NSTAR Urban Grid Monitoring and Renewables Integration

Technical Performance Report

Prepared for:

U.S. Department of Energy
On behalf of NSTAR Gas and Electric Corporation

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Executive Summary

NSTAR Electric & Gas Corporation ("NSTAR") is in the process of enhancing the grid monitoring instrumentation on one of its secondary area network grids, the Boston Area 492 North Grid, in downtown Boston, MA to provide unprecedented visibility into the operation of the grid. Using state-of-the-art sensor equipment along with a novel, low-cost approach to monitoring current and conductor temperature, NSTAR is in the process of greatly improving its understanding of grid status and behavior and allowing for proactive maintenance that improves safety and increases reliability. The visibility gained from this effort also offers the promise of increased capability for solar photovoltaics (PV) distributed generation (DG) injection. The results and knowledge gained from this demonstration will be broadly applicable to secondary area network grids in other urban areas across the U.S.

This Urban Grid Monitoring and Renewables Integration project is supported by the U.S. Department of Energy through the Smart Grid Demonstration Program grant.

Project Scope

To accomplish the demonstration, NSTAR has deployed advanced sensors and instrumentation on one of the 12 secondary area network grids that it operates in Boston, covering 436 nodes located within manholes downtown. A Collection Server at one of the NSTAR's Operations Centers collects data and alarms from these sensors via various forms of electronic communication. NSTAR also enhanced monitoring at distribution feeders to better characterize the supply side of the power flow onto the distribution grid. Finally, NSTAR installed AMR meters and PV power meters at customer-owned solar installations to monitor power flow to specific customers and obtain in-depth information about the behavior of these installations in addition to the power flow on the nearby section of the grid.

Project Status

As of the date of this report, NSTAR has installed all grid monitoring, communications, and data collection equipment. The project is now entering the data analysis phase, which consists of extensive data analysis and commissioning in order to better understand the operational characteristics of the secondary network and to investigate visibility for integration of PV DG.

Outcomes/Benefits

The broad benefits expected from the overall the project include:

- Greatly improving visibility into the status of the urban grid, both in terms of near real-time information about load distribution and of improved understanding of the grid asset inventory and condition.
- Investigating the visibility for integration of distributed generation such as PV.
- Enabling NSTAR to safely test inverter-based distributed resource integration (e.g. solar PV installations) into the secondary area network grid.

- Assisting in the development of preventive maintenance programs for secondary area networks in urban areas.
- Laying the groundwork for nationwide deployment of inverter-based distributed resources in major urban areas across the U.S., which NSTAR and other utilities have not yet significantly pursued due to safety and grid stability concerns.
- Applying the lessons learned from this demonstration to other secondary area networks in urban areas across the country.

1 Scope

NSTAR Electric & Gas Corporation ("NSTAR") is conducting the Urban Grid Monitoring and Renewables Integration demonstration project to enhance the grid monitoring instrumentation on one of its secondary area network grids, the Boston Area 492 North Grid, in downtown Boston, MA and provide unprecedented visibility into the operation of the grid. Using state-of-the-art sensor equipment along with a novel, low-cost approach to monitoring current and conductor temperature, NSTAR is in the process of greatly improving its understanding of grid status and behavior and allowing for proactive maintenance that improves safety and increases reliability. The visibility gained from this effort also offers the promise of increased capability for solar photovoltaics (PV) distributed generation (DG) injection, which has not generally been possible on this type of grid in the past. The results and knowledge gained from this demonstration are broadly applicable to secondary area network grids in other urban areas across the U.S.

This Urban Grid Monitoring and Renewables Integration project is supported by the U.S. Department of Energy through the Smart Grid Demonstration Program grant.

1.1 Project Team

Key members of the demonstration project team include the following:

NSTAR leverages team members from a range of functional organizations, including, Substation and Transmission Engineering, IT, Planning, Investment Planning, Project Management, and various technical contributors serving as subject matter experts.

DigitalGrid, Inc. is the vendor supplying the major node sensor technology, the communications technology to report the sensor readings, and integration of this information into the Collection Server that serves as the data repository. They also supply expertise to assist in the technology deployment and integration effort.

Softstuf, Inc. is the vendor supplying the minor node technology as well as expertise in the installation and troubleshooting of this new technology. NSTAR and Softstuf, Inc. have jointly developed the minor node technology approach and have an agreement in place for the commercialization of this technology.

Tendril Networks, Inc. is the vendor supplying the equipment installed at the customer premise, including the technology used to monitor and disconnect, if necessary, the customer solar PV installation from the grid.

Bahwan CyberTek, Inc. is conducting stability analysis of the minor nodes in order to determine proper operation of the system and the viability of PV, plug-in hybrids, and battery storage integration.

1.2 Project Objectives

The specific objectives of this demonstration include the following:

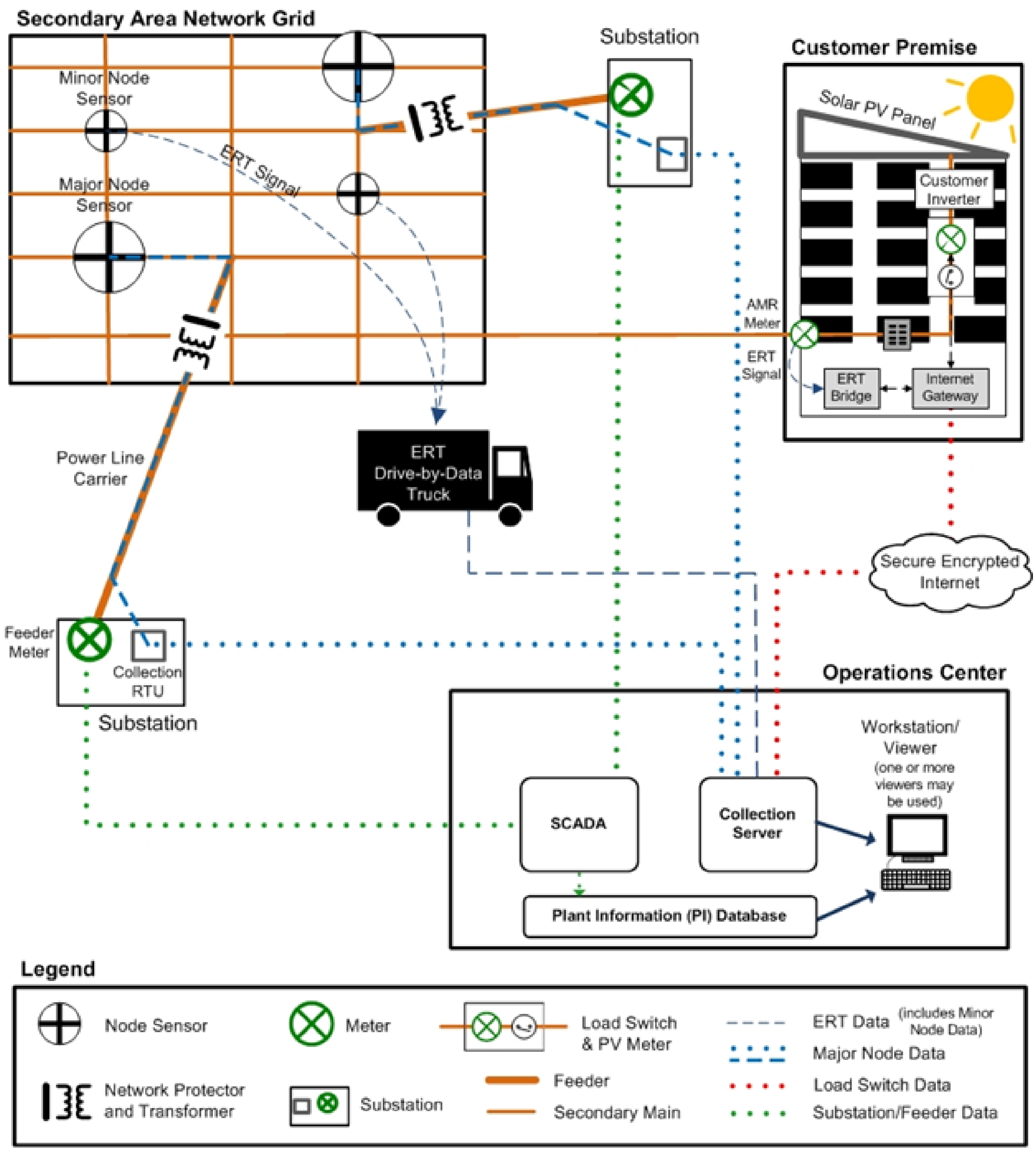
- Improve visibility into the status of the urban grid, both in terms of near real-time information about load distribution and in terms of improved understanding of the grid asset inventory and condition.
- Use the knowledge gained from the project to help investigate the visibility for integration of distributed generation such as PV.
- Enable NSTAR to safely test inverter-based distributed resource integration (e.g. solar PV installations) into the secondary area network grid.
- Assist in the development of preventive maintenance programs for secondary area networks in urban areas.
- Lay the groundwork for nationwide deployment of inverter-based distributed resources, such as solar PV and electric vehicles in major urban areas across the U.S., which is seldom pursued due to safety and grid stability concerns.
- Apply the lessons learned from this demonstration to other secondary area networks in urban areas across the country.

