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Deployment of a Centralized System for Remote Fault Localization

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SUMMARY

National Grid has successfully completed the implementation of all the schemes of its comprehensive Smart Grid Pilot in the city of Worcester, MA. The schemes deployed were designed to improve the quality of the service provided to the customers as well as the efficiency of the electrical system in the area. One of the components included in the suite of solutions is a centralized Fault Localization system that will allow operations personnel to better estimate the location of a fault on a distribution feeder, reducing restoration time and therefore improving system reliability. The following paper describes the required infrastructure development and functionality of a centralized Fault Localization system that could allow National Grid to monitor and improve the service to its customers in remote locations of its service territory.

KEYWORDS

Fault Locating, Smart Grid Pilot, Wireless Communication
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1. INTRODUCTION

National Grid received approval in August of 2012 [1] for the implementation of a Smart Grid Pilot in the city of Worcester, MA. This required the installation of new and advanced equipment from the distribution substations all the way to customers' homes. The result included several systems new to National Grid, covering aspects such as: automated restoration, voltage regulation and distribution line monitoring [2-3]. One of the systems included in the monitoring category was a Fault Localization scheme. The main objective of that effort was to implement a system able to quickly and accurately identify locations where distribution faults originated. This could help to significantly reduce time spent patrolling; allowing crews to repair damage sooner and therefore shorten customers' interruptions. One of the challenges posed by this implementation was the type of architecture (centralized vs. distributed) that would allow information retrieval from field devices and its subsequent processing for fault identification and localization. Distributed solutions normally suffer from higher equipment cost due to redundant infrastructure for each location, while centralized solutions can see their implementation cost rise due to communication and security provisions. Fortunately, as part of its Smart Grid Pilot development, National Grid designed and implemented a flexible communication and IT infrastructure that supported the integration of wireless-based devices via WiMAX mesh and cellular technology. The existence of this newly created network, allowed for the implementation of a centralized Fault Localization solution able to analyze information from remote devices in a secure manner without significant additional investment in communication infrastructure.

2. FAULT LOCATING SOLUTION

National Grid selected Electroket [4] as its provider for its Fault Locating solution and will be using its PQView® application for Fault Locating purposes. This is a database software application which is designed to store and analyze large quantities of power quality related disturbances and steady-state measurement data. PQView imports waveform and RMS samples from the fault recordings of a wide range of devices, storing the measurements in a Microsoft SQL Server database. The waveforms are analyzed automatically for characteristics that indicate the start and end of faults and other related conditions including voltage sags, magnetizing inrush, negative-sequence overcurrent, zero-sequence overcurrent, zero-current events and sub cycle faults. Fault analysis and location functionality in PQView is enabled via the Reactance-to-Fault Add-In Module. This add-in module combines three functions: fault identification from waveform samples, estimation of reactance-to-fault from the waveforms and display of the fault location using one-line diagrams and maps. A general diagram of the PQView solution with the Fault Localization Add-In can be seen in Figure 1. As the figure shows, the installation and configuration of a Database server with the PQView application is required. At the same time, the server needs to have access to the devices in the field so event files, containing pre- and post-fault information, can be retrieved and analyzed periodically by the Fault Localization Add-In. The format chosen for the files to be handled by the server was the COMTRADE format since most of the devices installed on the Smart Grid Pilot area are Schweitzer units. Additionally; the PQView application requires information of the feeders where the faults are being identified. For that, the server's database also needs to contain the models (in this case CYME) of the feeders to be monitored to provide reactance information and specific location for the identified faults.

