

# A Truly “Self-Healing” Distribution Grid Requires Technology AND Operational Change

Erik Gilbert, Lawrence Gelbien, Brad Rogers

NSTAR Electric & Gas Corporation  
One NSTAR Way  
Westwood, MA 02090

Summit Blue Consulting  
1722 14<sup>th</sup> Street, Suite 230  
Boulder, CO 80302

egilbert@summitblue.com  
Lawrence.Gelbien@nstar.com  
brogers@summitblue.com

**Keywords:** Distribution Automation, DA, Self-Healing

## Abstract

NSTAR has developed a program to demonstrate “self-healing” as a cutting edge approach to reduce the frequency, duration, and number of customer outages. The approach will *fully automate* the isolation of faulted circuits between sectionalizing switches and restore power to the remaining portions of the circuits.

The upgraded system will centrally collect real-time grid information and automatically restore undamaged portions of the circuits, including underground circuits—believed to be an industry first. Unlike many other self-healing grid systems, NSTAR’s features an open architecture that supports multiple remote terminal unit (RTU) and switch manufacturers, which will make it possible to retrofit or upgrade—rather than replace—many of the necessary components. The project includes the following:

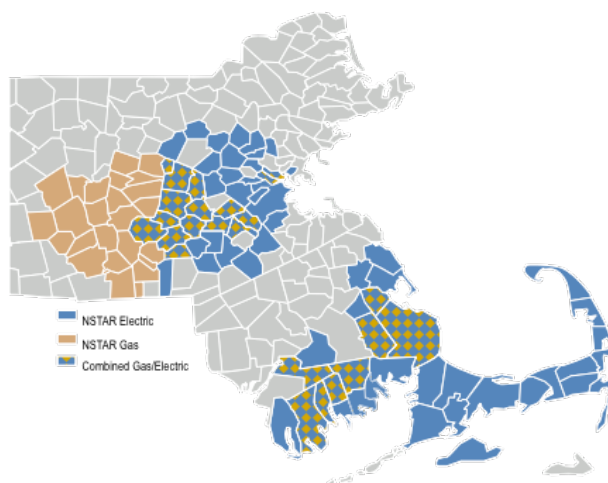
1. Installation of several hundred additional automatic sectionalizing unit (ASU) and vacuum fault interrupter (VFI) switches and monitoring points to provide further smart grid benefits and allow for NSTAR’s grid to become “self-healing.”
2. Implementation of centralized circuit restoral algorithms along with measurement and control using the remote switches with sensors for conductor current, voltage, and kVAR.

NSTAR has designed a program using three operational modes with successively greater levels of restoration automation to safely test each higher level of automation, as well as to obtain input and gain acceptance from Operations staff.

## 1. INTRODUCTION

Since 2003, NSTAR Electric has invested significantly in modernizing its distribution system and furthering the development of a smart grid by introducing many types of distribution automation (DA).

These capabilities have been installed across portions of NSTAR Electric’s North and South service territories, which can be seen in Figure 1-1.

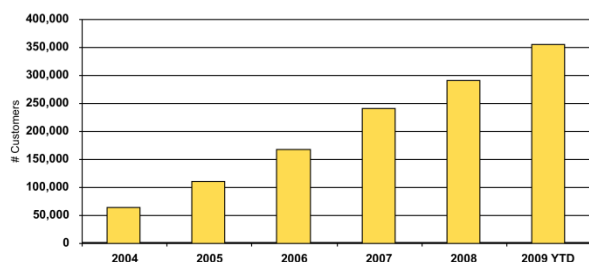


**Figure 1-1.** NSTAR North and South Service Territories

The existing system consists of telemetry communications, voltage and current sensors, and 1,200 “smart” switches strategically deployed throughout the service territory. The switches are remotely monitored and controlled via two-way radios, which help the dispatchers to quickly bypass main-line circuit problems and restore as many customers as possible, usually within five minutes. Sectionalizing has

been implemented across the NSTAR service territory and has been in operation at many locations for several years.

These capabilities have measurably contributed to the reliability of the distribution system, reducing NSTAR Electric's SAIFI and CAIDI indices. Without this investment, NSTAR Electric's overall CAIDI would be approximately 16 minutes higher annually. A cumulative total of over 300,000 customers have been saved from an outage over the past four years, as shown in Figure 1-2 below.



**Figure 1-2.** Cumulative Customer Outages Averted

NSTAR has developed plans to build on this recent experience by expanding its DA network and testing a new level of automated “self-healing.” These plans include the following:

- Several hundred additional switches and monitoring points will be installed. The definitive feature of a “self-healing” system is “auto-restoration” capability, which involves the *full automation* of these switches to restore faults during grid outages without human/operator interference.
- Advanced sensing and monitoring capabilities will be integrated into these switches and portions of the communications infrastructure will be upgraded.
- Information processing capabilities of the central monitoring and control center will be upgraded, and restoration algorithms will be fully automated to achieve system-wide “self-healing” functionality.

