Toolkit for Resilient Cities

Case Study: New York City Electrical Grid

A research project carried out by Arup, RPA and Siemens

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Scope

The aim of work for the project Toolkit for Resilient Cities has been to survey a wide spectrum of ideas for building resilience in multiple urban infrastructure systems around the globe. In order to test the ideas a case study for the electrical grid of New York City and its metropolitan area was undertaken.

The case study presents a high level review of the vulnerabilities in the electrical grid and the steps that could be taken to mitigate risk. We investigate the impacts of four types of natural hazards (drought, heat wave, wind and flood) on the generation, transmission and distribution of electricity, in order to extrapolate how New York City can ensure continuous electricity supply during a range of such extreme events. We propose a series of actions and investments that will contribute to advancing the resilience of the electrical grid and, in turn, the city.

Context

The city of New York is an international icon, offering an attractive environment for businesses and residents. The city has established a strong identity as a global enterprise hub; a center of commerce, highly connected to trade and industry throughout the world.

But with great strength, comes great vulnerability. During just a few hours in October 2012, Superstorm Sandy brought winds of up to 85mph (38 m/s) and a peak storm surge of 9 feet (2.7 meters), which occurred on top of a 5 foot (1.5 meter) high tide. The storm caused widespread loss of power to residents and businesses across the metropolitan region, and rapidly focused New York City on some very basic needs. It is estimated Superstorm Sandy caused more than $50 billion in overall damage to the greater New York area.

Apart from the short term impact on people and businesses, there is potentially a long term impact of increasing hazard frequency on the city's ability to attract and retain the scale of inward business investment that defines New York City. If business disruption becomes a regular event, and if quality of life cannot be assured, what kind of city will New York become? Action must be taken to ensure the resilience of critical infrastructure that supports city life.

Hazards and risks review

New York City has a long history of environmental events, ranging from floods and hurricanes to heat waves and drought. Our understanding of risk is based on historical data; the frequency and intensity of past events is used to estimate potential hazards of the future. However, recent events indicate that this understanding may no longer be accurate. Superstorm Sandy and Tropical Storms Lee and Irene occurred in consecutive years, and took a tremendous toll on the northeast region. New hazards are also arising; tornados, which are historically infrequent, have hit New York City each year since 2010.

In the past three years alone, New York City and the surrounding metropolitan area have endured an unprecedented variety and number of severe weather events, with substantial costs incurred due to direct damages and consequential disruptions. The variety of hazards experienced by the region affects all aspects of the electricity grid, from substation flooding to wind and ice damage of overhead lines. Looking ahead, climate scientists project that these events will increase in frequency and severity, leading to greater direct and indirect impacts such as increases in peak demand that strain generation facilities as summer temperatures trend upwards and the region's population grows.[2]

Frequency of Hazard Occurrence in New York City[1]

	Flooding	Drought	Heat Wave	Wind Events
Past Events (1970-2000)	1 in 100 years	1 in 100 years	2 per year	1 in 3 years
Projected Events due to climate change	1 in 15 years	Unclear	8 per year	Increased frequency

Effect of recent hazards on the New York City electrical grid

	2010		2011	2012
Event	Tornado	Blizzard	Heat Wave	Superstorm Sandy
Hazard	125 mph (56 m/s) winds	60 mph (27 m/s) gusts, 20 inches (51cm) of snow	104°F (52°C) temperature	14ft (4.3m) storm surge, 8 mph (3 m/s) gusts
Cost/Damage	Damage and outages – 45,000 customers affected	Outages and loss of subway service	Outages – 139,000 customers affected	Over $40 million (£26 million) in damages to the electricity grid

Options for making the grid more resilient

Understanding the current risks and resilience of New York's electricity infrastructure is vital to developing a plan for the area's future. Due to the complexity of electrical infrastructure, solutions for resilience will need to address all of the city's current assets with the appropriate level of action. There is no single technology or investment that can respond to every threat. Multiple, targeted investments combined with enabling actions are necessary to protect and maintain the grid.

