[Article 7 of 7]: ***Research on the Characteristics of a Smart Grid by the NETL Modern Grid Strategy Team***

Anticipates and Responds to Disturbances (Self Heals)

Last month we presented the 6th Principal Characteristic of a Smart Grid, ***Operates Resiliently Against Attack and Natural Disaster.*** This month we present the 7th characteristic, **Anticipates and Responds to Disturbances (Self Heals).** In the context of a modern grid, "self-healing" broadly refers to a design philosophy that supports early identification of system problems and enables rapid resolution of those problems, while requiring little or no human intervention. These actions result in minimal or no interruption of service to consumers. Self-healing is, in essence, the modern grid's immune system.

Summary

The modern, self-healing grid will perform continuous, online self-assessments to detect existing or emerging problems, predict potential future problems, and initiate immediate corrective responses. A self-healing grid will frequently employ a networked design, linking multiple energy sources. Advanced sensors on networked equipment will identify a weakness or malfunction and communicate to associated devices whenever degraded conditions occur. Sensors will also detect patterns that are precursors to faults, providing the ability to mitigate conditions before any disturbance actually occurs. The self-healing objective is to limit event impact to the smallest area possible.

Current State

Transmission

Today's transmission grid is designed with many self-healing features. The transmission system's mesh topology inherently supports self-healing, thanks to its built-in redundancy and protective relaying features such as high-speed reclosing and single-phase tripping. Protection engineers have analyzed the transmission system to verify that, under a normal system configuration, assumed loads can be met even during expected peak conditions. In addition, they have ensured that these same loads will still be met after the failure of one, and in some cases, multiple lines or components. Today's substation automation and communicating intelligent electronic devices, including the increasing use of wide area monitoring schemes (WAMS), have raised transmission protection to the next level. In addition, extensive use is made of substation supervisory control and data acquisition (SCADA) tools. Regional Transmission Organizations (RTOs), having a broad reliability and market performance focus, rely heavily on these and associated technologies. RTOs must meet reliability standards enforced by NERC; hence, the Smart Grid's self-healing feature fully supports their mission. Significant future advances in sensing, communications, and digital processing will further improve transmission's self-healing capability.

Distribution

As explained above, the basic design of the transmission grid—many geographically diverse generation sources feeding a redundant high-voltage network—nicely accommodates the self-healing characteristic. On the other hand, the fundamental design of today's distribution system does not, in most cases, allow the same depth of self-healing. The present distribution system, without distributed resources and without an intelligently controlled network that can accommodate two-way power flows, is severely limited from a self-healing perspective. Still, some progress is being made toward the self-healing objective. New distribution automation (DA) technologies are beginning to be deployed to increase reliability and efficiency, reconfigure the system after disturbances, and more quickly identify and resolve system problems. These DA applications can also be extended to coordinate customer applications such as demand-response (DR) and distributed energy resources (DER). And, distribution systems that include feeder-to-feeder backup can be enhanced using DA's real time control features.

Future State

The self-healing characteristic, at both transmission and distribution grid levels, will move forward through the integration of advanced capabilities in the following areas:

Look ahead features

Analytical computer programs, using accurate and near real-time state estimation results, will identify challenges to the system, both actual and predicted, and take immediate automatic corrective action. Where appropriate, and when time allows, these algorithms will also provide options for the system operator to take manual action. Probabilistic risk assessment, also done in near real time, will identify threats to the system associated with a wide range of contingencies. Improved load forecasting will support more accurate look-ahead simulations performed over various time horizons—minutes, hours, and days in support of operations; monthly, quarterly, and annually to support O&M planning activities; and longer term to support investment decisions.

Monitoring features

Command and control centers, at the regional level for transmission operations and at local levels for distribution operations, will serve as hubs for the new self-healing technologies. State estimators will utilize advanced data acquisition methods and powerful computers to evaluate problems within seconds. Advances in communication technology, combined with many new, low-cost smart sensors, will provide a significantly larger volume of various types of data, such as wide-area phasor measurements and dynamic line rating information. This dramatic increase in real-time data, combined with advanced visualization techniques that consolidate and present information in easily understood formats, will give system operators an accurate picture of the power delivery system's health. And, by analyzing equipment health data –

including high frequency emission signatures – condition monitoring technologies will provide additional perspectives on the risk of potential equipment failures.

Protection and control features

Advanced relaying will adapt to real-time conditions. High-speed communications between digital devices will go beyond single element protection, enabling area and even regional protection. High-speed switching, throttling, modulating, and fault-limiting power electronics devices will dynamically alter grid patterns, including faster isolation and sectionalization as well as rapid control of real and reactive power flows, in response to changing system conditions. And, intelligent control devices, such as grid friendly appliances, will modulate load accordingly.

