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Proposed Business Case Model for Implementing a Self-Healing Distribution Smart Grid

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SUMMARY
Over the last century, expectations for reliable electric service increased tremendously as equipment powered by electricity became central to our economies and our lives. Because power reliability is essential for economic competitiveness and high quality of life, utility regulators around the world have set varying standards to measure power interruptions and thus help measure reliability and drive improvements. Countries with the highest reliability standards have a competitive edge in attracting business. At the same time, utilities are under increasing pressure to minimize capital expenditures and operational costs. Utilities are thus grappling with the problem of identifying the best, most valuable solutions to improve system reliability.

A fast-acting, self-healing electric distribution grid can significantly reduce the time it takes for a utility to respond to interruptions and can thus make dramatic reliability improvements. Improved reliability in turn drives significant economic benefits while also improving quality of life. Different technologies for self-healing solutions can yield different results, however. This paper will review an economic justification for a self-healing grid, as well as the varying economic outcomes delivered by different automation technologies. It will also present a case study of how self-healing technology is benefiting one mid-sized U.S. city.

KEYWORDS
Smart Grid, Self-Healing Systems, Business Case, Reliability, Distribution Automation

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1.0 Definition of a Self-Healing Grid

A self-healing grid has the ability to quickly identify the location of a fault after a service interruption occurs, automatically reconfigure the distribution system, and quickly restore service to as many customers as possible. With some advanced technologies, self-healing technology can also reduce the number of customers who experience a momentary interruption. Self-healing systems typically have three main components: automated switching devices (which also contain sensors to measure system parameters like current and voltage levels), a communication system, and software with the logic to evaluate system conditions and direct switching operations to reconfigure the system after an interruption. The system measures current and voltage information captured at the switching device to determine if a fault has occurred and to identify the fault location. In the event of a short circuit, the self-healing grid then opens or closes automated switches to isolate the fault, and to connect loads in unfaulted segments to alternate power sources. The self-healing technology should also verify that the alternate source will not be overloaded before connecting additional loads to this source.

Control of a grid has traditionally been accomplished through centralized utility systems and processes. As a result, as some utilities looked to implement automatic reconfiguration systems, they initially considered using centralized servers to run reconfiguration software. Under this approach, field devices communicate data on system conditions back to the centralized servers, which then issue and send back switching commands as appropriate. This approach has drawbacks because response time is slower and there are many potential single points of failure that could prevent the self-healing system from working properly. As a result, over the last 20 years, a quiet evolution has been occurring where utilities have, instead, installed intelligent, microprocessor-based controls integrated with automated switching/protection devices in the field. This approach allows much faster response to interruptions while eliminating the single points of failure in a centralized self-healing system. This technology can also be integrated with other enterprise-level utility applications, like SCADA, geospatial information systems and distribution management systems, which can facilitate sharing of information from field devices and gives the utility the ability to control devices remotely.

2.0 Justifying Investment in Self-Healing Technology

With information on the value of reliable electric service to a community, as well as information on avoided utility costs, utilities can assess the economic benefits and the risk of potential investments in self-healing technology as compared to other potential projects. Some of the benefits of a self-healing grid are difficult to quantify, and thus harder to incorporate into a business model. For instance, improved power reliability undoubtedly provides a higher quality of life, but these benefits, though real, are not always straightforward to evaluate. However, many benefits can be reasonably quantified and thus incorporated into an economic model. Factors that drive the economic case for a self-healing grid are discussed below.

2.1 Evaluating the Cost of Outages to Customers

One of the biggest factors in evaluating the reliability benefit provided by self-healing technology is the cost to the community. Various studies have attempted to measure these costs, and these study results can be used to quantify the value provided by a self-healing grid. In 2003 the U.S. Department of Energy (DOE) funded a study of interruption costs, made the models to estimate interruption costs publicly available and, subsequently, employed those models to estimate interruption costs for U.S. electricity consumers. The data was used to estimate costs as a function of duration, time of day, consumption, business type, and other factors. Their estimated costs by customer type are shown and have been adopted from the report published by LBNL, Estimated Value of Service Reliability for Electric Utility Customers in the United States (June 2009). [1]

