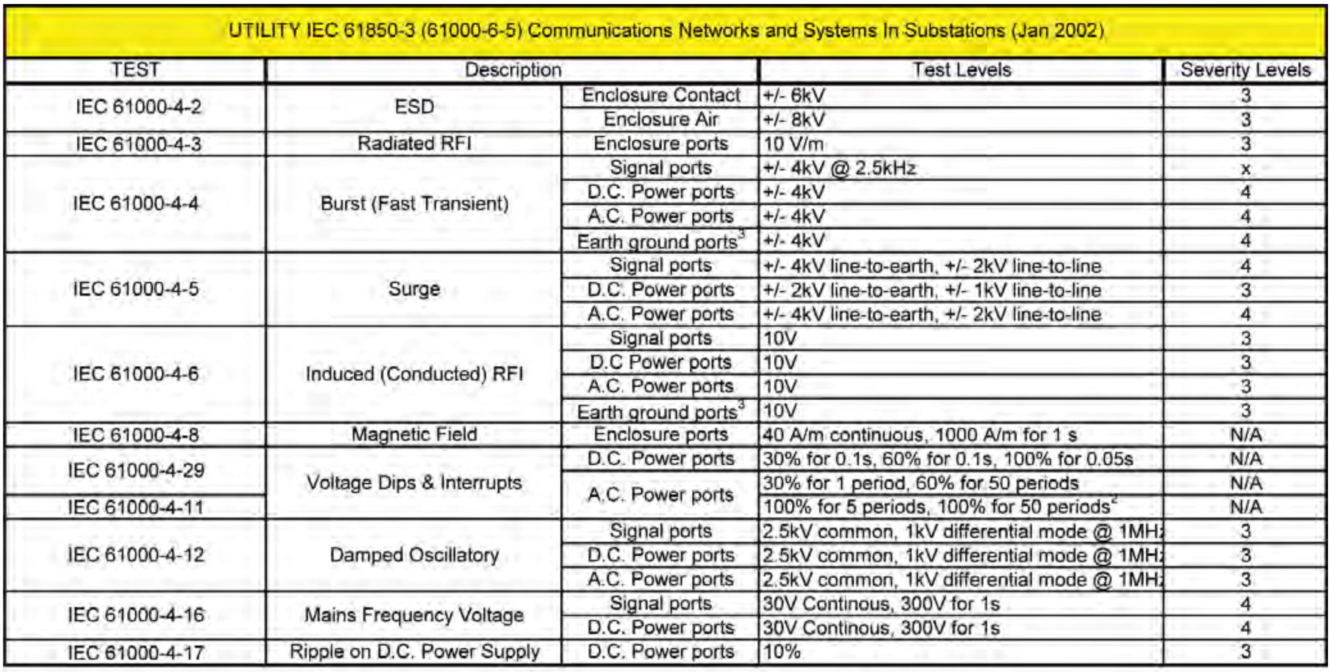
This article explores the emerging trends of using the network to perform mission critical real-time control applications, the new IEC and IEEE standards for communications systems and networking equipment in the substation, and the reasons/needs for Zero-Packet-Loss in the substation.

ETHERNET IN THE SUBSTATION – WHY?

Not so very long ago, every major vendor of relays, remote terminal units (RTU), meters and programmable logic controllers (PLC), to name but a few intelligent electronic devices (IED) used in substations, had their own communications protocol. What this often meant was that most of the IEDs were incompatible even at the physical layer interface as well as the communications protocol layer. Therefore, as was often the case, some sort of protocol converter device was required to bring all of the IEDs onto a common physical network and perform the translation to allow everyone to speak a common application layer protocol. This resulted in expensive integration with often-poor performance because of the insertion of protocol converters.