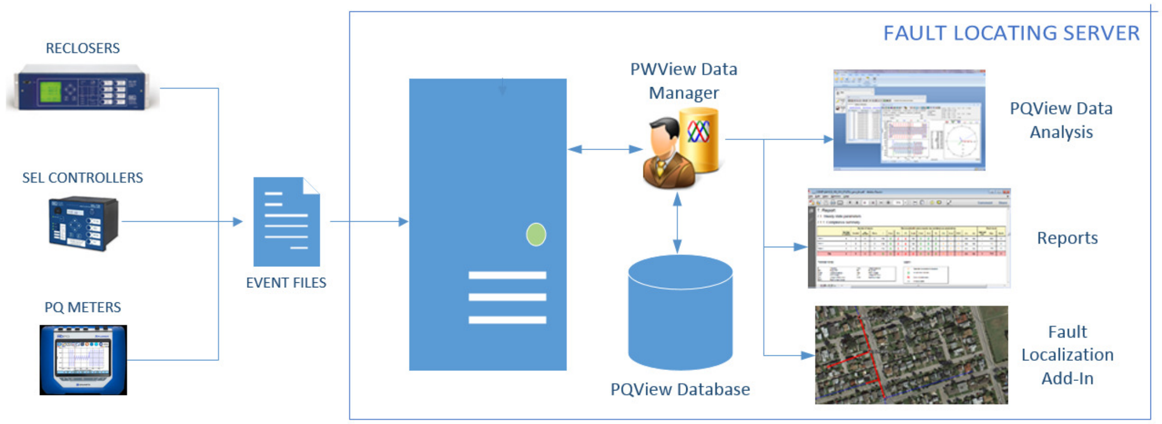

Figure 1 General diagram of Fault Locating Server functionality

3. NATIONAL GRID IMPLEMENTATION

As mentioned in the introduction, the design and implementation of a flexible communications network for the Smart Grid Pilot was key for the simplified deployment of the Fault Localization solution. The ability to securely and economically integrate wireless-based devices into the network allowed for the addition of Fault Localization capabilities to any distribution feeder where cellular coverage is available. This alone, saved thousands of dollars in communication equipment and IT infrastructure development.
The incorporation of the server into the newly developed network was done following the architecture already developed for the pilot and in line with Digital and Security Risk guidelines. Figure 2 shows a diagram of the Smart Grid network and the modifications introduced for the implementation.

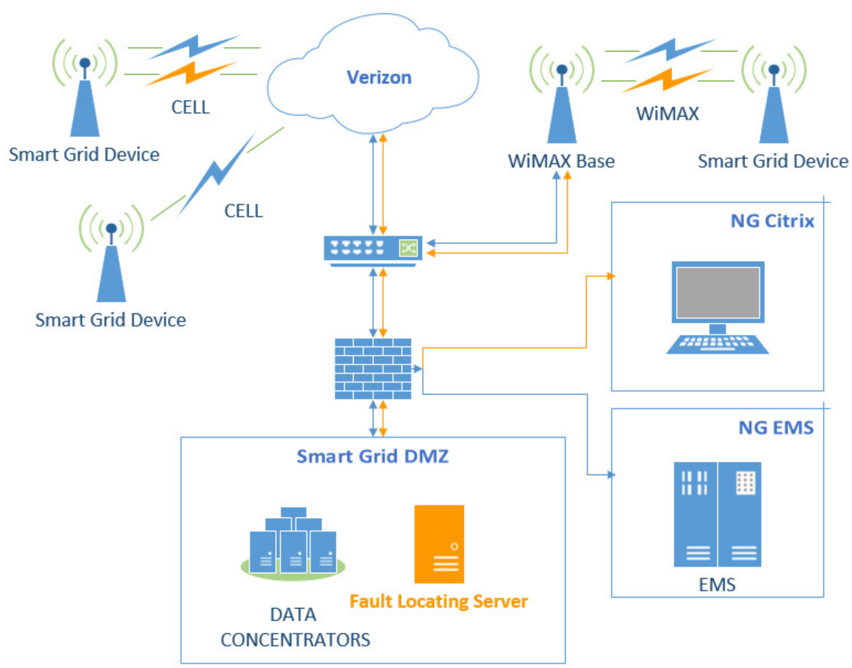

Figure 2 General diagram of the Smart Grid network (blue) including the Fault Localization Server work (orange)