1.3 System Design and Technologies

NSTAR operates 12 secondary area network grids in downtown Boston, with grid points covered by approximately 4,600 manholes across the metro area. This project has deployed additional sensors and monitoring instrumentation within one of these secondary area network grids, covering more than 400 manholes with various instrumentation grid points. NSTAR selected the specific grid based on the mix of commercial and residential customer sites, as well as recent customer interest for PV type solar integration. The monitoring effort will maximize safety as well as knowledge gained about the behavior of the grid near distributed solar installations.

Figure 1 shows the overall topology of the project, with the "urban grid monitoring" occurring on the secondary area network and the "renewables integration" enhancements appearing at the customer premise. Each project component is described in more detail below.

Figure 1. System Overview of Urban Grid Monitoring Demonstration



Secondary Area Network Grid:

- Underground ("manhole") instrumentation: NSTAR has instrumented 436 grid points for monitoring within the manholes covering the demonstration network. Each monitoring node has been classified as "major" node or a "minor" node. Those nodes located in manholes closest to the network transformers (grid supply sources) and power exchanges (multiple connections points in the grid) have current limiters that serve high density loads and are considered "major" nodes. Those nodes serving the remainder of the load, which are in manholes located on the secondary lines between the major nodes in the secondary grid and customers, are considered "minor" nodes. There are currently 126 "major" nodes and 310 "minor" nodes instrumented with these capabilities.

  - Minor Nodes: Minor nodes have been instrumented with sensors that detect high and low current and cable temperature threshold values on individual secondary-main cables within a grid-point. Presently, there is no low-cost means to determine if or when underground secondary mains (cables) on a particular grid are "broken" (open) or overloaded due to an "open limiter." Since utilities cannot remotely monitor these secondary limiters, when enough of them incorrectly become "open," the remaining secondary mains and their limiters start to become overloaded and can cause an increased risk of fire or wide area power outages, which can cause the shutting down of the network grid to make repairs. The installation of the monitors near the "limiter" in the manhole will detect when the limiter is open or becoming overloaded, thereby improving the performance of the grid.

    Originally, NSTAR intended to equip these nodes with an AMR type radio transmitter that would allow drive-by collection of this information. However, during the research and development of the minor nodes, NSTAR realized the importance of near real-time communication with the nodes. As a result, NSTAR updated the communication medium within the node to communicate over the existing wireless cell network. Wireless communications now provide NSTAR with near real-time alerts when low-current and high-temperature conditions takes place.

  - Major Nodes: Major nodes have been instrumented with DigitalGrid, Inc. technology, which provides current sensing on a real time basis. These nodes are also equipped with power line carrier technology that allows near real-time monitoring at the operations center. The major nodes are able to monitor the secondary mains current on a real time basis and provide information remotely on the status of the grid. Based on the information received, the system operators will be able to take appropriate actions to remedy any unusual event, thereby improving the performance level of the grid.

- Network transformers: These are insulating fluid-filled three phase transformers specifically designed and built to withstand high overload and short circuit current. These transformers are typically installed in vaults and manholes, and are fed by primary cables (at 13.8kV) and the secondary connected to the network at 208/120V. The network transformers are connected to the primary mains, which are interlaced, and adjacent transformers are fed by different feeders. The interlacing is arranged so that an outage of one feeder does not seriously impair voltage regulation on the network grid and the load will be picked up over the secondary grid by transformers on other feeders.

- Network protectors: A network protector is installed on the secondary side of each network transformer. The load side of the network protector is connected to the secondary grid. The operation of the network protectors is based on two principles:

- Automatic opening of the network protectors when a primary feeder breaker is opened or in the event of a fault on a primary feeder or in a network transformer.
- Automatic closing of network protectors to connect the network transformers to the secondary grid when the primary feeder is energized.

- Feeder data meters and collection RTUs: The original project plan also called for two substations that supply the demonstration grid to be outfitted with advanced RTUs to better understand the operating parameters at the substation. However, through field investigation, NSTAR determined that the existing feeder data meters and collection RTUs are sufficient for the purposes of this project and thus no upgrades to this equipment are required at this time. NSTAR will reassess whether additional equipment is needed closer to the end of the data analysis phase.

Customer Premise Equipment:

- AMR Meter: Will be installed at customer owned solar installation sites for customers who are integrating solar PV. NSTAR is not replacing or upgrading its back-end metering systems as part of this project.
- Encoder Receiver Transmitter (ERT) bridge and internet gateway: Will be installed at applicable customer premises. These devices, supplied by Tendril Networks, will be used to communicate interval meter reads to NSTAR.
- Customer PV installation
- Load switch/PV meter device: Will be installed within the customer premise for each PV installation and will communicate using customer broadband connectivity.

Communications:

- Cellular network: Used to communicate with the minor nodes.
- Power Line Carrier (PLC): Used to communicate with the major nodes.

Data Analysis Systems:

- Collection server: The information from the sensors and AMR meters are sent to a repository, which is implemented on a collection server. The load parameters are analyzed and appropriate actions taken to safely operate the secondary network. This improves overall understanding of the system dynamics and planning of the network grid.
- SCADA: Information from the feeder data meters are directly forwarded to SCADA including alarm points. This data is then forwarded to PI.
- Plant Information Database (PI): Information from SCADA is forwarded to the Plant Information (PI) system, which is an NSTAR client-server database system that provides information from field instrumentation to appropriate desktop computers throughout the organization. This makes it possible for multiple functional organizations, including Engineering, Planning, Dispatch, etc. to use this data for improving planning and operations.

NSTAR does not anticipate removing the monitoring devices. Assuming the demonstration continues yielding successful results, the demonstration will continue to operate into the future.

NSTAR's approach for the interoperability and cyber security of these technologies is discussed in Section 2.3.

