

Substation Flood Program and Flood Hardening Case Study

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Abstract— An effective flood resiliency program is a critical component to protecting society's critical infrastructure. This paper illustrates the need, and important considerations, for an effective flood resiliency program in the context of New England electric substations. A thorough alternatives analysis incorporating input from all key stakeholders was fundamental to identifying the most feasible options for immediate, short term, and long term flood mitigation. A case study is presented to illustrate some of the regulatory, physical, security, operational, electrical, and response factors requiring that required creative solutions employed to construct a barrier system at a bulk grid 115kV substation.

Index Terms — Substation, flooding, resilience, mitigation, barrier.

PROGRAM NEED

National Grid is a major US utility company serving gas and electric customers throughout the New England and upstate New York region. Like many utility companies throughout the world, climate change and climate resiliency has become an important focus for National Grid. This focus is in keeping with the 2010 U.S. National Security Strategy, which identifies protection of our Nation's critical infrastructure as a key component of strengthening America's security and resilience at home. Among the greatest evolving threats to our infrastructure is extreme weather, and the costliest in terms of loss of life and physical damage is flooding. As a result, the utility's ability to withstand flooding events that have an impact on its infrastructure, particularly substations, has led to the creation of a flood resiliency program that encompasses immediate, short-term, and long-range plans to deal with the problem.

In 2010 the Rhode Island area was severely affected by flooding in the Warwick area. Beginning with a February 23-24 storm, the National Weather Service registered 4 inches (10 cm) of rainfall on its Warwick rain gauge. On March 13 to 15 and March 22 to 23 the gauge logged a combined 7.1 inches (18 cm) of rainfall. Add to that amount the 8.8 inches (22.4 cm) of rain that fell between March 29 and April 1, and Rhode

Island was soaked by roughly 20 inches (50.8 cm) of rain in just 38 days. The Pawtuxet River crested at nearly 21 feet (6.4 m), more than 11 feet (3.4 m) above flood stage [1]. The record rainfall resulted in extreme river flooding on the order of a 500-year annual chance event and significant damage to area substations (ref. **Figure 1**).



Figure 1 - 2010 Flooding of RI Substation

In 2012 Super Storm Sandy, a category 3 hurricane at its peak, made landfall in New Jersey as a post-tropical cyclone with hurricane-force winds. Sandy brought a storm surge with subsequent flooding to the northeastern seaboard with a ferocity never seen before and was a devastating event for the utility infrastructure in both New Jersey and New York.

These two events were the catalysts that drove the idea at National Grid, along with many other utilities that a proactive approach was necessary to minimize the impacts related to flooding events. An inventory of all substations that were located within the 100-year floodplain was instituted and a risk management register was created that ranked the risk of occurrence, and severity of damage that a flood would incur, at any particular substation.

PROGRAM CONSIDERATIONS

Flood hardening as generally defined by the Department of Energy (DOE), is a physical alteration (referred herein as civil alternatives) to the substation to reduce susceptibility of contact between floodwaters and sensitive substation equipment and energized conductors. In simplest terms, hardening involves either physically raising the sensitive equipment and conductors or controlling the floodwater with physical barrier and pump systems. Flood hardening is similar to, but distinct from, flood proofing as defined by the Federal Emergency Management Agency (FEMA), and flood resistance as defined by ASCE 24. Flood hardening is a key component of *flood resiliency*, which is defined herein (as interpreted from the definition by DOE) as eliminating or reducing the number and duration of customer service interruptions from flooding impacts. Other components of flood resiliency include preparedness and programmatic changes such as network re-routing / sub networking, utilizing mobile substations, and expediting restoration (referred to herein as non-civil alternatives).

It was determined early in the process that stakeholder input would be a significant component of the alternatives analysis and program effectiveness and efficiency required that both hardening and resiliency approaches be continually considered throughout the evaluation process. As new flood hardening products were continually entering the market, the program needed to continually consider all practical and feasible alternatives, with attention paid to minimizing interruptions and effectively integrating with substation planning. Further, the program needed to effectively address the full spectrum of challenges and objectives from the big picture of managing risk and integrating with short- and long-term planning, down to the details of integration with other capital projects and minimizing interruption to daily facility operations and maintenance (O&M).