NSTAR has designed a program of three operational modes with successively greater levels of restoration automation to safely test each higher level of automation, and to get input and gain acceptance from Operations staff.

- Mode 1: “Supervisory Mode”—this is NSTAR’s current DA system, which leverages remote control of switches along with operator-determined and controlled grid restoration sequences.

- Mode 2: “Operational Acknowledgement Mode”—computer-simulated restoration sequences with operator-validated, manual implementation.
- Mode 3: “Self-Healing”— Auto-restoration that does not require human intervention.

The upgraded system will centrally collect real-time grid information and automatically restore undamaged portions of the circuits, including underground circuits—believed to be an industry first. Unlike many current and previous “self-healing” grid systems, NSTAR’s features an open architecture that supports multiple RTU and switch manufacturers, which will make it possible to retrofit or upgrade—rather than replace—many of the necessary components.

## 2. IMPLEMENTING “SELF-HEALING” DISTRIBUTION

To implement the broad set of reliability and efficiency capabilities that this project promises, NSTAR plans to invest in the following areas:

1. The various types of field instrumentation to be deployed;
2. The communications, computer control, and integration of these devices into the NSTAR infrastructure; and
3. Operational implementation strategy and processes.

These three investment areas are described in more detail in the three sections below.

### 2.1. Field Instrumentation

Several types of instrumentation will be added to the distribution network to enhance the operational monitoring capability and add points of control in the infrastructure. The NSTAR SCADA network will connect this instrumentation to the computer control capability (described below) to provide the necessary control infrastructure.

#### 2.1.1. Overhead Auto-Sectionalizing Unit (ASU) Switches

NSTAR’s system reliability has been significantly improved over the last several years through the conversion of many remote switches to Automatic Sectionalizing switches, as well as the installation of new ASU switches. An example of such an installation is shown in Figure 2-1.



**Figure 2-1.** ASU Placement on Overhead Line

For this project, over 100 additional new radio controlled switches will be installed on 13/25kV overhead circuits for auto-sectionalizing faulted sections and remote restoration of non-faulted sections. They can be opened and closed remotely and will have voltage and current sensors to enable real-time system assessment.

ASU Switches will be placed on circuits to limit the number of customers to 1,500 per segment (see Figure 2-2). This will improve customer protection by limiting exposure to faults.

### 2.1.2. Recloser Automation

Existing pole-top reclosers will be retrofitted with new state-of-the-art control boxes to enable the existing equipment to have advanced functionality. The units have an RTU with a communications and relay package, and they can be programmed to operate the recloser device as desired. Thus, they can be programmed as part of the sequence of automatic restoral logic to implement “self-healing” in the distribution grid.

These units will function as circuit breakers (interrupting fault current) and have the capability to open and reclose during transient faults. Approximately 20 additional units will be installed as part of this project, and they will function in conjunction with the ASU switches described above to facilitated the sectionalizing operation that is required as part of fault isolation.

Once the retrofit is completed, the existing equipment will have supervisory switching, automatic remote reporting of trouble areas and power failures, and sensor information about capacity deficiency.

### 2.1.3. Underground Vacuum Fault Interrupter (VFI) Switches

NSTAR will install 100 4KV VFI radio controlled switches on 4kV underground circuits for auto-sectionalizing faulted sections and remote restoration of non-faulted sections by system operators.

The VFI switch is a fault interrupting device that operates prior to a breaker operation on a fault condition. This operation provides isolation of a faulted area without having the entire circuit down due to an underground fault. The design will use one at midpoint and one as a tie, allowing remote switching capability for an actual breaker lockout.

Because communication from the underground environment is very difficult, NSTAR has a quick-study approach that is used to understand and deploy the most economical and effective communication technology for any given underground (typically a manhole) location, starting with spread-spectrum radio, then moving to licensed radio, and finally, if those options fail, moving to public network connection. Once the best technology is implemented, the switches communicate current, voltage, VAR, and status information to the monitoring and control center, providing visibility that was not previously possible.

## 2.2. Computer Control and Integration

To implement operational control of the new field instrumentation described above, the following capabilities are planned:

