IMPLEMENTING NEW TECHNOLOGY IN AN AGED INFRASTRUCTURE

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As the U.S. power delivery infrastructure ages, the stress placed on it increases. New equipment installations peaked in the early 1970s, and now the bulk of the infrastructure is at least 25 years old, yet the demand on the system grows steadily.

During the 1990s, capacity grew by only 15% but demand rose by twice that amount. During this decade, utilities invested just half of the traditional average, and much of this investment centered on generation rather than delivery infrastructure. The system's age becomes evident when specific parts of the infrastructure, namely transformers and circuit breakers, receive closer investigation.

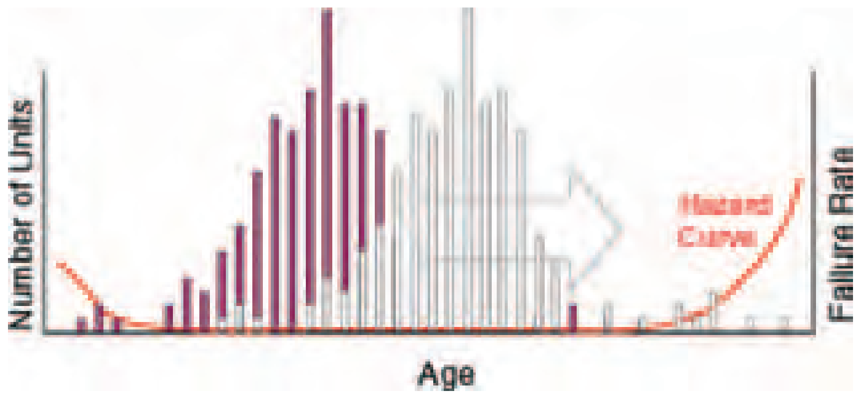

Figure 1

TRANSFORMERS

The average age of a transformer in the overall US utility fleet is 25 years and growing. Not only has investment in transformers nearly stalled, the transformers in service face increased utilization as demand grows.

As utilities load existing systems to higher capacity factors without expanding them, the system's life expectancy is forecast to decrease. Even without the increased aging effect, a significant portion of the fleet now approaches a hazard curve at which expected failures increase dramatically with age. Studies indicate that the 1% failure rate associated with younger transformers can quickly jump to 3% and rise exponentially when the transformers reach 40 to 50 years of age, potentially approaching 50%, as shown in Figure 1.

Samples of circuit breaker demographics indicate that 21% of the surveyed circuit breaker fleet is 30 – 40 years old and 17% is more than 40 years old. The infrastructure uses numerous types of breakers; the majority, for applications greater than 69kV, consist of bulk oil breakers (50%) followed by dead tank SF6 breakers (36%). Although some vintages and types of breaker suffer fewer aging effects than others, numerous operators see the potential problems as sufficient grounds for considering enhanced maintenance practices, including increased monitoring.

The control systems are also antiquated. They provide minimal system condition information and use decades-old technology. Additionally, the data networks serving as an interface were not installed or specified to accommodate high bandwidths. Compared to the modernization of infrastructure that's taken place in the telecom industry, little has been done in the electric utility industry.

In the face of limited budgets, operators interested in sustaining high reliability levels must consider alternative technology solutions and system automation. Some visions of enhanced monitoring and ensuing automation hold that these systems could become self-healing and self-optimizing, such that they anticipate and respond quickly to disturbances, thereby greatly minimizing disruptions to the end users.

BARRIERS TO IMPLEMENTATION

Numerous barriers have led to this situation. Some are obvious and some are more systemic in nature. Systemic barriers include the complexity of utility ownership and the overlapping and sometimes conflicting regulatory jurisdictions, which can, in turn, yield conflicting regulations.

Market reforms, both wholesale and retail, have impacted financing costs because these reforms present more risk to borrowers. Conflicting environmental policies from various levels of government have added further to the uncertainty in the industry.

Market research corroborates that such systemic issues comprise the main barriers to retrofit technology and substation automation, but expresses them in more day-to-day operational terms, the most prevalent being:

- Benefits do not outweigh costs
- Lack of funding
- Economic justification not made
- Lack of appropriate communications
- Uncertain management philosophy

COMPLEMENTARY INNOVATIONS

A possible path around these barriers involves combining innovative new technologies in ways that decrease costs while increasing sophistication and capability. The aim is to upgrade systems gradually in specific and concise directions and with an eye toward accommodating additional automation, thereby allowing further upgrades at a fraction of the original cost.