The work required the addition of a physical server on the existing Smart Grid DMZ and the opening of traffic to the devices on the cell network and the WiMAX mesh through the firewalls. Since the server is not part of the corporate network, a Citrix interface was set up to facilitate that access. In that way, any company user logged into the corporate network could reach the Fault Locating application. This is of particular importance considering that National Grid operates in different states with remote offices and control center facilities. In particular, for this implementation, feeders from stations located 50 miles away for each other were selected, as it can bee seen in Figure 3.

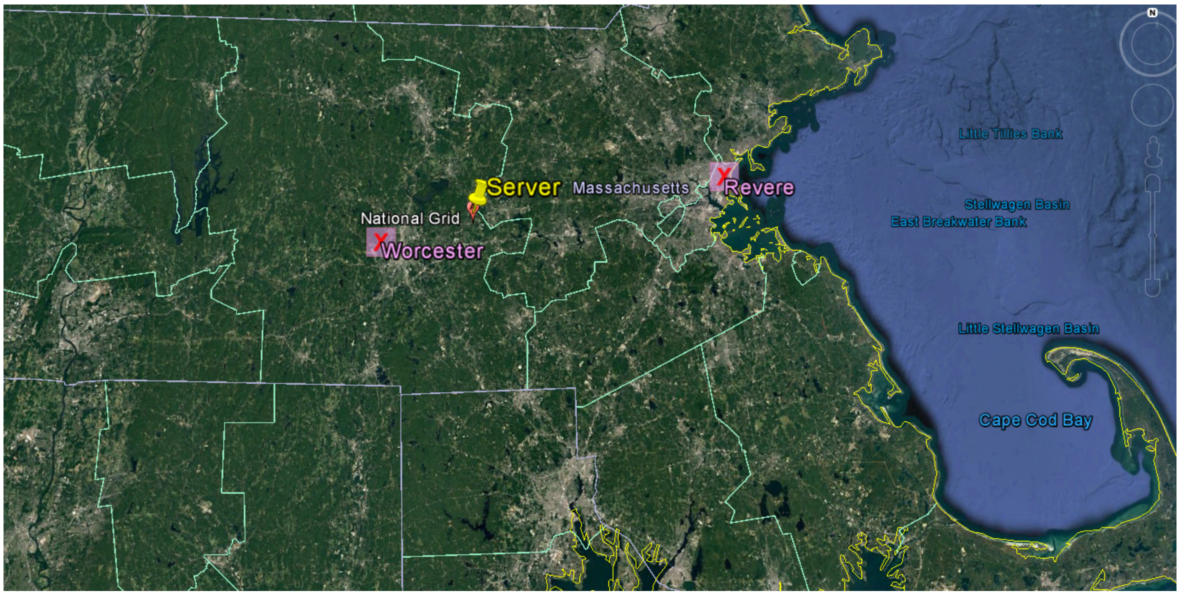

Figure 3 Map representation of the geographical locations (red) chosen for the implementation

The locations, Worcester and Revere, were selected for their unique characteristics and the value they could bring to the implementation. The Worcester location consists of two 13.8kV overhead feeders with some underground sections and several Smart Grid Devices already installed on them. Typical Fault Localization systems of these charactesitcs use measurements from the relays at the station, however National Grid wanted to explore the value of using distributed intelligent devices for Fault Localization. For the Worcester feeders, this translated into the selection of the devices shown in Figure 4. Two devices per feeder, for redundancy purposes, were selected as close as possible to the station. The devices' characteristics are listed in Table 1.

Table 1 Characteristics of the devices for the Worcester portion of the implementation

Feeder	Device Type	Model
F1	Recloser	SEL 651R Control
F1	Capacitor	SEL 734B Cap
F2	Recloser	SEL 651R Control
F2	Recloser	SEL 651R Control

All of these units were part of the Smart Grid Pilot WiMAX mesh and were configured to generate fault events.