Electricity assets can be categorized into substation equipment, transmission and distribution infrastructure, and generation facilities. Con Edison is New York City's primary utility provider, and serves approximately 3.3 million electricity customers in New York City alone. It owns 61 substations within the city, approximately 18 of which are in flood zones. The area's transmission and distribution infrastructure includes 2,200 primary feeders consisting of 94,000 miles (151,300 kilometers) of underground cable and 34,000 miles (54,700 kilometers) of overhead lines.

Each asset is vulnerable to a particular range of risks and requires specific solutions to withstand future shocks and stresses. However, assets must be addressed collectively to provide resilience throughout the system. Additionally, a number of non-energy systems are affected by impacts to the grid – including water distribution and transportation – and must be accounted for when determining a response to sudden events. An understanding of these interdependencies is necessary to achieve comprehensive and cost-effective strategies for resilience.

Potential environmental hazards that could affect the NYC metro electricity grid

Hazards		
Tidal surges	High winds	Heat waves
Flash floods	Blizzards	Drought

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Despite the well-known reliability of Con Edison's systems, Superstorm Sandy caused extensive damage to New York City's electricity grid. One of the most visible effects of the storm was the failure of Con Edison's 13th Street substation. On the evening of October 29, 2012 water from the storm surge began to inundate the city's low-lying areas. The substation, located in a designated flood zone, had been designed to withstand a peak water level of 12.5 feet (3.8 meters). However, this design standard was not enough to withstand the 14 foot peak brought by Sandy.[3] Sea water inundated circuits and blew the transformer, leaving lower Manhattan in darkness. The explosion resulted in outages for nearly 250,000 customers,[4] and forced the evacuation of critical facilities. Several other neighborhoods were disconnected as a precaution, due to concern for potential equipment damages and load constraints. Hundreds of thousands of customers were left without power over the next six days.

$1 billion (£646 million) is the cost to New York City of a day without power.[5]

Potential resilience investment options

From the analysis of the threats to the grid, we developed a range of investment options.

Making equipment more robust

In the short term, technologies that promote robustness will be essential. For example, gas insulated switchgear is contained in a sealed vessel to provide a degree of waterproofing. Since it requires considerably less space than conventional switchgear, it may also allow electrical equipment to be located on higher floors or even below ground. Additional protection measures include flood-proofing and waterproofing substations and installing submersible equipment, undergrounding critical overhead lines, adding hydrophobic coatings on overhead lines, and installing fuse-saving technologies.

Expanding demand reduction programs to reduce peak demand and network congestion

Demand reduction and energy efficiency in infrastructure and buildings must also continue. The Distribution Load Relief Program and the Commercial System Relief Program are two demand response programs available to businesses. The CoolNYC program allows residential customers to wirelessly control their window air conditioners. The New York Independent System Operators (NYISO) provides several demand response programs to industrial and commercial consumers.

Demand response programs are typically voluntary programs with incentives that are initiated by the utility contacting the customer but there are greater opportunities with advanced metering infrastructure (AMI) and Energy Management Systems (EMS) at the building level for automated demand response through the internet.

Developing a smart grid for greater flexibility and responsiveness

In the medium term, investing in AMI will provide detailed, real time information to help manage the large and dynamic power grid. Smart meters communicate with a wide range of user control systems, and securely and reliably communicate performance information, price signals and customer information to the utility. This information allows utility providers to monitor system performance and take rapid action where required.

Distributed automation of the systems will integrate smart technologies and provide a monitoring and control function to allow for system performance optimization. Intelligent feeders and relays, voltage/Voltage Ampere Reactive (VAR[6]) controls, and automated switches are essential to enable this function. Many of these technologies are currently in pilot stages across the metropolitan region; however there is a number of enabling factors required for these technologies to be deployed at scale (discussed below).

In the long term, investments such as increased deployment of distributed generation, Automated Demand Management (ADM) – which connects buildings to the grid and reduces grid load by automatically powering down non-critical appliances – and vehicle-to-grid (V2G) technologies will all make the grid more resilient by increasing the diversity of supply, creating system capacity at times of peak demand, and enabling flexible means of energy storage.