Figure 2

Figure 3

Numerous technological innovations have arisen that could significantly alter the design and implementation of sensors and control schemes in the substation environment. One of the most significant and meaningful is in wireless communication. A sample of the applicable innovations follows:

Wireless Communications – recent advances in wireless mesh networks have made it feasible to place low-cost radios or motes and receptive gateways in substation environments, even under high EMF noise conditions. With a mesh network each radio not only transmits but receives and retransmits signals from its neighboring radios (Figure 2). Each radio then supports the network dynamically: if one radio drops out, others pick up and support the signals it was conveying in a self-healing fashion (Figure 3). The motes themselves are low-cost, plus they eliminate the cost of wiring. The radios are currently manufactured to be very adaptable in terms of operating parameters and power usages.

Sensors – Micro-machining techniques have not only advanced the accuracy but also decreased the size of numerous transducers. Pressure and temperature transducers alone have seen significant size and cost reductions that do not sacrifice high levels of accuracy.

IEDs – With advances in chip technology IEDs can perform much more analysis on the sensor chip with a sharp reduction in chip size and power consumption.

Algorithms – Advances in software and chip technology allow much more sophisticated analysis to take place at the sensor rather than on the desktop.

SPECIFIC SOLUTION

These technology innovations, when focused on a specific issue with a potential high cost/benefit ratio, provide an entry point for the automation process. This case involves monitoring targeted circuit breakers for SF6 gas content to enable more-efficient maintenance practices. A low-cost, robust wireless solution will allow expansion to sensor points at minimal cost.

As mentioned, a significant portion of the existing breaker population employs SF6. Because of the critical nature of these breakers, diligent management of SF6 gas content has become essential. Utilities expend significant operation and maintenance resources to monitor and maintain proper SF6 levels. In most instances, unplanned maintenance occurs when breakers alarm low levels of gas. This translates to expensive overtime or unscheduled dispatch of personnel.

Additionally, SF6 breakers present an environmental exposure. Due to its inherent chemical stability, SF6 has environmental implications if released into the atmosphere. Classified as a Greenhouse Gas (GHG), SF6 has a global warming potential 23,900 times greater than CO2, along with an atmospheric life of 3,200 years. Put in different terms, one pound of SF6 has the same global warming potential as 11 tons of CO2. In the interest of both environmental stewardship and continuous improvement of maintenance practices, utilities have investigated better ways to monitor utility equipment that uses SF6.

Available SF6 detection/monitoring technologies occupy a spectrum ranging from very high-cost, advanced leak-imaging technology to lower-cost, on-line density monitors that survey and report the measured gas content within a utility breaker. Even the lower-cost solutions, however, do not yield an adequate cost-benefit ratio to justify widespread monitoring. Their true installed costs include expensive installation and wiring. Further, their accuracy suffers from the ambient-driven diurnal and annual pressure variations, which

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PROBLEM:

arc flash!

HEAT - PRESSURE WAVE - PLASMA - SEVERE BURNS
CONCUSSIONS - MOLTEN METAL PROJECTILES
HEARING LOSS - COLLAPSED LUNGS - BROKEN BONES
LOSS OF LIMB - MENTAL HANDICAPS - LOSS OF LIFE

SOLUTION:

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- Suitable for both low-voltage and high-voltage applications (480 volts and up)
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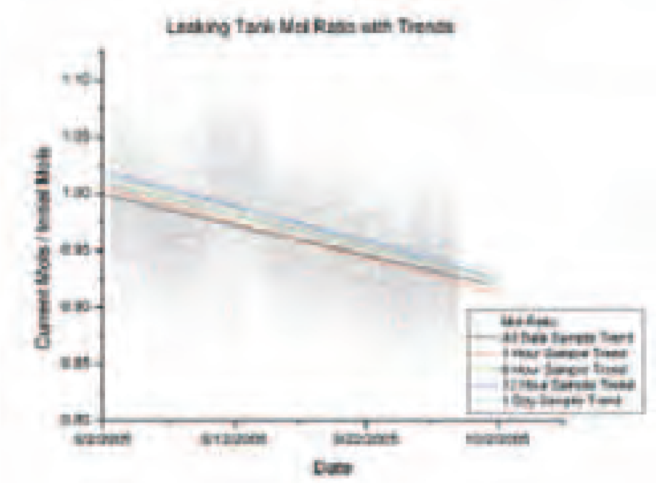

Figure 4

impact the baseline pressure measurements and therefore limit detection and accurate forecasting of leak rates.

A unique solution has developed: an even lower-cost on-line SF6 monitor that implements the latest sensor and communications technology advances, coupled with a new, more-accurate way to account for the annual and diurnal pressure variations. This monitor detects and forecasts leak rates much more accurately, allowing utility personnel to manage and maintain the SF6 breakers more efficiently. The approach used to develop this sensor couples improved SF6 content-measurement algorithms with a complementary low-cost sensor, battery and wireless communication package.

The algorithms compensate for diurnal pressure variations by using two different temperature measurements to derive gas temperature. The ideal gas equation gives the initial molar content of the gas, which is subsequently compared to ensuing molar content calculations.

