Final Report R20-05

Independent Assessment of Dislodged Manhole Covers

Prepared for

The Commonwealth of Massachusetts
Department of Telecommunications & Energy

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Contents

Legal Notice........................................................................................................................................v

Executive Summary ...........................................................................................................................vii

Section 1 Background and Perspective ......................................................................................... 1-1
  1.1 Underground Electric Distribution Systems ........................................................................... 1-1
  1.2 Manhole Events ..................................................................................................................... 1-2
  1.3 Causes of Dislodged Manhole Covers .................................................................................... 1-3
    1.3.1 Energy Release in Manholes .......................................................................................... 1-3
    1.3.2 Feeder Faults .................................................................................................................. 1-4
    1.3.3 Overloads ...................................................................................................................... 1-4
    1.3.4 PILC Cable Failure Modes ............................................................................................ 1-5
  1.4 Mitigation Methods for Dislodged Manhole Covers .............................................................. 1-7
  1.5 History of Manhole Events ..................................................................................................... 1-9
    1.5.1 Other Studies Relating to Manhole Events .................................................................... 1-10
  1.6 Industry Research Regarding Manhole Event Mitigation ................................................... 1-10

Section 2 Recommendations ............................................................................................................ 2-1
  2.1 Recommendation 1: Definition of Manhole Events .............................................................. 2-1
  2.2 Recommendation 2: Inspection and Maintenance Practices ................................................ 2-2
  2.3 Recommendation 3: Splicing Logs ....................................................................................... 2-3
  2.4 Recommendation 4: Failure Analysis and Trends ............................................................... 2-4
  2.5 Recommendation 5: Data Collection and Reporting ............................................................ 2-5
  2.6 Recommendation 6: Inter-Company Cooperation ............................................................... 2-6
  2.7 Recommendation 7: Outreach ............................................................................................ 2-6

Section 3 NSTAR ................................................................................................................................. 3-1
  3.1 Underground Systems .......................................................................................................... 3-1
    3.1.1 Design and Integrity of the Underground System .......................................................... 3-1
    3.1.2 Underground Distribution System Metrics ................................................................. 3-5
  3.2 Manhole Maintenance and Inspection Practices ................................................................. 3-6
  3.3 Manhole Event Records and Trends ..................................................................................... 3-7
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Executive Summary

Introduction and Scope
Beginning in June 2004, a number of manhole covers were dislodged on the underground electric distribution systems of electric companies regulated by the Massachusetts Department of Telecommunications & Energy (DTE). Several of these manhole events reportedly caused injuries to persons and property. As a result, Siemens Power Technologies International (PTI) was retained to perform an independent assessment of the potential causes and remedies for dislodged manhole covers on the underground systems of:

- National Grid – comprised of Massachusetts Electric Company and Nantucket Electric Company
- Western Massachusetts Electric Company (WMECo) – an operating division of Northeast Utilities
- Unitil – comprised of Fitchburg Gas & Electric Light Company

Objectives
The overall objective of this project is to provide an independent assessment of the potential causes and remedies of manhole events, and provide recommendations for future action to assure the integrity of underground electrical distribution systems in Massachusetts electric companies. More specifically, the project requires PTI’s assessment and opinion regarding:

- Adequacy of maintenance and inspection practices for underground facilities
- Adequacy of record keeping practices
- Adequacy of remediation plans and their implementation
- Adequacy of practices to anticipate risk of future failures
- Causes and remedies for dislodged manhole covers
- Whether changes in manhole design, circuitry, or equipment have contributed to occurrences
- Whether occurrences have increased since March 1, 1998
- Actions that should be taken by non-regulated entities
- Further actions to improve the integrity of the underground systems and ensure public safety
Executive Summary

Approach and Methodology
PTI conducted its assessment during the period of June through August 2005. A team of five consultants participated in the project along with DTE Staff involvement and guidance. More specifically, PTI’s approach and methodology included the following elements:

- Review and analysis of all materials and reports compiled by the DTE for each of the four companies under study.
- Individual project kickoff meetings with management representatives from each of the companies and DTE Staff.
- Submission of a comprehensive data request to each company (see Appendix E for details) and subsequent review and analysis of responses.
- Preparation of a mid-project briefing and presentation to DTE Staff for comment and discussion.
- Team interviews with a total of 26 members of the four companies’ power delivery management organizations and technical staffs (see Appendix F for details).
- Preparation of findings and summary of proposed recommendations presented to DTE Commissioners and Staff for comment and discussion.
- Preparation and submission of a draft final report to the electric companies for comments, questions, and factual verification.
- Preparation and submission of the final report.

In addition to the above, PTI prepared and submitted monthly project activity reports to the DTE (see Appendix G).

Overall Conclusion and Findings
In general, Massachusetts underground electric distribution manhole systems would substantially benefit from a more active and anticipatory program to inspect, test, and maintain underground facilities. This is primarily due to the belief that manhole events are relatively infrequent and, therefore, a program of scheduled manhole inspections and repairs lacks sufficient cost benefit to become part of a company’s standard operating and maintenance procedures. As a result, we find a number of improvement opportunities exist to enhance the electric utilities’ current efforts to predict and mitigate manhole events. These improvement opportunities span the following categories:

- definition of manhole event
- inspection and maintenance practices
- logs of new and repair splices
- failure analysis and trends
- data collection and reporting
• inter-company cooperation

In addition, there is opportunity for the DTE to reach out and attempt to engage the non-jurisdictional operators of underground electric distribution systems (e.g., municipal utilities) in a cooperative effort to enhance public safety through manhole event mitigation.

Summary of Recommendations
Recommendations have been developed in each of the improvement opportunity categories shown above. They are intended to focus attention on underground electric distribution manhole systems and thereby reduce hazards they may pose to public safety while improving the reliability performance of the systems. The specific recommendations for each category are as follow:

➢ **Definition of Manhole Event:** Broaden the definition to include smoke, fire, and explosions with and/or without dislodged manhole covers.

➢ **Inspection and Maintenance Practices:** Implement a program designed to inspect all manholes over the five-year period beginning January 1, 2006 and create a database of manhole conditions and required repairs. The resulting data should be used to prioritize future manhole inspections and/or determine an appropriate periodic re-inspection cycle for each individual company. Additionally, adopt a standardized repair priority schedule and track repair backlogs by priority.

➢ **Splicing Logs:** Maintain a database of splices and splice repairs made by employees and contractor crews in order to determine possible workmanship issues and related training needs.

➢ **Failure Analysis and Trends:** Perform field failure analysis for all manhole events. Analysis should be performed by employee(s) trained in forensic failure analysis. Prepare annual trend assessments of root-cause failure analysis results and submit to the DTE.

➢ **Data Collection and Reporting:** Employ standardized manhole inspection and manhole event data collection forms that maximize checklists and minimize the need for free-form comments. Submit quarterly and annual reports with prescribed summary analysis to the DTE. Submit individual standardized reports on all events involving dislodged covers.

➢ **Inter-Company Cooperation:** Create a Working Group comprised of representatives from the four companies and DTE Staff to meet quarterly for sharing information on manhole event trends, root cause analyses, research studies, results of pilot programs, new technologies, and lessons learned. The Working Group could also address broader issues related to electric distribution reliability and safety, as appropriate.

➢ **Outreach:** Survey non-jurisdictional operators of underground electric distribution systems regarding manhole events and manhole inspection practices, and determine their interest in participating in the Working Group.
1.1 Underground Electric Distribution Systems

Underground electric distribution duct-manhole systems (see Appendix A for detailed discussion) require a significant number of splices and connections to be made to the various primary and secondary cables. These splices and connections are made in underground manholes. In order to allow access for construction and maintenance, manholes have openings on the top, which are fitted with manhole covers (typically made of steel or cast iron) that are removed when necessary to allow entrance to the manhole.

Figure 1-1 Photograph of Solid Manhole Cover

Underground electrical systems are significantly different from overhead electrical systems. Overhead electrical systems rely on air as the primary insulating medium, except for the support insulators at structures. Splices and connections are relatively simple and are in the
open air. In contrast, underground electrical systems rely on insulating material along the entire length of a cable to provide the necessary insulation. This insulating material may be either fluid impregnated paper-insulated lead-covered cable (PILC), or solid dielectric such as ethylene propylene rubber (EPR) or cross-linked polyethylene (XLPE). Splices and connections are much more complicated than with overhead construction because of the need to maintain insulation integrity.

Underground systems are very unforgiving compared to overhead systems. A phase-to-ground fault on an overhead distribution line (for example a fault resulting from a lightning strike) may not cause damage to the line components. Usually, the line can be reenergized in a few seconds, as soon as the hot gases caused by the fault arc have had time to dissipate. In contrast, a phase-to-ground fault on an underground system causes significant damage to the affected insulation. This damage precludes restoration of the circuit until repairs are made. Because of the need to repair insulation to the necessary degree of insulation integrity in an underground system, the repair time for an underground failure can be significantly greater than for an overhead failure. Access considerations also can increase the repair time for an underground system.

Fault energy in an overhead system is dissipated in the surrounding air. Fault energy in an underground system is confined in the manholes and ducts and can result in dislodgement of the manhole covers. In addition, underground systems are also susceptible to energy released in the underground facilities from combustion of gases or oil contained in oil-filled equipment.

1.2 Manhole Events

Manhole events are typically defined by the electric distribution utility industry as follows:

1) Smoking manhole: Smoke, but no visible flame, is escaping from holes in the manhole cover or around the cover’s edge.

2) Manhole fire: Flame is visible at holes in the manhole’s cover or around the cover’s edge and the cover remains seated in the frame.

3) Manhole explosion: A release of energy from the manhole occurs, and one or more manhole covers are dislodged from their respective frames, or other debris, such as cement or dirt is projected into the air.

There are two general categories of manhole explosions:

- Manhole explosions that primarily involve ignition and combustion of flammable gas. Perhaps the most common source of flammable gas in manholes is gas generated by degradation of cable insulation as a result of overloads or tracking (insulation surface electrical discharges). Flammable gas can also accumulate in a manhole as a result of ingress of gas from an external source. Natural gas can be present as a result of a leak on a nearby gas line. Sewer gas is rich in methane and can accumulate under certain conditions. Ignition of flammable gas is the mechanism often implicated when a manhole event is related to overloaded secondary cables.
Manhole explosions that primarily involve energy released in the manhole directly as a result of the fault arc. These explosions are most often associated with primary cable or splice failures, which can generate sufficient increased pressure in a manhole to dislodge the cover without the presence of combustible gas.

The methods available to mitigate the effects of manhole events differ for the two categories of causes, as discussed below.

1.3 Causes of Dislodged Manhole Covers

1.3.1 Energy Release in Manholes

Dislodged manhole covers are caused by high pressure buildups within the manhole. The most common causes for the high pressure are:

- Electric faults in a primary cable or primary cable splice
- Electric faults in a low-voltage secondary cable
- Ignition of explosive gases, such as natural gas or sewer gas, or flammable gas produced by decomposition of insulation of overloaded cables

Electrical short circuits (faults) result in the release of large amounts of energy in the fault arc. Arc energy is present for both primary and secondary cable faults, but the amount of energy is generally greater for primary faults. Sufficient pressure may be generated by the arc energy itself to cause a pressure rise sufficient to lift a manhole cover.

Overloads on secondary cables can lead to insulation deterioration and subsequent faults, especially when the manholes become filled with water. This condition is especially severe when the manhole fills with water contaminated by road salt or other chemicals that render the water electrically conducting. These faults can also occur in the absence of overloading if water is able to penetrate the insulation, especially at joints and taps.

Another source of energy release in a manhole comes from the combustion of flammable gases produced by decomposition of overheated cable insulation. Overloaded cables (whether from load current or fault current) produce quantities of combustible gases. If ignited, burning of these gases releases significant energy in the manhole. Overheated cables and accessories (splices, etc.) can produce smoke and result in smoking manholes. If ignited, a manhole fire or explosion results.

A related concern is for faults in oil-filled equipment such as switches, cable terminal compartments, and transformers. Such faults can rupture the enclosure and result in fire if filled with oil. As this equipment is frequently located in underground vaults with venting, fire and smoke emanate from the vault. The EEI AC Network Operations Reports, which were last published for the years 1959-1961, document that faults have been occurring in network transformers and the oil-filled switches on the primary side of the network transformers for decades. Faults in compartments typically result in tremendous amounts of energy delivered to the arc, producing pressures that rupture the compartment. These incidents have occurred around the country in the network systems operated by many utilities, and are an industry problem.
1.3.2 Feeder Faults

When an electric fault occurs in a primary cable or splice, an arc is formed between the central phase conductor and the grounded shield or splice. The electric system supplies energy to the arc until detected by protective devices and de-energized. The power input to the arc is dependent upon the available short circuit current. Assuming an available current of 20,000 amperes rms, and an arc voltage of 500 volts, the corresponding power input to the arc is 10 megawatts. This vaporizes conductor material and heats the surrounding air to extremely high temperatures, producing high pressures within the manhole. It has been hypothesized that prior to formation of the power arc in the cable insulation or splice, tracking within the splice or insulation may produce explosive gases, which upon formation of the power arc are ignited, adding to the pressure produced by the energy input to the power arc.

Cable failure mechanisms are illustrated in Section 1.3.4 for paper insulated lead cable (PILC).

1.3.3 Overloads

Another potentially major cause of failures is overloading of the cables, either primary or secondary, and the overloading of transformers. Overloading can cause the cable, splice, or transformer to operate at a temperature that is higher than what it is intended to operate at for a normal life expectancy. Operating at temperatures above the rated temperature does not necessarily result in an immediate failure, but starts to degrade the integrity of the electrical insulation. Overloading can degrade the insulation and ultimately result in an electrical fault. Overloading can also cause chemical deterioration of the cable insulation that results in production of flammable gases that can cause an explosion if they are ignited.

Another potential cause of damage to cables is high temperatures from the flow of short circuit current. Generally this occurs only with small cables in primary feeders in situations where the available short circuit current is high, and the clearing time is long. This can occur in a network system that has large cable for the station exits, but has very small cable for the taps to the network transformers. The protection for the small tap cable is supplied by the relaying for the station breaker. This relaying must be set to carry the full load current of the feeder. Inspection will not identify these situations.

If severe overloading does occur in primary cables and their splices, it may create conditions that permit moisture to enter into the insulation of the cable or splice. This may be from cracks on or near the wipe on splices, or non-uniform shrinkage of heat-shrink non-leded splices. This condition in a dry environment may not cause a failure. However, should water enter the manhole or duct with a cable or splice where water can be drawn into the insulation, a failure will likely occur. A failure is more probable if the water in the manhole is contaminated with road ice melting chemicals. Small cracks that will allow moisture entry into a cable or splice may not always be visible, especially if arc-proofing tape is applied over the cable and splice in the manhole. In many cases an inspection may detect a potential problem, depending on the severity of the crack or gap, presence of high water marks, and insulation on secondary taps or splices.
1.3.4 PILC Cable Failure Modes

The mechanisms involved in primary cable failures can be illustrated by consideration of aspects of paper insulated lead cables (PILC) and their splices and terminations. Other cable types have corresponding failure mechanisms.

Splices and terminations are the least reliable components in any cable system. At these locations the factory-manufactured cable will be interrupted, and field handling of the insulation will be performed in a manhole, trench, or substation. If the cable system fails, it is most likely that the failure will be associated with a section of cable that has been exposed to field handling, such as the splice or termination locations. A PILC splice has several failure modes (not in order of probability of occurrence):

- Degradation of the insulation due to contamination during installation
- Mechanical deterioration of the lead sheath
- Thermal overload of the insulation

Several possible scenarios exist for splice contamination during installation. The field conditions for splicing the cables are often not perfect, so the splicing craftsmen must be very careful during the preparation and splicing operation. Over time, contamination introduced during installation can result in electrical failure. Some of the potential areas for contamination entering the splice during the splicing operation include:

- Moisture getting into the paper tapes
- Manhole debris being inadvertently included during the taping operation of the splice
- The splice not being completely filled with compound, resulting in an imploded splice

Other problems that can occur in splicing include the possibility of a poor crimped connection between the conductors. A poor connection can result in high resistance and the splice operating at higher than normal temperature.

The lead sheath of a PILC splice creates a hermetic seal that should prevent water and other contaminants from entering the insulation. However, cracks can form over time that will allow moisture to enter the paper insulation and lead to an electrical failure. Therefore, locating leaking cables and repairing lead sheaths should result in fewer PILC cable/splice failures within manholes. The normal daily load cycle on a cable causes the cable materials to expand and contract as its temperature changes. The thermal expansion of 500 feet of a copper conductor will be about 6.5 inches when going from an ambient temperature of 20° C (68° F) to the maximum conductor operating temperature of 85° C (185° F). Most of this expansion results in cable bending, which starts where the cable already has a bend, such as at the splice location within a manhole. Repeated cable expansion and contraction may mechanically fatigue the lead sheath and eventually cracks develop. Also, the lead sheath can deteriorate at the duct mouth in the manhole and at support brackets if the porcelain insulator is missing.

The paper insulation of PILC deteriorates when exposed for extended periods to temperatures exceeding 105° C (221° F), which is the emergency operating temperature. The electrical properties of the paper insulation deteriorate, and this deterioration can lead to
Background and Perspective

a thermal runaway type electrical failure, where increasing temperature causes further deterioration, which causes additional temperature increase, and on and on. Also, paper insulation that is degraded from severe overloading may withstand normal operating voltage, but fail to withstand temporary overvoltages.

When PILC cable operates at high temperatures over a long period of time, the insulating paper becomes brittle with a degradation of mechanical strength. If fault current passes through the cable, the mechanical forces and movement can further damage the insulation and result in an electrical failure.

Imploded splices in PILC cables can be detected during manhole inspections. Even in feeders with low fault current a splice failure can ignite any flammable gases that may have accumulated in the manhole. On solidly grounded feeders with high ground fault current the consequences of a splice failure could be severe.

A lead cable splice is filled with a tar-like compound. If insufficiently filled, the lead will partially collapse (implode) over time as shown in Figure 2 (not from a Massachusetts utility). The lead covering the splice should be cylindrical. In this case, the upper surface of the outside lead is indented, appearing like a groove on the top of the splice. While not an immediate concern for failure, imploded splices should be replaced to prevent premature failure. This is an example of the kind of condition a manhole inspection program is designed to detect so that necessary repairs can be prioritized.

![Figure 2 Imploded Primary PILC Splice](image)

Imploded splices as well as other abnormal splice and cable conditions should be identified during manhole inspections. Detection of such conditions can mitigate manhole events and/or their severity. Figure 5 shows a damaged cable found during an inspection performed by PTI for a utility outside of Massachusetts.
1.4 Mitigation Methods for Dislodged Manhole Covers

There are several methods to mitigate the frequency of dislodged manhole covers due to faults in primary cables or splices in underground network systems:

- Reduce the number of faults
- Reduce the fault current magnitude
- Reduce the fault current duration

Any method that reduces the chance of an electric fault in the cable or splice will reduce the frequency of dislodged manhole covers. Examples include good workmanship when installing the cable and making the splices, loading the cable or splice within its rating, and maintenance of a dry/non-corrosive environment in the manholes.

Any method that reduces the electric power that can be transferred to an electric arc in a cable or splice will reduce the probability of dislodged manhole covers. As the available short-circuit current for an arc goes down, the power that will be transferred into the arc will
Background and Perspective

decrease proportionally, assuming arc voltage independent of available current. In general, short circuit currents on the substation buses supplying the feeders increase as the size of the substation increases. However, use of neutral reactors to ground the system can reduce the current for the single line-to-ground fault to values that are much lower than the currents for phase-to-phase faults. This approach is used by NSTAR in the networks in Boston to limit SLG fault current to 4 kA or less. It is used by National Grid in the networks in Worcester and Lynn to limit the SLG fault current to 5.6 kA and 1.9 kA respectively, where the corresponding currents for the three-phase faults are 32.9 kA and 18.2 kA respectively. Further, the installation of phase reactors in the feeders at the substation can reduce the fault current for phase-to-phase faults to much lower values than for faults on the substation bus.