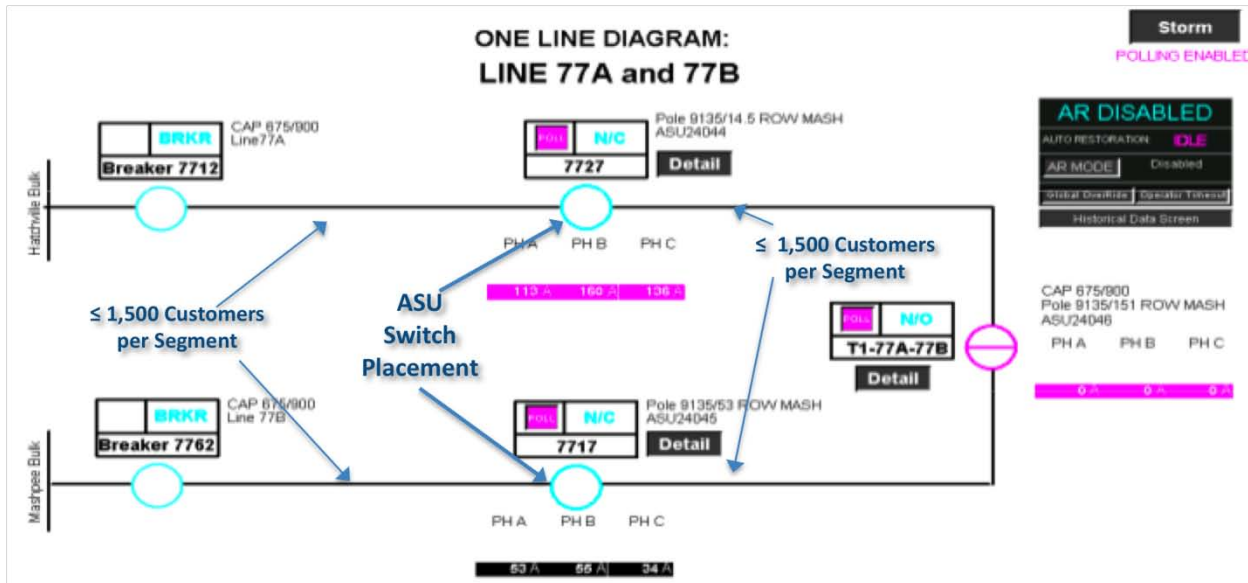
- An upgrade to the central control software, GE *PowerLink Advantage*[7];
- Distribution Automation *Plant Information* (PI) System Integration; and
- Development of Advanced Auto-Restoration Algorithms for Circuit “self-healing.”

These capabilities are described in more detail below.

### 2.2.1. PowerLink Advantage and Communications Implementation

PowerLink Advantage is a General Electric substation monitoring product that NSTAR has evaluated. NSTAR has done a prototype installation using this product on a five circuit test implementation in its South service territory. This installation has allowed staff to begin working with the auto-restoration capabilities that this system can perform.

[Figure 2-2](#) shows a control interface for this software (called a “one line diagram”) that is used by operators to review the status and perform control functions on a specific circuit. The initial results of this test installation have convinced NSTAR Engineering that the “self-healing” capability will be quite valuable and should be expanded.



**Figure 2-2.** ASU switch placement on circuits improves customer protection by limiting exposure to 1,500 customers per segment.

The proposed project will expand the use of this tool to cover a greater portion of the South service territory and implement another instance in the North service territory to take full advantage of its capabilities.

PowerLink Advantage will be installed in the NSTAR North Service Center and the instance in the South Service Center will be upgraded to allow it to be added to the corporate computer network.

With the introduction of PowerLink in the North, the NSTAR North data will be transferred to a D200 system, which is a computerized collection system for a wide range of telemetry data from the distribution system, and made available on PI via a D200/PI interface (described below) in the same manner as the South DA data.

This upgraded implementation will allow NSTAR to create a standard system between NSTAR North and South and will also free up data points on the current NSTAR SCADA system by sending data directly from the D200 to PowerLink and PI rather than through the SCADA system, as shown in [Figure 2-3](#).

### 2.2.2. Plant Information (PI) Database Integration

PI is a client-server software application with a sophisticated database that logs a wide range of metrics received from the field, including SCADA information, switch status, analog values, etc. Examples of some of the key data include open/closed status of the devices and the magnitude of voltage, current, and kVAR, among other information. Data that is captured in the PI server can be made available over the corporate network to PI client computers used by Engineering, Planning, and other departments that need this information.

The D200 system, by contrast, is used to collect and process data from distribution switches, execute the auto-restoration scheme, and forward commands to these switches. It provides real-time and historic data for the various devices in the field, such as the feeder breakers and the “smart” devices on circuits. The data flows between these two systems is shown in [Figure 2-3](#).