1.4 Project Schedule and Decision Points

NSTAR's Urban Grid Monitoring and Renewables Integration project began in Q4 of 2010. As of Q3 of 2014, NSTAR has installed all project-related grid monitoring, communications, and data collection equipment. The project is now entering the data analysis phase, which consists of system commissioning and extensive data analysis in order to maximize the potential for PV distributed generation injection within the network area as well as other DG options.

The current statuses of the key decision points outlined in NSTAR's Project Management Plan are presented below and a more detailed project schedule can be found in Appendix A.

Decision Point 1: Minor Node Instrumentation Viability Review
Description: The minor node sensors that NSTAR is currently testing for low-cost urban grid monitoring are unique to NSTAR and have never been deployed on a large-scale basis. The vendor of these sensors, Softstuf, Inc., also provides expertise in the installation and troubleshooting of the technology.

Criteria: Cable load and temperature flag data is must be >80% readable and determined to be accurate at the Collection Server, ensuring that the data is available for analysis and operational decision making.

Status: As of January 22, 2014, there was 100% installation of 13 Itron and 297 Nighthawk minor nodes, with the Nighthawk server successfully providing a log of date and times of alarms.

Decision Point 2: Preliminary Design and NEPA Compliance Review
Description: Before making significant resource investments in equipment procurement and installation, NSTAR will seek approval to proceed with the final project design and construction. This will occur upon completion of the system design process and approval from the DOE based on full NEPA compliance.

Criteria: Passage of the NEPA Compliance Review.

Status: NEPA Compliance Review passed.

Decision Point 3: Major Node Communications Systems Review
Description: Issues communicating with DigitalGrid systems have occurred in NSTAR's network in the past. DigitalGrid and NSTAR have since made significant progress towards addressing these issues and DigitalGrid systems are currently functioning as intended across NSTAR's network; NSTAR does not anticipate future problems. However, it is worth noting that the inability to consistently communicate with the major nodes would require a change in project approach.

Criteria: Cable data on the following attributes--cable load condition, cable voltage, temperature-- is determined to be > 90% available at the Collection Server and the readings are determined to be accurate.

Status: As of January 2, 2014, the DG4001 server was successfully collecting data from 126 major nodes with sufficient coverage.

Decision Point 4: Operational Readiness Review
Description: At the end of 2013, NSTAR will have a fully installed, integrated, and tested system with trained staff. With these benchmarks in place, NSTAR will seek approval to proceed with Commissioning and Operations.

Criteria: Approval of the DOE after readiness review.

Status: All equipment installed, operated, and tested. NSTAR received DOE approval to proceed.

Decision Point 5: Review of System Readiness for PV Integration
Description: Once the software and database components are in place, the data collected will be analyzed for proper system operation. Based on the analysis results, determination will be made regarding the viability of allowing PV generation to interface with the secondary network urban grid. The PMP will be updated as needed to include the impact of this significant project decision on the project scope of activities and benefits.

Criteria: The system will be determined to be ready for PV integration once monitoring near the PV installation determines that there has been no recent, inadvertent operation of Network Protectors (described in more detail below) in the region of the install.

Status: NSTAR contracted Bahwan Cybertek, Inc. to analyze the system data for proper operation and determine the viability of PV integration. This contract was awarded on 5/30/2014 and is scheduled for completion by 11/30/2014. Upon completion of this contract, NSTAR will have the ability to continuously collect and analyze data via an application designed by Bahwan Cybertek, Inc.

1.5 Smart Grid Functions and Benefits

The primary smart grid function of the Urban Grid Monitoring and Renewables Integration demonstration project is the Diagnosis & Notification of Equipment Condition, which will facilitate the increased deployment of distributed resources on NSTAR's secondary area networks.

The following table summarizes the smart grid benefits of the project by economic, reliability, environmental, and security categories. These benefits are also outlined in NSTAR's Metrics and Benefits Reporting Plan.

Figure 2. Benefits from the Urban Grid Monitoring Demonstration

Benefit Category	Benefit Sub-Category	Benefit	Provided by Project?	Remarks
Economic	T&D Capital Savings	**Reduced Equipment Failures (utility/ratepayer)**	**YES**	Enhanced monitoring will allow NSTAR to identify and address potential equipment failures, such as secondary main cable failures.
	T&D O&M Savings	**Reduced Distribution Equipment Maintenance Cost (utility/ratepayer)**	**YES**	Enhanced monitoring will assist with preventive maintenance and allow for maintenance savings.
		Reduced Distribution Operations Cost (utility/ratepayer)	**YES**	Enhanced monitoring will allow NSTAR to identify and address potential distribution equipment overloads; thus, avoiding the need for emergency truck rolls to eliminate overloads.
		Reduced Meter Reading Cost* (utility/ratepayer)	NO	Although a small number of AMI meters will be deployed in this project, truck rolls are not expected to be reduced at this time since the trucks will continue their routes to gather meter data.
Reliability	Power Interruptions	**Reduced Sustained Outages (consumer)**	YES	The urban grid is designed to be 99.9% reliable and the occurrence of outages is extremely rare. The intent of this project is to maintain this reliability, while safely integrating PV onto the grid. If this project results in any measurable change in outage response time, it will be addressed in the Technology Performance Report.
		Reduced Major Outages (consumer)	YES	The monitoring and preventive maintenance resulting from this project will help avoid major events on the secondary area network.
		Reduced Restoration Cost (utility/ratepayer)	NO	NSTAR anticipates that this will be a benefit of this project; however, NSTAR will not be tracking and reporting these impacts at the project level.

Benefit Category	Benefit Sub-Category	Benefit	Provided by Project?	Remarks
Environmental	**Air Emissions**	**Reduced carbon dioxide Emissions (society)**	**YES**	Emissions will be reduced by this project through the integration of solar PV onto the secondary area network and reduced emergency truck rolls due to enhanced network monitoring.
		Reduced SOX, NOX, and PM-2.5 Emissions (society)	**YES**	Emissions will be reduced by this project through the integration of solar PV onto the secondary area network and reduced emergency truck rolls due to enhanced network monitoring.
Security	**Energy Security**	**Reduced Oil Usage (society)**	**YES**	Oil usage will be reduced by this project through a reduction in emergency truck rolls due to enhanced network monitoring.

2 Technical Approach

This section discusses the technical approach to the project, which includes a summary of the project plan, the data collection and benefits analysis activities, and the interoperability and cyber security approaches, per the Technical Performance Report Guidance issued by the DOE in 2011.

2.1 *Project Plan*

NSTAR is implementing grid monitoring in a layered approach. NSTAR has already deployed various types of instrumentation at grid points within manholes throughout the distribution network, as described in Section 1.3 above. These basic, relatively inexpensive instruments have been deployed at "minor nodes" in the grid, and more expensive instruments with near real-time monitoring have been deployed at "major nodes."

For the current phase of the project, which began in May 2014, NSTAR contracted Bahwan Cybertek, Inc. to conduct extensive analysis of the node data in order to optimize system operation and determine the viability of PV integration. The results of this data analysis will allow NSTAR to determine whether assets and infrastructure throughout the grid are operating at or beyond specified operating limits and, where practicable, to adjust the infrastructure accordingly to within the operating limits. The increased visibility of grid conditions will limit improper operation of secondary mains and allow for the integration of distributed generation into the system without causing undue disturbance.

Once the equipment and protocols needed to effectively enforce system safeguards are in place, NSTAR will install AMR meters at the PV test site chosen in the system design process and connect the PV load to the nearest major node. Controlled operation of the system and incremental testing of the various safeguards will determine system readiness for additional PV integration. NSTAR will perform testing of the system with an end goal of validating that the system operates successfully and safely under the IEEE 1547.6 recommendations.[1] Once this testing process is complete, NSTAR will install additional AMR meters near customer-owned solar installations to monitor specific customer interface points. Performance of the grid in the location of installed PV will continue to be measured after the installation of the PV.