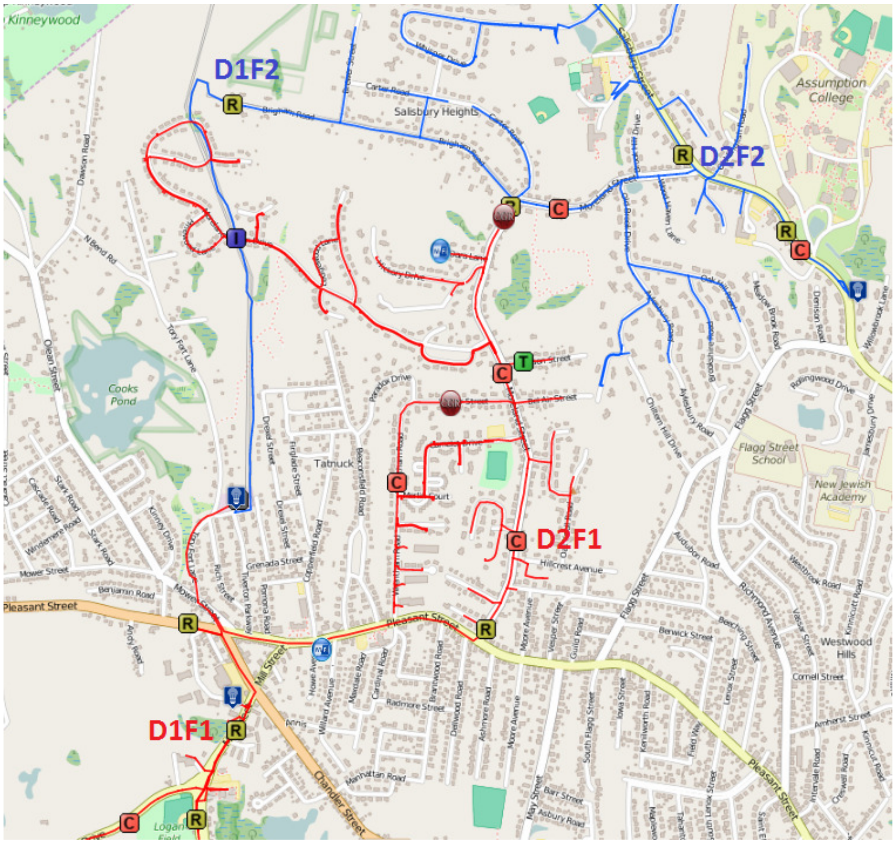

Figure 4 Devices selected for event retrieval for fault localization in Worcester, MA

The Revere side of the implementation, as shown in Figure 5, covers two underground 23kV distribution feeders that were selected due to their physical characteristics and historical fault data.