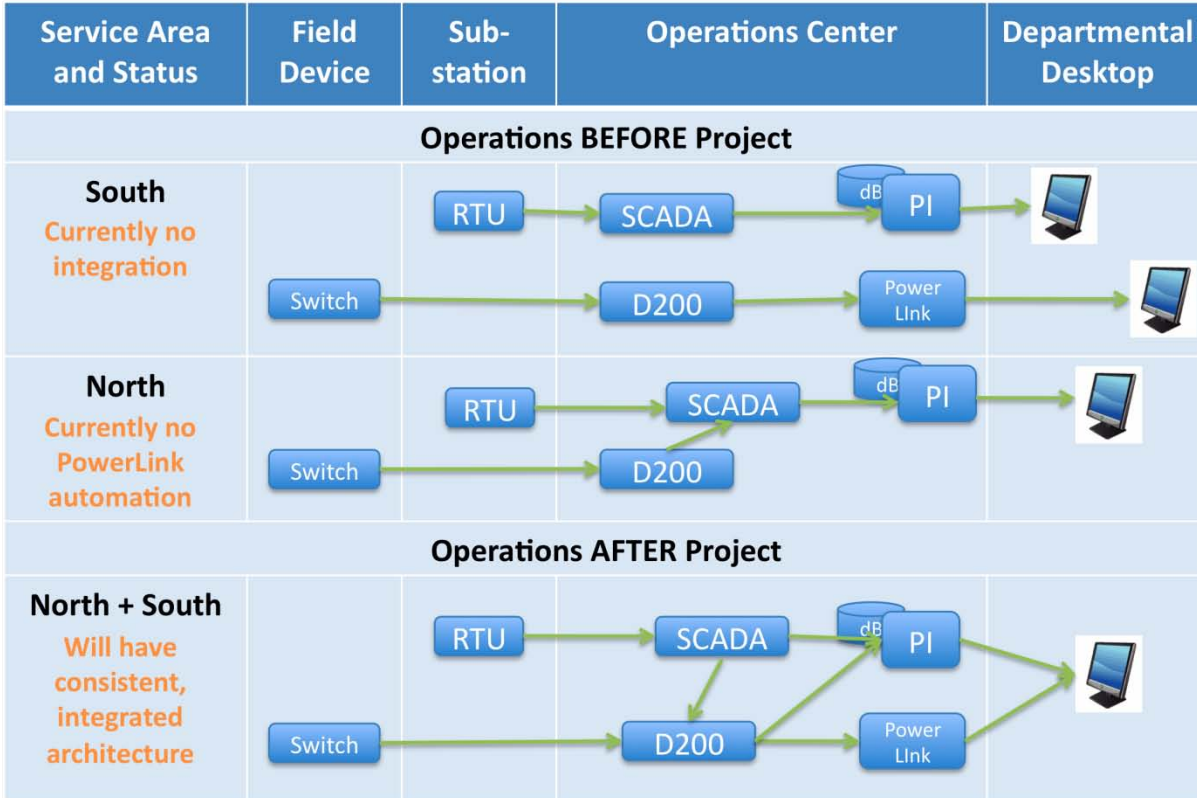


Figure 2-3. Integrated Control and Monitoring Systems Before and After Project

The self-healing project effort requires new interfaces between the D200 systems and the Plant Information (PI) system. The integration will allow collection of distribution automation data from the South service territory for over 500 additional devices in the field.

The D200 integration with the PI system, along with the increased SCADA data collection, will make this additional information available much more broadly, and in real-time, over the corporate network for the first time, directly to the desktops of NSTAR South territory personnel who need it. Thus, a much higher degree of real-time and historic operational intelligence will be available within the organization. It will facilitate real-time decision-making and auto-restoration by system dispatchers, and will provide ready access to distribution data for analysis by Distribution Engineering, as well as by Planning and other organizations that need this information to better perform their operations.

**2.3. Operational Implementation Strategy**

To fully leverage the capabilities of this, proper algorithms and logic will be developed for the restoration of each

specific circuit under the various possible fault conditions. The algorithms are developed with support from GE experts on PowerLink Advantage programming, in conjunction with experts on specific network circuit configurations from NSTAR.

The monitoring and control of sectionalizing and restoring circuits are core functions of distribution system operation. NSTAR’s Operations staff are testing and working through the three distinct modes of operation in order to move operational capability from manual operation towards a fully automated self-healing grid. These modes—implemented by the PowerLink Advantage and D200 products, but controlled by Operations staff—are briefly described below:

- Mode 1: “Supervisory Mode”—Provides a centrally controlled, but *manually sequenced and implemented*, procedure for restoring outages. This is the mode currently used for fault restoration.
- Mode 2: “Operational Acknowledgement Mode”—Allows the computer (PowerLink Advantage) to

simulate and diagnose problems based on sensor data and recommend a sequence of actions to the operator to most effectively address the problem at hand. However, the operator has final say and can override the computer's recommendation.

- **Mode 3: "Self-Healing"**—Implements the *fully automatic mode*, in which the computer determines the restoration steps and implements these steps without human intervention to provide "self-healing." In case of electrical faults, the algorithms running in the computers will automatically isolate problem areas and restore service to as many customers as possible in a very short time to minimize the duration and the number of customers impacted.

It will be a significant change in practice for experienced operators to allow full automation of the restoration process. Monitoring the system's automated operation will be essential to building trust among operators in the system's efficacy and to ensuring continued employee and customer safety. NSTAR is committed to providing its operators with the necessary training to work through these issues and encourage the automation and self-healing capabilities envisioned as part of the smart grid.

NSTAR will leverage knowledge gained from a current project that has begun to implement algorithm-based self-healing on five simulated loops in NSTAR's South service territory. This project is exploring Mode 2: "Operational Acknowledgement Mode," in which auto-restoration runs the algorithm following a fault and recommends the optimal switching operation for the system operator to perform.

Once the algorithms described above are developed, they can be used to facilitate auto-restoration capabilities in any of the three modes of operation. The goal is to move as many incidents as practicable to Mode 3: "Self-Healing," to have maximum impact on customer reliability.