To remedy these woes, utilities turned to the Electric Power Research Institute (EPRI) and, along with IED manufacturers and leading utilities such as American Electric Power, collaborated to develop the Utility Communications Architecture (UCA2.0) which is the international standard IEC 61850. It provides a set of standards and specifications with a common application layer protocol to ensure everyone speaks the same language and several communications profiles with Ethernet at the physical layer to ensure everyone resides on the same physical network. This is because Ethernet brings with it a multitude of advantages:

- 10Mbps, 100Mbps, 1Gbps, 10Gbps and growing speeds;
- Support for fiber, copper and wireless media;
- Network redundancy and fault tolerant ring architectures per IEEE 802.1w Rapid Spanning Tree protocol;
- Message Prioritization and Class of Service for real-time control per IEEE 802.1p Priority Queuing;
- Virtual LANs which allows for traffic isolation and system security per IEEE 802.1Q VLAN;
- Deterministic (yes that's right I said 'deterministic') full-duplex operation with no collisions per IEEE 802.3x Flow Control (Modern Ethernet Switches which support IEEE 802.3x do not allow, nor support, nor experience collisions! Collisions are a thing of the past associated with Ethernet networks implement-



UTILITY IEC 61850-3 (61000-6-5) Communications Networks and Systems In Substations (Jan 2002)				
TEST	Description		Test Levels	Severity Levels
IEC 61000-4-2	ESD	Enclosure Contact	+/- 6kV	3
		Enclosure Air	+/- 8kV	3
IEC 61000-4-3	Radiated RFI	Enclosure ports	10 V/m	3
IEC 61000-4-4	Burst (Fast Transient)	Signal ports	+/- 4kV @ 2.5kHz	x
		D.C. Power ports	+/- 4kV	4
		A.C. Power ports	+/- 4kV	4
		Earth ground ports[3]	+/- 4kV	4
IEC 61000-4-5	Surge	Signal ports	+/- 4kV line-to-earth, +/- 2kV line-to-line	4
		D.C. Power ports	+/- 2kV line-to-earth, +/- 1kV line-to-line	3
		A.C. Power ports	+/- 4kV line-to-earth, +/- 2kV line-to-line	4
IEC 61000-4-6	Induced (Conducted) RFI	Signal ports	10V	3
		D.C Power ports	10V	3
		A.C. Power ports	10V	3
		Earth ground ports[3]	10V	3
IEC 61000-4-8	Magnetic Field	Enclosure ports	40 A/m continuous, 1000 A/m for 1 s	N/A
IEC 61000-4-29	Voltage Dips & Interrupts	D.C. Power ports	30% for 0.1s, 60% for 0.1s, 100% for 0.05s	N/A
		A.C. Power ports	30% for 1 period, 60% for 50 periods	N/A
IEC 61000-4-11			100% for 5 periods, 100% for 50 periods[2]	N/A
IEC 61000-4-12	Damped Oscillatory	Signal ports	2.5kV common, 1kV differential mode @ 1MH	3
		D.C. Power ports	2.5kV common, 1kV differential mode @ 1MH	3
		A.C. Power ports	2.5kV common, 1kV differential mode @ 1MH	3
IEC 61000-4-16	Mains Frequency Voltage	Signal ports	30V Continous, 300V for 1s	4
		D.C. Power ports	30V Continous, 300V for 1s	4
IEC 61000-4-17	Ripple on D.C. Power Supply	D.C. Power ports	10%	3

Table 1: IEC 61850-3 (IEC 61000-6-5) EMI Immunity Type Test Requirements

ed using shared media hubs/repeaters.);

- Ethernet is the world's most widely adopted local area network (LAN) technology and is now migrating into the wide area networking (WAN) space. In the future we could see a total Ethernet solution from the WAN to the MAN (Metropolitan Area Network) to the LAN;

- Every major manufacturer of IEDs (e.g. Relays, RTUs, Meters, PLCs) now provides at least one (some provide dual) Ethernet port on their devices.