In short, the technique involves deriving molar ratios and examining the trends of these ratios. Trending of the molar ratio allows accurate leak identification and forecast of service requirements for the breaker as shown in Figure 4. Tests on actual and simulated breakers indicate sufficient accuracy to easily detect leaks in the range of 0.2kg per year.

To significantly lower installation costs, the implementation embeds in the sensor package a wireless radio that uses a mesh network topology. Tests at a variety of frequencies in a 345kV substation environment yielded a selection at which the radios communicated with each other within a 120-foot range. This allowed for wide dispersion of the sensors throughout the substation yard.

Engineers chose data transmission requirements for the mesh network radios to minimize their power usage.

Sensor specifications also favored highly accurate, silicon-based and micro-machined sensors and low power consumption circuitry. The sensor's overall low power consumption then allowed for power to be supplied by a commercially available Lithium Ion battery. Design tests indicate the battery should last 3-5 years. The battery's position in the package will allow easy replacement (Figure 5 shows the prototype product).

Simultaneous to the design and development of the sensor product, analysts reviewed utility O&M records and industry data to determine the extent of savings that could be generated by better information about SF6 gas content in the utility breakers. Findings indicated that most SF6 maintenance occurred in response to low pressure alarms. Most of these events occurred outside regular business hours, requiring overtime maintenance labor.

The potential savings of eliminating unscheduled maintenance of the breakers, with its associated travel and overtime labor costs, combines with the sensor's low cost to produce attractive paybacks. Especially for remote substations, with their higher travel time, the solution would yield a one-year payback and in some cases less.

Reliability impact analysis showed that, in critical applications, avoiding the typical 4-hour unscheduled breaker maintenance job could substantially impact associated wholesale market transactions. One conservative analysis estimated that a 4-hour unplanned outage due to an SF6 leak on one breaker could easily cost tens of thousands in lost revenue.

Additionally, in cases where an unscheduled outage on one breaker leaves a utility dependent on a single breaker at a large generation asset, the reliability impact becomes enormous if the remaining breaker fails and forces the generation asset to shut down. The bottom line showed that, for a small incremental cost, the ability to accurately detect SF6 levels

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and forecast the molar ratio trend allowed for prevention of overtime call outs and, more importantly, would allow operators to align O&M activities on the breaker without impacting system reliability.

Finally, better management of SF6 could become a key element of many utilities' environmental stewardship programs. Even though the CO2-equivalent overall emissions from SF6 breakers are relatively low compared to power plant emissions, the low cost of enhanced monitoring and the high GHG factor of SF6 combine in a compelling argument for better monitoring. When viewed from a potential perspective of cap and trade allowances where 1 ton of CO2 is mitigated at a price of $5/ton, preventing emissions from a single source at a low sensor cost can, in itself, produce a very attractive cost/benefit ratio.

The benefits do not end here, however. The implementation's wireless infrastructure entailed not only placement of sensor-based radios but also a low-cost gateway device to collect the data and place it securely on the utilities' LAN or SCADA. The gateway communicates using DNP3 over a TCP/IP link, allowing for integration into higher-level networks.

The gateway can support as many as 250 sensors of various types. This opens the possibility of additional sensors and other devices at very low incremental communication costs.

Additional sensors under consideration include:

• Transformer temperature sensors, aligned with online DGA monitors;

• SF6 online monitoring for chemical degradation;

• Air compressor run-time monitors for two pressure breakers;

• Intrusion detection monitors for security purposes;

• Traditional status point reporting for specific substation operating points that aren't currently monitored – using low-cost cell modems to transfer data into the utility LAN or SCADA environment.

In this framework, each element can be added based on its own merits, increasing the breadth of data available to the utility. This gives utility substation personnel and utility management a path to automation that allows for:

• Benefits that more clearly outweigh costs because they are identified on an individual rather than a collective basis;

• Incremental funding that allows for one automation step to be taken at a time while creating a cost efficiency for future steps;

• Economic justification made because the criticality of each piece of substation equipment tends to be analyzed separately, not only as it relates to overall system reliability, but as it relates to everyday O & M activities and environmental impact;

• Implementation of appropriate technology through the use of the latest advances in robust wireless communication that functions in high EMF noise environments;

• Focused management philosophy in which incremental solutions are presented with defensible cost-benefit ratios.

Figure 5

CONCLUSION

Traditional approaches to substation upgrades have focused on broad implementation of enhanced monitoring and control systems. These efforts have, for the most part, failed to overcome market barriers because they did not address singular issues. Approaching upgrades incrementally allows clearer definition of the costs and benefits for specific operational issues which, in turn, increases the probability of implementation.

Further, by incorporating recent technologies into these initial projects, utilities can construct easily scalable communications platforms that will accommodate future upgrades at a much lower cost.