#### 2.4. Interoperability

NSTAR believes the proposed self-healing smart grid system to be one of the most open-architecture systems of its kind, and the system meets the vast majority of the functional criteria defined by GWAC (see [Table 2-1](#)). The architecture being used has demonstrated system compatibility with many RTU manufacturers (S&C, GE, Microsol, Cooper), as well as switch types (S&C, Cooper, Thomas and Betts, etc.), which mitigates concerns regarding vendor lock-in or lack of adequate supply competition. Additionally, general telemetry radios with a standard serial interface are used communicating to the field instrumentation, so alternate communications mechanisms can be easily substituted if necessary.

#### 2.4.1. Interface and Interoperability Standards

Key standards and interfaces used in this project, many of which have been selected by the NIST smart grid interoperability effort [1] include:

- Switches, sensors, and other "smart" field devices communicate using radios via standard RS-232 serial interfaces. These interfaces make exchange or replacement of the radios or the device itself flexible and easy, without impacting the overall system.
- Radio-Frequency (RF) communication from these field devices to Operations Centers (for example to SCADA or with the D200 system) use traditional radio systems, e.g., spread-spectrum radio, licensed band radios, or cellular radios using Verizon public network. The radio system used can be chosen based on the requirements at a particular monitoring and control point in the field, providing a great deal of flexibility and interchangeability.
- Traditional radio communication mechanisms used in the field often use, and are increasingly migrating to standards based protocols at the higher layers, including DNP3 over IP, as described below.
- DNP3 - Distributed Network Protocol (DNP3) – RTU and switch Communications leverage DNP3 over IP, and DNP3 over Serial.
- The common suite of IP protocols is used for communication between major substations and Operations Centers and/or once the data transitions to the corporate communications network.
- North American Electric Reliability Corp. (NERC) Critical Infrastructure Protection (CIP) 002-009 - Cyber security standards for the bulk power system.

In addition, NSTAR's intent is to evolve to support relevant aspects of IEC 61850 as technology permits (e.g., NSTAR is following the discussions of IEC "61850-lite" about reduction in protocol overhead required for some field device and sensors).

#### 2.4.2. Decision Maker's Interoperability Checklist

The self-healing approach described rates favorably relative to more traditional approaches when evaluated based on the Gridwise Architecture Council (GWAC) checklist, as shown in [Table 2-1](#).

**Table 2-1.** GWAC Interoperability Checklist [3][2]

Checklist Category	Traditional Approaches	New Approach
<b>Architecture and Design</b>		
1) Specifies Points of Interface	r	4
2) “Open” Architecture	5	4
3) Specifies Performance Results, Not Technology	5	4
4) Can Be Supplied by Multiple Vendors	5	4
5) Rely on Open, Published Standards	5	4
<b>Interconnectivity and Security</b>		
6) Capability to Interconnect with Communications Media	5	4
7) Uses Standard Communications Protocols	5	4
8) Makes Basic Data Available to Authorized Users/Devices	4	4
9) Manage Multiple Devices Form a Central Source/Command	5	4
10) Use Basic Cyber-Security Measures as NERC-CIP, etc.	5	4
11) Fail In A Way To Not Harm the System or User	4	4
<b>Evolutionary Capability and Service Life</b>		
12) Upgrades by Software/Configuration Download	5	4
13) Integrate Easily with Earlier Versions and Equipment	5	4
<b>Collaborator Independence</b>		
14) Collaborators Make Independent Decisions	r	r
<b>Legend:</b>		
4 -approach has this capability		
5 -approach typically doesn't have this capability		
r approach may or may not have this capability		

Of course, as GWAC notes in the checklist document, this list should be used as a starting point for interoperability assessment, not an end point. As methods like this are leveraged on a broader scale, the components will evolve toward a more flexible, even “plug-n-play” type architecture that should prove even more robust than the one described here.

**2.5. Deployment Scope Metrics**

NSTAR’s goal is to have fewer than 1,500 customers on any (13/25 kV) overhead circuit segment across its service territory, and to have the ability to isolate damaged and

restore undamaged sections of the underground 4kV circuits. Completion of this project and the realization of these goals will limit customer fault exposure. NSTAR estimates that approximately three-quarters of customers will be served with self-healing distribution network as a result of this project. As a result, NSTAR expects customer outages for these segments will be reduced by approximately 50 percent.

Pre- and post-project deployment metrics are show in [Table 2-2](#).