Any method that reduces the electric energy that can be transferred to an electric arc in a cable or splice. For a given power level, methods that reduce the time that the arc persists will reduce the energy input to the arc. For example, use of instantaneous current relays with the feeder circuit breakers, if allowed based on coordination considerations, will reduce energy input to the fault, although the time to clear will never be less than the breaker interrupting time. As another example, use of electronic current-limiting fuses at the station, such as the G&W CLIP®, or the S&C Fault Fiter® will reduce the time that the current flows in the arc from perhaps 5 cycles with breaker to less than 1 cycle. Although these devices may be applicable in primary feeders that supply only network transformers (dedicated network feeders), they may not be applicable in non-network feeders due to coordination considerations.

Manhole inspections can be used to detect overloads by making “tong” (clamp-on ammeter) measurements of current on low-voltage cables, and by use of temperature measuring devices. Temperature measurements can also identify defective secondary cable splices or taps. In many cases an inspection may detect other potential problems such as insulation damage resulting from overloads or mechanical damage. Such damage includes insulation cracks or gaps and surface indications of excessive temperature. Another indicator of a potential problem is the presence of high water marks, especially with respect to the location of insulation on secondary taps or splices.

Anticipating the impending failure of cables, splices, and equipment requires identification of the major causes of failure, and the development of policies and practices that will eliminate the causes of failure. Mitigation methods to reduce the frequency of failures can be summarized as:

- Measures designed to reduce the frequency of cable and splice failures, including manhole inspections and improved materials and practices.

- Measures to reduce the incidence of overloaded cables. To minimize the chance of overloads occurring, load flow studies are run on the system, spot load checks are made in the field when vaults are entered for this purpose or to perform regular work, and in the case of NSTAR’s low-voltage network systems, real-time measurements are made of the load on the network transformers within the system.

These measures are intended to reduce the number of failures on the underground system. Other suggested mitigation methods are designed to limit the effect and severity of a failure once it occurs. Examples of mitigation methods for limiting the severity of failures can be summarized as:
- Measures to limit energy released in a manhole during a primary cable fault, such as fast-acting protection measures.

- Measures that allow dissipation of flammable gases to prevent explosions from occurring, or venting of gas pressure produced during a cable or splice failure. The installation of vented manhole covers has been suggested for this purpose. Vented covers allow smoke generated as a result of an incipient failure to be removed from the manhole, thus providing an alert that a problem exists. This can reduce the severity of an event from an explosion to a smoker.

- Measures that limit the trajectory of the manhole cover when subjected to high pressures. The installation of tethers (steel or composite material cables) to limit manhole cover travel has been suggested for this purpose. Use of lightweight covers has also been proposed, the theory being that a lightweight cover dislodges at a lower pressure within the manhole, thus reducing the pressure rise before the cover moves.

1.5 History of Manhole Events

Manhole events are not unique to Massachusetts, but have occurred around the United States in a number of cities for many years. For example, the Miami, Florida secondary network was about the third ac network installed in this country, constructed in 1923-1925. Isolated manhole incidents started in the 1940’s. One manhole event in Miami in 1969 involved a sustained fire in two manholes. The network was de-energized for 23 minutes to cut cables in three manholes and to open a protector before service could be restored.

The South Bend, Indiana system was converted from 27 kV to 34.5 kV in the 1980’s. Failures started soon after the conversion. The failures multiplied during single phase fault conditions that resulted in overvoltages and additional cable faults. Interruptions occurred in April and December 2000 and January, February, and March 2001. Major reconstruction of the system resulted from these failures.

Other utilities and cities in which manhole incidents have occurred are:

- Los Angeles Department of Water and Power on both 4.8 kV and 138 kV systems. One explosion at 4.8 kV lifted the 4 foot square concrete cover of the manhole.

- Tampa Electric (Tampa, Florida), which has investigated a technique for reduction of energy release during faults and mitigation of manhole incidents.

- Pittsburgh, where a female was killed by a flying manhole cover on August 1, 1991.

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4 Joe Koepfinger presentation at IEEE Insulated Conductors Committee meeting in Toronto April 8, 1998.
New York City has had numerous incidents.\(^5\)

Pacific Gas and Electric (San Francisco), where one event resulted in a manhole cover resting on the roof of a Honda automobile.

Consolidated Edison (New York), Hawaiian Electric (Honolulu), and Duquesne Lighting Company (Pittsburgh) have installed ventilating or tethered manhole covers as a result of manhole incidents.\(^6\) While this has not affected the frequency of events, these techniques are believed to have mitigated the severity of some events.

### 1.5.1 Other Studies Relating to Manhole Events

The cables in the 208 volt secondary networks that were originally installed in the 1920’s and early 30’s did not have cable limiters (special fuses for secondary cables) as they were designed with the belief that cable faults in a duct would burn clear. A fault ‘burns clear’ when the arc energy creates a gap large enough to interrupt the current and open the circuit (e.g., similar to a blown fuse). As experience was gained with secondary networks in the 20’s and early 30’s, it was found that some faults persisted and did burn clear. Cables at that time had copper conductors with different types of insulation (paper or rubber) and a lead sheath. If a fault did not burn clear, current would feed into the fault from one or both directions. With the melting temperature of the copper being 1083 degrees C, the insulation remote from the fault could be damaged, allowing the fault to spread. If the fault spread back to a manhole at either end of the duct, the fault could propagate to other cables in the manhole, and there could be a massive event.

In the 1930’s, Consolidated Edison, working with the Burndy Corporation, developed the cable limiter, basically a fuse that is installed at either end of each cable. The intent was that if a fault did not burn clear, the cable limiters at either end would melt and interrupt the fault current before the temperature of the cable insulation, remote from the fault, could reach a point that would damage the insulation. Tests were also run on cables in ducts to establish the “insulation damage curve” for the cable insulation. For very low currents, the limiter may not protect the cable insulation for intermittent arcing faults. This is why today there are still cable fires in systems that have limiters.

Questions continued, and in 1957 the AIEE Insulated Conductors Committee formed a Task Group to “Develop a device to reduce manhole fires and explosions,” chaired by an engineer from Boston Edison. This group produced a 1963 technical paper “Faster Acting Limiters for Secondary Network Systems.” Research continues to the present day. Research specifically concerning manhole events resulting in dislodged covers is addressed in Section 1.6 below.

### 1.6 Industry Research Regarding Manhole Event Mitigation

Research into causes and mitigation of manhole events has intensified within the past fifteen years. This research has been both experimental (laboratory) and analytical (mathematical)

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\(^5\) Daily News, January 31, 1997

in nature. Experimental work has been performed on manholes constructed at the Electric Power Research Institute (EPRI) Lenox laboratory. The Lenox laboratory has performed tests for Potomac Electric Power Company, Consolidated Edison, Duquesne Light, and other clients. The Hydro Quebec Institute of Research (IREQ) has conducted tests in conjunction with the Los Angeles Department of Water and Power. Analytical research on developing mathematical simulations of manhole explosions is being conducted at Georgia Institute of Technology.

The EPRI experimental work for various utilities has concentrated on the frequency and severity of manhole cover dislodgement that results from increased gas pressure in the manhole, whether from energy released as a consequence of electrical faults or from ignition of flammable gas that has accumulated in a manhole. This flammable gas may be a result of gas line leakage. It may also be a product of electrical cable insulation deterioration due to overloading or tracking. Manholes, a vault, service boxes, and various types of conduit were constructed at the Lenox laboratory to study a range of representative conditions. Ignition of gases introduced into the test manholes created explosions that were used to evaluate different possible mitigation methods, including application of cover tethers and slotted covers. The effectiveness of cover tethers remains to be demonstrated. Metal tethers are not desirable in structures with energized cables, but other materials are possibilities. The Lenox experimental work has been used as the basis for installation of vented covers by some utilities to reduce the frequency and severity of manhole events.

In addition, EPRI sponsored an earlier project performed by Underwriters Laboratories (UL) on the evaluation of gases generated by the heating and burning of underground cables. The UL study focused on the underground secondary network system, and characterized the mechanism by which overheating caused by overload currents and low voltage arcing can result in manhole events. It has been known for many years that degradation of insulation in transformers results in production of flammable gases, with different types of insulation problems resulting in different gases. Gas in oil analysis is a well-established diagnostic technique for oil filled transformers. Large power transformers are commonly tested at intervals for gas to check for incipient failures. This project extended this knowledge to the secondary network system. Among the items considered are:

- Conditions necessary for low voltage arcing and thermal decomposition of cable insulation.
- Kind and quantity of flammable gases generated from decomposition of cable insulation.
- Propagation of gases through underground facilities as related to airflow in ducts and manholes.
- Flammability limits of gases as they collect in manholes.

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- Explosive force and consequences for manhole covers.

A 1998 EPRI report\(^\text{11}\) followed up on the UL report, and focused on the explosion mechanisms within manholes and the consequences of the resulting blasts. A large variety of explosions is possible depending on details of fuel, oxidizer, geometry of the manhole installation, cover, and other parameters. For example, once a solid manhole cover has been dislodged, air from the outside can enter the manhole and result in a secondary explosion that can be as violent as the original explosion.

These two reports form the basis for the experimental tests performed by EPRI at the Lenox laboratory for individual utilities. These tests evaluated specific mitigation methods for the companies involved.

While the results of EPRI testing are not generally available without purchase of the reports from EPRI, the Georgia Tech analytical work is documented in several IEEE papers. One of these papers appeared in April 2005\(^\text{12}\) and deals with methods of mitigating the effects of explosions in manholes when they occur. Mitigating the effects of explosions as they occur is contrasted with methods proposed for preventing manhole explosions by monitoring and reporting conditions in manholes. Monitoring methods may be cumbersome, expensive, and fail to prevent all events, and as a consequence are not widely applied.

The theoretical background for predicting the effects of gas explosions in manholes is given in an earlier paper.\(^\text{13}\) The analysis is based on combustion of a methane-air mixture in a manhole, and predicts changing pressure and temperature of the gas in the manhole as a function of time. The analytical equations are contained in a computer program that predicts the general temperature and pressure rise that results from a gaseous explosion within a manhole. These pressure rise calculations are then used to predict the motion of the manhole cover if it is dislodged from its normal position. A subsequent paper on the theoretical basis for pressure and temperature changes as a result of short circuit faults appeared in July 2005.\(^\text{14}\) This analysis demonstrates that it is possible for a short circuit failure to release sufficient energy within a manhole to dislodge the cover without the additional energy release provided by the combustion of flammable gases. Thus, the analytical model confirms that there are two independent mechanisms that can account for manhole cover dislodgements: combustion of accumulated gases and energy directly released by the electrical fault itself.

Mitigation methods evaluated by the Georgia Tech analytical methods include:

- Bolted covers. This method presumes the manhole cover is bolted to the manhole to isolate the exterior environment from the effects of the explosion. This method is


unsatisfactory as pressures within the manhole may be sufficiently high to break the bolts or to lift the manhole roof itself.

- Tethered covers. A proposed mitigation method is to restrain the movement of the manhole cover by means of a tether. The tether must have sufficient slack length to vent the gases produced in the manhole by the cause of the event, and it must be sufficiently strong to withstand the forces involved in restraint of the movement of the heavy cover. This method fails to reduce the incidence of manhole cover dislodgements.

- Lightweight covers. Lightweight covers move more quickly at a lower pressure than cast iron covers, allowing the pressure within the manhole to be relieved sooner. As a consequence, the lightweight covers absorb less energy and move less distance than conventional covers. They can be more easily tethered because of their lower mass.

- Vented covers. Vented covers have an advantage because they help prevent lightweight combustible gases from accumulating in a manhole, reducing the possibility of an explosion. However, the presence of vents in the manhole cover does not materially reduce the predicted movement of the cover in case of a severe explosion.

- Gas displacing methods. These methods are based on the premise of reducing the amount of gas that can accumulate inside a manhole. A flexible membrane is inserted in the manhole and filled with an inert gas to fill a portion of the manhole. Practical challenges limit the applicability of this approach, and it is not effective for arcing faults.

- Combinations of design methods were also evaluated.

A weakness of the Georgia Tech research is that, while it compares a comparison of the effects of various mitigation methods together with variations of other relevant parameters, comparisons with experimental data are limited. The calculated conditions are extreme, and may not be representative of all situations.

There are also some other possible mitigating factors that are not considered in the Georgia Tech papers. For example, vented manhole covers may reduce the incidence of explosions because smoke from an incipient failure is vented from the manhole and thus visible. The concentration of flammable gases in the manhole is reduced, and earlier warning of a problem may be received by the utility in time for action to be taken before an explosion occurs. Thus, explosive manhole events may be reduced to smoking manhole events by use of slotted covers.

Other research has focused on the nature of the fault arc itself in an attempt to understand some of the phenomena associated with secondary cables.\(^\text{15}\) This project was conducted at the Hydro Quebec Institute of Research (IREQ) and sought to explain why faults sometimes would last for long periods of time when the available short circuit current and protection methods would indicate the fault should have been cleared. One theory was that some faults

Background and Perspective

are “intermittent,” that is, the fault current does not flow continuously, but starts and stops frequently during the event. To test the theory, intermittent faults were generated in cables in ductbanks in the IREQ laboratory. Among the items studied were arc reignition frequency, arc voltages and currents, current flow between arcing periods, explosion of gases produced during intermittent faults, and cable erosion during the tests and in the field. The level of moisture and dirt present turned out to be important factors in the formation of intermittent faults. The presence of salt in the water was virtually necessary to secure intermittent faults.

The typical pattern described in the paper for development of an intermittent fault is a cable with a weakness in its insulation in a duct containing polluted water. The fault starts with an initial current of a few amperes flowing through the water. This current continues to degrade the insulation and produces hydrogen and oxygen as a result of electrolysis of the water. The current gradually increases, but no arc is formed at this point, although combustible gases may be formed. This condition may persist for days, and may disappear if the duct dries out. Eventually an arc will form. The arc will lengthen, its voltage drop increases, and the arc extinguishes. Later, the arc will form again. The insulation suffers further damage as the arc appears and disappears. Eventually either the flammable gases created by degradation of the cable insulation ignite, or a sustained fault develops.

One problem with intermittent faults is that they may not cause the operation of fuses or cable limiters. Fuses and limiters have time-current curves determined by their manufacturer, and the intermittency of the faults allows the protection to cool between fault periods below the time-current curve levels. Thus, the protection may not be effective against intermittent faults. Development of a satisfactory protection scheme awaits future research.

The IREQ research presents a mechanism that helps to explain some of the phenomena that have been observed in manhole events associated with failures of secondary cables, including the ability of a fault to persist for a sufficiently long time to generate appreciable flammable gases and also provide an ignition source. Together with the work conducted at EPRI and Georgia Tech, a picture has emerged to allow application of methods to reduce the frequency and severity of manhole events.
Section 2

Recommendations

Based on an independent assessment of information provided by the four companies, interview meetings with representatives from the management and technical staffs of each company, and our experience in dealing with the issues involved in mitigating manhole events, PTI has developed a set of recommendations to be considered for implementation by the companies. Following each recommendation is a discussion intended to provide context and rationale for the recommendation.

2.1 Recommendation 1: Definition of Manhole Events

PTI recommends the following definition for manhole events, which addresses smoking manholes, manhole fires, and manhole explosions:

*Smoking Manhole* – A manhole event in which smoke is visible, but no visible flame is escaping from the edge of the manhole cover or from holes in the cover.

*Manhole Fire* – A manhole event in which the cover remains seated in its frame and there is visible flame escaping from the cover's edge or from holes in the cover.

*Manhole Explosion* – A manhole event in which a release of energy from the manhole occurs and the manhole cover is dislodged from its frame, or debris such as cement and dirt is projected into the air although the manhole cover remains seated.

Discussion

The current definition used by the Massachusetts companies narrowly applies only to manhole explosions that cause dislodged manhole covers. This definition is the starting point for data collection and analysis of manhole event causes and potential remedies. As such, a narrow definition ignores a broader and more comprehensive view of the condition of the underground system, and in all likelihood ignores the majority of abnormal events that occur (i.e., smoke, fires, and explosions without dislodged covers). In addition, it is our opinion that the electric utility industry is generally moving toward the broader definition.

As a practical matter, it is difficult to justify a narrow definition that may exclude dramatic and disruptive manhole events merely because the cover is not dislodged. For example, recent manhole fires in Cambridge and Worcester, which caused significant public disruption and received considerable media attention, would not be included since they did not entail manhole cover dislodgements.

Finally, manhole event mitigation may also involve actions designed to minimize the severity of events, i.e., reduce the number of explosions as a percentage of total manhole events.
Recommendations

Another way to view mitigation of manhole event severity is for explosions to be reduced to fires, fires to smoking manholes, etc. In order to perform this analysis, information on all manhole events must be collected.

2.2 Recommendation 2: Inspection and Maintenance Practices

PTI recommends implementation of a program designed to inspect all manholes over the five-year period beginning January 1, 2006 and create a database of manhole conditions and required repairs. The resulting data should be used to prioritize future manhole inspections and/or determine an appropriate periodic re-inspection cycle for each individual company. Required repairs should be prioritized in accordance with a standardized repair priority schedule, and the resulting manhole inspection repair backlog should be monitored and tracked by priority level. (Abnormal conditions found during the manhole inspections should be recorded and reported per Recommendation 5, below.)

Discussion

Except for Unitil, which annually inspects all of its 192 manholes, NSTAR (38,000 manholes), National Grid (20,735 manholes), and WMECo (3,750 manholes) only inspect manholes upon entry for another reason. For example, manholes may be entered to tap an existing circuit, pull a new circuit through, pumped out for fault location or other purposes. It is only during such occasions that a formal manhole inspection would be performed. As a result, many if not most manholes may never be inspected or receive maintenance and repair until they experience a manhole event. This maintenance approach is sometimes known as “run to failure”, and if failure events do not create significant public safety or electric outtage issues may be a viable and cost beneficial strategy. However, it may be argued that manhole events, particularly explosions, create unacceptable hazards that sometimes result in injuries to persons and property.

Manhole inspections may be one of the best preventive and predictive tools available to companies in order to anticipate and mitigate the risk of future failures and manhole events. Based on information supplied to PTI by the Massachusetts companies, splices were implicated in about half of the 94 manhole events (i.e., events involving dislodged manhole covers) recorded. Virtually all splices on underground distribution systems are found in manholes. Although not performed as part of this study, PTI has performed manhole inspections in other jurisdictions and found splices requiring immediate repair to avert a possible manhole event. Our manhole inspection team has also found cable with damaged and/or deteriorated insulation such that the conductor was exposed. This presents a condition that may lead to an event, particularly with ingress of water into the manhole.

In a study of 177 manhole events (i.e., smoke, fires, and explosion) over a two-year period for an electric utility in another primarily urban jurisdiction, PTI found that event rates experienced in manholes that had been inspected were less than half the rates experienced in manholes that were not inspected. Additionally, we note that Unitil, which inspects its manholes annually, reported that it experienced no manhole events (i.e., events involving dislodged manhole covers) during the period January 1998 to date. While we do not claim direct correlation or causality, we find this to be interesting.

With regard to the prioritization of manhole repairs, information received from the companies showed that each one employed a different schedule for prioritizing repairs stemming from
manhole inspections. They ranged from a two-priority to a five-priority schedule for setting forth the requirements for completing maintenance activities. Shown in Appendix B.1 is our recommended template intended to provide reasonable and comprehensive guidelines for the types of conditions requiring repair and the suggested timeframes within which the repairs should be made. Additionally, the companies should monitor and track manhole inspection repair backlogs and report this information to the DTE on a quarterly basis.