In the process control industry (i.e. industrial automation) a similar transformation has taken place with every major vendor of process control IEDs now providing Ethernet connectivity to the degree that many have espoused the notion that "Ethernet is becoming the RS232 for process control…"

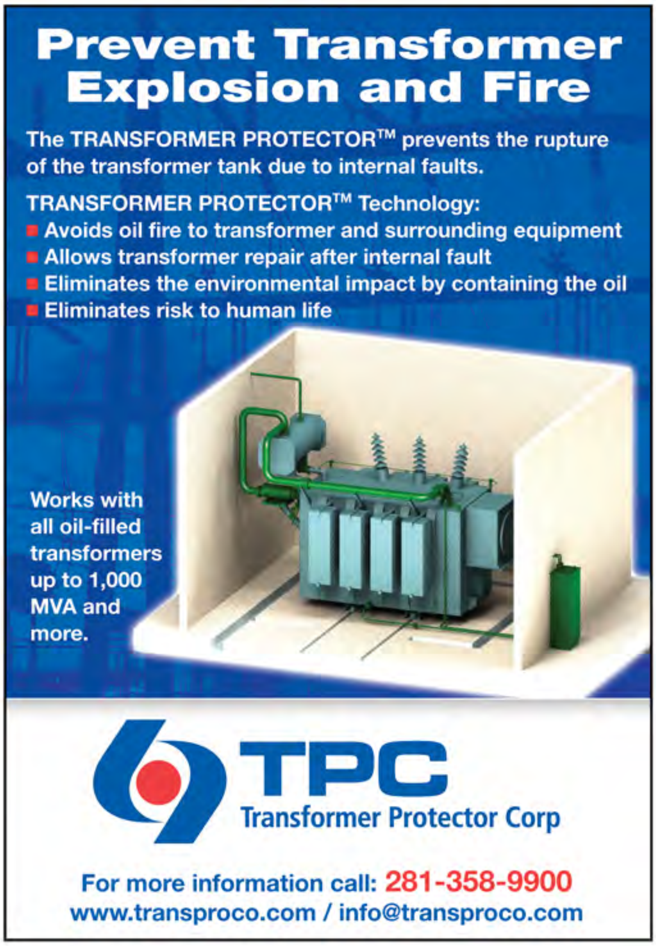
NEW STANDARDS COVERING NETWORKS IN SUBSTATIONS

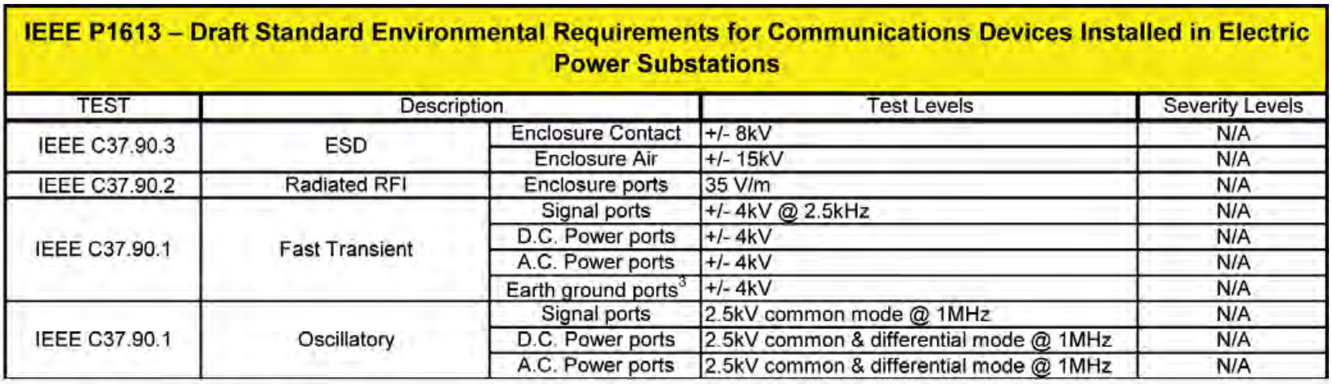
IEC - First Off the Mark

In January 2002, the International Electrotechnical Commission (IEC) released a standard entitled IEC 61850-3 "Communications networks and systems in substations" to specifically address the general environmental and electromagnetic interference (EMI) immunity requirements for network equipment used in substations. In particular, section 5.7 EMI Immunity states that "The general immunity requirements for the industrial environment are considered not sufficient for substations. Therefore, dedicated requirements are defined in IEC 61000-6-5…".

Table 1 above summarizes the possible worst case test levels defined by IEC 61000-6-5 depending on location of the equipment within the substation.