2.2 *Data Collection and Benefits Analysis*

This section discusses which data are being recorded or calculated and describes how the benefits analysis will be performed.

2.2.1 Data Collection

This project will extend system visibility and data collection down to the cable level, which has never been possible in the past. The various instrumentation and sensor points will provide data that will be accumulated in the Collection Server (repository). In addition, certain elements of the data will be made available for other uses (e.g., the PI—Plant Information System, which provides access to other

[1] http://standards.ieee.org/findstds/standard/1547.6-2011.html

Departments for planning and operations purposes), and the data will also be made available for DOE analysis. Expected data includes:

- **Major Node Information:** Each cable at a major node will now have monitoring down to the individual cable level (e.g., there will be approximately 36 conductor cables within a typical node in a single manhole). Each conductor cable will be monitored for the following attributes
  - temperature,
  - load (Amperes), and
  - voltage (Volts).

  This information will be sampled on an hourly basis and will also be available when polled manually and collected at the Collection Server.

- **Minor Node Information:** Each cable at a minor node (e.g., there will be approximately 15 cables within the manhole) will be monitored for the following flags:
  - over temperature (at particular threshold), and
  - under current (at a particular threshold).

  Flags indicated on any cable will be transmitted via cellular network. This will provide specific information on which nodes (manhole) have issues that require investigation.

- **Feeder Data Meters:** Interval consumption data on a real time (10 seconds) sample rate will be collected from each of 10 feeders supplying the selected secondary area network grid. This information will be fed into the Collection Server and correlated with other demonstration data.

- **Network Protector Information:** Network Protectors are installed at all transformer locations on the secondary area network grid and are a primary source of the data that NSTAR currently collects. The load side of each Network Protector is connected to the secondary grid and automatically opens or closes in response to grid conditions.[2] NSTAR collects the following information from every Network Protector:
  - Network Protector Position (open/close)
  - Network Protector current measure
  - Network Protector Nitrogen Pressure (in the protective encasement)

This set of information will provide an understanding of the power flow on the grid, which will allow characterization of the behavior of the local grid characteristics prior to integration of any customer PV. It will also provide the information needed to more proactively determine problem areas on the grid and perform maintenance where necessary to avoid larger problems.

Once customer PV locations are determined, NSTAR will deploy instrumentation to collect the following additional information:

[2] Network protectors automatically open when a primary feeder breaker is opened or in the event of a fault on a primary feeder or in a network transformer. Network protectors automatically close to connect the network transformers to the secondary grid when the primary feeder is energized.

- **AMR Meters:** Interval consumption data on a 15 minute sample rate will be collected from each of these AMR meters at relevant customer premises through an ERT signal transmitted to an ERT “bridge,” which will translate the data to an internet gateway device. This gateway device will then send the interval data to NSTAR’s Collection Server via the customer’s broadband connection. Tendril will provide the ERT bridge and internet gateway devices.

- **Customer PV-Meter/Switches:** For each PV installation, 15 minute to 1 hour sampled power flow from the PV installation and building load will be monitored and collected by the internet gateway device.

This information will allow for more complete characterization of the grid behavior near the customer PV integration, and also allow determination of a proper safety margin for operation of the PV.

2.2.2 Benefits Analysis

NSTAR will calculate the benefits from this project in accordance with the methodology outlined in NSTAR’s most recent Metrics and Benefits Reporting Plan, dated September 2011. NSTAR does not expect significant changes for this approach once the data analysis begins.

The enhanced distribution monitoring enabled through this project will greatly improve visibility into the status of the urban grid, both in terms of near real-time information about load distribution and in terms of improved understanding of the grid asset inventory and condition. The primary impact that will be reported for these enhancements is the proactive identification and management of potential distribution feeder and equipment overload incidents. NSTAR anticipates that this project will help determine the status of equipment failures related to distribution operations and maintenance.

The impact metrics reported to the DOE under AMI and Customer Systems relate to the possible impacts from integration of distributed PV into the urban grid. If this project results in a significant amount of integrated PV capacity added to the network, as the energy export is realized NSTAR will apply the appropriate formula to calculate emissions reductions. The AMI meters installed through this project will enable the data collection needed for these metrics.

2.3 Interoperability and Cyber Security Approach

A key component of this project is ensuring that NSTAR properly addresses interoperability and cyber security issues. The project will achieve interoperability by converting all collected data into a common format via the Collection Server for consumption by other systems for engineering analysis, and operational planning purposes. Additionally, the various instruments (major nodes, minor nodes, AMR meters), communication devices, and other components will be flexibly replaceable and interchangeable without significant impact to system operation or performance. NSTAR is addressing cyber security concerns using the Distribution Cyber-Security Framework (DCS-F), which is summarized in NSTAR’s Interoperability and Cyber Security Plan. The following sections discuss NSTAR’s approach to interoperability and cyber security for this project in more detail.

2.3.1 Interoperability

NSTAR is fully committed to keeping abreast of relevant developing standards, with particular attention on the emerging NIST standards for interoperability, to gauge impact on existing and planned deployments. NSTAR's strategy for communications technology solutions is to implement standards-based solutions whenever project requirements allow it.

NSTAR expects the various instruments (major nodes, minor nodes, AMR meters), communication devices, and other components to be flexibly replaceable and interchangeable, without significant impact to system operation or performance. Failure of any of these would result in a situation no worse than that before the device was installed, and the device would be repaired in the field using normal field maintenance and repair operations.

All the information that is brought back to the Collection Server will be put in a common format for consumption by other systems for engineering analysis, and operational planning purposes. To accomplish this, NSTAR will leverage NSTAR's proven system integration testing methodology and Bahwan Cybertek, Inc.'s data analysis application.

2.3.2 Cyber Security

NSTAR is approaching cyber security for this project proactively, taking a holistic and ground-up approach to ensuring the confidentiality, integrity, and availability of the system. NSTAR is leveraging the National Institute of Standards and Technology (NIST) cyber security guidance as well as its experience with and knowledge of the NERC Critical Infrastructure Protection (CIP) framework to develop an appropriate security approach for the distribution system and ensure that security best practices are being applied. NSTAR refers to this approach as the Distribution Cyber-Security Framework (DCS-F).

To demonstrate and validate the effectiveness of NSTAR's cyber security controls through DCS-F, NSTAR will perform the following reviews, as needed:

- Periodic vulnerability assessments of infrastructure and documentation of results;
- Development of a remediation plan for evidence and review;
- Periodic system security analysis, including reviews of architecture, operating procedures, deployment and hardening process, event management and patch management;
- Review on a periodic basis of all system accounts that result in disabling and/or terminating any account that cannot be associated with an owner or process;
- Periodic maintenance, monitoring and analysis of audit logs;
- Periodic review of enterprise systems to insure up to date anti-malware signatures; and
- Periodic review of services and ports, along with a change control program to document all changes with an associated business justification.

3 Results

NSTAR has installed all grid monitoring, communications, and data collection equipment as of August 2013. The project is now entering the data analysis phase, which consist of extensive data analysis and commissioning in order to maximize the integration of PV DG. Once the vendor-supplied data analysis application is fully online and providing NSTAR with detailed real-time visibility into grid operating conditions, NSTAR will have a better understanding of the overall success of the project.