In order to determine the cost of implementing a manhole inspection program, we have developed the following estimates and the assumptions on which they are based.

<table>
<thead>
<tr>
<th>Crew Size</th>
<th>Labor $/Day</th>
<th>Truck $/Day</th>
<th>Total $/Day</th>
<th>Manholes/Day</th>
<th>$/Manhole</th>
</tr>
</thead>
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<td>$100</td>
<td>$1,100</td>
<td>8</td>
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<tr>
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<td>$1,000</td>
<td>$100</td>
<td>$1,100</td>
<td>6</td>
<td>$183</td>
</tr>
</tbody>
</table>

Assumptions:
1. Crew skill level equivalent to journeyman lineman.
2. Labor includes data recording.
3. Standard truck equipment includes gas reading instrument and ladder.
4. Special equipment includes temperature probe, voltmeter, and clamp-on ammeter.
5. Number of manholes per day is affected by urban vs. suburban locations.

2.3 Recommendation 3: Splicing Logs

PTI recommends that each company maintain a database of new and repair splices made by employees and contractor crews in order to determine possible workmanship issues and related splicing training needs.

Discussion

According to information received from the four companies, none of them is currently maintaining a splicing log. Although some information on splicing work may be available, though more difficult to retrieve from a company’s work management system, it is our opinion that such logs can provide valuable insight and bases for analysis of possible workmanship-related trends in splice-implicated manhole events. Such information is particularly useful in assessing training needs. Moreover, with some companies making greater use of contractor crews, this provides an additional quality assurance tool in assessing the skills of the outside work force.

Although the manhole event data provided by the companies was not of sufficient depth to determine potential root causes such as workmanship, we did receive one failure investigation report that explicitly stated, “The cable failure was due to workmanship.”
Recommendations

However, no further information was available as to when or by whom the failed 15kV cable splice was made.

Additionally, we note that the DTE has had experience with analogous workmanship-related issues. In its “Standards to be Employed by Public Utility Operators When Restoring any of the Streets, Lanes and Highways in Municipalities” (August 26, 1999), the DTE included a detailed accountability provision directed at crews responsible for street excavation and repair. The provision included a requirement to identify and correct patterns of substandard performance. Shown in Appendix B.2 is a listing of the information that should be captured in the splicing log.

2.4 Recommendation 4: Failure Analysis and Trends

PTI recommends that each company train a sufficient number of employees in forensic failure analysis so that a field failure analysis is performed and a report generated for all manhole events in order to determine the root cause of the event. Additionally, the failure analyses reports should be compiled and assessed each year, and a report of annual trends prepared and submitted to the DTE.

Discussion

Based on information provided by the companies, root-cause failure analyses are not customarily performed except in instances of “major” manhole events and, in some cases, the failure of new equipment. This makes an analysis of trends in root causes virtually impossible to perform with confidence. Although we recommend a field failure analysis be performed for all manhole events, it should be noted that the failed equipment (e.g., splice, cable, etc.) may have been destroyed during the event, and/or there may be need to contract services from forensic laboratories specializing in this area. Additionally, it is often the case that the need to repair and restore service to customers may preclude or abbreviate a thorough on-site failure analysis. However, given that these limitations may exist, the companies should make a best-effort root-cause analysis for each manhole event.

Just as manhole events vary in severity (i.e., explosion, fire, or only smoke), so should the extent and level of detail in the failure investigation report depend on the severity and significance of the event. For example, an explosion caused by a primary cable splice failure will normally receive a more detailed investigation than a smoke condition caused by a deteriorated secondary cable. Nonetheless, the intent of failure analysis is to determine the root cause(s) of each event and provide recommendations designed to preclude recurrence of similar events and/or mitigate the severity of such events should they occur in the future.

It is our understanding that the companies do not have employees specifically trained in the forensic techniques that may be applied to root-cause failure analyses of manhole events. Investigative steps such as collecting available data from automated systems, interviewing crew members at the scene of the event, taking photographs of the as-found conditions, taking samples of failed cable or equipment for internal or external laboratory tests, obtaining records of recent inspections and maintenance activities, and others should comprise standard investigative procedures taken by properly trained employees.

Appendix B.3 presents a listing of information to be collected and recorded during failure investigations.
2.5 Recommendation 5: Data Collection and Reporting

PTI recommends that the companies employ standardized manhole inspection and manhole event data collection forms that maximize checklists and minimize the need for free-form comments. Quarterly and annual manhole inspection and manhole event reports with a prescribed summary analysis should be prepared and submitted to the DTE. Additionally, individual standardized reports on all events involving dislodged covers should be submitted to the DTE as soon after the event as possible.

Discussion

Although the companies maintain historical computerized databases of underground system failures and repair records, historical manhole event records are lacking. Our data request asked for this information for the period January 1998 to date. The responses fell short of this. One company could only provide manhole event data beginning July 2004, while a second company from August 2004. A third company produced data from June 1999, while the fourth found no record of any events for the period in question. As a result of the historical data limitations we are unable to determine whether manhole events have increased since March 1, 1998, the initial date of the restructured electric business in Massachusetts.

We also found some of the data that was submitted to be incomplete and lacking in the requested detail. For example, “equipment involved” was often unrecorded on the data collection form we provided each company. In a few cases the voltage level of the affected system was unrecorded. And in all cases, there was no date of last manhole inspection. (See Appendix C). It should be noted that one of the companies subsequently provided inspection dates for 29 of the 44 manholes listed on their manhole event data collection form. However, they were unable to provide any completed inspection forms, reports, or formal documentation of the inspections. Moreover, in 16 cases, the affected manhole had been inspected within one year prior to the manhole event. However, the company stated that no work orders were generated as a result of any of the inspections. As a result, we are unable to verify the thoroughness or quality of the inspections.

We believe the inconsistent capture of manhole event data may be due to an over-reliance on hand written notes entered into a free-form “comments” field by the companies’ various personnel charged with the responsibility of collecting manhole event and manhole inspection information. In our opinion, explicit checklists need to be maximized in order to promote complete and consistent data collection, while comment fields should be minimized. Therefore, we have provided a suggested manhole event data collection form and manhole inspection checklist items shown in Appendix B.4 and in Appendix B.5, respectively.

With regard to reporting, we believe the companies should provide quarterly and annual manhole event summary reports and manhole inspection summary reports to the DTE. At a minimum, these reports should include the analyses suggested on the attached exhibits, rather than merely a listing of all reportable manhole events and reportable manhole conditions.

Initial notification of all manhole events (i.e., explosions, fires, and smokers) should be submitted to the DTE by the companies as soon as possible, but no later than 24 hours after the event. In addition, individual standardized reports on all events involving dislodged manhole covers should be submitted to the DTE by the companies as soon after the event as
possible. This should be a standard procedure not requiring a letter of inquiry from the Commission after each event. At minimum, these reports should contain the information shown in Appendix B.6.

### 2.6 Recommendation 6: Inter-Company Cooperation

PTI recommends the creation of a Working Group comprised of representatives from the four companies and DTE Staff to meet quarterly for sharing information on manhole event trends, root cause analyses, research studies, results of pilot programs, new technologies, and lessons learned. The Working Group could also address broader issues related to electric distribution reliability and safety, as appropriate.

**Discussion**

Although the DTE has not required formal manhole event remediation plans, each of the companies employs various strategies and tactics intended to mitigate manhole events. These include items such as a partial discharge testing pilot programs, heat shrink splicing, focus on workmanship and training, annual manhole inspections, formation of a special company committee, participation in industry trade organization committees, and others. It seems reasonable to assume that all companies may not have the resources to perform all of these activities, but could learn from one another if a forum existed for the sharing and exchange of information. We suggest creation of such a forum under the auspices of the DTE with quarterly (if not monthly) meetings, and rotating annual chairmanships among the four companies.

### 2.7 Recommendation 7: Outreach

PTI recommends a survey be taken of non-jurisdictional operators of underground electric distribution systems in Massachusetts. The survey should consist of questions regarding manhole events and manhole inspection practices, and determine the responding municipalities/organizations interest in participating in the Working Group (see Recommendation 6).

**Discussion**

In an effort to enhance public safety in areas served by underground electric distribution manhole systems not regulated by the Commission, we suggest a survey be taken to determine which municipalities or other organizations operate such systems, the number of manholes and recent historical experience with manhole events, their manhole inspection practices, and their level of interest in participating in a Working Group.

We have formulated a brief survey document and cover letter which are shown in Appendix B.7.
Section 3

NSTAR

3.1 Underground Systems

3.1.1 Design and Integrity of the Underground System

NSTAR’s underground distribution system consists primarily of the low-voltage networks in the downtown Boston area, the radial 4 kV systems, and the loop 13.8 kV systems. The findings with regard to the network system and the loop system are discussed separately below.

3.1.1.1 Low Voltage Network

All of NSTAR’S low-voltage networks in downtown Boston are supplied from six substations in the immediate area. The substations are designed for single contingency operation at time of peak load, with four of them having the “H” bus configuration, and the newer stations using the “ring bus” design. Furthermore, the primary feeders to a given network are arranged such that a fault on any 13.8 kV bus section in the station will not result in an outage to the system.

The neutral point of the wye connected windings of the substation transformers supplying the 13.8 kV station are grounded through a resistor, in contrast to solid grounding. With this grounding, the ratio of the zero-sequence resistance, \( R_0 \), to the positive-sequence reactance, \( X_1 \), at the substation is very high, typically in the range of 25 to 30. This limits the current for a single line-to-ground (SLG) fault on any 13.8 kV network feeder to 4 kA or less, depending on fault location along the feeder. There are two major benefits with this type of grounding for the medium voltage source that supplies the LV network.

First, with the network transformers connected delta on the HV side and grounded-wye on the LV side, a SLG fault on a HV feeder cable will result in about a 6% dip in voltage in the LV network, with the duration being the time for the primary feeder breaker to open. This should have little effect on the equipment of users supplied from the secondary network. In comparison, with solid grounding of the source as used in many systems, the voltage in the LV network will drop about 43% until the primary feeder breaker opens. Clearly, the use of the resistance grounding for the primary system for the secondary network results in improved power quality to customers served from the network. Not only are outages rare, voltage sags for single line-to-ground faults on the primary system are virtually non-existent.

Second, it is believed that when a fault occurs on a primary feeder, in most cases it starts as a fault from one phase to ground (a SLG fault), whether the fault is in a single conductor cable or splice, or a three-conductor cable or splice. With the fault current limited to 4 kA, it is
less likely that the fault will spread to a second phase. Furthermore, with the fault current limited to just 4 kA, it can be argued that the energy into the fault, and consequently the pressures generated from the arc energy, are lowered, and the probability of the manhole cover being dislodged is reduced. Our analysis of the limited data on manhole dislodgements in the NSTAR system shows that of the 44 events experienced since data was logged, none of the cover dislodgements have occurred on network primary feeders. In 2005, there have been 25 faults to date on network primary feeders, but none have resulted in the dislodgement of manhole covers.

All primary feeders to NSTAR’s networks in Boston are dedicated to the network, supplying only network transformers. This gives the greatest flexibility in operation and allows the use of sensitive ground fault relaying. The system is designed to carry the peak load with any one primary feeder out-of-service. Equipment loading is limited to 85% of rating during normal and contingency conditions.

The loading on network transformers and protectors in the Boston system is monitored in real time with the Digital Grid system, formerly known as the “Hazeltine System”. This system, using power line carrier to transmit data to the substation, allows system operators to have real-time data on loadings, network protector position, network protector fuse status, and other quantities in the network vault that might impact reliability. In effect, it allows them to conduct many of the vault inspection functions on a daily basis without entering the vault. NSTAR believes that this system provides excellent data on the loading and conditions of the 1350 network transformers and protectors on its system.

NSTAR stressed that its philosophy of operating the Boston networks is to never exceed the equipment ratings, during both normal and contingency conditions, whereas some utilities will overload significantly during contingency conditions. Company representatives stated that this operating philosophy originates from top management, is strictly adhered to by system operators, and discovery of equipment overloads results in remedial action. However, it should be noted that our assessment does not include an examination of actual loadings on NSTAR equipment and facilities.

NSTAR stated in our meeting that they believe the main reasons for the absence of dislodgement of manhole covers in the network system are:

- Conservative operating practices
- Fast clearing of faults
- Remote monitoring which prevents overloads

In addition, it is our opinion that the high-resistance grounding of the primary feeders is also a significant reason, as discussed above. (It appeared from our meetings that NSTAR has not considered this a reason for the absence of manhole dislodgements for faults on network primary feeders.)

NSTAR’s network systems in Cambridge and New Bedford are small relative to the Boston system. The low-voltage network in New Bedford has about 15 network transformers, with virtually no load growth on the system. There are a total of 84 network transformers and protectors in Cambridge. However, the system is broken up into 11 smaller “mini-networks”
with the largest network, Harvard Square, containing 36 transformers. And one of the “mini-networks” is operated at 480-volts, but consists of only 3 or 4 transformers.

Many of the primary feeders for the Cambridge network are not dedicated to the networks, but supply both network transformers and non-network transformers. This creates operational constraints, but they are easier to accommodate in the small system operated in Cambridge.

From the responses to our data request and the information gained at the meeting, we believe that the NSTAR network systems are designed, operated, and monitored consistent with good practices.

There have been no manhole dislodgements on the primary feeders of the network systems in Boston, which we believe is due in part to low available ground fault currents and fast clearing time. From our discussions with NSTAR personnel, it was determined that all feeders from the two newest substations supplying the networks have instantaneous ground current relays. However, the network feeders supplied from the four older substations use slower acting time-overcurrent relays for ground fault protection.

3.1.1.2 Radial 4 kV and 13.8 kV Underground Systems

NSTAR’s in-duct underground distribution systems operate at 4 kV and 13.8 kV, but the two systems are radically different in design. The 4 kV system is radial with normally open ties to adjacent feeders, whereas the 13.8 kV system employs a loop configuration.

The early underground systems operated at 4 kV, with the design and protection practices based on philosophy and available equipment in a pre-WW II time period. The systems were operated in a radial fashion, used lead-covered cable for the primary, and vault installed distribution transformers, both single-phase and three-phase. However, some of the systems in operation have distribution transformers with no primary side fuses, and all primary laterals taped from the main primary feeder are not fused. The only overcurrent device in the system is the relay-controlled circuit breaker at the substation, similar to that of a network feeder. The reasons why the single-phase taps and transformers were not fused could not be determined from our interview at NSTAR. However, we speculate a number of possibilities: 1) fuse equipment was not available for use in the submersible environment or vaults, 2) its available short-circuit interrupting rating was not adequate, 3) there was inadequate space in the vaults for this equipment, or 4) the reliability requirements of the systems at the time of design could be met without the addition of these sectionalizing devices.

In those circuits without lateral fuses and distribution transformer fuses, no matter where the fault occurred on the 4 kV feeder system, or within a distribution transformer, the fault caused an outage to all customers on the feeder. However, all of NSTAR’s 4 kV underground feeders have isolation switches and at least one tie switch to other 4 kV facilities. With these switches, NSTAR is able to restore service to most customers via switching once the failure is located. After the failure is repaired, the same switches are used to restore the system to its original configuration for normal operation.

NSTAR has an ongoing program of identifying and upgrading or replacing poor performing 4 kV feeders. They emphasize that age by itself is not justification for replacing an asset. When deemed prudent, upgrading of 4 kV facilities has included addition of high-speed vacuum interrupters in the underground feeder that are selectively coordinated with the
station breaker, without need to slow-down the station breaker. With these devices, a fault downstream of the vacuum interrupter on the main does not cause an outage to the entire feeder. This helps minimize the number of customers experiencing an outage, helps in locating the fault, and reduces restoration time.

Some poor-performing underground radial 4 kV circuits are to be replaced with 13.8 kV circuits of a loop design. The loop design is also used for all new 13.8 kV construction. Figure 3-1 shows the basic configuration of the looped system. The main three-phase feeder is sectionalized with pad-mounted or submersible switches, with the loop open at one point. These switches can be either manually operated or equipped for remote operation. The main loop is supplied from two different sources at each end, from either the same or different substations. The taps to the main feeder are supplied from the pad-mounted switches that sectionalize the three-phase mains, through either expulsion fuses or current-limiting type fuses. The taps, either single or three-phase, are configured and operated in a normally open loop.

Should a fault occur on the main three-phase feeder, only the customers served from the faulted half will experience an outage. Similarly, should a fault occur on a fused tap, only the customers supplied from the fused tap will experience an outage. However, once the fault is located, whether on the main feeder or lateral, service can be restored to all customers simply by opening and closing the appropriate switches, without need to repair the fault. It was mentioned that fault indicators will be used on the system to speed the location of faults.

Should a fault occur in the HV winding of the distribution transformer, only customers supplied from the faulted transformer will experience an outage. By comparison, in those 4 kV systems without lateral fuses and transformer fuses, all customers on the feeder would experience an outage until the fault was located and switching performed.

Although the 4 kV distribution systems are older on average than the 13.8 kV systems, age alone is not necessarily an indicator of the condition or expected performance of the components of the system. NSTAR indicates that performance and loading capability, rather than age, are the key factors in determining when upgrades are made.

Many of the 13.8 to 4.16 kV substations in the NSTAR system are supplied from two or more Distribution System Supply (DSS) lines. These substations supply the 4 kV radial feeders. The 13.8 kV to 4 kV substations have two or more transformers, configured and operated such that the failure of a single DSS line or fault in a 13.8 kV to 4 kV transformer does not cause an outage to the 4 kV station. Most of these DSS lines, unlike the network primary feeders, are supplied from 13.8 kV substations that are solidly grounded, because in addition to supplying DSS lines, these stations also supply 13.8 kV multi-grounded neutral distribution lines. NSTAR has reported several manhole cover dislodgements for faults on DSS lines supplied from solidly-grounded sources. These occurrences are consistent with our hypothesis that manhole events from faults on 13.8 kV cables that produce dislodged covers are more likely as the available current for the single line-to-ground fault increases.

We believe that replacement of poor performing, non-fused 4 kV radial underground systems with the 13.8 kV loop systems will result in a significant improvement in reliability for NSTAR distribution customers who were served from the poor-performing 4 kV feeders. However, this change in 4 kV configuration will not impact occurrences with manhole covers for faults on the 13.8 kV DSS lines that supply the 4 kV substations. The grounding of the supply systems for the 13.8 kV DSS lines usually cannot be changed as they also supply 4-wire
multi-grounded neutral feeders. However, NSTAR indicates that if a poor performing DSS line is identified, the poor performing components are replaced. This should reduce the probability of a fault, and consequently the probability of a manhole event. The Company believes that its long-standing replacement activities are a valuable mitigation strategy, which they have been committed to for many years.

From our inquiries, we believe that NSTAR’s non-network underground systems are designed and operated in accordance with accepted industry practices. The Company is well aware of industry practices, and the deficiencies identified in the older 4 kV systems are being corrected.