Interruption Cost	Interruption Duration: Momentary	30 minutes	1 hour	4 hours	8 hours
Medium and Large C&I					
Agriculture	$4,382	$6,044	$8,049	$25,628	$41,250
Mining	$9,874	$12,883	$16,366	$44,708	$70,281
Construction	$27,048	$36,097	$46,733	$135,383	$214,644
Manufacturing	$22,106	$29,098	$37,238	$104,019	$164,033
Telecommunications & Utilities	$11,243	$15,249	$20,015	$60,663	$96,857
Trade & Retail	$7,625	$10,113	$13,025	$37,112	$58,694
Finance, Insurance & Real Estate	$17,451	$23,573	$30,834	$92,375	$147,219
Services	$8,283	$11,254	$14,793	$45,057	$71,997
Public Administration	$9,360	$12,670	$16,601	$50,022	$79,793
Small C&I					
Agriculture	$293	$434	$615	$2,521	$4,868
Mining	$935	$1,285	$1,707	$5,424	$9,465
Construction	$1,052	$1,436	$1,895	$5,881	$10,177
Manufacturing	$609	$836	$1,110	$3,515	$6,127
Telecommunications & Utilities	$583	$810	$1,085	$3,560	$6,286
Trade & Retail	$420	$575	$760	$2,383	$4,138
Finance, Insurance & Real Estate	$597	$831	$1,115	$3,685	$6,525
Services	$333	$465	$625	$2,080	$3,691
Public Administration	$230	$332	$461	$1,724	$3,205
Residential	$2.7	$3.3	$3.9	$7.8	$10.7

Table 1: Estimated Average Electric Customer Interruption Costs Per Event in US$ 2008 by duration and business type (summer weekday afternoon). [2]

By considering the load profile of customers who would be served by a self-healing system, along with the history of interruptions on that portion of a utility distribution system, utilities can begin to quantify how a self-healing grid will reduce power interruption costs to the community. Later in this paper, we show an example of how to do this. Although only part of a justification for the business case for a self-healing grid, we have chosen to show a model for the customer costs involved in a power interruption. To build support for an investment in self-healing technology, it is crucial to take customer cost savings into account and ensure these considerable savings are made visible to all stakeholders. For instance, it is a major hurdle if a rate base only considers costs to the utility, rather than those to the entire community. Such an approach could lead to adverse decisions on reliability investments that provide broad economic benefits. In this situation, alternate approaches may be needed to help ensure the customer interruption costs are considered. Unfortunately, in some areas, there is a very real "two horse" race happening today where investor-owned utilities driven by rate recovery cannot recoup their investment if their rate base does not include consumer-related cost improvements, whereas public utilities may face a lower hurdle in that regard.

2.2 Utility Economic Benefits

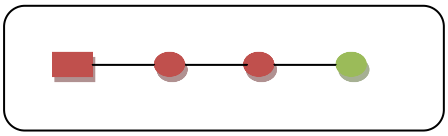
Self-healing technology can also provide direct economic benefits to the utility, which can typically be estimated and built into a model to evaluate self-healing technology. Although not as significant, one of the economic benefits could include increased revenue, as self-healing grids reduce the amount of revenue that would otherwise be lost during an interruption. Utilities can also reduce operating costs by preventing reliability related penalties where mandated, reducing crew time to locate faults and restore service, reducing equipment costs (like fewer truck rolls) to respond to an interruption, and reducing the cost of responding to customer complaints. Utility maintenance costs can also be reduced by remotely capturing information made available in a self-healing system in order to better target maintenance programs. Other benefits include the ability to monitor, configure, and interrogate intelligent devices remotely, which can facilitate troubleshooting and reduce the time that engineers need to spend maintaining the system and evaluating interruptions. [3]

3.0 Example of a Self-Healing Justification Based on Customer Outage Costs

In order to better understand how the cost of customer interruptions might be reduced by self-healing grids, and why they are so crucial to consider, let's consider a sample circuit. This case will also consider the impact of different self-healing technologies on reliability improvement and thus the economic case.

3.1 Sample Single Line Circuit

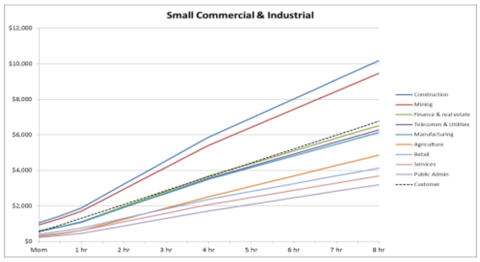
The red circles indicate devices that are closed. The green circle indicates a device that is open and the tie point to another feeder/source. The red (closed) square indicates the source or the substation side breaker.