3.1 Operation of Smart Grid Technologies and Systems

NSTAR reported the following operational data as of January 2014:

Major Nodes

- 6,480 sensors are distributed among 126 manholes throughout the Boston Area 492 North Grid.
- 16 sensors are alarming every day due to faulted sensors. NSTAR confirmed the presence of faulted sensors with true load readings taken in the field.
- Eleven sensors have recently alarmed due to the load exceeding 208 Amps beyond the set threshold.
- NSTAR identified two broken limiters with the use of this technology.

Minor Nodes

- 4,386 sensors distributed among 310 manholes throughout the Boston Area 492 North Grid
- 193 sensors are alarming every day (periodically throughout the day) due to load cycling above and below the 8 Amp threshold.
- 56 sensors alarming everyday (96 times per day). 51 sensors had field load readings taken, indicating that there is verified low load (less than 8 Amps) on the mains.

3.2 System Design Changes

Originally, NSTAR intended to equip these nodes with an AMR type radio transmitter that would allow drive-by collection of this information, as discussed in Section 1.3. However, during the research and development of the minor nodes, NSTAR realized the importance of near real-time communication with the nodes. As a result, NSTAR updated the communication medium within the node to communicate over NSTAR's existing wireless cell network. Wireless communications now provide NSTAR with near real-time alerts when low-current and high-temperature conditions takes place. The benefits of this approach include:

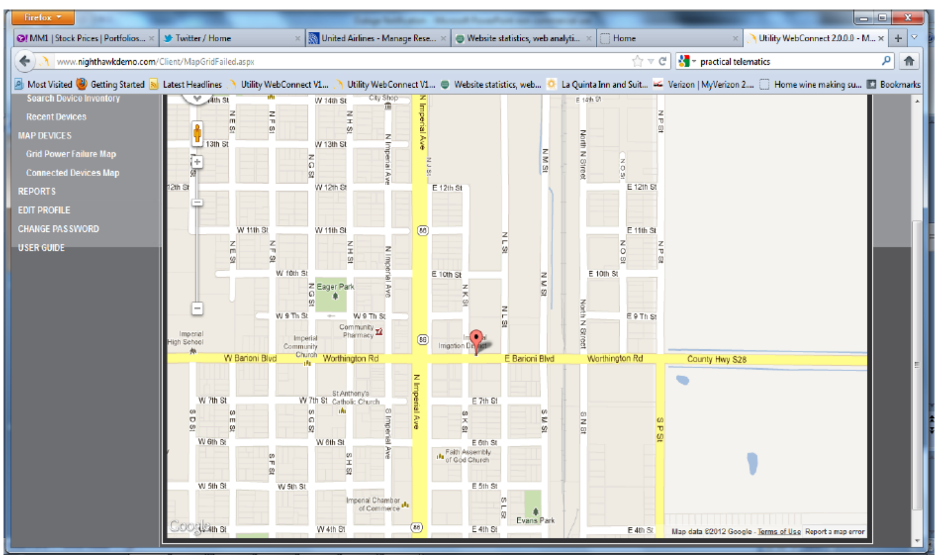
- Leveraging existing wireless cell network,
- Eliminating the need for a drive-by van to collect data,
- Providing real-time alarm notifications,
- Minor nodes reporting immediately,
- Enabling quicker response to open limiters or overload, and

- Unit reports providing comprehensive views (i.e., timestamp and location of alarm with mapping view, unit number, ID number, last time and location the unit was powered on, and last time and location the unit reported data). Figure 3 and Figure 4 below show examples of screenshots that are available to NSTAR that display real-time alerts.

Figure 3. Example Screenshot of Unit Report Tabular View

Command	Time Command Issued	Command Status	Time Command Status Reported
HomeOwner Button Pressed	12/16/2013 8:37:20 AM	contactor closed by home owner /ARM button being p	12/16/2013 8:37:20 AM
HomeOwner Button Pressed	12/16/2013 8:22:18 AM	contactor closed by home owner /ARM button being p	12/16/2013 8:22:18 AM
HomeOwner Button Pressed	12/16/2013 8:07:25 AM	contactor closed by home owner /ARM button being p	12/16/2013 8:07:25 AM
HomeOwner Button Pressed	12/16/2013 7:52:23 AM	contactor closed by home owner /ARM button being p	12/16/2013 7:52:23 AM
HomeOwner Button Pressed	12/16/2013 7:37:26 AM	contactor closed by home owner /ARM button being p	12/16/2013 7:37:26 AM
HomeOwner Button Pressed	12/16/2013 7:22:32 AM	contactor closed by home owner /ARM button being p	12/16/2013 7:22:32 AM
HomeOwner Button Pressed	12/16/2013 7:07:32 AM	contactor closed by home owner /ARM button being p	12/16/2013 7:07:32 AM
HomeOwner Button Pressed	12/16/2013 6:52:31 AM	contactor closed by home owner /ARM button being p	12/16/2013 6:52:31 AM

Figure 4. Example Screenshot of Unit Report Mapping View



While testing the wireless minor node communications, NSTAR found that it was difficult to send the wireless signal from the node inside the manhole to the nearest wireless tower. However, NSTAR also found it difficult to find a commercially-available manhole cover that facilitates wireless communications and is durable to street traffic and winter weather. Thus, NSTAR worked closely with vendors to design a traffic-durable manhole cover that is also suitable to attach a wireless antenna.

NSTAR also made the following design improvements to the minor nodes:

- Added a fully connectorized enclosure, with a clear molded metal oxide varistor (MOV) circuit board to protect the node against underground secondary fault current;
- Used an IP68 connecter as a RTU alarm, which is a water proof connector suitable for underground applications
- Incorporated a detachable power supply cable to enable easy maintenance and replacement of the units; and
- Added a detachable and chainable sensor harness to facilitate easy additions of sensors without the need of additional units.

Finally, the major nodes were originally designed using a larger, less accurate current transformer (CT) sensor; these were improved to use a smaller, more accurate CT sensor.

3.3 Impact Metrics and Benefits Analysis

As of the end of January 2014, NSTAR has installed 436 distribution feeder monitors/indicators, using $3,669,609 of project funding and $3,669,609 of DOE cost share. NSTAR's most recent Build Metrics report with this information is attached in Appendix B.

NSTAR has not yet collected sufficient information to report on any of the project's impact metrics.

4 Conclusions

This section presents the conclusions from the installation phase of NSTAR's Urban Grid Monitoring and Renewables Integration project, including the potential implications of the project's findings for commercial-scale development and deployment across the U.S. More complete findings are expected once the data analysis and commissioning phases of the project are completed.

Minor Node Instrumentation

The minor node instrumentation used in this project leverages a unique and low-cost approach to monitoring underground grid points and may provide a new, more cost effective way to deploy such systems in urban grids across the U.S. NSTAR has developed the product, which has been manufactured by the vendor, and is committed to pursuing a path that leverages flexible, standards based interconnectivity should the approach prove successful. NSTAR has a licensing arrangement with the vendor to commercialize the technology upon successful demonstration of its capabilities. Thus far, the new minor node technology and approach has shown to be viable on NSTAR's grid using the existing cellular network. The visibility provided by the minor nodes, in conjunction with the other project instrumentation, will provide the information needed to more proactively determine problem areas on the grid and perform maintenance where necessary to avoid larger problems.

Inverter-Based Distributed Resource Deployment

This demonstration project will also help facilitate large-scale deployment of inverter-based distributed resources such as solar PV and electric vehicles, which NSTAR and other utilities have seldom pursued in the past due to safety and grid stability concerns. This project will lay the groundwork for nationwide deployment of these inverter-based distributed resources in major urban areas across the U.S. In addition, this project will help the development of preventive maintenance programs for secondary area networks in urban areas across the country.