New York

Contribution of potential investments to advancing resilience characteristics

Robustness	Gas insulated switchgear Flood proofing and water proofing Undergrounding Hydrophobic coatings Fuse saving technologies Voltage/VAR controls
Redundancy	Battery storage Vehicle-to-grid Demand reduction and energy efficiency
Diversity and flexibility	Distributed generation Intelligent feeders and relays Automated switches Battery storage Vehicle-to-grid
Responsiveness	Advanced Metering Infrastructure (AMI) including smart meters Automated Demand Management Intelligent feeders and relays Automated switches
Coordination	Advanced Metering Infrastructure (AMI) Geographic Information Systems (GIS)

Economic analysis

An economic analysis was developed to demonstrate the business case for investing in technologies that enhance resilience and help to manage risk by improving robustness, redundancy, responsiveness, flexibility and diversity to the grid, while also increasing capacity and efficiency in normal times.

Recent events have changed our understanding of our risk profile, and show that investments in resilience can be worthwhile.

When an event occurs, the city – and therefore the tax/rate payer – must pay to respond and repair the damage. Our analysis projected a cost of $350 to $450 million (£225-290 million) every three years, based on the damages caused by recent events and their projected frequency in the future.[7] If this scenario prevails, the city and the tax/rate payers will pay up to $3 billion over 20 years just to repair the damage (in red in graph labeled as 'no action').

The simplest course of action to avoid these costs is to increase infrastructure robustness. Flood and wind protection measures for critical assets can be implemented relatively quickly (within three years on an accelerated schedule) with a cost in the range of $400 million (£258 million). Implementing these measures should reduce the cost of repair and

We can do nothing and expose ourselves to an increasing frequency of Sandy-like storms that do more and more damage, or we can abandon the waterfront. Or, we can make the investments necessary to build a stronger, more resilient New York – investments that will pay for themselves many times over in the years to come.

Mayor Michael R. Bloomberg, speaking in New York City, June 11, 2013[8]

response in the next 20 years by approximately $2 billion (£1.3 billion) (in blue in graph labeled as 'partial investment').

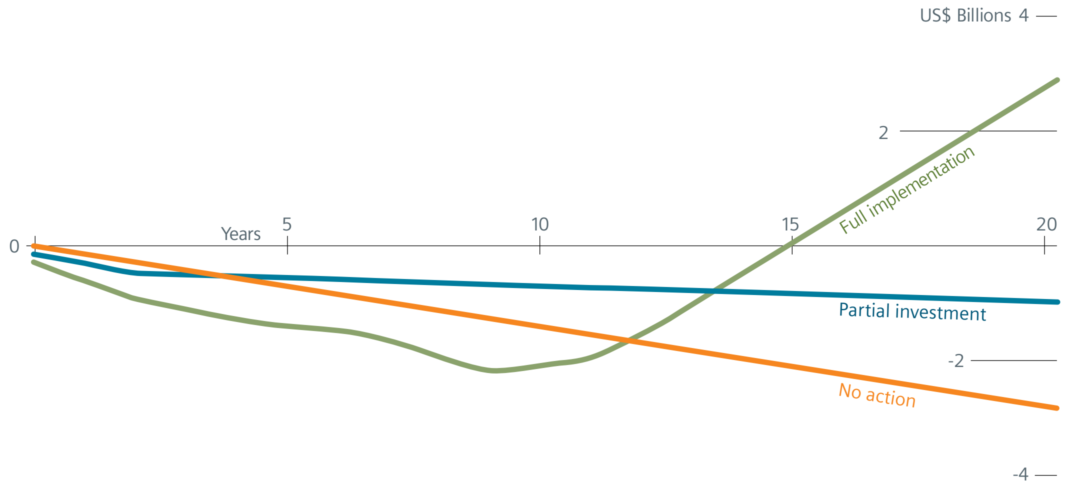
However, the robustness investments provide only a defensive solution which can at best reduce losses. Meanwhile, full investment in protection together with smarter infrastructure solutions will not only reduce the impact of future events event, but will also provide long term added benefits to the city, its residents and its businesses. On an ambitious 12-year investment program, city agencies and utilities will need to spend approximately $3 billion (£1.9 billion) to introduce an effective system of smart technologies. This is a significant cost, but these investments should lead to:

- Fewer outages and increased reliability for the utility and the customer
- Decreased transmission and distribution losses, with consequent system cost reductions
- Reduced need for additional generation capacity due to improved system energy efficiency
- Reduced disruption to priority energy consumers, including medical and emergency services, businesses and industry
- Reduction of greenhouse gas emissions and other pollutants
- The continued ability of the city to maintain its global competitiveness.

The financial value of these benefits may reach $4 billion (£2.6 billion) (in green in graph labeled as 'Full Investment').

In this model, investment costs and benefits have not been attributed to different parties, but instead reflect the costs and benefits to the whole system. In practice, they are likely to accrue asymmetrically to stakeholders including the federal government, the city, utilities, ratepayers, private business and individual consumers. A key next step for this case study, or for another city investigating its own resilience opportunities, would be to map the "investors" or "contributors" and the "beneficiaries" across the system, leading to the development of planning, regulatory and market mechanisms to capture the value created by resilience benefits from the beneficiaries.

Economic analysis of future scenarios for New York City electrical grid (the methodology is presented in full in Appendix 2).



Enabling actions to support resilience investments

As discussed in Chapter 3, the recommended technologies need a package of enabling actions to support their widespread deployment. Policy and regulation will need to keep pace with new technologies. New York City has a progressive government, which has taken action in recent years to further the goals of sustainability and efficiency, with a growing focus on resilience since Superstorm Sandy. Nevertheless, there are further changes that can facilitate a large scale shift towards greater resilience.

Existing city regulations prevent non-utilities from operating power lines to serve microgrid customers. Other regulations stop utilities from owning energy generation facilities. Currently, such regulations are inhibiting the adoption of local energy generation and supply networks. These regulations need to be reconsidered.[9]

The cost of real estate in New York City and the complex nature of the existing grid[10] inhibit the optimal siting of infrastructure technologies.

Integrated planning solutions are necessary, which incorporate power supplies as part of the design by, for example, undergrounding power lines in new developments and planning for cogeneration. Building and zoning codes should be modified to prevent the location of critical infrastructure in exposed areas. In addition, more pilot project opportunities should be promoted to trial and demonstrate smart technologies, especially in areas with high electricity demand.

Ownership and operating structures for new infrastructure must be better defined and understood, including local energy generation, storage and vehicle-to-grid (V2G) technologies. This would remove uncertainty surrounding responsibilities for payment, maintenance and management, with greater clarity attracting more frequent adoption.

The location of critical infrastructure is fundamental. This information should be known by utilities, and shared with planners and engineers. Utilities should map out their assets using Geographic Information Systems (GIS), because a map-based database is widely understood and well suited to track assets, identify exposed infrastructure and monitor the status of dispersed equipment.

It will also be essential to communicate the benefits of proposed infrastructure improvements and service changes (such as real time pricing) to communities and businesses to ensure widespread understanding about the benefits new systems will bring. Furthermore, utilities and technology companies must ensure that the reasons for neighborhood construction projects are widely understood in terms of long term safety, security and reduced risk exposure.

The level of investment necessary for these infrastructure renewals will not be possible without government involvement. It is the responsibility of state, local and federal entities to establish a legislative and regulatory environment, and flexible protocols that supports resilience planning. Governments also have greater access to financing, and can effectively communicate with the public and business to coordinate interests.