**Table 2-2.** Pre- and Post-Project Implementation Metrics

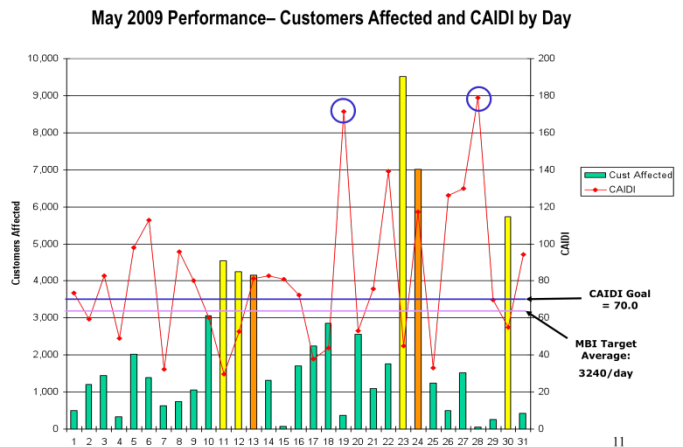
Metric	Current	Post-Project	Difference
Percent of (13/25kV) Overhead Circuits with Auto-Sectionalizing (via ASU switches)	705/862=82%	775/862=90%	70=8%
Percent of (4kV) Underground Circuits with Auto-Sectionalizing (via VFI switches)	38/192=20%	138/192=72%	100=52%
Number of (13/25kV) Overhead Circuits with each mode of auto-restoration capability implemented	<u>Overhead 13/25kV</u> Mode 1 = 695 Mode 2 = 10 Mode 3 = 0	<u>Overhead 13/25kV</u> Mode 1 = 0 Mode 2 = 160 Mode 3 = 615	<u>Overhead 13/25kV</u> Mode 1 = (695) Mode 2 = 150 Mode 3 = 615
Number of (4kV) Underground Circuits with each mode of auto-restoration capability implemented	<u>Underground 4kV</u> Mode 1 = 38 Mode 2 = 0 Mode 3 = 0	<u>Underground 4kV</u> Mode 1 = 0 Mode 2 = 0 Mode 3 = 138	<u>Underground 4kV</u> Mode 1 = (38) Mode 2 = 0 Mode 3 = 138

**3. RESULTING BENEFITS**

The grid’s “self-healing” capability implemented across portions of NSTAR’s distribution network will improve service reliability and improve customer satisfaction by reducing the duration of customer outages caused by main line circuit faults.

**3.1. Improved Distribution Reliability**

NSTAR has developed data collection and analysis capabilities to measure and monitor its own progress toward customer satisfaction goals and other operational targets. As an example, [Figure 3-1](#) below shows several of the metrics for customer impact that are currently tracked by NSTAR - CAIDI, MBI, and number of customers impacted is tracked on a daily basis.



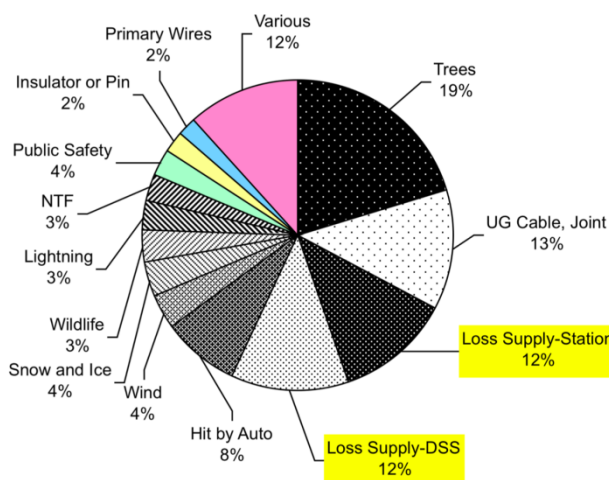
**Figure 3-1.** Example Metrics Tracked to Measure Customer Impact

The number and types of faults experienced varies considerably over time and depends on a range of variables. [Figure 3-2](#) shows the wide range of causes for various customer outages.



### 2008 (Jan-May) Customers Affected

Total Customers = 390,392



Note: Category "Various" consists of 29 miscellaneous causes, each contributing less than 2% to overall COH total.

Data is "NSTAR Reportable" from Cognos database. Exclusions: major events, planned outages, customer outages, outages with durations under five minutes.

Figure 3-2. Outage Cause Summary (Jan-May '09)

Due to the wide variation over time, it is sometimes difficult to draw conclusions from a year-over-year comparison of standard reliability metrics such as SAIFI, CAIDI, etc. So, rather than simply using these metrics, NSTAR tracks the specific impact that automation is having on customer outages, as shown in **Error! Reference source not found.** Significant benefits are already being achieved by the increased automation. Detailed reliability metrics are tracked on a per-circuit basis to allow baseline establishment and measurement of affect of investments such as this.

Table 3-1. Customer Out ages Averted Due to Automation

	September 2009	October 2009	2009 YTD
ASU Customers Averted	1,585	22,261	63,059
VFI Customers Averted	0	511	2,891
Customers restored within less than 5 minutes due to switching	17,003	17,416	120,597
<b>TOTAL Customers Averted</b>	<b>18,588</b>	<b>40,188</b>	<b>186,547</b>

Customers restored within 5-9 minutes due to switching	5,178	1,384	43,750
Customers restored within 10-15 minutes due to switching	0	0	9,131

Most of the impact shown in the table above is from the auto-sectionalizing that has already been done and is operating in Mode 1, as the radio controlled capability helps dispatchers quickly switch around problem

locations and restore as many customers as possible, usually in less than five minutes.