Of critical importance in the IEC 61000-6-5 specification is the performance criteria defined for key functions within the substation. Essentially, it allows for no delays or data loss for





IEEE P1613 – Draft Standard Environmental Requirements for Communications Devices Installed in Electric Power Substations

TEST	Description		Test Levels	Severity Levels
IEEE C37.90.3	ESD	Enclosure Contact	+/- 8kV	N/A
		Enclosure Air	+/- 15kV	N/A
IEEE C37.90.2	Radiated RFI	Enclosure ports	35 V/m	N/A
IEEE C37.90.1	Fast Transient	Signal ports	+/- 4kV @ 2.5kHz	N/A
		D.C. Power ports	+/- 4kV	N/A
		A.C. Power ports	+/- 4kV	N/A
		Earth ground ports[3]	+/- 4kV	N/A
IEEE C37.90.1	Oscillatory	Signal ports	2.5kV common mode @ 1MHz	N/A
		D.C. Power ports	2.5kV common & differential mode @ 1MHz	N/A
		A.C. Power ports	2.5kV common & differential mode @ 1MHz	N/A

Table 2: IEEE P1613 EMI Immunity Type Test Requirements

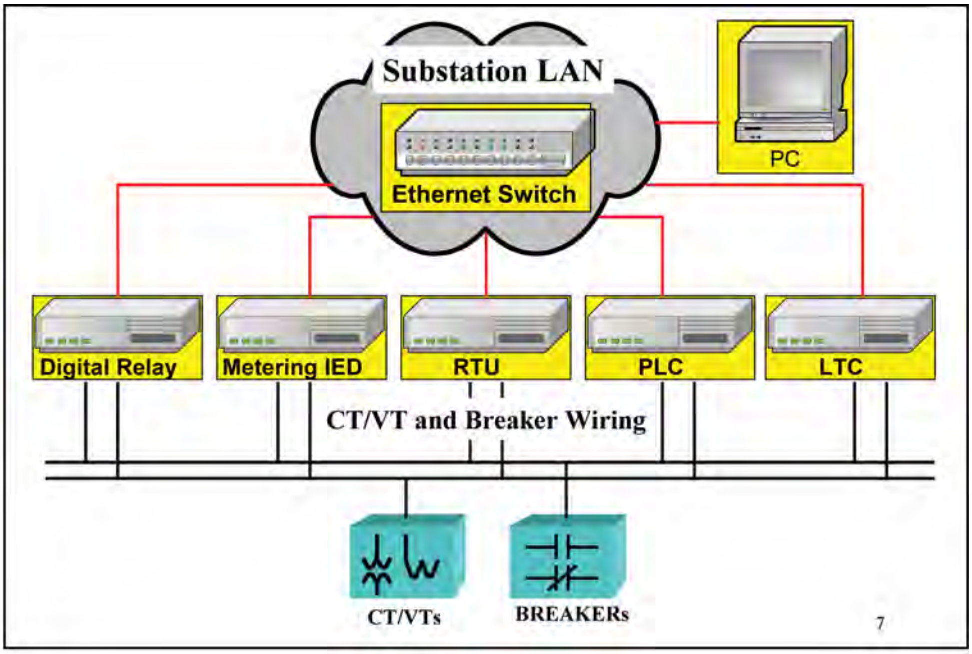


Figure 2: All IED's connected to a common physical Substation LAN. For the more adventurous; all inter-IED control signaling is done over the Substation LAN.

critical functions such as Protection and Teleprotection functions, On-line Processing and Regulation, and Metering when exposed to various EMI phenomena.

IEEE – Following Suit

The Substations Committee of the IEEE Power Engineering Society via the C2TF1 Task Force was also busy producing its own equivalent standard for communications networks in substations entitled IEEE P1613 - "Environmental and Testing Requirements for Communications Networking Devices in Electric Power Substations". Table 2 summarizes the key EMI immunity requirements defined in the standard.

A key definition in the standard is the definition of two classes of communications devices: Class 1 communications devices allow for communications errors and delays during the application of the required type tests while Class 2 devices allow for no communications errors or delays during the application of the required type tests.