![Diagram](image)

**Figure 3-1. Simplified Diagram of 13.8 kV Loop System to Replace 4 kV Radial Systems**

### 3.1.2 Underground Distribution System Metrics

The following tables of information provided by NSTAR show the following trends:

- The number of customers on NSTAR’s underground electric distribution system has steadily decreased over the past five years

- The number of underground department employees has decreased during the past five years at about the same rate as underground customer decrease (8%)

- NSTAR’s underground maintenance and construction expenditures have increased substantially over the past five years (Note: NSTAR’s maintenance expenditures include operations)
### Metrics Table

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<th>2000</th>
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<td>305</td>
<td>300</td>
<td>290</td>
<td>281</td>
<td>-8%</td>
</tr>
<tr>
<td>Customers per employee</td>
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<td>677</td>
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</tr>
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<td>$18.12</td>
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<td>31%</td>
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<td>$69</td>
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</tr>
<tr>
<td>Construction $ (millions)</td>
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<td>$294</td>
<td>$472</td>
<td>$317</td>
<td>$341</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 3.2 Manhole Maintenance and Inspection Practices

NSTAR does not perform scheduled inspections or maintenance of manholes. Typically, manhole inspections are performed upon entry for reasons such as troubleshooting, switching, construction, and others. The Company also states that manhole inspections are performed based on reliability data and a prioritization process that considers outage statistics, number of cables in the manhole, proximity to the source station, and supply to critical customers. NSTAR estimates that its field employees enter about 10,000 manholes per year, or roughly 26% of its 38,000 manholes. However, the “last inspection date” column of the manhole events data collection form (see Appendix C) was left blank for all 44 reported occurrences.

A key component of the low-voltage network system is the network protector. The reliability and security of the system depends upon successful operation of the protectors. NSTAR does network protector maintenance every four years, consisting of inspection, relay testing and calibration, submersible-housing seal testing (to check for water tightness), and other tests (minimum voltage close and trip) and inspections of the protector mechanism. They further have a program of replacing the older electro-mechanical relays in the network with
the new microprocessor relays. Recently, NSTAR obtained the latest ETI network protector test set for field testing of network protector relays, and performing of minimum voltage close and trip tests.

Network vaults are entered on a scheduled basis, once every 4 years for a complete inspection of the vault and testing of the network protector. This is consistent with industry practice. They stated that with their remote monitoring system, in effect, they are entering the vault every day for a partial inspection. This is a valid argument since they are remotely taking load readings, checking for blown network protector fuses and open protectors many times each day. The engineers receive reports whenever the remote monitoring system detects a transformer with loads above 85% of rating. With the remote monitoring system they can tell if a protector is malfunctioning, and dispatch a trouble crew should the need arise. We believe that NSTAR's maintenance and inspection of network protectors in the Boston systems is above the norm used in the industry, due to the implementation of its remote monitoring system.

For the network vaults in Cambridge and New Bedford, NSTAR performs 100% inspection as part of its “summer preparedness program”. The network systems in these two areas are experiencing very little growth.

Although NSTAR network systems can operate with any one primary feeder out-of-service, their operations are set up to return a feeder to service within 24 hours of an opening due to protective relay action. Considering switching time, fault location time, repair time, and test time, this is equal to or better than the performance of Con Edison of New York.

### 3.3 Manhole Event Records and Trends

NSTAR reported that they experienced 44 manhole events involving dislodged covers during the period July 2004 to date. Manhole event data prior to that date was not available. The information provided was insufficient to determine whether any trends exist in the root causes of these events, nor was it possible to determine if manhole events have increased since March 1998. We also note that NSTAR does not customarily perform root cause failure analysis of manhole events. The Company states that these analyses are performed for major manhole events and the failure of new equipment. In such cases, NSTAR has technical staff and facilities to perform forensics on failed cable, cable splices, and other equipment. Additionally, outside experts are used when deemed necessary.

A visual examination of the NSTAR service territory map, shown below in Figure 3-2 superimposed with the locations of all reported manhole events, does not appear to indicate a geographical clustering of occurrences. However, we note a preponderance of events (38%) occurred during the shoulder months of February and November. This is depicted in Figure 3-3.
Figure 3-2. NSTAR service territory map with locations of all reported manhole events
3.4 Causes of Dislodged Manhole Covers

Although the information provided to us by NSTAR was not sufficient to determine root causes of the manhole events experienced on their underground systems, we note several statistics depicted in the pie charts in Figure 3-4. First, manhole events have occurred on systems of all voltage levels, i.e., low voltage secondaries, 4 kV, and 13.8 kV, with 50% on the 4 kV system and 48% on the 13 kV system. However, only one event was reported on the low voltage secondary system. Secondly, splices (also referred to as joints) and terminations were implicated in 36% of the manhole events. These are found in manholes. Regarding the remainder, cable failures were implicated in 52% of the occurrences and the rest classified as other.

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Figure 3-3. NSTAR - reported manhole events by month

Figure 3-4. Pie charts of NSTAR manhole event statistics
3.5 Practices to Anticipate/Mitigate Future Manhole Events

NSTAR’s principal strategy is to devote resources to underground system maintenance and replacement activities. Their practices to anticipate and mitigate future manhole events include the following efforts:

Partial Discharge Testing Pilot Program

Begun in 2004, diagnostic technology is being tested to assess the condition of underground cables and attempt to identify trouble areas. This new type of condition assessment has the following characteristics:

- Analyzes the cable system using an on-line technique that does not require circuit isolation or shut-down
- Potential to identify type, location, and extent of undetected faults based on partial discharges of deteriorating cable
- Performs non-destructive analysis of the cable system electrical state at operating conditions

The pilot program is ongoing, and the Company claims mixed results to date.

EPR Cable Technology

NSTAR has used EPR cable for all of its cable replacement and maintenance projects initiated within the last 15-20 years. Further, they utilize only copper conductors, with the inherent advantages of lower losses and better corrosion resistance. They cite the following benefits for EPR cables:

- Environmentally friendly
- Good insulating and thermal properties; additional compounding increases flame retardant properties
- Its flexibility allows for ease of installation

Heat Shrink Splicing

NSTAR uses heat shrink splicing for underground system cable splices. This technique uses pre-engineered splice kits, reduces the complexity of installation, and thereby improves consistency of workmanship.

Special Company Committee

In 2004, the Company formed a special committee to evaluate and recommend manhole event mitigation strategies. The committee includes representatives from the Operations and Engineering departments charged with the following responsibilities:

- Keep abreast of new technologies and best practices targeted at safe and reliable underground distribution system operations
- Stay apprised of industry research, studies, and pilot programs (e.g., manhole cover designs)
- Coordinate efforts with other companies and research entities, and participate on relevant committees of industry trade organizations (e.g., IEEE and AEIC)

**Manhole Cover Design**

NSTAR has a program underway to evaluate the advantages and disadvantages of various manhole cover designs. They recently designed a new perforated cover that is being tested and compared with the traditional solid and slotted covers.

### 3.5.1.1 New Technology Discussion

Two new technologies that have been applied by some users of network systems to improve the operation and integrity of the system are remote monitoring of network transformer/protector vaults, and the use of current-limiting devices to reduce the energy that goes into faults in primary cables and cable splices.

As discussed above, NSTAR has installed a remote monitoring system for the low-voltage networks in Boston, using the Digital Grid power line carrier system. The Company believes this system is very valuable for maintaining up-to-date operating and engineering data on its system. NSTAR plans to install this system in its low-voltage networks in Cambridge and New Bedford in the near future. These networks are less than 10% of the size of the Boston networks, and the need for remote monitoring is not as great in smaller systems, where engineering and operating personnel can keep better track of “what is going on” in the system.

The use of fault current-limiting devices such as the G&W Electric CLiP® and the S&C fault filter electronic fuses, appears to have little value on any of the NSTAR underground systems. Since these current-limiting devices could cause mis-coordination with down stream fault current protection devices on radial or looped systems, they would only be considered for network primary feeders. However, the data reported by NSTAR shows that there have been no manhole cover dislodgements on their network systems in Boston. We have hypothesized that this may be due to the use of resistance grounding for the 13.8 kV feeders. As discussed above, this limits the current for a single line-to-ground fault to 4 kA or less on the NSTAR feeders. Therefore, fault current-limiting devices are not seen as beneficial.

Our interview meeting with NSTAR personnel revealed that they participate in industry committees, and communicate directly with other large metropolitan utilities operating underground systems, such as Con Edision and Pepco. They also are active in the Electric Network Forum, where engineers involved in networks can post questions and others respond voluntarily. They stay abreast of the latest technologies and methods being used to enhance the integrity of the low-voltage network systems.
3.6 Conclusions

1. The integrity of the NSTAR underground electric distribution systems is acceptable, and their designs are consistent with accepted utility practices. We note that our assessment does not include field inspections of the Company’s underground facilities.

2. Although NSTAR has experienced events involving dislodged manhole covers, their records of same only date back to July 2004. As a result, we are unable to determine if manhole events have increased on their underground system during the period March 1998 to date.

3. The manhole event information recorded and provided to us by NSTAR was not sufficient to determine root cause trends of the manhole events experienced on their underground systems. Additional data and root cause failure analyses are needed.

4. Although NSTAR’s manhole inspection practices result in entry of about 10,000 manholes per year, the absence of a scheduled manhole inspection and maintenance program designed to assure inclusion of all manholes hampers its ability to anticipate and mitigate manhole events. Additionally, although no dislodged manhole covers were reported for the downtown Boston network system for the period dating back to July 2004, we believe it is important to include all manholes in the inspection and maintenance program.

5. All recommendations contained in the Recommendations Section of this report are applicable to NSTAR.
4 National Grid

4.1 Underground Systems

4.1.1 Design and Integrity of the Underground System

National Grid has separate underground distribution systems in many of the cities and towns in its service territory. The systems include low voltage secondary networks, duct/manhole radial systems, and URD systems. The duct/manhole radial systems and URD systems are usually connected to an overhead system. Additionally, the low voltage networks represent no more than 2% of the total in terms of miles of primary cable installed.

4.1.1.1 Low Voltage Network

National Grid has low-voltage secondary network systems in Worcester, Brockton, and Lynn. The largest low-voltage network system is in Worcester, supplying approximately 31 MW of load from the 208-volt grid network, and the 480-volt spot networks. There are much smaller networks in Brockton and Lynn. The load on the Lynn network is 15.5 MW, and the load on the Brockton network is only 6.3 MW. Loads on all of the secondary networks are not growing, and some 208 volt networks are experiencing load reductions. Most of the load on the secondary networks are commercial, with very little residential. The significance of this is that unexpected load increases on the 208-volt grid network, which can possibly result in overloading, are not anticipated. There are no plans to expand the area supplied by secondary networks. Many of the network transformers in National Grid’s systems are relatively new, having been installed in the late 70’s and early 80’s when PCB filled units were replaced.

All of the network systems are designed to operate under an “N-1” condition, meaning any one primary feeder can be out of service, and the peak load can still be supplied. In systems of the size operated by National Grid in Massachusetts, it would not be expected that the system could be operated under a double contingency condition. While the PTI team was in Worcester on July 20, 2005, a fault occurred in the HV switch compartment of a network transformer in the Worcester network. This fault was isolated without causing an interruption to any load served from the network. In contrast, such a fault in a radial system would have resulted in customer outages.

Figure 4-1 shows the configuration of the supply for the 13.8 kV feeders for the Worcester secondary network. The feeders to the network emanate from three different substations, which are connected together through three 13.8 kV tie lines. When networks are supplied from different substations, there can be operating problems with the network protectors (protectors sitting open and/or pumping), due to voltage magnitude and phase angle.
differences between the supply feeders. However, the experience with the system in Worcester has shown that the 13.8 kV tie lines maintain the differences in bus voltage magnitude and angle to the extent that there are no circulating current problems that create protector operating concerns.

The three substations supplying the 13.8 kV feeders for the Worcester network are reactance grounded, which makes the currents for the single line-to-ground (SLG) fault much lower than those for the three-phase fault. Figure 4-1 lists the available three-phase and SLG fault currents, as well as the ratio of $Z_0$ to $Z_1$ for faults on the three 13.8 kV buses supplying the network. A similar relationship exists for the NSTAR network systems in Boston, except that the substations for the NSTAR system are resistance grounded rather than reactance grounded. Since most faults initiate as SLG faults, it can be hypothesized that if the fault is cleared before it develops into a multi-phase fault, the energy input to the fault is limited and the likelihood of a manhole cover dislodgement for fault in a primary cable or splice is lower.

For the low-voltage network system in Lynn, the 13.8 kV source is also reactance grounded. The three-phase and SLG fault currents are 18.2 kA and 1.9 kA respectively ($Z_0/Z_1 = 26.7$). For the supply to the Lynn network the current for the ground fault is relatively low. If fast relaying is used for ground faults, the likelihood of the arc energy in a single line-to-ground fault causing a manhole cover dislodgement is very small.

The Brockton system is supplied from a 13 kV delta source, but grounded through a zig-zag grounding transformer. Currents for the three-phase and SLG faults on the source bus are 13.9 kA and 9.8 kA, respectively ($Z_0/Z_1 = 2.26$). For the system in Brockton, the SLG fault
current is lower than that for the three-phase fault, but higher than the SLG fault currents for the Worcester and Lynn networks.

The cables in the 208-volt portion of the networks are predominately paper-lead, rubber lead, and more recently solid dielectric with an outer protective jacket. Cable limiters are not used on the leaded low-voltage cable except in cases where the available fault current is not high enough to burn clear a solid fault. However, in the non-leaded cables, cable limiters are used extensively.

From our interviews at National Grid, we believe that their network systems are designed and operated in accordance with good engineering practices. The systems are capable of handling the present loads. National Grid has sufficient data on the network systems, through modeling and load checks, to determine in advance if overloads may occur from load additions or growth of present loads. It is also our professional opinion that the employees we interviewed are competent power engineers, well educated and versed in power system engineering topics, active in industry professional groups, able to design, engineer, and operate a system in a manner that is consistent with good industry practice. Whenever reliability of a portion of the system becomes unacceptable, as discussed below for the Worcester 4 kV system, corrective actions are implemented.

### 4.1.2 Radial 4 kV and 13.8 kV Underground Systems

The manhole and duct underground distribution systems operate at either 4 kV or 13.8 kV in most areas served by National Grid. These systems, which operate in a radial fashion or an open loop configuration, obviously do not provide the same levels of reliability as the secondary network systems. However, secondary network systems are not applicable in many service areas where the radial and loop 4 kV systems are installed. Furthermore, the cost of the secondary network would prohibit its use for service to loads in non-downtown commercial areas, other than perhaps heavy concentrated loads in suburban areas where spot networks might be applicable.

National Grid evaluates system reliability using the standard measures, SAIFI, SAIDI, and CAIDI. This reliability data is kept for the entire National Grid system, the National Grid systems in Massachusetts, the served towns, and for the individual feeders. It is reviewed by planning engineers, and identifies for the non-network underground systems those feeders or portions of the system that have sub-par performance. Work is then ordered with the intention of improving system reliability. Distribution feeder management and planning is performed locally by engineers most familiar with the service territory and the developments taking place therein. There is a central staff of planning engineers who perform long-term planning and planning that involves multiple operating divisions.

Approximately 41 MW of load is served from the Worcester 4 kV underground system. Reliability data collected during the middle nineties revealed that this system was not performing acceptably. National Grid formed a team of personnel from various departments and disciplines to study the causes of the sub-par reliability performance. Causes were identified and design changes to improve the performance of the 4 kV system in Worcester were studied. Resulting from this was a multi-year program to replace the oil fused cutouts (OFC), not only in Worcester but across the National Grid system, and the development of standards and selection of vendors for new fuse and sectionalizing equipment, and fault indicators. Changes to the rear-lot system design configuration, to be applied to those
portions of the Worcester system that are the poorest in performance, were devised. The new standards will also be used to design new feeders in the Worcester area, as well as other areas served by National Grid.

We reviewed the overcurrent and overvoltage protection practices used on both the duct bank and direct-buried URD systems operated by National Grid. When selecting new switching devices and fuses for the 4 kV systems, they consider selective coordination, interrupting rating, and protection requirements. When selecting surge arresters for application at riser poles, they recognize the importance of short lead lengths (as observed during our visit to the Training Center). In the 15 kV class systems, surge arresters are applied at the normally open points to prevent doubling of a surge voltage that could occur in the absence of the arrester.

### 4.1.3 Underground Distribution System Metrics

The following tables of information provided by National Grid show the following trends:

- The number of customers on National Grid’s underground electric distribution system has decreased substantially (23%) over the past five years
- The number of underground department employees has increased slightly during the past five years
- National Grid’s underground maintenance and construction expenditures have increased substantially over the past five years

<p>| | |</p>
<table>
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### 4.2 Manhole Maintenance and Inspection Practices

National Grid does not perform scheduled inspections or maintenance of manholes. The only time a manhole inspection is performed is upon entry for some other reason. National Grid estimates they enter about 10% of their manholes per year. However, some of these are multiple entries of the same manhole.

National Grid’s maintenance practices for network protectors require a thorough check on the protector once every five years. This consists of relay calibration checks, minimum voltage close and trip tests, insulation resistance checks of the phase-to-phase and phase-to-ground insulation, contact resistance checks, dead bus checks, and other inspections performed by prudent practitioners. Although their network systems are relatively small, at the Training Center outside of Worcester they maintain both a GE and Westinghouse network protector for training purposes. National Grid crews check cable currents in the secondary network when working in manholes with secondary cable, and when working in vaults with network transformers and protectors.

We were given a tour of the National Grid training center where training is provided on both underground and overhead equipment and systems. It is a first-class training facility with a wide range of equipment in both the indoor and outdoor portions of the facility. We were not only impressed with the training facilities and equipment, but also with the cleanliness of the center, the knowledge and dedication of the instructor we met, and the high-quality of the training materials given to the employees in training.

### 4.3 Manhole Event Records and Trends

National Grid reported that they experienced 20 manhole events involving dislodged covers during the period August 2004 to date. Manhole event data prior to that date was not available. The information provided was insufficient to determine whether any trends exist in the root causes of these events, nor was it possible to determine if manhole events have increased since March 1998. We also note that National Grid does not customarily perform root cause failure analysis of manhole events.
A visual examination of National Grid’s service territory map, shown below in Figure 4-2 superimposed with the locations of all reported manhole events, does not appear to indicate a geographical clustering of occurrences. However, we note a preponderance of events (40%) occurred during the month of February 2005. This is depicted in Figure 4-3.

![National Grid service territory map with locations of all reported manhole events](image)

**Figure 4-2.** National Grid service territory map with locations of all reported manhole events
4.4 Causes of Dislodged Manhole Covers

Although the information provided to us by National Grid was not sufficient to determine root causes of the manhole events experienced on their underground systems, we note several statistics depicted in the pie charts in Figure 4-4. First, manhole events have occurred on systems of all voltage levels, i.e., low voltage, 4 kV, 13.8 kV, and 23 kV, with the majority (35%) on the 4 kV system. However, for five of the 20 events, the voltage levels were not reported on the data collection form. Secondly, splices (also referred to as joints) and terminations were implicated in 45% of the manhole events. These are found in manholes. Regarding the remainder, cable failures were implicated in 40% of the occurrences and the rest classified as other.
4.5 Practices to Anticipate/Mitigate Future Manhole Events

National Grid’s primary manhole event mitigation strategy is to prevent failures in manholes by employing a four-pronged approach:

1. Purchase high quality materials
2. Ensure workmanship through training
3. Control the operating conditions
4. Monitor the above items

Purchase High Quality Materials
The Company’s emphasis on materials quality includes the following activities:

- Cable and splice materials are graded and rated by independent labs
- Company engineers inspect and certify vendors’ facilities and manufacturing processes, and follow-up visits are made to monitor same
- Materials placed in service are tracked by the Company’s failure analysis program to identify signs of poor reliability

Workmanship and Training
National Grid believes that cable-splicing workmanship is a critical component of a reliable underground distribution system. It operates a three-year cable splicer apprenticeship program that is also attended by other utilities and non-utility companies. During the program, which uses one teacher for every three students, employees spend more than six months in classrooms and an equal amount of hands-on training time with senior splicers. Upon completing the apprenticeship program, splicers receive annual refresher training and special classes on new materials.

Control of Operating Conditions
Control entails monitoring the quality of equipment and cables, as well as the skills and performance of splicers. Monitoring operating conditions enables the Company to determine if cable and equipment is operating outside the recommended parameters, so corrective action may be taken. Controlling operating conditions such as loading and operating temperature, per manufacturers’ recommendations, maximizes the life of underground cable systems.