Due to the breadth of possible resiliency alternatives, going forward the discussion of this paper is limited to only civil flood hardening approaches.

A. Immediate, Short-Term, and Long-Term Objectives

The time scale component of flood hardening was found to be a key planning concept. A direct relationship was found to exist between the technical and operational effectiveness of a flood hardening solution and the time to place that flood hardening solution into service. It was also found that rapidly-implemented solutions tended to have a shorter service life. In the interim, technically and operationally less-effective flood hardening alternatives requiring less, or no, initial construction and with inherently shorter service lives, were pursued to satisfy both immediate and short-term flood hardening needs. In some cases, the interim (immediate or short-term) alternatives were found to be sufficient or even appropriate for substations of lesser criticality, and/or shorter remaining substation service lives.

B. Prioritization

Substation criticality was also considered when prioritizing the utility's substations for flood hardening. FEMA's continual updating of Flood Insurance Rate Maps, especially

for many coastal communities, meant that during the course of the program, additional substations were added to the program. A substation prioritization ranking, comprised of flood risk and damage potential, was created to focus the flood hardening efforts toward resources in order of highest to lowest importance. Flood risk considered the anticipated frequency of surrounding flood waters rising to a height that impacts various low-lying substation features such as the yard level, control building floor, control panels, sensitive components of pad-mounted equipment, etc. Damage potential considered asset value and service criticality. Several variables were considered including the substation's role in New England Independent System Operator's reliability analysis of the bulk grid, the number and primary voltages of transformers, the customer count and the potential for customers to be served by re-routing alternatives, and the substation's remaining service life.

C. Alternatives Analysis

Early in the flood program process, a review of the various flood resiliency concepts and commercial products identified approximately two dozen possible flood hardening options. These options translated to hundreds of possible options when combining two or more options at the same substation (e.g., raising outside control panels combined with dry-proofing the control house building).

An initial review of technically feasible civil hardening approaches provided up to three hardening concepts for each substation. A standardized evaluation matrix was created and followed to help fine-tune the concepts and then to identify a preferred hardening solution. The matrix was used effectively to weigh several factors specific to each hardening alternative: capital cost and duration; operations, maintenance, and replacement cost; and risks and opportunities of each hardening alternative at each substation.

In addition to construction, the capital cost and duration concept estimates considered permitting and engineering, which can have a significant impact on duration, as either coastal or inland floodplain regulatory approvals will be required. Operation, maintenance, and replacement of the flood hardening components were estimated over the remaining service life of the substation.

The risks and opportunities evaluation considered potential positive and negative impacts to future yard construction, shared property operations, scalability to address future protection levels, planned outages, normal substation O&M, abutter relations, security, environmental conditions, and post-storm recovery. Considering that some flood hardening alternatives such as barrier systems rely on specialty materials and are historically non-conventional at substations, additional consideration was given to the increased risks of project complexity and cost and schedule volatility.

CASE STUDY OBJECTIVES

The Flood Resiliency Program at National Grid encompasses a wide variety of substations and locations throughout the electric system. Many of the substations chosen for flood hardening present similar challenges whether located along the shoreline or within inland waterways. In addition, several of the locations offer unique challenges including two island locations. One substation located near Boston, Massachusetts was chosen for this case study to illustrate the complexities involved with hardening a major urban electrical load center that is subjected to coastal flood threats.

Our case study substation serves metropolitan Boston and is the eastern terminus of a major inner city 115kV underground cable tie and transmission network. This case study involves a short-term interim flood hardening solution. The long-term solution alternatives required substantial planning, design, and construction with anticipated in-service date of three to five years later. The short-term flood hardening solution required a system that could be planned, designed, constructed and placed in service within six months, with a minimum three- to five-year service life. Further, the hardening solution needed to protect all of the high voltage components and be feasibly integrated into the substation's on-going O&M and equipment upgrades and into the immediate and long-term planning considerations of the substation.

The short-term flood hardening was focused on the 115kV outdoor yard containing a control house, exterior control panels, and vulnerable pad-mounted equipment, in addition to the 115kV underground cable pump house located separate from the 115kV yard (ref. **Figure 2**). It was decided that a flood barrier solution that could be installed and in service within three to six months was the preferred approach (ref. **Figure 3**). The barrier solution needed to meet several installation, serviceability, and operational criteria.