THE ESSENCE OF ZERO-PACKET-LOSS UNDER EMI STRESS

For an Ethernet LAN in the substation the performance requirements of IEC 61850-3 for critical functions and IEEE P1613 Class 2 devices translate to zero-packet-loss under EMI stress which in practical terms means that one must be able to apply all of the EMI type tests listed in Tables 1 & 2 while network traffic through the Ethernet LAN is at its maximum (i.e. 100% frame/packet rate) and experience no frame/packet errors, delays or losses.

This, in essence, guarantees that the LAN equipment has the same level of EMI immunity as the protective relaying IED's connected to it. Bear in mind that protective relaying IED's must also pass these very same type tests under simulated operational conditions without any 'misoperation' or failures.

WHEN IS ZERO-PACKET-LOSS UNDER EMI STRESS NEEDED?

Utilities and vendors alike are no longer simply talking about pilot projects and proof of concept scenarios. In ever-growing numbers, utilities in North America and around the world are deploying substation Ethernet LANs and leveraging them to perform a variety of tasks.

Those who tread cautiously are doing the following:

- IED data collection and monitoring over a high-speed (10/100Mbps) LAN.

- Leveraging the fact that Ethernet LANs allow IEDs supporting different application layer protocols (e.g. Modbus/TCP, DNP3.0, UCA2.0) to coexist harmoniously on a common physical network without protocol converters. This allows one to continue to leverage the investment made in existing protocols and incrementally migrate to a common protocol such as UCA/61850 when there is a sufficient comfort factor.

For this level of performance Zero-Packet-Loss is optional.

The more “adventurous” are starting to do the following:

- Relay ‘Trip’ and ‘Block’ signaling via UCA/61850 GOOSE messaging over the LAN;
- Relay Voting Schemes (e.g. 2 out of 3 relays say ‘TRIP’) – where again GOOSE messaging is used over the LAN;
- Bus Blocking/Trip Co-ordination schemes via GOOSE message signaling over the LAN;
- Load shedding and restoration schemes via GOOSE messaging over the LAN.

For this level of performance, and critical functionality of the LAN, Zero-Packet-Loss under EMI is an essential requirement.