National Grid has installed some vented manhole covers and network vault grates to dissipate heat. However, the Company raises two concerns: 1) their ability to prevent dislodged covers, and 2) the corrosive effects of potential ingress of greater amounts of road salt. Additionally, the Company is aware of manhole cover tethering and permanently installed manhole gas monitors, but is not convinced that either technology would mitigate dislodgements.
4.5.1.1 New Technology Discussion

From our meetings with National Grid personnel, it is apparent that they are aware of new technologies being applied to underground distribution systems, and are making use of these when appropriate for their system. Examples are for the Worcester 4 kV system where the old oil fused cutouts (OFC) are being replaced with encapsulated vacuum interrupters with electronic controls that have time-current characteristics similar to fuses, network protectors where electro-mechanical network relays are being replaced with microprocessor relays. Pad-mounted switchgear with current limiting fuses have been adopted for those areas of the 4 kV system where fault currents preclude the use of expulsion fuses.

The latest technologies for geographic information systems, system analysis, and outage management are being utilized at National Grid in Massachusetts. National Grid has engineers who are very active in the IEEE Power Engineering Society, keeping them abreast of the latest technologies used throughout the utility industry.

4.6 Conclusions

1. The integrity of National Grid’s underground electric distribution systems is acceptable, and their designs are consistent with accepted utility practices. We note that our assessment does not include field inspections of the Company’s underground facilities.

2. Although National Grid has experienced events involving dislodged manhole covers, there records of same only date back to August 2004. As a result, we are unable to determine if manhole events have increased on their underground system during the period March 1998 to date.

3. The manhole event information recorded and provided to us by National Grid was not sufficient to determine root cause trends of the manhole events experienced on their underground systems. Additional data and root cause failure analyses are needed.

4. National Grid’s practice of performing manhole inspections only when a manhole is open for another purpose hampers its ability to anticipate and mitigate manhole events. Although the Company estimates entry to about 10% of its manholes per year, some of those represent multiple entries of the same manhole.

5. All recommendations contained in the Recommendations Section of this report are applicable to National Grid.
WMECo

5.1 Underground Systems

5.1.1 Design and Integrity of the Underground System

The WMECo underground distribution systems are not centralized in one large metropolitan area, but scattered around their service territory. The Company operates low-voltage secondary network systems in Springfield (Downtown and Winchester Square), Pittsfield, and Greenfield. The networks represent a very small portion of the total load and customers served compared to the UG duct/manhole systems and URD systems. The findings with regard to the network and non-network systems are discussed separately.

5.1.1.1 Low Voltage Network

The largest low-voltage network system is in Downtown Springfield, consisting of approximately 110 network transformers, supplying about 20 MW of load. All load is supplied from a 208Y/120-volt grid network. WMECo does not have 480-volt spot networks in Springfield or elsewhere. The other low-voltage networks in the Winchester Square area of Springfield, Pittsfield and Greenfield are small, each containing about 10 network transformers. The systems in Springfield and Pittsfield are supplied at 13.8 kV and 23 kV, respectively, while the small system in Greenfield is supplied from a 4800-volt ungrounded primary system. However, the network transformers in the Greenfield system are dual voltage, capable of operating at 13.8 kV should the primary voltage be converted.

The Downtown Springfield network (as well as all of WMECo's network systems) is designed for an N-1 condition, being able to supply the peak load when any primary feeder is out of service. However, the primary feeders are not dedicated to the network since they supply both network and non-network transformers. The Downtown network feeders emanate from the West Springfield substation, where the fault currents at 13.8 kV are relatively low. There are two 47 MVA, 115 kV to 13.8 kV transformers in the substation, with the peak load on the station being 40 MVA. The currents for faults on the feeders are only 5400 amperes for the single line-to-ground fault current, and 7200 amperes for the three-phase fault, due to the installation of phase reactors in each feeder. With low fault currents such as this, there is a decreased likelihood of manhole cover ejections from high arc energies. The bus arrangement at the West Springfield substation is a closed ring, so the load division is good and the network protectors will have very few operations.

WMECo maintains analytical models of its low-voltage network systems and performs load flow studies whenever there are any significant changes in load. In addition, spot load checks are made with a clamp-on ammeter whenever they go into a vault to inspect the
network transformers and protectors. Installed in the Pittsfield network is a drive-by system similar to that used for their automatic meter reading, whereby load levels are read without entering of the vault. This system was recently installed in the Winchester Square network, and will be expanded to the Downtown network in the future.

The load on the WMECo low-voltage network systems is not growing, and is rather stagnant. Any major load in the network area that requires 480-volt service is supplied from dual primary feeders, using either manual transfer or automatic transfer equipment. Northeast Utilities’ (NU) philosophy is to not supply new large loads from low-voltage networks, and this applies at WMECo.

The small network in Greenfield is the only one in the WMECo system with dedicated primary feeders. It uses single-phase transformers in banks, with wall-mounted network protectors. This, along with the use of ungrounded 4800-volt feeders, would suggest that the network system in Greenfield is rather old. However, the old 5 kV primary cables have been replaced with 15 kV cables, and the old 5 kV network transformers have been replaced with dual voltage 4.8 kV X 13.8 kV network transformers in preparation for converting the network supply circuits to 13.8 kV in the future. Also, with 4800-volt ungrounded feeders, virtually no current flows for a single line-to-ground (SLG) fault, so that the probability of high fault energies is very small, provided the SLG fault is cleared before a second fault occurs on a different phase. This means the probability of a manhole cover displacement from high fault energies is very low.

From our interviews at WMECo and review of their response to our data request, we believe that their network systems are designed and operated in accordance with good engineering practices. Since they are in the Northeast Utilities organization, they use NU’s design standards for any new additions to the network. From our meeting with the NU principal engineer involved in networks, we learned that they now limit the size of the secondary main cables (the cables running from manhole to manhole that make up the secondary grid) in the low-voltage network system to 4/0 (211.6 kcmil), and 500 kcmil cables are only used for network transformer getaway cables for transformers 500 kVA and above and large services. As the secondary mains make up the vast majority of the secondary cable in a network system, the chances of a manhole event are reduced because secondary faults are more likely to blow cable limiters when 4/0 cables are used. Although this is more expensive than using the 500 kcmil cables as done in the past, it is a step that lowers the chance of a manhole event from a fault in secondary cable. This philosophy is being applied to NU’s networks in its Connecticut Light and Power subsidiary. The network systems in WMECo were originally built with 4/0 main secondary cables.

WMECo has sufficient data on the network systems, through modeling and load checks, to determine in advance if overloads may occur from load additions or growth of present loads. Moreover, it is our professional opinion that the Company representatives who met with us are well-qualified power engineers, capable of designing and operating network systems in a manner that is consistent with industry practice.

5.1.1.2 Radial 4 kV, 13.8 kV and 23 kV Underground Systems

The manhole and duct underground distribution systems operate predominately at 4160 V (4 kV), 13.8 kV or 23 kV in most areas served by WMECo. Springfield has 4 kV and 13.8 kV systems, Pittsfield has 4 kV and 23 kV systems, and Greenfield has 13.8 kV systems. The total number of feet of primary cable installed at these three voltage levels in the duct system
is 2,657,911 feet, with 28% being used at 4 kV, 67% at 13.8 kV, and 5% at 23 kV. As time goes on, the percentage of total for the 4 kV systems will decrease due to conversions. These systems, which operate in a radial fashion or an open loop configuration, obviously do not provide the same levels of reliability as the secondary network systems. However, secondary network systems are not applicable in many service areas where the radial and loop systems are installed. Furthermore, the cost of the secondary network would prohibit its use for service to loads in non-downtown commercial areas.

The reliability of the older 4 kV systems is not as good as that of the 13.8 kV underground systems, and in some areas the 4 kV systems are being replaced. WMECo has plans and projects to convert 4 kV to 13.8 kV in Springfield and to 23 kV in Pittsfield, with approximately 2/3 of the 4 kV stations converted to date in Springfield, with four 4 kV substations still in service. The Company has recently started conversion work in Pittsfield and has seven 4 kV substations to convert there. However, most of the 4 kV systems in duct and manhole have fuse protection for laterals and distribution transformers, as well as sectionalizing switches in the main feeder and ties to adjacent feeders. Figure 5-1 is a sketch of a typical 4 kV radial feeder showing these features. In the early 1980's, WMECo installed rope and pulley systems so that the oil fused cutouts (OFC) could be operated from outside manholes with all personnel at grade level. This was done for operator safety, in the event of a switch failure during operation.

WMECo, like the other utilities in Massachusetts, recognizes the weaknesses and loading limitations of the old 4 kV systems. When appropriate, 4 kV systems are being converted to 13.8 kV and 23 kV looped systems using pad mounted switchgear rather than below-grade switch and fuse equipment whenever possible. Automatic transfer switchgear supplied by two different primary circuits is utilized at the source end of the conversion loops. All outgoing cables within the loop system are equipped with fault indicators to speed-up fault location and reduce outage durations. In these systems, the overcurrent protection will consist of the station breaker, in some cases a line recloser, the fuses in the pad-mounted switchgear, and the transformer fuses.

Figure 5-1. Simplified single line diagram of typical 4 kV duct-bank distribution system
We reviewed the overcurrent and overvoltage protection practices used on both the duct bank and direct-buried URD systems operated by WMECo. Their engineers are well versed in these topics, and are current on the latest technologies and practices to optimize the available resources. Being under the NU umbrella, WMECo should be aware of the latest technologies, equipment, and system designs available to support underground electric distribution operations.

5.1.2 Underground Distribution System Metrics

The following tables of information provided by WMECo show the following trends:

- The number of customers on WMECo’s underground electric distribution system has remained relatively constant over the past five years
- The number of underground department employees has increased slightly during the past five years
- WMECo’s underground maintenance and construction expenditures have increased over the past five years

<table>
<thead>
<tr>
<th>Metrics</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of customers</td>
<td>27,413</td>
<td>28,150</td>
<td>28,798</td>
<td>28,940</td>
<td>28,824</td>
<td></td>
<td>5%</td>
</tr>
<tr>
<td>No. of employees</td>
<td>32</td>
<td>31</td>
<td>33</td>
<td>31</td>
<td>33</td>
<td>35</td>
<td>9%</td>
</tr>
<tr>
<td>Customers per employee</td>
<td>857</td>
<td>908</td>
<td>873</td>
<td>934</td>
<td>873</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance $ (millions)</td>
<td>$2.04</td>
<td>$2.07</td>
<td>$2.08</td>
<td>$2.33</td>
<td>$2.55</td>
<td></td>
<td>25%</td>
</tr>
<tr>
<td>Maintenance $ per customer</td>
<td>$74</td>
<td>$74</td>
<td>$72</td>
<td>$81</td>
<td>$88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction $ (millions)</td>
<td>$4.14</td>
<td>$3.69</td>
<td>$2.85</td>
<td>$5.76</td>
<td>$5.98</td>
<td></td>
<td>45%</td>
</tr>
<tr>
<td>Construction $ per customer</td>
<td>$151</td>
<td>$131</td>
<td>$99</td>
<td>$199</td>
<td>$208</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.2 Manhole Maintenance and Inspection Practices

WMECo does not perform scheduled inspections or maintenance of manholes. The only time a manhole is inspected is upon entry for some other reason. According to Company representatives, many manholes in the WMECo system were rebuilt in the early 1980’s for structural reasons. At that time, drawings of the manholes were updated. It was also stated that in the WMECo system, splices are wrapped with fireproof tape. This reduces the chance of a fault in one cable causing damage to other cables in the same manhole, but also makes it difficult to detect certain weaknesses in the splice through visual inspection.

WMECo performs a visual inspection of network transformer vaults on a yearly basis. Network protectors attached to the transformers receive a thorough maintenance check every two years. A review of the inspection and maintenance checklist for network transformer vaults reveals that it is quite thorough, including measurement and recording of relay as-found and as-left settings, load checks, and assessment of structure conditions. WMECo has a network protector test set, accessible to all districts, which allows thorough electrical and mechanical testing of the network protectors. WMECo’s inspection and maintenance practices for its networks are consistent with those of prudent practitioners.

5.3 Manhole Event Records and Trends

WMECO reported that they experienced 30 manhole events involving explosion, fire, smoke or dislodged covers during the period June 1999 to date. Approximately half (14) of these events involved dislodged covers. Manhole data prior to that date was not available. The information provided was insufficient to determine whether any trends exist in the root causes of these events, nor was it possible to determine if manhole events have increased since March 1998.

A visual examination of WMECo’s service territory map, shown below in Figure 5-2 superimposed with the locations of all reported manhole events, does not appear to indicate a geographical clustering of occurrences. However, we note a preponderance of events (26%) occurred during the month of August. This is depicted in Figure 5-3.
**WMECO Manhole Events**

- **Greenfield:**
  - 2001: 1 event
  - 2003: 3 events

- **Pittsfield:**
  - 1999: 2 events
  - 2000: 3 events
  - 2003: 1 event
  - 2004: 2 events
  - 2005: 1 event

- **Springfield:**
  - 1999: 1 event
  - 2000: 4 events
  - 2002: 1 event
  - 2003: 6 events
  - 2004: 4 events
  - 2005: 1 event

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**Figure 5-2.** WMECo service territory map with locations of all reported manhole events

**Figure 5-3.** WMECo - reported manhole events by month
5.4 Causes of Dislodged Manhole Covers

Although the information provided to us from WMECo was not sufficient to determine root causes of the manhole events experienced on their underground systems, we note some statistics depicted in the pie charts in Figure 5-4. First, the reported manhole events have occurred on systems of all voltage levels, with 29% on the 4 kV system, 27% on the 13.8 kV system, 27% on the low voltage system, and 17% on the 23 kV system. Secondly, the majority of the reported manhole events (47%) involved explosions.

![Pie charts of WMECo manhole event statistics](image)

5.5 Practices to Anticipate/Mitigate Future Manhole Events

WMECo believes the most effective way to mitigate manhole events is to reduce the number of faults on underground distribution circuits. Much of this effort is the responsibility of the System Planning group including:

- Monitoring performance of underground distribution circuits
- Reviewing events to look for trends that indicate circuit performance is deteriorating
- Maintaining circuit prints on which are recorded all cable and joint failures
- Periodically reviewing failures to determine trends related to specific cable or splice types, vintages, manufacturers, etc.
- Performing annual 10-year load forecasts to determine upgrades needed to meet projected loads
- Using electronic models of its four low voltage (208Y/120) street networks to assess their ability to supply new or increased loads within the network system

The Company has an equipment failure reporting system and database, which is maintained by the Northeast Utilities Standards group. This group looks for equipment failure trends across the entire NU system.
WMECo is also in the fifteenth year of a 25+- year plan to eliminate all its underground 4 kV distribution circuits. This radial system is 55-65 years old and believed to be at the end of its useful life. It is being replaced with 13.8 kV or 23 kV looped systems that are expected to handle loads at improved levels of reliability. Conversions are based on reliability performance and load forecast results of the remaining 4 kV circuits.

5.5.1.1 New Technology Discussion

From our meetings with WMECo personnel, we believe that, with the support of NU, they are aware of new technologies being applied to underground distribution systems, and are making use of these when appropriate for their system. An example is their method of gathering load data in the networks using “drive-by” load reading technology. In addition, the Company has retained outside firms to perform partial discharge testing on key cables. However, like other utilities, they have concluded that the mixed results and benefits from this costly procedure are difficult to justify.

With regard to the network systems, the use of “electronic” current limiting fuses on the primary feeders to replace the breaker instantaneous relays is not justified or technically feasible because the feeders for the network are non-dedicated. Further, considering the small size of their networks, the use of a remote monitoring system, such as used by NSTAR in its large systems, cannot be justified.

5.6 Conclusions

Based on our assessment of the data provided by WMECo and the information received at our interview meeting with representatives of their management and technical staff, we conclude the following:

1. The integrity of the WMECo underground electric distribution systems is acceptable, and their designs are consistent with accepted utility practices. We note that our assessment does not include field inspections of the Company’s underground facilities.

2. Although WMECo has experienced events involving dislodged manhole covers, their records of same only date back to June 1999. As a result, we are unable to determine if manhole events have increased on their underground system during the period March 1998 to date.

3. The manhole event information recorded and provided to us by WMECo was not sufficient to determine root cause trends of the manhole events experienced on their underground systems. Additional data and root cause analyses are needed.

4. WMECo’s practice of performing manhole inspections only when a manhole is open for another purpose hampers its ability to anticipate and mitigate manhole events.

5. All recommendations contained in the Recommendations Section of this report are applicable to WMECo.
6.1 Underground Systems

6.1.1 Design and Integrity of the Underground System

The Unitil service territory in Massachusetts is the Fitchburg Gas and Electric Light Company. Its underground system is for all practical purposes the low-voltage secondary network system in the downtown area of Fitchburg. The secondary network is supplied from the 69 to 13.8 kV Sawyer Passway substation that was built in 2002. This substation also supplies two 13.8 kV feeders that serve another distribution substation, and two 13.8 kV feeders that serve distribution loads. The Sawyer Passway station contains two 12/16/20 MVA transformers supplying two 13.8 kV bus sections with the tie breaker closed. The remainder of the load in the Fitchburg downtown system is supplied from a single 4 kV circuit.

The network is supplied from three 13.8 kV feeders, two from one bus section and one from the second bus section. The total length of the three network primary feeders is less than three miles. With the station tie breaker operated normally closed, all network feeders have the same voltage, which gives the best possible load division in the network units, resulting in all network protectors sitting closed at all times. These three feeders are dedicated to the network, meaning they supply only network transformers. This configuration gives the greatest operating flexibility, allowing operations to take a network primary feeder out of service for maintenance at any time without creating an interruption. The feeders are protected with the ABB DPU-2000 digital relays at the station, providing both phase and ground time-overcurrent and instantaneous current protection. Under normal conditions, the phase-to-ground and three-phase fault currents are limited to 10.5 and 9.5 kA respectively on the station bus. These levels are well below the 20 kA to 30 kA or higher on the primary feeders of some metropolitan area network systems. The relays also provide fault current data, assisting in the location of faults on the primary feeders.

The installed network transformer capacity on the three feeders is eighteen 500 kVA units, and five 300 kVA units, having a total capacity of 10,500 kVA. The peak load on the system occurs in the winter, and was reported as about 2500 to 3000 kVA. It is designed to operate with any one primary feeder out of service, as verified by experience and power flow modeling. They have also operated the system with two feeders out of service, during the cutover to Sawyer Passway, and during an emergency. However, it is not normal practice to operate with two feeders out-of-service, unless it is an emergency situation. The system is conservatively designed, allowing for significant growth in the downtown area without need for additional network transformer capacity. A cursory review of duct bank drawings suggested there is adequate duct space for additional cables should the need arise. Further, it should be noted that all 500 kVA network transformers are new, having been installed in the
late 1990’s, as are the network protectors on the 500 kVA units. These protectors are equipped with the latest micro processor relays, supplied by ETI. Between the network transformer vault and street manhole, full size neutrals are used, eliminating the possibility of neutral heating under contingencies as is possible with reduced size neutrals.

Connections in the secondary system are made with moles, and cable limiters are inserted at both ends of each cable. All network load is served at 208Y/120 volts. There is only one spot network in the Fitchburg system.

Until maintains a model of the network system and runs load flows periodically using the CAI T2000 software program. Load flows are also run whenever a large load is to be connected to the system. These load flows are run for both normal conditions and with each primary feeder out of service, one at a time.

In summary the network system is conservatively designed, being able to operate under a single contingency with any primary feeder out-of-service. The loadings are well within the ratings of the equipment under normal and contingency conditions, allowing for future load growth. The overcurrent protection used for the primary feeders is consistent with good practice, having instantaneous current relays for rapid fault clearing. Major components of the system, the source substation and network transformers/protectors are relatively new, all having been installed within the last 10 years. We believe the engineers at Until are knowledgeable in network system design and operation, and that the network system is well designed and operated.