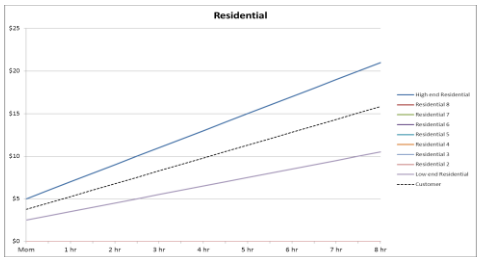
The sample feeder single-line has the following characteristics:

Total # of Feeders	1
Segments / Feeder	3 (variable)
Alternate Sources Available / Feeder	1
OH Main Feeder Circuit Miles	15
UG Main Feeder Circuit Miles	5
MTTR – Mean Time to Repair (minutes)	90
MTTS – Mean Time to Switch (minutes)	30
ATTS – Automation Time to Switch (minutes)	15
Fault Rate OH (faults / mile / year)	0.50
Fault Rate UG (faults / mile / year)	0.10

Most of these terms should be familiar to utilities that monitor their reliability indices. A new term, Automation Time to Switch (ATTS), represents the time it takes to perform a switching action other than the typical manual local method. This value varies depending on the type of system deployed. 15 minutes might represent the time required for a SCADA system where control room operators still must perform some analysis of the incoming data. In fact, many utilities require visual verification of the fault, resulting in very little savings from MTTS. For a self-healing system, ATTS is 0 since it is can restore service well under the regulated definition of an interruption. We assume the regulated definition of a sustained interruption is any interruption that lasts greater than 1 minute.



For this analysis, the total number of customers served is 2,000, of which 90% are residential, and 10% are "small" commercial & industrial customers. The customers are assumed to be evenly distributed across the feeder. The analysis also assumes that the modeled DA system cannot reduce interruptions downstream of fuses on lateral lines because fuse blowing is used. We also assume that main line feeder faults represent about 50% of overall system faults. (We assume lateral faults account for the remaining 50% contribution to the overall system faults).



To better apply the LBNL data, we define our customer categories very selectively by identifying an average customer definition for industrial and commercial customers, as shown by the dotted line on the chart above. The dotted line represents where the customer selection would fit in comparison to LBNL provided values. We have normalized the data from LBNL to display how the cost of interruptions changes depending on interruption length for the different types of customers. In the residential case, the low estimate of a momentary interruption was $3(rounded from $2.7 per LBNL) and the high cost was $5 (which we determined). We then selected the curve that would fit the middle of the two curves (dotted line). The charts on the right show this analysis. Rather than defining each customer by precise type and numbers, this model defines an average customer in each category. This is seen in the graph as the dotted black line.

3.3 Comparison of Reliability Impact of Different Technologies

Different self-healing technologies will impact the reliability improvement and thus the economic justification for such an investment. This model categorizes and compares available technologies as follows:

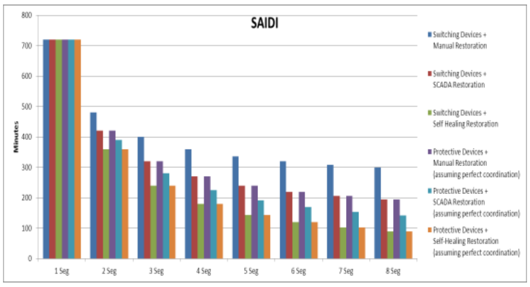
1) Switching Devices (Load-breaking capability only)
    a. Manual Restoration based where field crews gather data locally and manually operate switches.
    b. SCADA Restoration based on remote data collection and remote switching decisions by control room personnel.
    c. Self-Healing Restoration using software running on controls embedded in automated switching devices to make switching decisions
2) Protective Devices (Fault-interrupting capability plus open/close switching)
    a. Manual Restoration
    b. SCADA Restoration
    c. Self-Healing Restoration

Note: Protective devices are assumed to have perfect protection coordination, which may be impractical for most three-phase protective devices today.

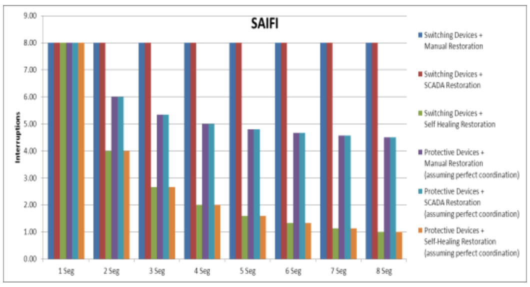
These six different technology permutations are evaluated using a predictive reliability calculator. The other variable considered is the number of segments in each feeder. This predictive reliability calculator uses values defined in the circuit characteristics section and shows annual expected performance indices and costs.

3.4 Comparing Predicted Annualized Results from Different Technologies to improve reliability

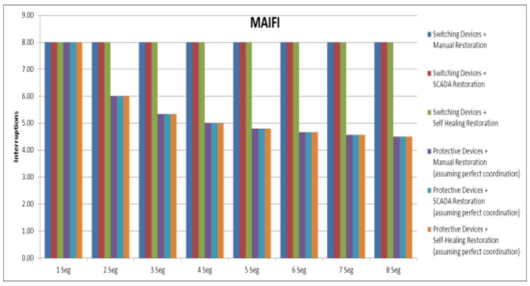
The chart on the right shows the SAIDI for the different technology types and how it changes with increasing number of segments. It can be seen that Switching and Protection devices utilizing self-healing restoration offer the best performance.