Continuing to progress through Modes 2 and 3 towards self-healing will lead to even fewer customer outages, as well as shorter outage durations. Relative to expected system conditions and historical experience, a 50% reduction in the SAIFI index and a 50% reduction in the SAIDI index is possible for the three-quarters of NSTAR customers served by a self-healing grid. Roughly half of the customers on a given circuit would be spared an outage.

### 3.2. Improved Customer Satisfaction

The benefits that accrue to customers from improved power quality and reliability manifest themselves as customer satisfaction, which is very important to NSTAR.

Customers in the U.S. today have a much higher expectation of power quality and reliability than they did even 20 years ago. In particular, power outages affecting commercial, industrial, and institutional customers often have a very high cost, although this cost is sometimes difficult to quantify. To a degree, the same is true of many residential customers, who sometimes work from home and/or rely on computer connectivity to achieve their daily tasks.

The trend is seen clearly in the increasing number of customers requesting 100% reliable power from NSTAR to avoid significant issues in their operations and business. Some notable instances of institutional and industrial customers include:

- Universities: Harvard University, MIT, Boston University, and other Colleges and Universities in NSTAR service territory.
- Commercial Manufacturers such as Genzyme and Biogen, bio-technology companies, and Ember Networks, which runs semiconductor fabrication processes that are very sensitive to power interruptions.
- Public Facilities such Logan Airport, which requires uninterrupted power for its continuing operations, and townships like Lexington.

This anecdotal evidence illustrates why the reliability and power quality measures NSTAR is taking are critical to customer satisfaction, and why NSTAR currently collects a fair amount of historical data on reliability and power quality.

In the past five years, NSTAR has been able to achieve a 25% reduction in customer outages with the occurrence of a main line fault. NSTAR's goal is an overall 50% reduction after implementation of this project. No other type of investment (e.g., additional trucks/crews,

proactive tree-trimming programs, or other technologies, etc.) can have as significant a net reliability and quality effect.

### 3.3. Customer Benefit Quantification

As described anecdotally above, many organizations understand that the cost and disruption of a power outages or poor power quality is very high. The direct dollar cost is hard to quantify, although attempts have been made to quantify the impact in dollars for various types of customers as well as the operational benefit to the utility.

A recent study by Lawrence Berkely National Laboratory (LBNL) attempts to estimate the cost to customers of outages[4]. The LBNL study estimates a dollar value on outage occurrence by interruption duration (momentary, 30 min, 1hr, 4hrs, 8hrs) and by customer type (Medium & Large C&I, Small C&I, Residential). Using this information, along with the statistics on customer outages prevented by NSTAR's DA investments, it is possible to estimate the customer value of reduced outages.

The year-to-date averted outages were adjusted linearly based on year-to-date actual numbers to represent annual numbers. Averted outages were divided into residential and small commercial customers based on NSTAR's total proportions of those two groups as shown in [Table 3-2](#) below. Large commercial and industrial customers were excluded from this analysis since the deployment of DA described here predominately excluded industrial customers.

**Table 3-2. Customer Outages Averted**

Annual Customer Outages Averted		
Category	Residential	Commercial
ASU Customers Averted	64,813	10,857
VFI Customers Averted	2,971	498
Customers Restored within 5min	123,952	20,764
Customers Restored within 10 min	44,967	7,533
Customers Restored within 15 min	9,385	1,572
	<b>86%</b>	<b>14%</b>

[Table 3-3](#) below shows the estimated cost of outages to residential and small commercial customers based on the LBNL study. For restoration times where values were not explicitly estimated by the study, values were linearly interpolated.

**Table 3-3. Averted Cost per Outage Event**

Averted Cost per Event		
Category	Residential	Commercial
ASU Customers Averted	\$1.20	\$379.00
VFI Customers Averted	\$3.90	\$818.00
Customers Restored within 5min	\$1.10	\$350.50
Customers Restored within 10 min	\$1.00	\$322.00
Customers Restored within 15 min	\$0.90	\$293.50

[Table 3-4](#) below shows the estimated customer savings by outage restoration category and by customer type. Residential customers represent the largest fraction of prevented outages, but prevented outages are estimated to be much less than for commercial customers. Residential customers result in approximately 2% of the total customer value of this DA deployment, with the remaining 98% of the value falling on commercial customers.

**Table 3-4. Value of Customer Outages Averted**

Value of Customers Averted or Quickly Restored				
Category	Residential	Commercial	Total	
ASU Averted	\$77,776	\$4,114,956	\$4,192,732	28%
VFI Averted	\$11,589	\$407,174	\$418,763	3%
5 min Restored	\$136,347	\$7,277,855	\$7,414,202	50%
10 min Restored	\$44,967	\$2,425,564	\$2,470,531	17%
15 min Restored	\$8,447	\$461,429	\$469,876	3%
	<b>\$279,126</b>	<b>\$14,686,978</b>	<b>\$14,966,104</b>	<b>100%</b>

NSTAR believes that the customer cost and impact of power interruptions will continue to rise, and so reliability and power quality measures like those proposed in this project will continue to grow in importance.