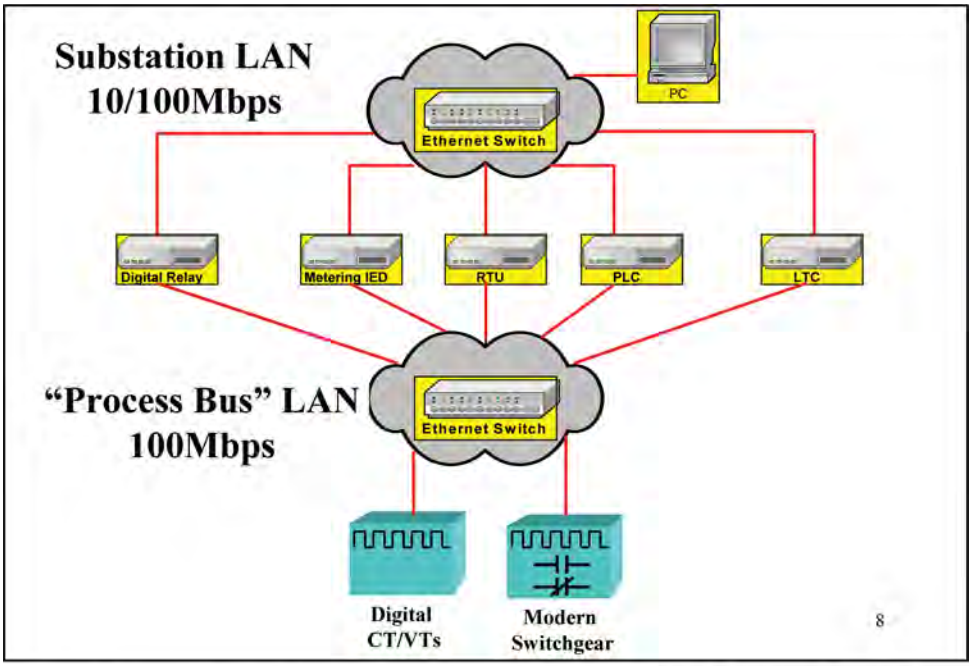
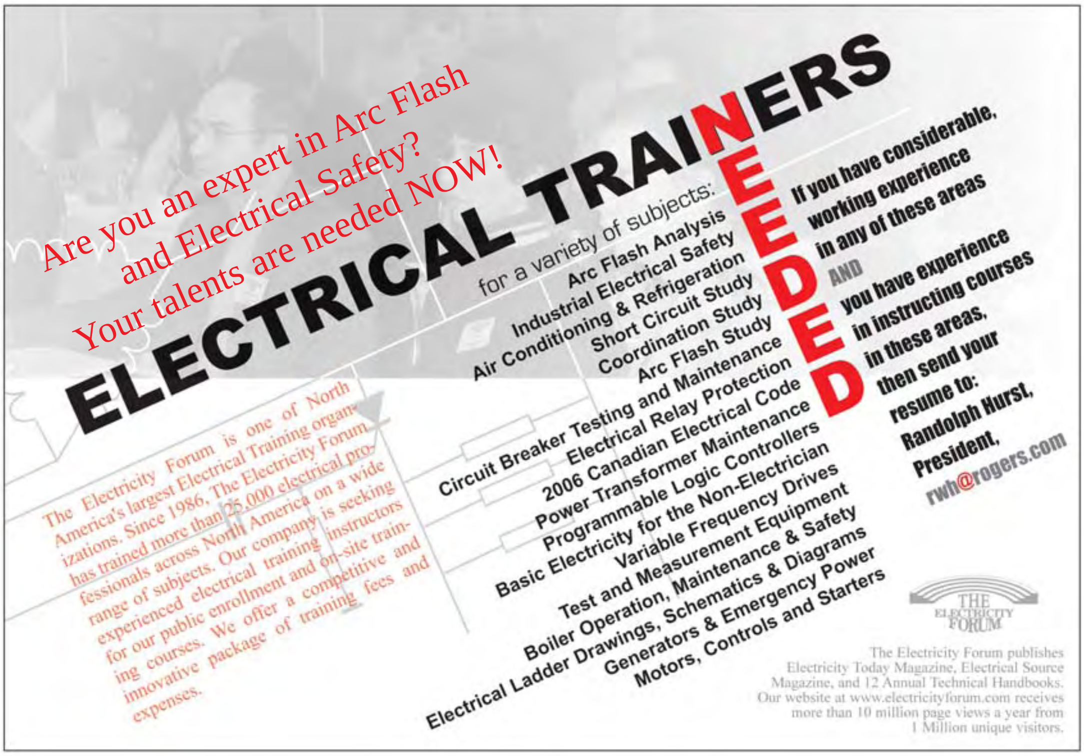


Figure 3: A complete LAN based solution with both IEDs, CT/VTs and Breaker’s connected to Ethernet LANs.

The truly “visionary” are looking at:

- A complete LAN-based solution where even the CT/VT wiring and breaker control wiring has been replaced by single IEDs which interface to the CTs and VTs and provide all the current, voltage and other power system parameters over the LAN in a broadcast manner, allowing any or all IEDs connected to the LAN to have access to this information.
- At present, companies such as ABB, Siemens and Alstom have been collaborating and have developed digital CT/VT sensors and breaker IEDs which interface to a 100Mbps Ethernet LAN. This is often referred to in the industry as a “process bus” and is accommodated in sections of soon to be released IEC 61850 specification.

For this level of performance and critical functionality of the LAN, Zero-Packet-Loss under EMI is a must!



CONCLUSIONS

Zero-Packet-Loss performance by networking equipment in the substation environment is essential for current trends to continue.

The basic requirement of having all of the electronic equipment involved in the protection and control system (i.e. Relays, PLCs, and the LAN) capable of passing the same EMI immunity type tests without ‘misoperation’ will give protection and control engineers the confidence to take advantage of the many new possibilities afforded to them by a high-speed LAN based system.

GE

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.