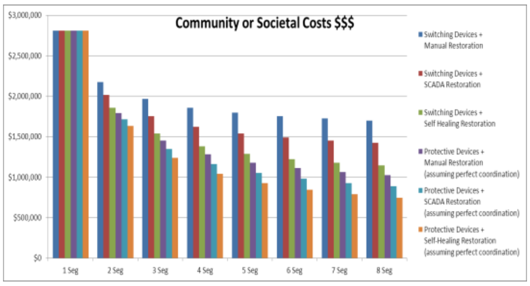
The next chart shows the System Average Interruption Frequency index. The Y-axis shows the interruptions the system will experience under different technologies. Again it can be seen that both Switching and Protection devices with self-healing technology offer the best performance. However, we still see that these two front-runner technologies are still tied neck-to-neck. This is where the next index, MAIFI comes into play.



The last chart shows the $MAIFI_E$ analysis, the Momentary Average Interruption Frequency Index (by event). When MAIFI is considered, it is clear that protective devices using self-healing technology offer the best performance. This chart also shows that it is important to consider the impact on all three indices—SAIDI, SAIFI, and MAIFI—because only this comparison will provide a complete view of the impact of different technologies on reliability.



Lastly, and most importantly, the chart that shows the cost of power interruptions to the community is shown. The Y axis measures what interruptions would cost annually with the different technologies. Let’s now compare a 3-segment system that has all manual switches versus one that has protective devices that can offer self-healing restoration. The interruptions would typically cost under a manual system about US$2 million. If a utility instead uses protective devices with self-healing technology, that cost is reduced to US$1.239 million. That is an annual savings of US$761,000 to the community just on this one feeder alone.



Furthermore, it can be inferred from the charts that as the number of segments increases, the results in general improve. However, after a certain amount of segments, or the optimum segmentation point, the law of diminishing returns starts to apply and there is not much benefit observed.

It is also important to note that this analysis assumes that protective devices can be perfectly coordinated in all cases. This is important since if perfect coordination is not possible, it may be unlikely that more than 3 segments can be properly coordinated. However, in the case of S&C’s IntelliRupter, which offers a pulsefinding feature that overcomes time-coordination constraints, it is possible to achieve high levels of segmentation.

4.0 Case Study: Self-Healing Technology in Chattanooga, Tennessee

The city of Chattanooga, TN, is served by Electric Power Board (EPB), a public power distributor that serves over 170,000 homes and businesses in a 600-square mile area. EPB has worked over the last few years to deploy self-healing technology across their entire system using roughly 1200 fault protective devices combined with a distributed-intelligence self-healing system. A central driver for this investment was to improve electric power reliability. Based on the DOE study, it can be inferred that interruptions cost a community the size of Chattanooga roughly $100 million annually. Since EPB embarked on their automation program, they have already seen significant reliability improvements that are delivering economic benefits to the community and to EPB. For instance, over Labor Day weekend in 2011, an extended rainstorm hit the community. At that point, only 20% of the planned fault protective devices were installed and configured as part of a self-healing automatic restoration system. However, of the 63,000 homes and businesses that would have experienced a power interruption prior to the smart grid installation, 16,000 (25%) avoided interruption all together. An additional 14% (9,000 customers) experienced less than a two-second interruption. Even though the automation deployment was only partially completed, Chattanooga’s grid automation technology avoided 1,917,000 customer minutes of interruption (CMI).

On July 5 of this year, Chattanooga experienced a major wind storm. If the automation were not in place, roughly 77,000 homes and businesses would have experienced an outage. Instead, 42,000 either did not experience an outage at all or were restored without needing a truck roll. EPB was also able to accelerate its restoration efforts to the 35,000 customers who did experience an extended outage because of the distribution automation technology. What would have been a five-day restoration effort only took about three and a half days—a 30% reduction.

5.0 Bibliography

[1] Lawrence Berkeley National Laboratory. “Estimated Value of Service Reliability for Electric Utility Customers in the United States” (Report #2132E June 2009 pages xxi and xxiii)

[2] Lawrence Berkeley National Laboratory. “Estimated Value of Service Reliability for Electric Utility Customers in the United States” (Report #2132E June 2009 pages xxi and xxiii)

[3] James Northcote-Green & Robert Wilson, Control & Automation of Electric Power Distribution Systems 2006. (pages 368-369)