### References

- [1] Office of National Coordinator for Smart Grid Interoperability. "NIST Framework and Roadmap for Smart Grid Interoperability Standards Release: Draft." V1.0 (September 2009).
- [2] GridWise Architecture Council. "GridWise Interoperability Context-Setting Framework." [http://www.gridwiseac.org/pdfs/interopframework\\_v1\\_1.pdf](http://www.gridwiseac.org/pdfs/interopframework_v1_1.pdf) (March 2008).
- [3] GridWise Architecture Council. "GridWise Architecture Council Decision Maker's Interoperability Checklist."
- [4] "Estimated Value of Service Reliability for Electric Utility Customers in the United States," LBNL-2132E, Ernest Orlando Lawrence Berkeley National Laboratory, June 2009

[5] Electric Power Research Institute. "Report to NIST on the Smart Grid Interoperability Standards Roadmap." <http://www.nist.gov/smartgrid/InterimSmartGridRoadmap/NISTRestructure.pdf> (June 2009).

[6] DOE/OEDER - U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability. "Metrics for Measuring Progress Toward Implementation of the Smart Grid: Results of the Breakout Session Discussions," Smart Grid Implementation Workshop (2008b).

[7] GE Energy, Products and Services Website, [http://www.gepower.com/prod\\_serv/index.htm](http://www.gepower.com/prod_serv/index.htm).

[8] Institute of Electrical and Electronics Engineers: Working Group on Distribution Reliability. "IEEE Benchmarking 2005 Results." Power Engineering Society, Institute of Electrical and Electronics Engineers, Piscataway, New Jersey (2006). <http://grouper.ieee.org/groups/td/dist/sd/doc/2006-07-BenchmarkingUpdate.pdf> (November 7, 2008).

### **Biography**

Erik Gilbert is a Senior Consultant at Summit Blue Consulting who focuses on smart grid technology, strategy, costs-benefits assessment and helping clients with smart grid funding strategy. Mr. Gilbert has over 20 years of experience in development and management of networking products and protocols as well as experience in strategic business assessment for technology solutions. In his most recent role, Mr. Gilbert served as Director of Smart-Energy Products for residential energy management system vendor Tendril Networks, Inc., where he defined and executed their hardware roadmap, including in-home energy displays, IP-to-HAN gateways, AMR/ERT-to-ZigBee bridges and other products. Previously Mr. Gilbert held various management positions at Cisco Systems, Inc., where he built and launched a number of products. He created and drove the company's Managed Broadband Access program, enabling cable providers to offer billable services over common IP infrastructure. Mr. Gilbert's other experience includes associate work at the Bay Area venture capital firm Hummer Winblad Venture Partners and several years of technology strategy development with Ernst & Young Management Consulting. Mr. Gilbert holds a BS in Electrical Engineering and Computer Science from the Massachusetts Institute of Technology and an MBA in Marketing from the University of California at Berkeley.

Lawrence "Larry" Gelbien is Vice President of Engineering at NSTAR Electric and Gas Corporation. NSTAR is an electric and gas utility servicing 1.4 million customers in Massachusetts including the City of Boston. As Vice President of Engineering, Mr. Gelbien is responsible for electric system planning, transmission, substation, and electric distribution design. Mr. Gelbien is

presently heading up NSTAR's Smart Grid Program and has done evaluation on electric battery storage technology. Prior to joining NSTAR Mr. Gelbien worked 21 years at Long Island Lighting Company, an electric and gas utility located on Long Island, New York and which is now presently a National Grid Company. At Long Island Lighting Company, Mr. Gelbien held a number of positions with responsibility for Distributed Generation, Distribution Automation, and System Control and Protection, to name a few. Mr. Gelbien holds three patents in Distribution Automation, which is commonly known as "Grid Self-Healing." Mr. Gelbien has a Masters Degree in Business Administration from Nichols College and a Bachelors Degree in Engineering from New York Institute of Technology.

Brad Rogers is a Consultant at Summit Blue Consulting with quantitative expertise in the fields of optimization, Monte Carlo simulation, system dynamics, risk analysis, and decision analysis. He has applied these skills to the economic and technical assessment of energy technologies, to the improvement of product development processes, and to project management practices in the energy and aerospace industries. Mr. Rogers has a working knowledge of renewable energy sources, nuclear technology, transmission, distribution, and issues pertaining to smart grid. Mr. Rogers earned an MBA and an MS in Engineering Systems concentrated in Energy and Sustainability at the Massachusetts Institute of Technology as a Leaders for Global Operations Fellow and Merit Scholar. He received a BS in Mechanical Engineering with a minor in Business Engineering Technology from Auburn University, where he graduated summa cum laude. Prior to joining Summit Blue, Mr. Rogers worked for Spirit AeroSystems, Nuvera Fuel Cells, and the US Peace Corps.