### 6.1.2 Underground Distribution System Metrics

The following tables of information provided by Until show the following trends:

- The number of customers on Until’s underground electric distribution system has decreased substantially (36%) over the past five years. This is due to system reconfiguration, and not from degradation of customer base.

- The number of underground department employees has remained constant

- Until’s underground maintenance expenditures have remained relatively constant while construction expenditures have varied substantially percentage-wise, but dollar amounts and differences are small due to the size of the system

<table>
<thead>
<tr>
<th>No. of manholes</th>
<th>192</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of vaults</td>
<td>30</td>
</tr>
<tr>
<td>No. of service boxes</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>221</td>
</tr>
<tr>
<td>Maintenance $ per manhole</td>
<td>$646</td>
</tr>
<tr>
<td>Circuit miles</td>
<td>8</td>
</tr>
<tr>
<td>Maintenance $ per circuit mile</td>
<td>$15,500</td>
</tr>
</tbody>
</table>
### 6.2 Manhole Maintenance and Inspection Practices

The Unitil underground system is relatively small, consisting of 192 manholes and 23 network vaults. Unlike other electric utilities, each manhole is inspected annually; a practice the Company characterizes as historic. Routine inspections have identified problems, such as a leaking PILC splice, that would ultimately result in a failure if not repaired. In the last year, 5 leaky splices were discovered; three have been repaired this year, with two remaining to be done. The repair procedure is to apply a heat-shrink sleeve around the leak, which keeps the splice insulating material in and the water out of the splice.

A two man crew on average inspects about 16 manholes per week. About 30% of their time is spent on this activity, with the remainder dedicated to maintenance and construction work. At Unitil, the employees who perform the manhole inspections also make the repairs, except when lead to lead splices must be made. For this, outside contractors are used.

It was reported that the underground crew is meticulous, and manholes are kept unusually clean. Following heavy rain or melting of snow, it is the Company’s normal practice to pump out the manholes that are known to collect water in them.

Network vaults are entered twice per year, in the winter and summer, to check the load on each transformer/protector. At the same time, checks are made on individual low-voltage cables to check for blown limiters. This is done using flexible core current transformers and an appropriate meter.

The Company does not have a network protector test set at this time. In the past, an outside contractor was brought in to check the protectors and the calibration of the relays. At present, they periodically drop the feeder at the station in order to confirm that all protectors will trip under low-current backfeeds and faults. With the new microprocessor relays in the protectors, the need to do an over-voltage close test is virtually eliminated, especially since it is known that the protectors are found closed following re-energizing of a feeder that was out of service. Considering the size of the system and the ability to check protector positions manually, the need for the test set is minimal.
6.3 Manhole Event Records and Trends

Unitil reports that they have had no manhole events involving dislodged covers during the period 1998 to present. This claim is based upon Unitil’s examination of the “comments section” of its outage database for the period 1998 to present where no indications of manhole event occurrences were found. Additionally, the underground crew that inspects and repairs Unitil’s small underground manhole system verifies this claim.

6.4 Causes of Dislodged Manhole Covers

It is interesting to note that Unitil inspects its manholes annually and has experienced no events causing dislodged manhole covers.

6.5 Practices to Anticipate/Mitigate Future Manhole Events

Unitil believes its current approach to underground manhole inspections and maintenance, as described in its Operation Bulletin #OP6.00, has proven to effectively minimize dislodged manhole covers. The key element of this practice is the annual inspection of its manhole system. This is a visual inspection of all exposed components in manholes and vaults (e.g., condition of the electrical system, equipment, tagging, interior of structure, etc.) at least once per calendar year, in conjunction with a comparative temperature check on all connections (i.e., heat check between phases preferably during circuit peak periods).

As stated above, Unitil examined the notes section of its outage database for the period 1998 through present and found no indication of a manhole event occurring within this timeframe. Therefore, it has no additional mitigation plans.

6.5.1.1 New Technology Discussion

Two relatively new technologies have been installed by some utilities on their underground network systems to obtain better information, and to reduce the chance of a manhole lid dislodging due to high fault currents. One is remote monitoring of network vaults, which is used to obtain real-time load data and protector status (without requiring vault entry). The other involves the use of current-limiting devices in the primary feeders. Examples of such devices are the G&W Current Limiting Protector (CLiP) and the S&C Fault Filter.

It would be extremely difficult to justify the application of current-limiting devices on the Unitil network system. First, the fault currents are limited to 10.5 kA at the station. Second, they have had no events where manhole covers have been dislodged due to primary faults, or any other type of fault.

Similarly, it would be difficult to justify the use of a remote monitoring system for the Unitil system. First, the system is conservatively designed, with the ratio of installed transformer capacity to peak load in the range of 3.3 to 4.0. Second, load checks are made twice per year in each network vault. Third, the small size of the system allows the operators to become familiar with not only the system, but what is “going on in town” that could result in significant changes in loading. Finally, their operating practice of dropping the feeder to check protector operation, and twice-per-year load measurements provide the data needed to evaluate transformer loading and protector operation.
In summary, we would not recommend that Unitil make the investment in these new technologies that have been justified by a few large utilities with hundreds or thousands of network vaults on their systems.

6.6 Conclusions

Based on our assessment of the data provided by Unitil and the information received at our interview meeting with representatives of their management and technical staff, we conclude the following:

1. The integrity of Unitil’s underground electric distribution system is acceptable, and its design is consistent with accepted utility practices. We note that our assessment does not include field inspections of the Company’s underground facilities.

2. Unitil has not experienced an event involving a dislodged manhole cover during the period January 1998 to date. However, Unitil’s reliance on the free-form comments field of its outage database to make this determination could be improved by a prescriptive manhole event data collection form that maximizes checklists.

3. Unitil’s practice of annual manhole inspections appears to be an effective means of anticipating and mitigating manhole events. This practice should be continued.

4. All recommendations contained in the Recommendations Section of this report are applicable to Unitil except the proposed five-year manhole inspection program.
Underground Electric Distribution Systems

This appendix contains general background information on the various types of underground electric distribution systems found in Massachusetts. In general, there are two types of physical construction used for underground systems:

- Duct-manhole construction, and
- Direct buried (URD) construction

Only systems using duct-manhole construction are in the scope of this report because the URD systems have few, if any manholes. All of the Massachusetts utilities have duct-manhole construction.

In general, there are two types of electrical systems using duct manhole construction:

- Radial systems, and
- Low-voltage network secondary systems

The Massachusetts electric companies operate both radial distribution systems and low-voltage network systems. Low-voltage network systems are used mainly in the downtown areas of cities. Radial systems have a simpler configuration and lower cost than low-voltage network systems, and they are generally found in residential areas.

Each type of distribution system has primary and secondary circuits. In Massachusetts, the nominal voltages of primary circuits are typically 4 kV or 13 kV, although other voltage levels are also used. Most residential and small commercial customers are connected to secondary circuits. A typical house has a 120/240 volt, single-phase, three-wire connection to the utility.

A.1 Radial Systems

For this example, 13 kV primaries are used. Figure A-1 shows a simplified radial primary distribution system with one 13 kV primary circuit.
Figure A-1. Simplified Radial Primary Distribution System

The radial distribution system originates in the distribution substation. The main components of the radial system are the 13 kV feeder circuit breakers located in the distribution substation, the 13 kV feeders, the distribution transformers, and the low-voltage secondary circuits that provide service to individual customers. Other important components are the 13 kV switches located in the 13 kV feeders and the 13 kV fuses on the primary side of each distribution transformer.

In the simplified system of Figure A-1, only one radial 13 kV feeder is shown emanating from the distribution substation. In an actual system, there would be many such feeders emanating from the substation, going in different directions to supply the loads.

Distribution transformers connected to the primary feeders step the voltage down to the customer utilization level (e.g., 120/240 volt, single-phase, three-wire service). Low-voltage secondary circuits carry the power from the distribution transformer to the customer's premises.

Under normal (unfaulted) conditions in a radial system, the power flow in each component is always away from the distribution substation towards the customer. The topology of the system is similar to that of a tree. The 13 kV feeder main corresponds to the tree's trunk; the 13 kV feeder branches correspond to the tree's branches connected to the tree's trunk; the distribution transformers correspond to second-level branches of the tree; and the low-
voltage services correspond to third-level branches of the tree. As long as there are no interruptions in any of the paths of the radial distribution system, power will flow from the distribution substation to all customers fed from the system. This is analogous to nutrients flowing from the earth to the tree’s leaves as long as the trunk and none of the branches are completely severed.

When a short circuit (fault) occurs on the 13 kV feeder main or one of the 13 kV feeder branches, the feeder circuit breaker should open to de-energize the entire feeder. Therefore, all customers will be out of service until further action is taken. After the fault is located, all or a portion of the customers will remain out of service until the fault can be repaired and the feeder re-energized. When the main feeder has a fault, all customers are without service until the fault is located, repaired and the circuit re-energized. If there are emergency tie circuits to other 13 kV feeders, then service can be restored to some or all of the customers before the fault is repaired.

If the fault were on 13 kV feeder branch 1 in Figure A-1, all customers are without service until the fault is located. After the fault is located, 13 kV switch 1 can be opened to isolate the faulted section of the feeder. Then the 13 kV circuit breaker at the substation is closed to energize the 13 kV main feeder and 13 kV feeder branch 2. This restores electric service to all customers supplied from the transformers connected to these portions of the radial circuit. After the fault is repaired, service can be restored to the customers supplied from 13 kV feeder branch 1 by the closing of 13 kV switch 1.

If a short circuit occurs in any one distribution transformer, the 13 kV fuse feeding the transformer blows, and only those customers served from the faulted transformer experience a power outage. Some older systems were constructed without primary fuses for the individual distribution transformers. In these systems, a faulty distribution transformer disrupts service to all customers on the primary circuit.

When faults occur in radial systems a large number of customers can be affected, and the length of the power outage can be quite long to all or a portion of the customers fed from the primary feeder. This is especially true in radial distribution systems that are located below ground, because it may be difficult and time consuming to locate the fault. Faulted circuit indicators can be used to reduce the time required to locate faults.

Some radial distribution systems have branch fuses which lower the number of customers experiencing a power outage from faults. Further, some radial circuits also have a loop configuration, which allows service restoration, in many cases, without need to repair the fault.

All four utilities have duct-manhole non-network systems, operating at 4 kV, 13.8 kV, or a higher primary voltage. In these systems, the primary and secondary cables are installed in ducts. The distribution transformers, either single phase or three-phase, are installed in vaults if there is ventilation, or a manhole. There can be and usually is more than one customer served from the secondary supplied by each transformer, but the secondary windings of one distribution transformer are not interconnected to the secondary windings of another distribution transformer at another location as in a 208-volt network system. That is, the secondaries are operated in a radial fashion (not networked) The supplied voltage is 120/240 volt single-phase, 208Y/120-volt three-phase, or 480Y/277 volts three-phase. These systems operate in a radial fashion on the primary, and may be configured as either radial or open loop on the primary side.
A.2 Low-Voltage Network Secondary Systems

Low-voltage secondary network systems were developed in the 1920’s to provide highly reliable service to commercial areas of cities and towns. Massachusetts has several of these networks. All of the four Massachusetts utilities supply some loads through low-voltage secondary networks.

Figure A-2 shows a simplified low-voltage secondary network system serving the same loads as the radial system in Figure A-1. In a network system a short circuit on a 13 kV feeder circuit, in a network transformer, and in a low-voltage secondary main does not cause a loss of power to customers. The reason for this is that there is a multiplicity of paths from the distribution substation to the customers. When any one path is opened, there still are other paths for delivering power from the substation to the customers.

The low-voltage network system originates at the distribution substation. The main components of the low-voltage network system are the 13 kV feeder circuit breakers located at the Distribution Substation, the 13 kV feeders, and the network units (consisting of a network transformer and a network protector). Each network unit feeds a 208 volt (or 480 volt) secondary bus adjacent to each network unit. Low-voltage 208-volt secondary mains connect the 208 volt buses at different locations in the load area. Low-voltage services to the customers are fed from the 208 (or 480 volt) volt buses. Sometimes, customers are fed directly from taps to the secondary mains.
In the simplified system of Figure A-2, there are three 13 kV feeders with just one network unit (transformer and protector) fed from each 13 kV feeder. The actual number of primary 13 kV feeders varies from network to network. A multiplicity of network units are fed from each 13 kV feeder, which depends upon the load levels served.

Under normal conditions in the low-voltage network system, the power flow in each 13 kV feeder is from the distribution substation to the network unit (network transformer and protector). In each network unit the power flow is from the network unit to the secondary buses, and along the secondary mains. There is more than one path for the power to flow from the distribution substation to any one customer. The system is protected such that if a short circuit (fault) occurs in any one path, the short circuit is automatically isolated without causing an interruption to the customers served from the network. The system is designed so that with any one 13 kV feeder and its associated network transformers removed from service, the remaining parts of the system can carry the peak load. This is referred to as single-contingency design, or N-1 design.

Low-voltage network systems can be designed so that if a short circuit occurs on any one bus section in the distribution substation, no customer will experience an outage. Similarly, if there is a failure of any one main power transformer, there will be no customer outages.

If a short circuit occurs on a secondary main, it will either burn clear or be isolated by the cable limiters at each end of the secondary mains. This also will not result in an outage to any customers served from the secondary buses. However, if there are customers tapped directly from the secondary main which has the short circuit, the customers on the shorted secondary main will lose power until repairs can be made.

It is clear that most short circuits in the system do not cause power outages to the customers supplied from the network. The main reason for this is that there is a multiplicity of paths from the substation to the customer loads, and the short circuits are automatically isolated. This is why the low-voltage network system offers the highest levels of reliability possible with conventional power systems, and is used extensively in many metropolitan areas.

All of the low-voltage network systems employ duct, manhole, vault construction. The primary and secondary cables are in ducts that interconnect manholes, or bring primary and secondary cables into vaults. The straight joints (splices) and taps of the primary cables are usually made in manholes. The junctions in the 208-volt cables in the grid network are made in manholes, and the individual services to the 208Y/120-volt customers originate in manholes, and in hand-holes or service boxes in some systems.

The following photographs show the types of cable and equipment that may be found in electric distribution system manholes. They were taken by PTI field inspection teams during a previous assessment of a utility located outside of Massachusetts.
Underground Electric Distribution Systems

Figure A-3 Manhole with Primary and Secondary Cables and Splices

Figure A-4 Terracotta Ducts with Primary and Secondary Cables within a Duct Bank
The network transformers and protectors of the low-voltage network, whether supplying the 208-volt grid network, or an isolated 480-volt spot network, are located in vaults. In the 208-volt grid network system, the network transformers and protectors that feed the secondary are scattered around the network area, and are interconnected through a grid (mesh) of low-voltage cables. The transformers frequently are located at the larger loads. Small load and buildings are fed from the manholes with the 208-volt cables.

Isolated spot networks usually supply just one customer, such as a high rise building. They have two or more network transformers that are located in the same vault. Figure A-6 shows an isolated spot network arrangement used by some utilities. Figure A-7 shows a portion of an isolated 480-volt spot network that has three transformers with network protectors. The primary cables for the network transformers come to the vault through ducts. Usually there are no ducts on the 480-volt side of the spot network. The secondary sides of the network transformers are paralleled to a bus on the secondary side, and the customer switchgear fed directly from this paralleling bus.
Underground Electric Distribution Systems

Figure A-6 Isolated Spot Network Arrangement

Figure A-7. Isolated 480-volt spot network, showing network transformers, network protectors, cables to paralleling bus, and portion of paralleling bus
A.3 URD Systems

In the early days, starting in the middle 60’s, Underground Residential Distribution (URD) systems were originally constructed without ducts and manholes. The primary cables were direct buried. The distribution transformers were either pad mounted, or installed in below grade vaults. Many utilities that used below-grade transformer installation have switched to pad mounted transformers because of corrosion and operating problems. The secondary cables and services are located below ground, and direct buried, and operate in a radial fashion. They are not networked on the secondary side. Sometimes connections of secondary cables to service cables are made in handholes. As implied by the name, “residential distribution”, the secondary voltage delivered is usually 120/240-volts single phase.

In recent years, some utilities have stopped using direct buried primary cables in the URD systems, due to the high cost to repair faults. The primary cable is installed in conduit that is direct buried in the earth so that the cable can be pulled out if necessary. The conduit is not encased in concrete as in the conventional duct manhole system found in and around the inner cities, but the conduit is direct buried.

All of the Massachusetts utilities operate the URD systems, as do most utilities in the US. These URD systems are often found on the fringes of cities and towns and in suburbs. Frequently the URD system is fed from an overhead distribution feeder circuit.
Forms and Checklists

The Forms and Checklists herein support the recommendations found in Section 2.

Contents of Appendix B:

- B.1 Repair Priority Checklist
- B.2 Splicing Log
- B.3 Failure Investigation Checklist
- B.4 Manhole Event Data Collection Checklist and Summary Analysis
- B.5 Manhole Inspection Checklist
- B.6 Standard Information For All Events Involving Dislodged Manhole Covers
- B.7 Outreach - Manhole Survey of Non-jurisdictional Utility Operators
B.1  Repair Priority Checklist

The following checklist supports Recommendation No.2 found in Section 2 of this report. The intend is to provide reasonable and comprehensive guidelines for the types of conditions requiring repair and the suggested timeframes within which the repairs should be made.

Priority 1 – Urgent: Repair within five days
- Elevated gas readings to be reported to gas company ASAP
- Cable smoking
- Joint smoking
- Insulation damage – bare conductor
- Burnout visible
- Cable loading greater than 140% of rating
- Severe fluid leaks, joint swelling, joint deformation, neutral corrosion.
- Temperatures above 200° F

Priority 2 – Repair within six months
- Minor fluid leaks, joint swelling, joint deformation, neutral corrosion.
- Insulation damage
- Severe rust on equipment housings
- Loadings between 120% and 140% of rating
- Temperatures between 175° F and 200° F

Priority 3 – Repair within 12 months
- Obsolete cable types (if any)
- Loadings between 100% and 120% of rating
- Temperatures between 150° F and 175° F

Priority 4 – Repair within 18 months
- Re-racking
- Cables not secure
- Structural repairs
- Retag feeders and buses
- All remaining reportable non-electrical conditions

Non-Repair Referrals
- Water in manhole
- Debris
- Cracked walls
B.2 Splicing Log

The following list of information requirements for a splicing log supports Recommendation No. 3 found in Section 2 of this report. Splices are a weak link component of underground electric distribution systems. The splicing log will aid the development of a database to support analyses of possible workmanship issues, splicer training needs, and the splice kit with the best performance.

Information for all new Splices

- Date of installation
- Splicing crew members
- Manhole identification number (street number, grid numbers, etc.)
- Feeder voltage
- Type of cable(s) being spliced
- Type and manufacturer of splice kit being installed
- Reason for splicing
  - new installation
  - cable failure
  - replacement of cable
  - splice failure

Additional Information when the reason for splicing is a splice failure

- Date of installation of the failed splice
- Splicing crew that installed the splice
- Type and manufacturer of failed splice
B.3 Failure Investigation Checklist

The following list of information to be collected and recorded during failure investigations supports Recommendation No. 4 found in Section 2 of this report.