A. Installation Criteria

- No outages required
- Limited subsurface disturbance
- Minimal heavy equipment

B. Performance and Serviceability Criteria

- Minimum 3-foot (1 meter) height
- Minimum three- to five-year service life
- Non-conductive materials

C. Operational Criteria

- Minimal manpower and equipment required to activate the barrier system in response to an impending storm.
- Quick and easy removal of barriers in the event of either planned or emergency equipment repair or replacement.

CASE STUDY



Figure 2 – UG Cable Pump House Located in Floodplain



Figure 3 – Floodstop® Flood Barriers



Figure 4 - Non-Security Fence Crossing

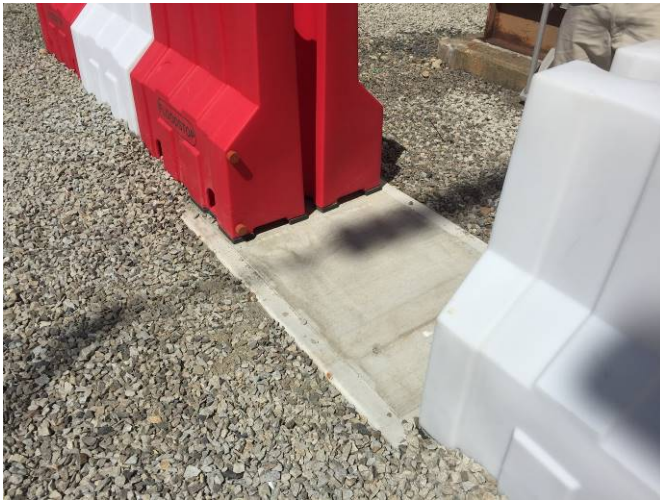


Figure 5 - Barrier Opening for Pedestrian Access



Figure 6 - Materials to Seal Barrier Access Point

D. Planning, Design, and Construction Considerations

Stakeholder input was found to be critical in effectively selecting and designing the short-term flood hardening system. The regulatory permitting process included local, state, and federal regulations that encompassed tidal and wave action along shoreline locations.

Tidal and wave action issues in flooding of substations located along the shoreline have been met to a large degree with flood barriers. Coastal flooding required addressing the challenge of tidal action, wave action, and salt water.

The problem of wave action at another substation has been met with the installation of a physical wave break as part of an ongoing project to rehabilitate a seawall. A physically robust timber barrier system with a subsurface seepage cutoff barrier was installed at another substation to ensure resistance to wave action and minimize seepage. Neither alternative was feasible at the case study substation given the specific constraints at the facility.

For safety reasons, the barrier and pump systems were designed to be activated in advance of the impending storm

event and left to operate reliably and effectively without any manpower. This constraint led to selecting float-activated electrical submersible pumps powered by emergency backup generators. Portable generators were sized to operate the pumps until permanently-installed emergency backup generator sets could be designed and installed with the long-term objective of powering the sump pumps, station service, and the oil pumping system that maintains oil pressure on the underground electric cable.

A redundant system of stainless steel electric submersible pumps with solids handling capability and automated float activation were selected for reliability reasons. For environmental reasons, propane-fired generators were selected to increase run time duration and to avoid concerns with the accidental release of liquid fuel or water intrusion of the fuel during the storm event. For increased reliability and ease of mobilization, multiple, smaller portable generators were chosen and sized to operate up to four pumps at peak draw.

Abutter impacts were also considered. At this case study substation, maintaining the perimeter tree screen and using a special-order muted barrier color at locations visible to abutters was useful in solving visual impacts (ref. **Figure 4**).

Installation of the barriers has presented myriad challenges in the field. Ground preparation typically requires removal of open-graded yard stone and replacement with a low-permeable structural fill subgrade. Subgrade construction is complicated by elevation changes within the yard, as well as stormwater and environmental controls such as containment dikes and berms. Pressure-treated timber sidewalls were successful in raising low areas and with flow fill offered robust scour protection beneath the flood barrier (ref. **Figure 4**).