Distributed technology features

Transformation of the distribution system from a one-way, radial design to an intelligent two-way network through the addition of more circuit-to-circuit ties, and the application of advanced communication, control, and protection technology is one key to achieving a self-healing distribution grid. Distributed generation and energy storage technologies will then be broadly deployed on that grid, and dispatched to help meet system-wide needs. The utility, or other organizations, will also have the ability to aggregate DR and consumer-owned DG/storage into dispatchable virtual power plants. The deep penetration of Plug-in Hybrid Electric Vehicles (PHEVs), which can greatly enhance both self-healing and environmental efforts, will require these new capabilities. DR programs will be widely expanded to assist in the management of system overloads, peaks, and voltage problems. DR will also be used to support local circuit needs. DA will be further expanded and integrated with widespread DER/DR programs and, in conjunction with new operating tools and micro-grids, will enable successful dynamic islanding.

These advances in technology, taken together, will create a sophisticated self-healing capability that will dramatically improve overall reliability, efficiency, safety, and security.

Barriers

Implementing major change usually means addressing substantial barriers; the shift to a smart grid is no exception. The business case for a self-healing grid is good, particularly if it includes societal benefits. But, regulators will need to be convinced that these harder-to-quantify benefits will materialize before they will authorize major investments. And, even if they do, the industry may not have the financial capacity to fund these new technologies without the aid of government incentives. The currently depressed economy will make funding all the more difficult.

Early retirement of equipment may be another issue. Some older equipment will need to be replaced, as it is incompatible with the requirements of self-healing. This may present a problem for utilities and regulators since keeping equipment through, and even beyond, its depreciated life minimizes capital costs to consumers.

Also, the pace of technology advancement needs to accelerate. Fifty years ago, it was predicted that the solar shingle, the basement fuel cell, and the chimney wind generator would be an integral part of the home of the future. Specific areas that will need to be more fully developed and deployed include:

- Integrated high-speed communications platforms.
- Intelligent electronic devices (both front end sensors and back end control devices)
- Distribution automation schemes to provide distribution level self-healing capabilities, to accommodate all forms of DER and to act as an asset to the transmission system.
- Cost-effective environmentally acceptable DERs, including energy storage devices capable of coexisting among residential populations.
- DR systems using real-time pricing.

Utility regulators will also need to jump on board. Today, they sometimes take a parochial view of new construction projects. For example, critical circuit ties crossing state boundaries have been known to meet significant resistance. These perspectives need to change.

Finally, consumer acceptance of the entire Smart Grid concept is essential since, without this critical element, a consensus to move forward will not be achievable.

Benefits

The benefits of implementing a self-healing grid are many and diverse, accruing to consumers, utilities, and government.

The first and best understood benefit will be a substantial improvement in grid reliability. The annual cost of power disturbances to the U.S. economy is significant (on the order of $100 billion). And, the savings from avoiding a massive blackout is estimated on the order of $10 billion per event as described in the *'Final Report on the Aug. 14, 2003, Blackout in the United States and Canada'*. Since blackout events are increasing in frequency, it is not unreasonable to assume another one will occur within a few years.

Closely related to reliability is national security. A self-healing grid is almost by definition the most secure grid possible. A grid that continuously monitors itself and self-heals is also a less attractive terrorist target since its resiliency reduces the impact of any attack. Also, the consequences of an attack are reduced because energy sources are broadly distributed and self-healing technologies can quickly restore service.

Increased public safety will be another benefit of the self-healing smart grid. Grid re-configurations will quickly de-energize downed wires. Restoring power faster to more people will reduce the impact to customers who rely on the grid for medical necessities, as well as maintaining HVAC to elder care facilities. And, fewer outages reduce the opportunities for criminal acts and civil disturbances.

Power quality defects represent another large cost to society, estimated to be in the tens of billions of dollars. The self-healing grid will detect and correct many power quality issues.

Several secondary benefits related to a self-healing smart grid are worth noting. The wide application of DER and DR will create opportunities for peak shaving and the accumulation of energy reserves. Both are commercial products in an energy market that can produce new revenue streams for their owners. As an additional benefit, the self-healing grid will accommodate multiple green resources, both distributed and centralized, resulting in substantial reductions in emissions. And, a more efficient grid equates to lower electrical losses (hence, still lower emissions). Finally, the environmental impact associated with outages and major equipment failures will be dramatically reduced.

Conclusions

The health of an electric system, like that of the human body, is determined in large part by the strength of its immune system, i.e., by its ability to heal itself. And, in that context, the North American grid's immune system is not especially strong. Today, there are ways to strengthen this system, to improve its ability to detect and fight off stress. Modern technology can make it much more resistant to the challenges of a 21st century society.

Today's advances in computers, communications, materials, and chemistry have yet to be applied in a meaningful way to this task. That is what can and must be done. There can be no doubt that a prosperous society is built upon a healthy electric power infrastructure. This is most apparent when that infrastructure is weakened or disabled, as it is during a major blackout. In fact, an extended blackout would have a crippling effect on the fundamental structure of society.

Of course, modernizing the grid infrastructure requires an investment of considerable magnitude. But, the resultant benefits, when viewed from a societal perspective, will return that investment many fold.

This article was prepared by Bruce Renz of the Modern Grid Strategy team.