Lessons Learned during the Installation Phase

Finally, NSTAR also identified the following findings and associated lessons learned from the installation phase of the project that NSTAR recently completed:

- *Finding*: Downtown Boston's permitting policies caused delays, and NSTAR did not originally anticipate difficulties due to traffic and the need to work off-peak hours.
  Lesson Learned: The project timeline and budget should account for the various spatial and temporal challenges that occur when working in dense urban areas.

- *Finding*: Manhole cleaning and water plumbing incurred additional costs which NSTAR had not originally accounted for.
  Lesson Learned: Manhole cleaning and water plumbing costs should be incorporated into the project budget.

- *Finding*: Signals sent from inside the underground manhole transmitted poorly and created challenges for the receivers to properly read the data packet. Finding a suitable manhole and antenna location to accommodate traffic load and winter weather also proved to be difficult.
  Lesson Learned: Optimizing manhole and antenna locations is imperative to high quality and uninterrupted data transfer.

- *Finding*: The system generated false alarms due to an incorrectly set current limit. NSTAR originally set this limit based on customer load profiles in the area for which the utility did not have sufficient data.
  Lesson Learned: The current limit should either be less stringently set, or a more detailed customer load profile should be understood prior to setting the alarms.

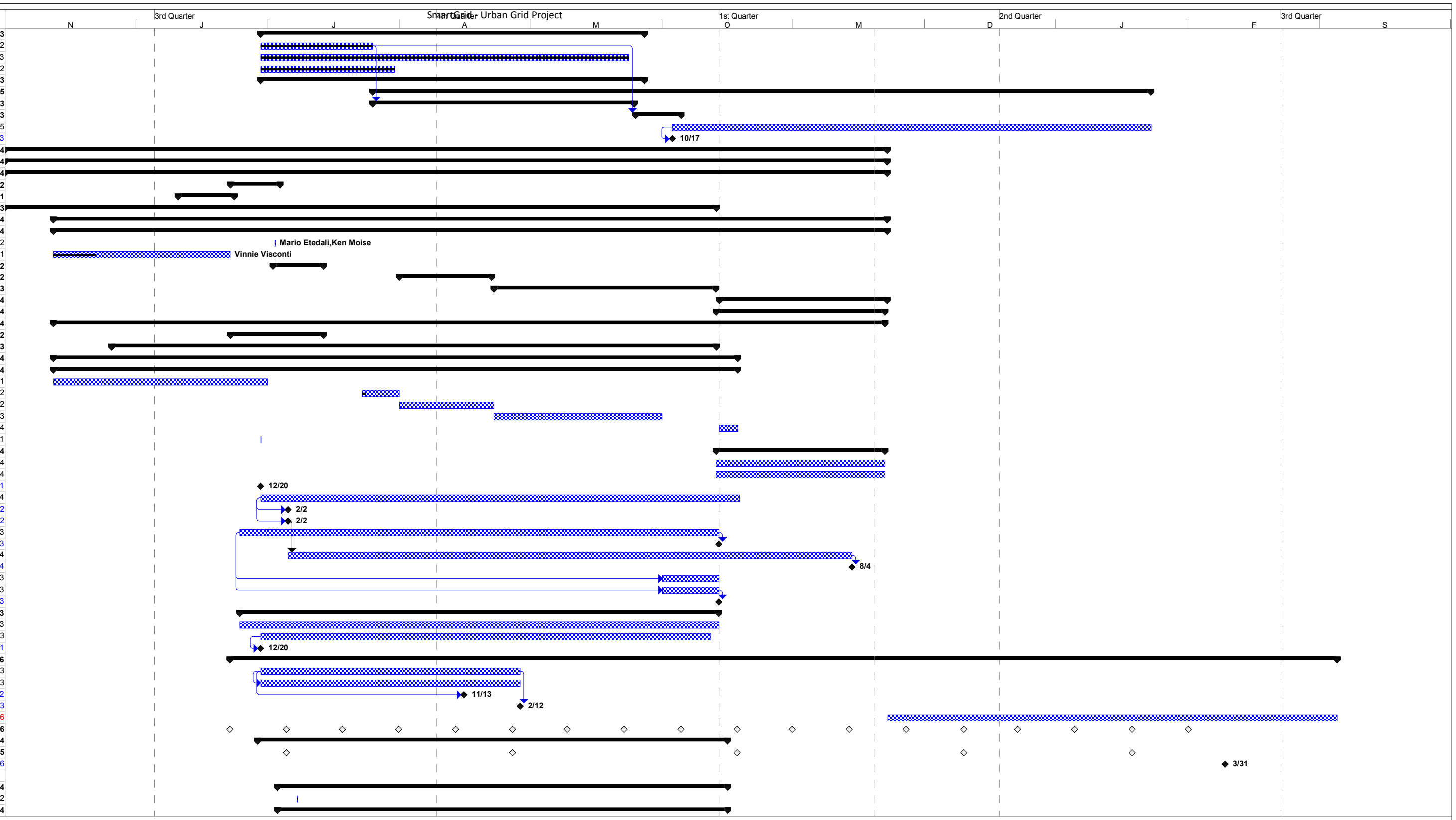
NSTAR expects to learn additional lessons and develop best practices upon completion of the data analysis and commissioning phases of the project.

Appendix A Project Schedule – GANTT Chart

The project schedule is summarized below in the most recent project GANTT chart. NSTAR submitted this document to the DOE in March 2014.