Root Cause Failure Investigation Checklist

Background Information
- Manhole event record number
- Date and time of failure
- Location of failure (city/town and street address)
- Manhole ID number
- Manhole size
- Event type (smoke, fire, explosion)
- Manhole cover type: (solid or slotted)
- Failed equipment (cable, splice, switch, transformer, etc.)
- Cable type, manufacturer, size
- Feeder number for primary cable failure
- Voltage
- System (primary/secondary, network/non-network)
- Supply substation identification
- Date of most recent manhole inspection (attach inspection sheet)

Description of the Event
The description of the event has to be sufficiently detailed to allow reconstruction of what took place.
- Sequence of occurrences during the event
- How the event was identified and reported
- Observations of first response crew
- Location of failure (ducts, manhole, in splice or inches from splice)
- Number of circuits and phases failed
- Visible signs of failure, including digital photographs
- Manhole conditions (dry/damp/inches of water/failure under water)
- Number of customers interrupted
- Restoration efforts at scene

Analysis Performed to Identify Root Cause of Failure
The identified root cause of the failure has to be sufficiently detailed to allow tracking of causes of failures. For example, secondary cable insulation may be degraded by overheating due to electrical overload conditions, taped joints or splices may have water ingress, or there may have been some mechanical damage. Merely stating “insulation damage” does not give real information.

➢ Identification of material saved for analysis
  ▪ Cable section, splice, switch, etc.

➢ If no material saved for analysis, note the reasons why, for example:
• Repairs made on site destroyed evidence
• Damage due to failure obliterated evidence

➢ Root cause analysis performed:
  ▪ Tear down of splice and/or cable observations
  ▪ Electrical, chemical, or mechanical tests performed and results

➢ Other supporting evidence
  ▪ signs of cable overheating, rodent damage, etc.

**Findings and Analysis**
This section summarizes the findings and any analysis performed to support those findings.

• Observations
• Cable/equipment data and examination results
• Load flow analysis to check for cable overloading
• Fault current analysis
• Discussion
• Engineering commentary

**Conclusions and Recommendations for Future Action**
Example: Deteriorated cable insulation resulting from combination of load cycling, temperature and environment facilitated moisture penetration. Inspect other manholes on this circuit for similar conditions.
### B.4 Manhole Event Data Collection Checklist and Summary Analysis

The following manhole event data collection checklist supports Recommendation No. 5 found in Section 2 of this report.

#### Sample Manhole Event Data Collection Form

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Circuit No.</th>
<th>Manhole ID No.</th>
<th>City or Town</th>
<th>Street Address</th>
<th>Event Type (E, F, S)</th>
<th>MH cover type</th>
<th>Equipment Involved</th>
<th>Cable Type</th>
<th>Voltage System</th>
<th>Cause/Description</th>
<th>Action Taken</th>
<th>Last Inspection Date</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

Summary analysis of manhole events to be included with the quarterly and annual reports of the above data:

- Total number of events
- Service territory map with locations of all reported events
- Number and percentage of events by:
  - Primary vs. secondary
  - Network vs. non-network
  - Voltage level
  - Splice vs. cable vs. other equipment
  - Explosions vs. fire vs. smoking manholes
  - Monthly distribution of total
  - City or town
B.5  Manhole Inspection Checklist

The following Manhole Inspection Checklist supports Recommendation No. 5 found in Section 2 of this report.

**Inspection Team**
- Name of inspectors
- Date of inspection
- Reason for inspection

**Location**
- City or town
- Street address or other specific location information
- Grid #
- Feeder #/name
- From/to Substations #/name

**Stray Voltage, Gas and Temperature Readings**
- Stray voltage measurements
- Gas % combustible
- Ambient manhole temperature

**Equipment Information**
- Transformer type and ratings
- Breaker information
- Other equipment information
- Condition of equipment

**Manhole Information**
- Type of manhole cover (solid/slotted/grating)
- Sidewalk/roadway location
- Roof type (recessed/flush/pavers)
- Roof condition (good/damaged/loose cover)
- Sump pump
- Sewer connection
- Manhole condition (good/ too small/large cracks)
- Water level (dry/below cables/above cables/full)
- Debris (below ducts/ducts obstructed)
- Manhole size

**Voltages in Manhole**
- Primary voltage
- Number of feeders
- Secondary voltage
Cable Conditions
• Types of primary cables
• Types of secondary cables
• Cable/joint conditions
• Cable leak
• Joint leak
• Joint swelling
• Deformed (imploded) joint
• Upright supports
• Racking
• Burnout visible
• Insulation damage
• Neutral damage and/or corrosion
• Cables covered with mud or water
• Rodent droppings visible

Current and Temperature Readings of Secondary Cables
• Record each cable’s current
• Record cable temperature

Inspector’s Comments
• Primary cable system problems
• Secondary cable problems
• Manhole problems
• Temperature problems
• Overloading
• Debris
• Pictures taken

Refer Problems to Appropriate Department for Repair
• Name of department(s)

Sample Manhole Inspection Form
A sample manhole inspection form is shown on the following two pages.
# Example of Manhole Inspection Sheet

**Date:** __ / __ / __

**Inspection:**

**Area #:** __

**Vehicle #:** __

**Inspection Type:**

- [ ] Scheduled
- [ ] Random

**Grid #:** (12 digits)

**Jurisdiction:**

- [ ] NW
- [ ] NE
- [ ] SW
- [ ] SE
- [ ] NW
- [ ] MO

**MANHOLE INFORMATION**

- **Location:**
- **Ambient Air Temperature:**
- **No. Digital:**
- **Pic:**

**Other:**

- [ ] Roadway
- [ ] Sidewalk
- [ ] Alley
- [ ] Empty
- [ ] Abandoned

**Cover Slik:**

- [ ] 24" (Choose one)
- [ ] 28" (Choose one)
- [ ] Other:

**Cover Condition:**

- [ ] Good
- [ ] Poor
- [ ] No

**Drainage:**

- [ ] Poor
- [ ] Full
- [ ] Partial
- [ ] None

**Manhole Condition:**

- [ ] Good
- [ ] Poor
- [ ] No

**Problem:**

- [ ] Large Crack
- [ ] Concrete Missed
- [ ] Steel
- [ ] Showing

**Roof Type:**

- [ ] Recased
- [ ] Flash
- [ ] Favors

**Sump Pump Present:**

- [ ] None
- [ ] Working
- [ ] Broken

**Sewer Connection:**

- [ ] Yes
- [ ] No
- [ ] Unknown

<table>
<thead>
<tr>
<th>Manhole Content</th>
<th>Primary</th>
<th>Secondary</th>
<th>Both</th>
<th>Removed</th>
<th>Empty</th>
</tr>
</thead>
</table>

**FEEDER NUMBERS**

- **Substation #:** __

**equipment information**

- **Transformer Type:**
  - [ ] None
  - [ ] OH
  - [ ] Subsurface
  - [ ] Subway
  - [ ] Network
  - [ ] Pole Type

- **Transformer Condition:**
  - [ ] Good
  - [ ] Leaky
  - [ ] Rust
  - [ ] Cracked Bushing

- **Phases:**
  - [ ] A
  - [ ] B
  - [ ] C

- **Transformer Connectivity:**
  - [ ] 1-Phase
  - [ ] Parallel
  - [ ] Delta / Y
  - [ ] Y / Y

**Primary Voltage:**

- [ ] 4 kV

**Secondary Voltage:**

- [ ] 120 / 240
- [ ] 125 / 215
- [ ] 277 / 480

- **Transformer Size:**
  - [ ] 10
  - [ ] 25
  - [ ] 37.5
  - [ ] 50
  - [ ] 75
  - [ ] 100
  - [ ] 112.5
  - [ ] 150
  - [ ] 167
  - [ ] 250
  - [ ] 300
  - [ ] 333
  - [ ] 500
  - [ ] 750
  - [ ] 1000

- **1500**

**Other:**

- [ ] Non

- **Network Protector**
  - [ ] Good
  - [ ] Rusted

- **2 W Switch**
  - [ ] Good
  - [ ] Damaged

- **3 W Switch**
  - [ ] Good
  - [ ] Damaged

- **3 W Switch & Fuse Box**
  - [ ] Good
  - [ ] Damaged

- **3 W Switch & 2 Fuse Boxes**
  - [ ] Good
  - [ ] Damaged

- **Taphole**
  - [ ] Good
  - [ ] Damaged

- **Capacitor**
  - [ ] Good
  - [ ] Damaged

- **STOP Box**
  - [ ] Good
  - [ ] Damaged

- **UGD Module**
  - [ ] Good
  - [ ] Replace

- **Shunt Controller**
  - [ ] Good
  - [ ] Defective

- **Fuse Pod**
  - [ ] Good
  - [ ] Defective

**Cable/Joint CONDITION INFORMATION**

- **Good (No problems)**
- [ ] Yes
- [ ] No

- **Problems (Check all that apply):**
  - [ ] Cable Leak (CL)
  - [ ] Joint Leak (JL)
  - [ ] Joint Damaged (JD)
  - [ ] Insulation Damage (ID)
  - [ ] Neutral Corroded (NC)
  - [ ] Open - Not Tied (ONT)
  - [ ] Braided Cable (BC)
  - [ ] Fireproofing (FP)
  - [ ] Other (OR)

**REFER TO**

- **Underground Lines**
- **Conduit**
- **Distribution Engineering**
- **General Shop**
- **Transformer Shop**
- **T&D Test**

**Coordinator Review Date:** __

**Corrective Action:**

**W.O. #:** __

**INSPECTOR COMMENTS**
## Example of Manhole Inspection Sheet

<table>
<thead>
<tr>
<th>Grid #</th>
<th>Duct Bank Detail Information</th>
<th>Date</th>
<th>Condition of Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Duct Bank Detail Information</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cell Location</td>
<td>Type of Cable</td>
<td># Current Limiters</td>
</tr>
<tr>
<td></td>
<td>Duct Bank Detail Information</td>
<td>SET 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Duct Bank Detail Information</td>
<td>SET 2</td>
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<td>Duct Bank Detail Information</td>
<td>SET 5</td>
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<table>
<thead>
<tr>
<th>AMPS</th>
<th>TEMPERATURE</th>
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</thead>
<tbody>
<tr>
<td>B</td>
<td>C</td>
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<tr>
<td>D</td>
<td>E</td>
</tr>
</tbody>
</table>

### Siemens Power Transmission & Distribution, Inc.
Power Technologies International
B.6 Standard Information For All Events Involving Dislodged Manhole Covers

The following information should be included in required reports for all events involving dislodged manhole covers. This supports Recommendation No. 5 found in Section 2 of this report.

- Event record number
- Location of failure
- Date and time of failure
- Weather conditions for previous 24 hours
- Manholes involved in event
  - Number and location
  - Manhole size
  - Manhole cover type (solid or slotted)
  - Whether manhole cover was dislodged
- Failed equipment type (cable, splice, etc.)
  - Feeder number for primary cable failure
  - Voltage
  - Cable type and age
  - Cable loading
  - Other equipment involved and age
- Supply substation identification
- Event type (smoke, fire, explosion)
- Manhole entry
  - Date of most recent manhole inspection (attach inspection sheet)
  - Date of most recent manhole entry and reason (e.g. maintenance)
  - Failures at this location in the past 5 years
  - Gas detected in manhole
- Sequence of occurrences during the event
  - Number of customers interrupted
  - Duration of interruption
  - Personal injuries and/or property damage
  - Related outages
- Summary of initial investigation into cause of failure
B.7 Outreach - Manhole Survey of Non-jurisdictional Utility Operators

The following manhole survey and cover letter support Recommendation No. 7 found in Section 2 of this report.

B.7.1 Manhole Survey - Underground Electric Distribution Systems

1. Does your organization operate an underground electric distribution system containing manholes?  Y  N
2. If yes, approximately how many manholes are on your system?  __________
3. Do your maintenance practices require a scheduled inspection of all manholes?  Y  N
4. If yes, how frequently must each manhole be inspected?  ________________
5. Have you had any of the following manhole events occur on your system during the past three years:
   a. Manhole explosion with dislodged manhole cover.  Y  N
   b. Manhole explosion without dislodged cover.  Y  N
   c. Manhole fire.  Y  N
   d. Smoking manhole.  Y  N
6. If yes, has public safety or property been affected.  Y  N
7. What systems, methods, or technologies do you employ to anticipate underground failures in splices, cables, and equipment?
   a. Splices: _____________________________________________________________
   b. Cable: _____________________________________________________________
   c. Equipment: _________________________________________________________
8. Would your organization consider participating in a Working Group designed to study topics related to minimizing and mitigating the impact of manhole events on public safety and electric system reliability?  Y  N

Name of Municipality/Organization: ____________________________________________
Address: _____________________________________________________________________
Name of Survey Respondent: ____________________________________________________
Telephone Number: ___________________________________________________________
Email Address: _______________________________________________________________
B.7.2 Manhole Survey Cover Letter

Dear (City, Town, Municipal Electric Department, etc.):

As part of our ongoing efforts to examine and promote practices that improve the safety and reliability of electric distribution systems, the Massachusetts Department of Telecommunication & Energy has focused attention on the issue of manhole events in the underground electric distribution systems of regulated utilities in the state. Because these events may impact the safety of the general public in all areas where electric distribution manhole facilities are located, we are reaching out to municipalities and other organizations that may operate such systems. If your organization is one of those, we ask that you complete the attached questionnaire, which is intended to broaden our information base regarding the location and maintenance practices regarding these systems.

Additionally, we are considering the creation of a Working Group comprised of representatives of the DTE, the regulated utilities, and organizations such as yours, to help minimize manhole events and mitigate their potential hazards to public safety. Therefore, our questionnaire also seeks to determine the level of interest your organization may have in participating. The working group would meet periodically to discuss manhole event trends, root cause analyses, lessons learned, new technologies, industry research studies, and other related topics.

The DTE thanks you for your assistance and cooperation in supporting our efforts on this important issue.
Historical Manhole Event Records

The following tables contain data recorded and provided by the three companies that experienced manhole events with dislodged covers. (Unitil reported no events.) Data was requested for the period January 1, 1998 to present. However, each company’s records covered limited time periods:

- NSTAR: July 2004 to June 2005 (44 manhole events)
- National Grid: August 2004 to May 2005 (20 manhole events)
- WMECo: June 1999 to February 2005 (30 manhole events)
### NSTAR Manhole Events (1 of 2) – Lifted Covers

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Circuit No.</th>
<th>Manhole ID No.</th>
<th>Location (Address)</th>
<th>Event Type (F, or S)</th>
<th>MH cover type (Fire or Smoking manhole)</th>
<th>Equipment Involved (splice, joint, cable, xfr)</th>
<th>Cable Type (PILC, EPR, XLPE)</th>
<th>Voltage (13.8 kV, 4 kV, 480 V)</th>
<th>Cause/Description (overload, deterioration, dig-in, etc.)</th>
<th>Action Taken</th>
<th>Last Inspection (Date manhole was last inspected)</th>
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### Historical Manhole Event Records

#### NSTAR Manhole Events (2 of 2) – Covers Ajr

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<th>Circuit No.</th>
<th>Manhole ID No.</th>
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<th>Event Type</th>
<th>MH cover type</th>
<th>Equipment Involved</th>
<th>Cable Type</th>
<th>Voltage</th>
<th>Cause/Description</th>
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<th>Town</th>
<th>Time</th>
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<td>Manhole cover dislodged; No inj. The manhole cover became dislodged due to frost in manhole; unknown how high manhole cover lifted; no orbs at scene at time; no injuries.</td>
<td>MANHOLE #9, NORTH MAIN STREET, CORNER OF ODD STREET, FALL RIVER, MA</td>
<td>Fall River</td>
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<td>23A</td>
<td>200A Premold</td>
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<tr>
<td>0000676</td>
<td>08/16/2004</td>
<td>Manhole Cover Dislodged; No inj. There was a short circuit in the manhole causing the cover blow off approximately 20 feet</td>
<td>BROADWAY &amp; LANDDON STREET, Everett, MA</td>
<td>Everett</td>
<td>9:20 AM</td>
<td>230B</td>
<td>A-339</td>
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<td>200A Premold</td>
<td>23A</td>
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<td>0000676</td>
<td>09/01/2004</td>
<td>Manhole cover dislodged; No inj. A compact employee reported that a manhole cover in a public street blew off due to a cable failure on the 304 cable. The cover popped up and when the employee arrived at the site, the cover was off to the side of the hole. No injuries or property damage was reported.</td>
<td>200 ADAMS STREET, QUINCY, MA</td>
<td>Quincy</td>
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<td>304</td>
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<td>12A</td>
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<td>0000649</td>
<td>11/05/2004</td>
<td>Manhole cover dislodged; no injuries. The Worcester Fire Department reported that a manhole cover blew off on West Boylston Street in Worcester, MA. A high tension circuit was locked out. No injuries were reported.</td>
<td>716 WEST BOYLSTON STREET, WORCESTER, MA</td>
<td>Worcester</td>
<td></td>
<td></td>
<td>12A</td>
<td>12A</td>
<td>joint</td>
<td>12A</td>
</tr>
<tr>
<td>0000625</td>
<td>11/12/2004</td>
<td>Manhole Cover Dislodged; No inj. An underground cable failure caused the manhole cover to blow off the manhole. No gas was present in the manhole.</td>
<td>MH 2702 HAVELIN STREET, WORCESTER, MA</td>
<td>Worcester</td>
<td></td>
<td></td>
<td>12A</td>
<td>12A</td>
<td>joint</td>
<td>12A</td>
</tr>
<tr>
<td>0000677</td>
<td>12/09/2004</td>
<td>Manhole cover dislodged; No inj. The 4C cable failed in the manhole causing the cover to dislodge again. This was reported by the Melrose Fire Department.</td>
<td>MA-290 FRANKLIN &amp; CLIFF STREETS, Malden, MA</td>
<td>Malden</td>
<td>9:55 AM</td>
<td>4C3</td>
<td>200A</td>
<td>joint</td>
<td>200A</td>
<td></td>
</tr>
<tr>
<td>0000673</td>
<td>12/13/2004</td>
<td>Manhole Cover Dislodged; No inj. A public contractor installing a water main for the city of Fall River hit an underground service pipe to house #1691 South Main Street, Fall River causing the cover of MH 98 to blow. The cover flipped over and landed approximate 20’’ from the hole. Earlier that day, there was a gas main leak in the same area which may have contributed to the cover blowing off. When the second fire flash occurred later that day, it was possible that the gas leak contributed to the manhole explosion. There were arcing and flames coming out of the manhole. No injuries were reported.</td>
<td>MH 88, BLDG #1691 SOUTH MAIN STREET, SOMERSET, MA</td>
<td>Somerset</td>
<td></td>
<td></td>
<td>100A</td>
<td>Glycerin explosion</td>
<td>Secondary</td>
<td></td>
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<tr>
<td>0000714</td>
<td>02/01/2008</td>
<td>Manhole cover dislodged - manhole explosion causing 4 manhole cover dislodgements. Reported by Beverly police. 600 customer outage 3 1/2 hours.</td>
<td>PARK STREET (5), BOW STREET (1), BEVERLY, MA</td>
<td>Beverly</td>
<td>11:46</td>
<td>12:36</td>
<td>35A, 73A, 73A</td>
<td>joint</td>
<td>35A</td>
<td></td>
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<tr>
<td>0000722</td>
<td>02/02/2008</td>
<td>Manhole cover dislodged (1) - We lost a feeder and police reported manhole cover dislodged. No injuries were reported.</td>
<td>MANHOLE 3-15 KILOWATT STREET AND MANHOLE 396-13 POND STREET, FALL RIVER, MA</td>
<td>Fall River</td>
<td></td>
<td></td>
<td>12A</td>
<td>12A</td>
<td>joint</td>
<td>12A</td>
</tr>
<tr>
<td>0000722</td>
<td>02/03/2008</td>
<td>Manhole cover dislodged - Police reported the manhole cover dislodged. There was a man coming through the manhole. No injuries.</td>
<td>MANHOLE 191-4 KILBURN STREET, FALL RIVER, MA</td>
<td>Fall River</td>
<td>15:36</td>
<td>115V/65</td>
<td>151-6</td>
<td>050A separable connector</td>
<td>151-6</td>
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Siemens Power Transmission & Distribution, Inc.
Power Technologies International
## National Grid Manhole Events (2 of 2)

