Abstract: The impact of Super storm Sandy on the ConEdison underground distribution system was substantial. In the aftermath of this event ConEdison engineers investigated all possibilities to improve their network system’s reliability should such a severe flooding event occur in future. One of the improvements identified was to enable the Energy Control Center operators to isolate sub networks that were at high risk of flooding in order to prevent or minimize damage to the underground distribution system. The remaining portion of the network can then remain in service, thus minimizing the number of customers affected by a flood event.

The main challenge was the scope and performance requirements to execute such a sub network isolation. Up to 16 circuit breakers and 8 underground load break switches must be operated virtually synchronously or within 2 power cycles to maintain system stability and integrity. The circuit breakers are located in two substations. The submersible underground load break switches are located throughout sub networks.

The ConEdison team considered that using IEC61850 “GOOSE” messages to execute such synchronous operations might be a solution. Synchronous switching of underground switches was never attempted by ConEdison using “GOOSE” messages. Proof of concept tests were performed using 20 IEC61850 devices communicating the trip and close commands to primary switchgear. The 20 devices issued trip and close commands in a 4 millisecond bandwidth. The results were acceptable and it was decided to move forward with the project.

This paper will be a case study of this project as part of the ConEdison’s “Storm Hardening Initiative”. The paper will discuss the following in more detail: system topology, communication network design, operational functionality, unique system features, field implementation and test results. The synchronous operation of sub networks could have significant impact on the future operation of a Smart Distribution Network to better manage system loading.

Introduction: The scope of this project was to design, procure, install, test and commission a system of underground switches and controllers to partition two Manhattan distribution networks into two sub networks each, in order to be able to shut power to only those portions of the two networks that could be impacted by a flooding event, while leaving all non flooded portions powered up. Due to the interconnected nature of the distribution system, it is not possible to separate areas of the network without causing overloading of other areas. Individual opening of switches could exceed current carrying capacity of other circuits.

The project consists of the following major components or deliverables:

- Twenty Underground Switch Controllers (8 for Network 1 and 12 for Network 2).
- Seventeen street level vault fiber optic connection boxes.
- One Front End Processor / Data Concentrator for the Substation 1 Control Room with breaker controllers wired in parallel with existing RTU outputs to each substation Breaker. The new Control Output modules will be distributed IO type modules installed in each of four existing D20 breaker control cabinets and connected to the Front End Processor via the fiber optic LAN.
- One Front End Processor / Data Concentrator for the Substation 2 Control Room with a Siemens 6MD6 breaker controller wired in parallel with existing RTU outputs to each substation Breaker. The Siemens 6MD6 unit will be installed in the existing RTU cabinet and connected to the Front End Processor via a fiber optic LAN.
- Installation of a single mode fiber optic ring by LightTower to connect all Underground Switch Locations to the Substation 1 and Substation 2 Control Rooms.
- Connection of the Front End Processors to the existing Frame Relay communications channels.
- Connection of the Front End Processors to the existing time synchronization sources.
- Creation of new database points and display screens for ECC.
- Creation of new Operating Procedures for shutting down and restoring the networks.

**System Topology:** The system consists of two separate Substations supplying Networks 1 and 2. The networks are supplied from Sub 1 and Sub 2 in the same substation building. Sub 1 supply Network 1 through up to 8 breakers connected to 12 underground switches. Sub 2 supplies Network 2 through up to 16 breakers connected to 8 underground switches. Network 1 and Network 2 are interconnected through a mesh systems and each underground switch provide an in feed to the interconnected distribution network. Network 1 and Network 2 can each be subdivided in to two networks.

![System Topology Diagram](image-url)
Communication Topology:

The communication topology required fiber optic communications to all devices to achieve the required operational speed of the system. From the Substation Fiber optic cables were installed in a single ring topology. The ring consisted of two substation Ethernet routers and 20 switch controllers. Each substation Ethernet router is in turn connected to associated substation controllers and front end processors. The complete communication topology is shown in figure 2 below.

![Communication topology diagram](image)

Fiber Optic Design: The fiber optic system connections were a very challenging to complete on this project. The entire system is an underground system that had to connect the all underground switches in a single ring. The control cabinets for the underground switches are submersible in design. The fiber thus had to enter and exit each control cabinet and maintain the submersible qualities per figure 3 below.

Molded submersible connector blocks and pigtails were used connect the fiber optic ring patch panels to the controllers in the underground switch control cabinets (UGSC Cabinet). It was also required to create a cross over at each controller that was responsible for the fiber switch functionality. A dual connector block was developed to make the required connections in vaults containing 2 switches.

The network was set up in a RSTP ring. There was no real need for a high speed reconfiguration capability. The system will always be tested and primed before a switching operation is attempted. HSR could not be considered as the number of devices in the ring exceeded the limits.

The system was completely constructed with a single mode fiber.
Vault Installations: The vault installations are depicted in figure below. Each switch is connected to the control cabinet and to a hand held control switch control. Remote operations are performed through the controller in control cabinets and local operations using the hand held controller. Each switch is provided with ancillary power from the power supply unit.
Switch Control Redesign: The redesign of the control cabinet, depicted below in figure 5, was required to include controllers (7SC80) that could perform extensive logic and supported IEC51850. The device provided single mode fiber switch capability reducing the number of components required in the control cabinets. The control cabinet design also included an extended battery life of up to 96 hours and allowed for immediate operation after power restoration. The controller provided all the logic necessary to perform standard monitoring and testing of the underground switch. The device also provided voltage and current sensing inputs. See new design depicted in figure 5.