Other obstacles include the barrier alignment crossing non-security fences and concrete cable trench. Floodstop multi-hubs and sandbags were selected to seal the barrier at non-security fence crossings (ref. **Figure 4**). Crossing cable trench has required that the crossing location be selected to ensure that the number of trench lids impacted is minimized, and sandbags and Floodsax® within the trench itself have been used to seal the trench securely around cables to mitigate significant water from passing under the flood barrier.

Sump pits have been used for portable pump locations throughout the program. Many substation yards are extremely congested, with underground duct banks, conduits and grounding grids complicating any excavation for structures. Ground Penetrating Radar and vacuum excavations were employed to relocate sumps and protect underground features. Sump locations were selected at low areas inside the barrier system, and adjustments made as needed to avoid underground obstructions.

Conduits and underground penetrations that enter the substation from outside the perimeter of the flood barriers were identified and included in a conduit sealing program to prevent seepage into the yard and directly to sensitive controls and energized conductors. A waterproof conduit sealing product is injected into all open pipes and entrances for this purpose.

Maintaining substation security poses another design constraint when locating the flood barriers along the perimeter of the yard. Flood barriers must be located at a sufficient distance within the outer security fence to prevent unwanted access over the fence. In addition, flood barrier placement is critical when situated near animal deterrent devices. Electric fences are used in many National Grid substations for squirrel prevention. It is important that the flood barriers are placed in a manner that allows access and does not require personnel to come in close contact with these devices.

Substation daily operations play a large role in determining the use and placement of the flood barriers. Proximity to energized equipment, access for routine maintenance and switching, egress from control houses, and access for emergency repairs and installation of mobile transformers all influence the location used for the flood barriers. Openings in the barrier are strategically placed to provide local O&M personnel safe and efficient entry for all necessary work within the limits of the yard (ref. **Figure 5**). Flood barriers are maintained at the ready to seal these openings during an impending flooding event (ref. **Figure 6**).

Construction of the flood barriers within energized substations requires that all electrical safety measures be closely followed. Health and Safety plans are required by National Grid for all work within substations. In addition, all regulations including National Electric Safety Code (NESC) and Occupational Safety and Health organization (OSHA) must be followed. In this case study, constraints associated with maintaining minimum approach distance (MAD) to energized equipment and conductors during and after construction were addressed with the use of light-weight, non-conductive barriers. These barriers eliminated the need for heavy equipment to lift or fill in place. Equipment outages and grounding of the barriers were not required for this installation.

Response to flooding events must be carefully assessed to provide the appropriate level of action based on the weather forecast and the geographic region where the storm is anticipated to impact. Determining which action to take and what location to respond to during a storm event is the most critical aspect to successful flood resiliency management. Having flood barriers, pumps and generators already installed at high risk substations improves the likelihood of a fast response for the protection of substation infrastructure.

Executing a flood response effort requires close coordination with several departments including internal construction, contracted services, and local O&M personnel. Availability of manpower and staging of equipment all become important logistic considerations. Timing of mobilization is critical to any successful operation.

Material availability and location must be factored into the flood response as well. Having material at the substation itself versus a central location improves response time greatly. Transport of material to outlying substations can take valuable time away from the response time available when an impending storm is approaching.

E. Training, Operations, and Maintenance Considerations

Advance training exercises and individual training of employees and contractors in the installation of flood barriers, pumps and generators is an important tool in the overall flood response program. Mock storm response exercises revealed flaws that might otherwise be overlooked in the program from material and crew availability, familiarity with equipment setup, and integration with current storm response procedures, especially at remote substations.

In addition, training of local O&M personnel is necessary as these forces are often the first responders in an event located in their area. These workers are familiar with the local substations and are often experienced with the nature of the flooding that occurs at each location.

Maintenance of the flood barrier system is required to insure a robust approach to any flooding event. Use of local O&M personnel to routinely observe the systems in place and to report any problems is typically the first line of defense. Having additional material on hand at a central warehouse can expedite any needed repairs and eliminate delays in delivery of necessary additional material.

REFERENCES

- [1] Fisher, D. "What made the flood of 2010 so devastating?" www.ecori.org, June 7, 2010.