<table>
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<tr>
<th>Case #</th>
<th>Date</th>
<th>Description</th>
<th>Exact Location</th>
<th>TOWN</th>
<th>Time</th>
<th>Circuit</th>
<th>MH #</th>
<th>Equip Involved</th>
<th>Type</th>
<th>kV</th>
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<tbody>
<tr>
<td>00007238</td>
<td>02/05/2006</td>
<td>Manhole Cover Dislodged; No Inj. Two manhole covers dislodged due to a cable fault in a duct between two manholes. The Fire Department responded and called the trouble center. There were no outage calls and the underground crews were unable to locate the fault that day.</td>
<td>MH C67 &amp; A53 FERRY STREET AT ESSEX STREET, MALDEN, MA</td>
<td>Maiden</td>
<td>10:30 approx.</td>
<td>6C4</td>
<td>C67 and A53</td>
<td>cable</td>
<td>lead covered</td>
<td>4</td>
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<tr>
<td>00007244</td>
<td>02/06/2006</td>
<td>Manhole Cover Dislodged; No Inj. A manhole cover dislodged due to a cable fault in a duct between two manholes. The same cover had dislodged the previous day and the fault was not found. Underground crews were able to locate the fault this time and repairs were made.</td>
<td>MH C67 FERRY STREET AT ESSEX STREET, MALDEN, MA</td>
<td>Maiden</td>
<td>19:30 approx.</td>
<td>6C4</td>
<td>C67</td>
<td>cable</td>
<td>lead covered</td>
<td>4</td>
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<tr>
<td>00007248</td>
<td>02/07/2006</td>
<td>Manhole Cover Dislodged; No Inj. A gas explosion in the manhole caused the manhole cover, casting, pavement and curb to erupt. No injuries were reported.</td>
<td>MH B143 SALEM STREET AT ROUTE 93, MEDFORD, MA</td>
<td>Medford</td>
<td>19:30 approx.</td>
<td>B143</td>
<td>none gas leak</td>
<td>none gas leak</td>
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<tr>
<td>00007294</td>
<td>02/10/2006</td>
<td>Manhole Cover Dislodged; No Inj. A manhole cover blew half way off its casting due to a cable fault located in the hole. It will be repaired.</td>
<td>MH S26 EVERETT #5 SUBSTATION, EVERETT, MA</td>
<td>Everett</td>
<td>10:00 approx.</td>
<td>37W7</td>
<td>C25</td>
<td>wye joint</td>
<td>pre-molded</td>
<td>13</td>
</tr>
<tr>
<td>00007406</td>
<td>02/26/2006</td>
<td>Manhole cover dislodged - Failed OFC switch caused manhole cover dislodgement &amp; fees into air, no injuries. Reported by police driving past.</td>
<td>MANHOLE B07, PARK AVENUE, WORCESTER, MA</td>
<td>Worcester</td>
<td>807 approx.</td>
<td>0FC</td>
<td>4</td>
<td>OFC</td>
<td>4</td>
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<tr>
<td>00007550</td>
<td>03/09/2006</td>
<td>Manhole Cover Dislodgement - Pedestrian fall in manhole. An 15kV cable failure resulted in both an outage and manhole cover dislodgement. A pedestrian fell into the open manhole. Injuries were unknown.</td>
<td>BROADWAY AND CHESTNUT STREET, EVERETT, MA</td>
<td>Everett</td>
<td>10:40 approx.</td>
<td>6D2</td>
<td>J-X</td>
<td>lead single-multiple</td>
<td>4</td>
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<tr>
<td>00007677</td>
<td>03/21/2006</td>
<td>Manhole Cover Dislodgement - Fire Dept reported that a manhole cover was dislodged from Vernon &amp; Upsala Street in Worcester. Arrived and repaired fault. No injuries.</td>
<td>MANHOLE 2-164, U1055 CIRCUIT, VERNON &amp; UPSALA STREET, WORCESTER, MA</td>
<td>Worcester</td>
<td>15:15 approx.</td>
<td>GJ36</td>
<td>2104</td>
<td>joint</td>
<td>Heat Shrink</td>
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<tr>
<td>00007718</td>
<td>03/28/2006</td>
<td>Manhole Cover Dislodgement - Circuit failed. Employee at substation (Kevin Sinclair) went out and saw a manhole cover that is inside substation yard dislodged.</td>
<td>THORNHILL STREET SUBSTATION, EVERETT, MA</td>
<td>Everett</td>
<td>05:00 approx.</td>
<td>230MA</td>
<td>A-320</td>
<td>joint</td>
<td>3C lead</td>
<td>23</td>
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<tr>
<td>00007831</td>
<td>04/14/2006</td>
<td>Manhole Cover Dislodged; No Inj. Two manhole covers were dislodged approximately 6-8 inches from the hole caused by failed secondaries in one hole and gas present in both holes. No injuries were reported.</td>
<td>MH B347 &amp; B348 BROADWAY, EVERETT, MA</td>
<td>Everett</td>
<td>10:30 approx.</td>
<td>B347 and B348</td>
<td>paper lead</td>
<td>secondary</td>
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<tr>
<td>00009032</td>
<td>05/07/2006</td>
<td>Manhole Cover Dislodgements, NOA, questionable only - There was a cable fault at manhole 414, Fruit Street, Worcester, when crew arrived discovered manhole cover teetering on top of hole.</td>
<td>MANHOLE 4-14, FRUIT STREET, WORCESTER, MA</td>
<td>Worcester</td>
<td>414 approx.</td>
<td>414</td>
<td>cable</td>
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# Historical Manhole Event Records

## WMECo Manhole Events

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Circuit</th>
<th>Manhole</th>
<th>Location</th>
<th>Event Type</th>
<th>MH Cover Type</th>
<th>Dislodged Cover?</th>
<th>Equipment Involved</th>
<th>Cable Type</th>
<th>Voltage</th>
<th>Cause / Description</th>
<th>Action Taken</th>
<th>Last Inspection</th>
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<tbody>
<tr>
<td>6/30/1999</td>
<td>7:55</td>
<td>404</td>
<td>Pittsfield</td>
<td>E</td>
<td>N/A Y Primary</td>
<td>N/A</td>
<td>4160</td>
<td>404-2.</td>
<td></td>
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<td><strong>MANHOLE COVER BLWN OFF MH2879 ON CAREW ST. SWITCHED CUSTOMERS AND REPAIRED CABLE</strong></td>
<td>N/A</td>
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<td>9/16/1999</td>
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<td>Springfield</td>
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<td>N/A</td>
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<td>23,000</td>
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<td>1/29/2000</td>
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<td>1:02</td>
<td>15E2</td>
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<td>PER FIRE DEPT SMOKE COMING FROM MANHOLE AT INTERS OF NORTH AND MADISON / OUTAGE IN AREA</td>
<td>N/A</td>
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<td>6/2/2000</td>
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<td>21B10</td>
<td>Springfield</td>
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<td>N/A Y Primary</td>
<td>N/A</td>
<td>13,800</td>
<td>MANHOLE BLEW UP IN FRONT OF MOBL STATION / NEEDS EMERGENCY ASSISTANCE...FAST !</td>
<td>N/A</td>
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<td>6/12/2000</td>
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<td>Pittsfield</td>
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<td>Pittsfield FD REPORTS EXPLOSION ON 400 SUMMER AND FRANSIS...SMOKE COMING OUT OF MANHOLE</td>
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<td>UNDERGROUND TRANSFORMER BLEW / MANHOLE COVER OFF / FIRE ON SCENE</td>
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<td>SPRINGFIELD FIRE SAYS FIRE IN MH ON CORNER OF RIFLE ST AND ALLEN ST</td>
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<td>5U14A</td>
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<td>Springfield</td>
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<td>CALL FROM POLICE DEPT... STEAM COMING FROM MANHOLE. CORNER OF COMBS AVE</td>
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<td>3/2/2004</td>
<td>15:48</td>
<td>5G4</td>
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<td>4/13/2004</td>
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<td>N/A Y Primary</td>
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Appendix

**Detailed Work Plan and Schedule**

**May 16-31:**
- Prepare for a project kickoff meeting with the Massachusetts DTE
- Attend kick off meeting at DTE offices (May 18)
- Request data collected to date by the DTE form the four electric companies (5 binders received from DTE on May 31)

**June 1-17:**
- Initiate review and examination of data received from the DTE
- Prepare a comprehensive Data Request and sample data collection form for the four electric companies (completed June 3; distributed to the companies with request for response by June 17)
- Prepare for and attend project kickoff meetings with National Grid (June 8), WMCo (June 9), Unitil (June 9), and NStar (June 13).
- Prepare and submit a detailed work plan and schedule to the DTE (submitted June 15)
- Complete review and examination of data provided by the DTE

**June 18-30:**
- Initiate analysis and comparison of the four companies’ responses to Data Request
- Assess and compare manhole inspection and testing practices and schedules
- Assess and compare definitions of “manhole event”
- Assess the completeness of manhole event record keeping
- Analyze the service territory maps for manhole event “clusters”
- Prepare comparative tables, charts, and graphs for each company, including:
  - numbers of manholes, transformer vaults, and service boxes

*Siemens Power Transmission & Distribution, Inc.*
*Power Technologies International*
Detailed Work Plan and Schedule

- manhole inspection and maintenance practices
- backlogs of manhole repairs
- annual listings by month of all manhole events recorded from Jan.1, 1998 to date
- annual numbers of manhole events recorded during the past five years
- annual rate of manhole events per thousand manholes for the past five years
- frequency distributions of manhole event causes based on failure analyses
- 5-year history of underground staffing levels
- 5-year history of underground customer growth and peak load growth
- 5-year history of underground construction and maintenance budgets and actual expenditures
- 5-year history of annual SAIDI, SAIFI, and CAIDI for the underground systems

(Note: These analyses are premised upon receipt of the companies’ data on or about June 17.)

July 1-15:
- Submit June project status report to the DTE
- Provide project briefing to the DTE including rate of progress, initial findings, and plans to accomplish remaining work
- Review remediation plans to mitigate manhole events and manhole cover dislodgements, and assess implementation status of plan activities
- Review and examine reports and studies performed by the companies and/or their consultants regarding the design, operation, maintenance, and condition of the underground distribution system
- Request interviews, as needed, with company personnel responsible for organizational areas including: a) design, construction, maintenance and repair of the underground system, b) failure analysis of manhole events, c) analytic electronic modeling of the underground system, d) new technology assessments, e) coordination/communication with outside agencies to reduce hazards to public safety during underground system events

July 16-31
- Conduct interview meetings with Unitil (July 20), NSTAR (July 21), National Grid (July 25 and 26), and WMECo (July 28)
- Request additional data, as needed, for response by month-end July
Details Work Plan and Schedule

- Assess and compare the underground system practices among the four companies to determine best practices (e.g., inspection and maintenance of manholes, new technology applications, analytic modeling, underground system design, etc.)

- Prepare and submit a mid-project briefing document to the DTE (July 18)

**August 1-16**

- Submit July project status report to the DTE

- Attend mid-project briefing meeting with DTE Staff (August 4)

- Mid-project presentation of findings and recommendations to DTE Commissioners and Staff (August 9)

- Initiate preparation of draft final report with exhibits and supporting data to provide an independent assessment of findings and/or professional opinions regarding:
  - adequacy of the companies’ underground facilities maintenance and inspection practices,
  - adequacy of the companies’ manhole event remediation plans and their implementation,
  - adequacy of the companies’ practices to anticipate the risk of future cable, splice, and equipment failures,
  - adequacy of the companies’ record keeping procedures,
  - causes and remedies for dislodged manhole covers,
  - whether the occurrences of dislodged manhole covers have increased since March 1, 1998, and why,
  - whether changes in the design of manholes, circuitry or equipment have contributed to the occurrences of dislodged manhole covers, and
  - recommendations of further actions to be taken in order to improve the integrity of the underground distribution systems and remediate the public safety hazards inherent in these systems.

**August 17-31**

- Perform factual verification of company-specific data for each of the four companies sections of draft final report (August 17 – 20)

- Complete draft final report and submit to DTE for comment and discussion
Data Request

1. Provide inspection and maintenance policies, schedules, practices, checklists, and record keeping procedures for underground facilities including manholes, transformer vaults, and service boxes.

2. Provide your Company’s definition(s) of “manhole event” (e.g., explosion, fire, smoke, dislodged cover, etc.).

3. Provide the Company’s prioritization schedule for manhole conditions found during inspections requiring repairs (e.g., types of conditions requiring immediate repair vs. within one month, one year, etc.).

4. Provide a listing of the current backlog of manhole repairs by priority.

5. Provide the current number of manholes, vaults, and service boxes in the underground system.

6. Provide the number of manhole events and the number of manhole events per thousand manholes for each year of the last 5 years.

7. Provide an annual listing by month of every manhole event experienced from Jan. 1, 1998 to date. Please include data as shown on the attached “Sample Manhole Event Form” and provide annual analyses (e.g., frequency distributions) of event causes/descriptions, equipment involved, event type, slotted vs. solid covers, etc.

8. Provide a service territory map showing the location of manhole events from year 2000 to date. Color-code the event locations by year of occurrence.

9. Provide an annual summary listing of all failure analysis reports completed for the manhole events provided in question #7 above.

10. Provide copies of all failure analysis reports from year 2000 to date.

11. Provide all studies and reports, including recommendations and resulting implementation activities, by the Company or its consultants from year 2000 to date dealing with any aspect of the underground distribution system including: a) inspection, maintenance, design and construction of the underground system, b) analysis of trends and causes of manhole events, failures, and displaced manhole covers, c) assessments of new technologies for consideration or implementation (e.g., high speed electronic fuses), d) use of slotted manhole covers, e) reliability performance and outage restoration, f) others.
12. Provide a list and description of the types and uses of information systems to support the underground distribution system including analytical electric model(s), outage management, mobile dispatch, maintenance management, work management, GIS, etc.

13. Provide an organization chart and 5-year history plus current staffing levels for all underground departments by classification (e.g., cable splicer, conduit installer, supervisor, etc.), and the most recent staffing study performed by the Company and/or its consultant.

14. Provide the year-end number of customers and annual peak loads served by the underground distribution system for the past 5 years.

15. Provide a listing of PILC and extruded dielectric distribution voltage class cables installed on the system. Please indicate if there is any ongoing or anticipated cable replacement program(s).

16. Provide number of circuit miles by cable type (e.g., PILC, extruded dielectric, etc.) and voltage level.

17. Provide the last 5 years of SAIDI, SAIFI, and CAIDI for the underground system and any benchmarking studies/comparisons of these indices with other electric utilities.


19. Provide the actual annual underground construction and maintenance expenditures for year 2000 to date.

20. Provide documentation of the existence of a splice repair log and a sample of the data collected therein.

21. Provide a description of all plans and activities designed to reduce the frequency and the impact of manhole cover displacements and related safety hazards.

22. Provide a description of all cooperative agreements, activities, training, and communication protocols with cities, towns, police and fire agencies, emergency services, municipal electric departments, etc. in place to minimize public safety hazards due to underground system events.

23. Provide the names and titles of Company management employees responsible for the following activities on the underground distribution system: a) design, b) construction, c) maintenance, d) manhole inspections, e) failure analysis, f) analytic electric modeling, g) new technologies, h) reliability, i) staffing analysis, j) training, k) information systems (e.g., GIS, OMS, WMIS, MDS, etc.), and l) coordination with agencies listed in question #22 above.
Interview Meetings

**Unitil**
July 20, 2005

- Manager, Electric Systems
- Manager of Distribution Engineering
- System Supervisor
- Line Supervisor
- Distribution Engineer
- Manager – Energy Systems Engineering (by telephone)

**NSTAR**
July 21, 2005

- Vice President Engineering
- Manager – Distribution Technical Engineering
- Director - Distribution Engineering
- Director – Substation Engineering
- Lead Engineer – System Engineering
- Lead Engineer – System Engineering
Interview Meetings

National Grid
July 25 and 26, 2005

- Vice President, Engineering Services
- Vice President, Distribution Engineering & Asset Management
- Manager, Underground Engineering & Operations
- Staff Assistant, Operations - N. E.
- Director, Asset Strategy & Performance
- Principal Engineer, Distribution System Engineering
- Principal Engineer, Protection Department
- Coordinator, Underground Lines
- Manager, Protection Engineering
- Consulting Engineer – Protection & Integration Engineering

WMECO
July 28, 2005

- Manager, Operations Strategy
- Manager, System Planning
- Senior Engineer
- Principal Engineer, Distribution Asset Management (CL&P)
Appendix

Monthly Project Reports

G.1 June 2005

Prior to formal project initiation, Siemens PTI attended an introductory/project orientation meeting at the DTE offices on May 18 to discuss project approach, key issues, and receive initial direction. During the month of June, Siemens PTI initiated the DTE project with the following activities:

- Received five binders of project-related information from the DTE on May 31
- Initiated review and examination of project-related information collected by the DTE from the four companies
- Prepared project activity guidelines and lead assignments for the PTI project team members
- Prepared a comprehensive initial data request submitted to the DTE for comment on June 7, and submitted to the four companies on June 8-9
- Prepared for and participated in project kickoff meetings (held at each companies offices in Massachusetts) with National Grid on June 8, WMECo and Unitil on June 9, and NSTAR on June 13
- Prepared a detailed 3-month project work plan and schedule submitted to the DTE on June 15
- Received responses to Data Request #1 from National Grid, WMECo, and Unitil on June 17.
- Received partial response from NSTAR on June 28. Expecting to receive remainder during the week of July 4.
- Initiated assessment and comparison of responses to DR #1, and spoke by telephone with project liaisons from each company in order to clarify responses, as needed.

In addition to the above activities, we established communications protocols with the DTE Staff and the four companies in order to facilitate an orderly project execution and timely response to data and interview requests. We also received a Non-Disclosure agreement from NSTAR with a request that Siemens PTI treat all NSTAR materials as confidential until NSTAR decides which, if any of their documents should be protected.
G.2  July 2005

During the month of July, the Siemens PTI team engaged in the following Dislodged Manhole Covers Project activities:

- Submitted June monthly project report to the DTE on July 1.
- Completed review and examination of project-related information collected by the DTE from the four companies.
- Received final written responses and clarifications to Data Request #1 from National Grid, WMECo, Unitil, and NSTAR, and performed an individual and comparative assessment of responses.
- Prepared a Mid-Project Briefing presentation based primarily on responses to Data Request #1, and submitted it to the DTE on July 18.
- Scheduled and conducted interview meetings with representatives from each of the companies per the following schedule:
  1. Unitil – July 20
  2. NSTAR – July 21
  3. National Grid – July 25 and 26
  4. WMECo – July 28

In addition to the above activities, we initiated team discussion of possible areas of recommendations based upon our data analysis and interview meetings. These include the following:

- Recommend and propose a definition for “manhole event” that includes smoking manholes, manhole fires, and manhole explosions.
- Propose that formal root cause failure analysis be performed for all manhole explosions involving dislodged covers.
- Recommend and propose a standard data collection form for capturing and reporting all manhole events.
- Recommend and propose a standard data collection form for manhole inspections maximizing checklists and minimizing free-form comments.
- Recommend a manhole inspection program, the parameters and priorities of which to be determined.
- Recommend and propose a repair priority schedule for abnormal conditions that may be found during manhole inspections.
- Recommend the initiation of splicing/splicing repair logs in order to track possible workmanship issues and training needs.
- Recommend creation of a working group comprised of representatives of the four companies and the DTE to meet periodically and discuss manhole event trends, root cause analyses, lessons learned, new technologies, research studies, etc.
References