Substation Integration engineering:
The design of the components that had to be integrated with the substation equipment was mainly challenging due to the lack of available space in the substation. A single wall mount cabinet was developed to house all the equipment needed in each substation. The following equipment was installed in this cabinet. Two 7SC80 devices or FEP’s per substation. The FEP’s acted as the gateways between the DNP3 of ECC and Substation HMI hardened PC. The devices performed all control logic and protocol translation to IEC61850. One FEP also provided NTP server functionality. One HMI PC with a touch screen monitor for control. One terminal server was installed to connect to the ECC via a serial link and finally a power supply.

In Sub 1 a 6MD6 bay unit was used to interface the system to the substation breakers. This feeder breaker controller installation was extremely challenging as very little space was available for the integration of the 16 circuit breakers with the new synchronous control system. In figure 7 the available space is shown on the left and the actual installation on the right. Eight test switches were installed in the front of the panel door with the controller unit behind it. The 6MD6 interfaced to the synchronous control system using “GOOSE” messages and hardwired into the breaker control circuits.

The test switches were installed to be able to add or remove breakers from the system and for testing and commissioning purposes.
System Functional description: The function of the system is to synchronously open and close a preselected group of beakers and underground switches. Operation of all the primary switch contacts must operate within a bandwidth of two power cycles to safely add or remove a network.

Network isolation will be performed if and when a network is endangered by possible flooding of. This isolation will separate the flooded network from the rest of system, maintain stability and protect customer equipment form damage that could be caused by energized transformers.

The system is equipped with 2 front end processors for each network.

The first FEP is responsible to act as a hardened protocol translator. It converts DNP3 control commands into “GOOSE” messages and translate measure values and statuses from the field devices into from “GOOSE” messages into DNP3.

The second FEP in the control module that is responsible to issue controls to the field devices through “GOOSE” messages. The controller is also responsible for the logic to select the switches and breakers that will form path of a synchronous switching action.

The FEP can receive control and configuration commands from the Energy Control Center (ECC) or form a Substation HMI’s. ECC or HMI Control and configuration commands will pass through the Protocol Translator FEP to the Control FEP. The devices are indicated in figure 2.

The ECC are connected DNP 3 serial to a terminal server that connects to the FEP’s using DPN over IP. From the FEP’s all communication to the switch controllers are done through “GOOSE” messages.

From the ECC or the Substation HMI’s an operator has the ability to perform the following:

Switch Controls:

- Switch Controls - Open & Close, Cap Charge, Switch Test,
- The operator can also see a host of alarms and statuses indications associated with the switch in question as indicated in figure 9.
- Advance Control - Enable Multiplexing, Sense Load Side Voltage, Sense Line Side Voltage, Generate Fault Recording, Connect or Disconnect AC Inverter and Reset Fault Targets.

The HMI buttons are indicated in figure 8 below.

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Fig.8 - Advanced Switch Control

Fig.9 - Switch Control Screen
- Global Control – The operator will use the global controls to shut Network 1 or Network 2 down. The first step will be to perform a Switch test that will determine if the switches are healthy. He will then proceed to perform a global cap charge. The capacitors for the operation of the underground switches are always discharged according to the CoEdison standard. The HMI will provide feedback to the operator as to the health of each switch, if the capacitor is charged, the status of each switch and the communication health of all associated controllers in the system. See figure 11 for the information displayed to the operator.

Fig. 10 – Global Controls

If the operator is sure the system is healthy he can proceed to Shut Down a network using the Global Commands. He will select Network Shutdown that will proceed to open all switches and breakers associated with the Network. The command is sent From the HMI or ECC to the control FEP that will in turn send “GOOSE” messages to all the Breakers and Underground switches to open in the network. Each network can be restored in either of 2 sub networks. This is done to provide a staged approach to restore the networks. Once it is determined that a sub network is ready based on feedback from filed crews the operator can restore that portion of the network. See the controls available to the operators in figure 10. The HMI also provide the operator with a clear picture of the health of the communication system. Should any of communication links go down the system will graphically report the failed links. Figure 12 show a system where two links went down disabling remote control to the one switch.
**System testing and commissioning:** The testing and commissioning was again a very challenging undertaking. Due to the nature of the system situated in lower Manhattan testing and commissioning could not lead to any outages. It was essential to perform as much testing as possible before system deployment.

System testing was performed in numerous stages. The entire system was at first tested in the Siemens laboratory in Wendell North Carolina. This was mainly a digital test to test all system logic, system performance and proof of concept of the new control cabinets. All controllers we connected via fiber with the associated Ethernet routers and terminal servers. The complete ring of 22 devices was made to perform the testing. Tests were performed from the HMI and from a DNP simulator that acted as the ECC. Two actual underground switches with new control cabinets were also included in the testing to prove the new design and controllers. The testing included the calibration of the controller for the voltage and current sensing of the underground switches.

The factory acceptance was achieved as the system performed better than expected. The next step was to move produce all the control cabinets required and then commence with field testing.

As the control cabinets were received a series of tests were performed on each cabinet connected to a switch in the Con Edison facilities. All files were also downloaded to a single control cabinet and tested connected to a underground switch. The installation of the fiber optic ring took longer than expected but once completed the switches were upgraded with new controls as indicated in figure 13.

The testing of the fiber optic links was done in two stages. First the ring was broken to test communication from the current switch location to the location on either side of the switch. This was then followed up with testing the communication through the controller in the control cabinet. These tests proved the communication links at each switch site to, and to the next site. A switch simulator box was also connected to the control cabinet to prove switch operation from the HMI. The equipment used for this testing is shown in figure 14.

Final commission system was performed at night to minimize possible loss of load to customers connected in these networks. All testing was performed while maintaining power all customers on the networks under test. Two tests were performed one for each Network. Each switch in the system was equipped with a switch simulator. The substation breakers were simulated using additional simulators connected through the test switches. The operators then performed a complete system shut down from the ECC as well as a system restoration. The system operated as expected and was ultimately put into service.