Smart Grid - Urban Grid Project

ID	WBS	Task Name	Start	Finish
1	1	**NSTAR - Urban Grid Monitoring Project**	**Tue 12/20/11**	**Mon 9/2/13**
2	1.1	Detailed Project Plan	Tue 12/20/11	Mon 6/18/12
3	1.2	Update PMP	Tue 12/20/11	Wed 8/7/13
4	1.3	NEPA Compliance	Tue 12/20/11	Tue 7/24/12
5	**1.4**	**System Design and Testing**	**Tue 12/20/11**	**Mon 9/2/13**
10	**2**	**Procurement**	**Tue 6/19/12**	**Wed 12/2/15**
11	**2.1**	**RFP Process**	**Tue 6/19/12**	**Fri 8/16/13**
14	**2.2**	**Contracts and Purchase Orders**	**Mon 8/19/13**	**Thu 10/31/13**
17	2.3	Procurement and Delivery	Thu 10/17/13	Wed 12/2/15
18	M	Milestone: Initial Minor Node Sensor Manufacturing	Thu 10/17/13	Thu 10/17/13
19	**3**	**Installation**	**Mon 11/1/10**	**Tue 9/30/14**
20	**3.1**	**Install Grid Monitoring Equipment**	**Mon 11/1/10**	**Tue 9/30/14**
21	**3.1.1**	**Minor Nodes**	**Mon 11/1/10**	**Tue 9/30/14**
22	**3.1.1.1**	**Documentation**	**Tue 11/1/11**	**Fri 1/20/12**
25	**3.1.1.2**	**Manufacturing - Minor Nodes**	**Mon 8/8/11**	**Mon 11/7/11**
27	**3.1.1.3**	**Pre-Construction**	**Mon 11/1/10**	**Fri 12/27/13**
45	**3.1.1.4**	**Construction**	**Tue 1/18/11**	**Tue 9/30/14**
46	**3.1.1.4.1**	**Installation in 427 Minor Nodes**	**Tue 1/18/11**	**Tue 9/30/14**
47	3.1.1.4.1.1	Training for Underground Crew	Thu 1/12/12	Thu 1/12/12
48	3.1.1.4.1.2	M&C Lookup of Targeted Manholes	Tue 1/18/11	Mon 10/31/11
49	**3.1.1.4.1.3**	**Installation of 12 Minor Nodes**	**Mon 1/9/12**	**Fri 3/30/12**
55	**3.1.1.4.1.4**	**Installation of 90 Minor Nodes**	**Wed 8/1/12**	**Fri 12/28/12**
65	**3.1.1.4.1.5**	**Installation of 200 Minor Nodes**	**Tue 1/1/13**	**Fri 12/27/13**
80	**3.1.1.4.1.6**	**Installation of 125 Minor Nodes**	**Wed 1/1/14**	**Tue 9/30/14**
94	**3.1.1.5**	**Post-Construction**	**Fri 12/27/13**	**Fri 9/26/14**
97	**3.1.2**	**Major Nodes**	**Tue 1/18/11**	**Fri 9/26/14**
98	**3.1.2.1**	**Documnetation**	**Tue 11/1/11**	**Fri 3/30/12**
101	**3.1.2.2**	**Pre-Construction**	**Fri 4/22/11**	**Fri 12/27/13**
113	**3.1.2.3**	**Construction**	**Tue 1/18/11**	**Fri 1/31/14**
114	**3.1.2.3.1**	**Installation in 89 Major Nodes**	**Tue 1/18/11**	**Fri 1/31/14**
115	3.1.2.3.1.1	M&C Lookup of Targeted Manholes	Tue 1/18/11	Fri 12/30/11
116	3.1.2.3.1.2	Installation of 12 Major Nodes	Fri 6/1/12	Tue 7/31/12
117	3.1.2.3.1.3	Installation of 40 Major Nodes	Wed 8/1/12	Mon 12/31/12
118	3.1.2.3.1.4	Installation of 35 Major Nodes	Tue 1/1/13	Mon 9/30/13
119	3.1.2.3.1.5	Issuance of 2 Major Nodes	Wed 1/1/14	Fri 1/31/14
120	3.1.2.4	Communication of Major Nodes	Tue 12/20/11	Tue 12/20/11
121	**3.1.2.5**	**Post-Construction**	**Fri 12/27/13**	**Fri 9/26/14**
122	3.1.2.5.1	Close-Out Work Orders	Fri 12/27/13	Fri 9/26/14
123	3.1.2.5.2	Data Collection	Fri 12/27/13	Fri 9/26/14
124	M	Milestone: Completed Minor and Major Node Installation	Tue 12/20/11	Tue 12/20/11
125	3.2	Install Communications and Data Collection	Tue 12/20/11	Mon 2/3/14
126	D3	Decision: Major Node Communications Systems Review	Thu 2/2/12	Thu 2/2/12
127	M	Milestone: Validated Communications w/ Major- and Minor- Nodes	Thu 2/2/12	Thu 2/2/12
128	3.3	System Integration	Wed 11/16/11	Tue 12/31/13
129	M	Milestone: Meaningful and Useable Monitoring	Tue 12/31/13	Tue 12/31/13
130	3.4	Acceptance Testing	Fri 2/3/12	Mon 8/4/14
131	D4	Decision: Operational Readiness Review	Mon 8/4/14	Mon 8/4/14
132	3.5	Training	Tue 10/1/13	Tue 12/31/13
133	3.6	PV Test Site Validation	Tue 10/1/13	Tue 12/31/13
134	D5	Decision: Review of System Readiness for PV Integration	Tue 12/31/13	Tue 12/31/13
135	**4**	**Operations**	**Wed 11/16/11**	**Tue 12/31/13**
136	4.1	Commissioning and Operation of Urban Grid Monitoring	Wed 11/16/11	Tue 12/31/13
137	4.2	Integration of Customer PV	Tue 12/20/11	Wed 12/18/13
138	M	Milestone: Acceptability of PV into Urban Grid	Tue 12/20/11	Tue 12/20/11
139	**5**	**Data Collection, Analysis, and Reporting**	**Mon 10/31/11**	**Thu 9/29/16**
140	5.1	Develop Metrics and Benefits Reporting Plan	Tue 12/20/11	Tue 2/12/13
141	5.2	Baseline for Evaluating Project Performance	Tue 12/20/11	Tue 2/12/13
142	M	Deliverable: Draft Metrics and Benefits Reporting Plan to DOE	Tue 11/13/12	Tue 11/13/12
143	M	Deliverable: Final Metrics and Benefits Reporting Plan to DOE	Tue 2/12/13	Tue 2/12/13
144	6.2	Data Collection, Analysis, and Reporting	Wed 10/1/14	Thu 9/29/16
145	**M**	**Deliverable: Build Metrics Reports to DOE**	**Mon 10/31/11**	**Mon 2/1/16**
164	**M**	**Deliverable - Reporting for Minor/Major Node**	**Thu 12/15/11**	**Wed 1/15/14**
333	**M**	**Deliverable: TPR and Impact Metrics Reports to DOE**	**Tue 1/31/12**	**Mon 11/2/15**
339	M	Deliverable: Final Technical Report to DOE	Thu 3/31/16	Thu 3/31/16
340				
341	**1.4**	**Department of Energy**	**Mon 1/16/12**	**Wed 1/15/14**
342	1.4.1	Kick-Off Meeting	Fri 2/17/12	Fri 2/17/12
343	**1.4.3**	**Invoice for UGM**	**Mon 1/16/12**	**Wed 1/15/14**



Project: Smart Grid - UrbanGridMonito

Task	Summary	External Milestone	Inactive Milestone	Duration-only	Start-only	External Milestone	
Split	Project Summary	Inactive Task	Inactive Summary	Manual Summary Rollup	Finish-only	Progress	
Milestone	External Tasks	Inactive Milestone	Manual Task	Manual Summary	External Tasks	Deadline	

Appendix B Build Metrics Report

The most recent Build Metrics Report is attached below. NSTAR submitted this document to the DOE for Q4 2013.

AMI Assets - Build Metrics

All data should be cumulative. Project data pertains to the assets or programs that are funded by the ARRA and Recipient Cost Share. System data should include both project data and any like assets or programs that are deployed in the entire service territory. The system value should be equal to or greater than the project value.

AMI End Points Installed	Units	Project	System
End Points (meters) installed and operational	#		
Portion of customers with AMI: residential	#		
Portion of customers with AMI: commercial	#		
Portion of customers with AMI: industrial	#		

Implemented Meter Features	Units	Project	System
Reading interval for residential meters	minutes		
Reading interval for commercial meters	minutes		
Reading interval for industrial meters	minutes		
Remote Connect/Disconnect: is feature implemented?	yes/ no	☐	☐
Remote Connect/Disconnect: number of meters with feature implemented	#		
Outage Reporting: is feature implemented?	yes/ no	☐	☐
Outage Reporting: number of meters with feature implemented	#		
Power Quality Measurement: is feature implemented?	yes/ no	☐	☐
Power Quality Measurement: number of meters with feature implemented	#		
Tamper Detection: is feature implemented?	yes/ no	☐	☐
Tamper Detection: number of meters with feature implemented	#		
Other feature implemented	yes/ no	☐	☐
Other feature: number of meters with feature implemented	#		
Other feature implemented	yes/ no	☐	☐
Other feature: number of meters with feature implemented	#		
Other feature implemented	yes/ no	☐	☐