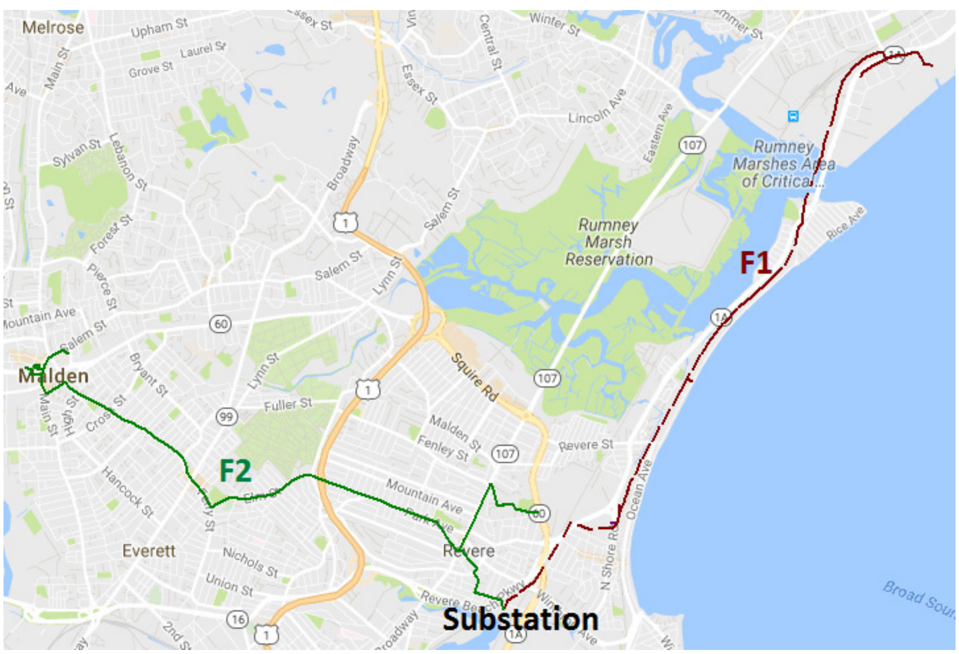

Figure 5 Feeders selected for fault localization in Revere, MA

This location provides National Grid with the opportunity to test the efficacy of the system on reducing the restoration time for underground distribution circuits, which normally require a more complex and lengthy process of troubleshooting and fault locating than overhead locations. Since the construction is all underground, the posibility of having sensing devices with wireless communication installed further downstream was not available. Instead, power quality meters with cellular communication capabilities were installed at the station, as described in Table 2.

Table 2 Characteristics of the devices for the Revere portion of the implementation

Feeder	Device Type	Model
F1	PQ Meter	Dranetz 61000
F2	PQ Meter	Dranetz 61000

The server is set to reach the power quality meters for events retrieval through the same cell based infrastructure developed for the pilot, already presented in Section 2.
In both instances, the event handler in the server was configured to ask for new event files every 15 minutes. This refresh rate doesn't translate into excessive data traffic for the cellular network as only the new files are downloaded and processed. In addition, since this is a verification post fault, the mentioned refresh rate and latency of the cell-based communication network is not considered to be detrimental to the restoration process. However, if the requirement arises, the request for event files could be increased in frequency by a simple change in the server data handler configuration.

4. RESULTS

Since the system was implemented and the monitoring phase started, several events have been captured. Some of the events have been matched against existing records in National Grid's Interruption Disturbance System (IDS). A clear example of it can be seen in Figure 6 and Figure 7 where a documented location for a fault that resulted from a blown fuse is given as one of the few estimated options.