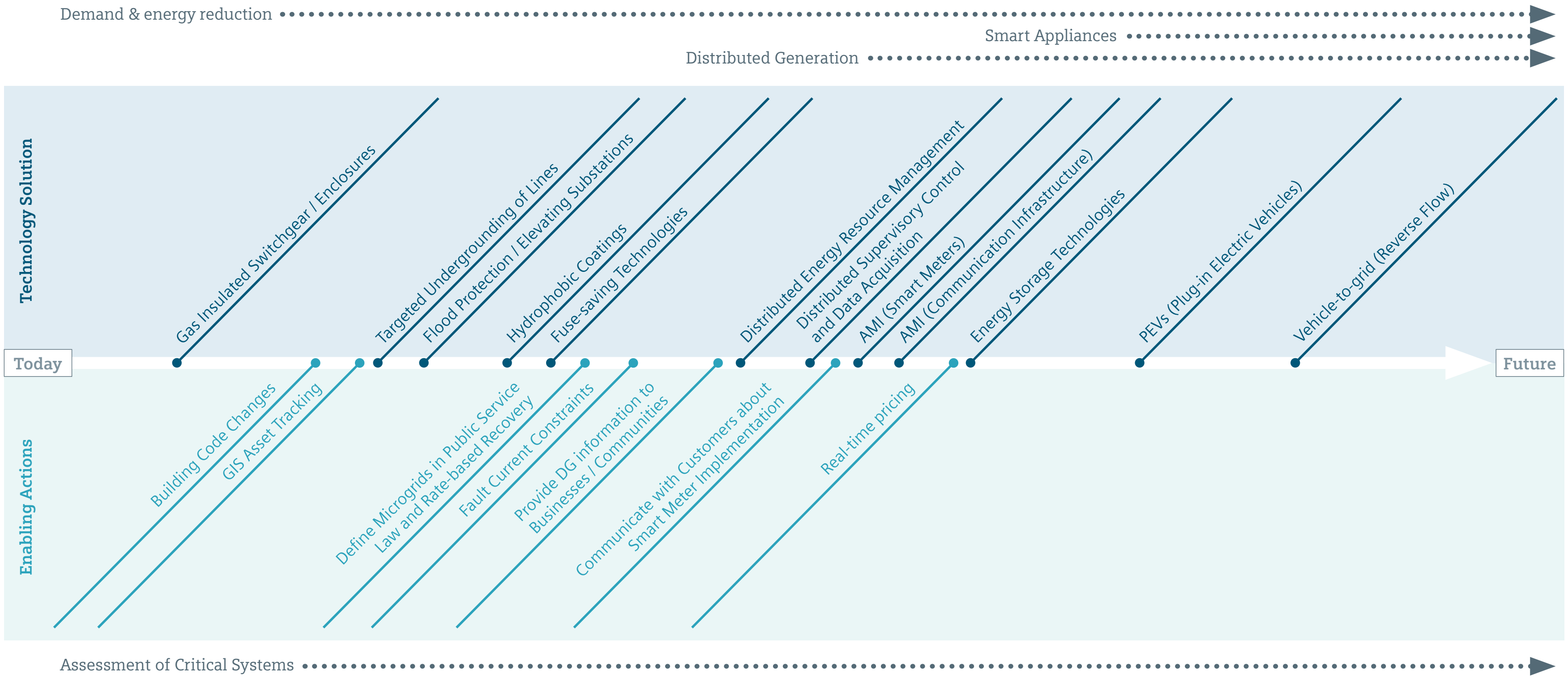
We don't know for certain that we'll ever see another storm as strong as Sandy and we all hope we don't. But we must prepare for that possibility – and others. Heat waves, drought, and sea level rise will also pose significant challenges in the years ahead.

Mayor Michael R. Bloomberg, speaking in New York City, June 11, 2013.

Road map for grid resilience

We have evaluated the potential future risks for the New York region and identified short, medium and long term technology investments to help prepare the area's electricity grid for future disasters. Additionally, we have examined the enabling actions that would aid the implementation of these technology solutions (summarized below). The actions listed here are not unique to New York – they are appropriate within the context of any city, regardless of infrastructure age or scale of operation.

Responses and effects of asset and system level impacts



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[10] Although the utilities have improved and updated the grid over the years, interconnection is very difficult and a complex process.

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