Implemented Meter Features

	Units	Project	System
Other feature: number of meters with feature implemented	#		

Implemented Enterprise Integration

	Units	Project	System
Billing System: is integration complete?	yes/ no	☐	☐
Customer Information System: is integration complete?	yes/ no	☐	☐
Outage Management System: is integration complete?	yes/ no	☐	☐
Distribution Management System: is integration complete?	yes/ no	☐	☐
Other Enterprise Systems: is integration complete?	yes/ no	☐	☐

AMI System Descriptions

	Project	System
Backhaul Network	Since NSTAR only expects to deploy a small number of AMI meters as part of this project, NSTAR is not replacing or upgrading its back-end metering systems as part of this project.	Not Applicable
Meter Communication Network	Since NSTAR only expects to deploy a small number of AMI meters as part of this project, NSTAR is not replacing or upgrading its back-end metering systems as part of this project.	Not Applicable
Headend System	Since NSTAR only expects to deploy a small number of AMI meters as part of this project, NSTAR is not replacing or upgrading its back-end metering systems as part of this project.	Not Applicable
Meter Data Management System	Since NSTAR only expects to deploy a small number of AMI meters as part of this project, NSTAR is not replacing or upgrading its back-end metering systems as part of this project.	Not Applicable

AMI System Descriptions

	Project	System
Meter Data Analysis	Since NSTAR only expects to deploy a small number of AMI meters as part of this project, NSTAR is not replacing or upgrading its back-end metering systems as part of this project.	Not Applicable
Other Meter Feature		
Other Meter Feature		
Other Meter Feature		

AMI Enterprise Integration Descriptions

	Project	System
Billing System	Meters will not be integrated with NSTAR's system in this way.	Not Applicable

AMI Enterprise Integration Descriptions

	Project	System
Customer Information System	No data related to this project will go through NSTAR's CIS system.	Not Applicable
Outage Management System	Meters will not be integrated with NSTAR's system in this way.	Not Applicable
Distribution Management System	Meters will not be integrated with NSTAR's system in this way.	Not Applicable
Other Enterprise Systems	Meters will not be integrated with NSTAR's system in this way.	Not Applicable
Additional Project Descriptions		

AMI Installed Costs

	Units	Project Funded	Cost Share
Back Office Systems	$		
Communications Equipment	$		
AMI Smart Meters	$		

AMI Installed Costs	Units	Project Funded	Cost Share
Other Costs	$		

Other Costs Description

Distributed Energy Resources - Build Metrics

All data should be cumulative. Project data pertains to the assets or programs that are funded by the ARRA and Recipient Cost Share. System data should include both project data and any like assets or programs that are deployed in the entire service territory. The system value should be equal to or greater than the project value.

Distributed Energy Resources	Units	Project	System
Distributed generation: number of units	#		4,343
Distributed generation: installed capacity	kW		238,892.96
Distributed generation: total energy delivered	* kWh		
Energy storage: number of units	#		
Energy storage: installed capacity	kW		
Energy storage: total energy delivered	* kWh		
Plug-in electric vehicles charging points: number of units	#		
Plug-in electric vehicles charging points: installed capacity	kW		
Plug-in electric vehicles charging points: total energy delivered	* kWh		
DER/DG interconnection equipment: number of units	#		4,343

* *Energy delivered should be reported just for the quarter being reported, not cumulative for the project to-date.*

Distributed Energy Resource Descriptions

	Project	System
Distributed Generation Interface Description	NSTAR does not currently own or plan to own any DG. All DG on the system is customer-owned. Thus, NSTAR will track and report this metric at the system level, but not the project level.	NSTAR interfaces with DG customer by the following means. For large systems, NSTAR installs a re-closer to trip facility off line under certain conditions. For small inverter based DG the customer's inverter (UL 1741 listed) is required to trip off line when the utility power is lost and will not allow the system to come back on line again until the utility power is back for 5 minutes. If the

Additional Project Descriptions

Distributed Energy Resources' Installed Costs	Units	Project Funded	Cost Share
DER Interface Control Systems	$		
Communications Equipment	$		
DER/DG Interconnection Equipment	$		
Renewable DER	$		
Distributed Generation Equipment	$		
Stationary Electric Storage Equipment	$		
PEVs and Charging Stations	$		
Other Costs	$		

Other Cost Description

Electric Distribution System Assets - Build Metrics

All data should be cumulative. Project data pertains to the assets or programs that are funded by the ARRA and Recipient Cost Share. System data should include both project data and any like assets or programs that are deployed in the entire service territory. The system value should be equal to or greater than the project value.

Implemented Distribution Devices	Units	Project	System
Portion of system with SCADA	%		
Portion of system with Distribution Automation (DA)	%		
Automated Feeder Switches: number of devices installed	#		
Automated Capacitors: number of devices installed	#		
Automated Regulators: number of devices installed	#		
Feeder Monitors: number of devices installed	#	436	436
Remote Fault Indicators: number of devices installed	#		
Transformer Monitors (line): number of devices installed	#		
Smart Relays: number of devices installed	#		
Fault Current Limiter: number of devices installed	#		
Other devices installed	#		
Other devices installed	#		
Other devices installed	#		

DA Applications in Operation	Units	Project	System
Fault Location, Isolation, and Service Restoration (FLISR): is this application in operation?	yes/ no	☐	☐
Voltage Optimization: is this application in operation?	yes/ no	☐	☐
Feeder Peak Load Management: is this application in operation?	yes/ no	☐	☐
Microgrids: is this application in operation?	yes/ no	☐	☐
Other DA Application: is this application in operation?	yes/ no	☐	☐

Distribution Management System Integration

	Units	Project	System
AMI: is integration complete?	yes/ no	☐	☐
Outage Management System: is integration complete?	yes/ no	☐	☐
Transmission Management System: is integration complete?	yes/ no	☐	☐
Distributed Energy Resources: is integration complete?	yes/ no	☐	☐
Other Systems: is integration complete?	yes/ no	☐	☐

Distribution Device Description

	Project	System
SCADA	Not Applicable	Not Applicable
Portion of system with SCADA	Not Applicable	Not Applicable
Portion of system with DA	Not Applicable	Not Applicable
DA devices	Not Applicable	Not Applicable

Distribution Device Description

	Project	System
DA communications network	Not Applicable	Not Applicable
Other device	Not Applicable	Not Applicable
Other device	Not Applicable	Not Applicable
Other device	Not Applicable	Not Applicable

Distribution Application Descriptions

	Project	System
FLISR	Not Applicable	Not Applicable

	Project	System
Voltage Optimization	Not Applicable	Not Applicable
Feeder Peak Load Management	Not Applicable	Not Applicable
Microgrids	Not Applicable	Not Applicable
Other DA Applications	Not Applicable	Not Applicable

Distribution Management Integration Descriptions

	Project	System
AMI	Not Applicable	Not Applicable
Outage Management	Not Applicable	Not Applicable

Distribution Management Integration Descriptions

	Project	System
Transmission Management	Not Applicable	Not Applicable
DER Systems	Integration with the customer PV installations will have implications for the secondary system and will be tracked.	
Distribution Management System		
Other Systems		
Additional Project Descriptions		

Distribution Systems Installed Costs

	Units	Project Funded	Cost Share
Back Office Systems	$		
Distribution Management System	$		
Communications Equipment and SCADA	$		

Distribution Systems Installed Costs	Units	Project Funded	Cost Share
Feeder Monitor/Indicator	$	3,669,609	3,669,609
Substation Monitors	$		
Automated Feeder Switches	$		
Capacitor Automation Equipment	$		
Regulator Automation Equipment	$		
Fault Current Limiter Equipment	$		
Cost of other devices installed	$		
Cost of other devices installed	$		
Cost of other devices installed	$		
Other Costs	$		

Other Cost Description