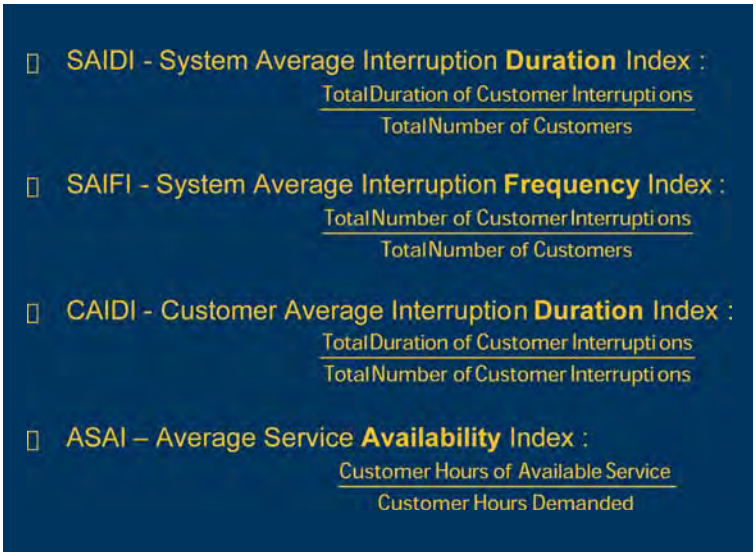
DFSS APPLICATIONS TO ENGINEERING DESIGN

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 circuit to support a key customer.



- 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 :

$$\frac{\text{Customer Hours of Available Service}}{\text{Customer Hours Demanded}}$$

“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:

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.

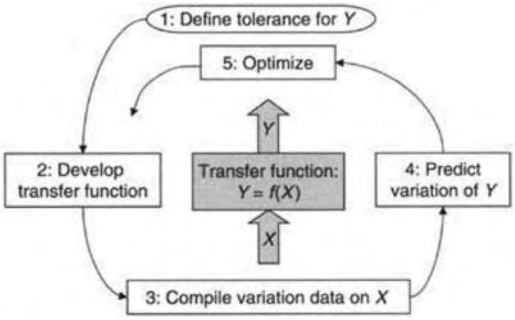


Figure 3: Example process flow for tolerance design, with a focus on the transfer function. From Sleeper, 2006.

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.

Direct Energy

Continued from Page 23

sumers pay artificially low electricity prices, they are unlikely to change their energy consumption behavior.

Let's take last summer as an example. On days with record high electricity usage, the grid was strained to its limits. When this happens, Ontario buys electricity on the spot market at prices more costly than the regulated rate that was provided to consumers.

So, although we heard public service pleas to conserve energy every day, consumers saw that all their electricity needs were met at an artificially low price regardless of whether they turned off their air conditioning or blasted it at full force. Without accurate price signals, there is limited incentive to conserve.

Regulated rates that distort prices also discourage much needed investment in Ontario's electricity supply. Investor confidence is needed to fund the $40 billion in electricity infrastructure investment required to support Ontario's economy over the long term. In order to build investor confidence that the Ontario market is working, suppliers need to know that true market prices will be passed on to consumers.

A healthy competitive electricity sector that supports both conservation and investment requires real and timely price signals.

There are steps that can be taken to remove price distortion from electricity prices. For example, Ontario's natural gas prices are set every three months, and although this process is not perfect, it sends significantly more accurate price signals than those provided by the six-month electricity rate.

In other markets we've also seen a monthly rate based on market projections for the month ahead. More frequent pricing leads to truer market prices while giving consumers greater visibility of the economic results of their energy choices.

That's not to say there isn't good work happening on the conservation front in Ontario.

The province has been active in implementing conservation and demand management programs for consumers. They also have a strong agenda to bring smart electricity meters to consumers, which would impose time-of-use pricing and help consumers better understand their energy consumption during peak periods.

In spite of this progress, we continue with pricing in Ontario that does not reflect the true economic cost of electricity. In doing so, we fail to encourage the kind of conservation behavior that everyone agrees we need, at a time when we need it most. We must realize that failing to conserve carries costs far greater than passing on the true cost of electricity to consumers. It is critical that businesses and individuals work together with government to take every necessary step to ensure sustainable supply that does not come at a detriment to the environment.

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