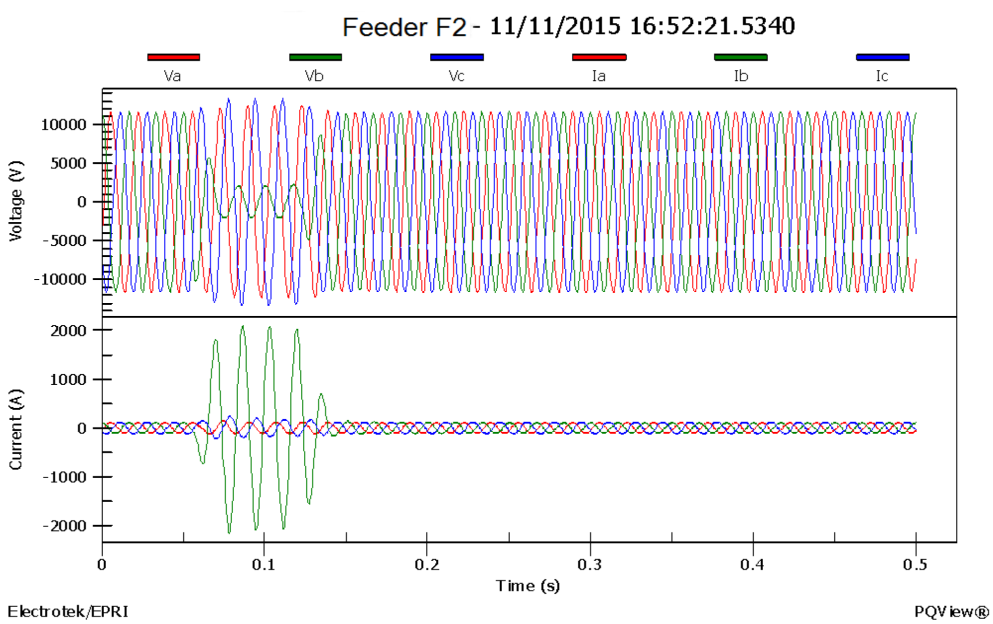

Figure 6 Current and Voltage waveforms captured by the device showing the fault event

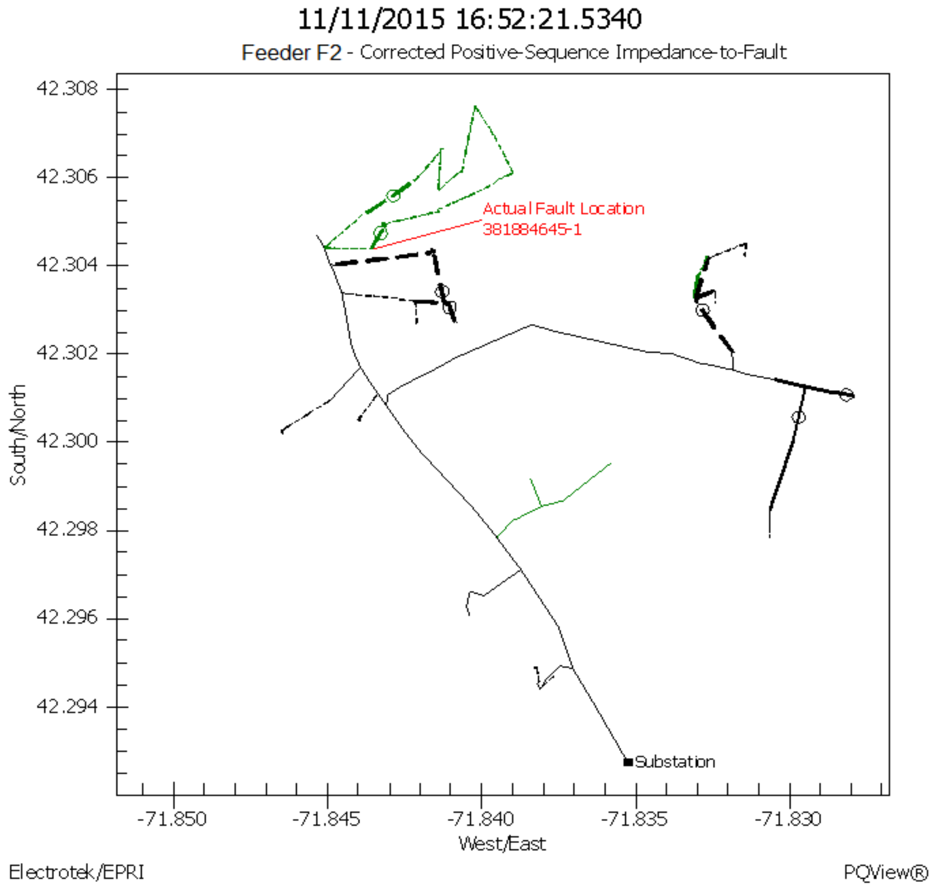

Figure 7 Estimation of fault locations based on the calculated reactance to fault magnitudes

Although the fault was quickly cleared by the fuse, the system was able to obtain enough information to make an assesment of the potential locations for the fault. In this particular case, the number of potential locations can be reduced even further by considering the right phase for the fault (phase B of this event). The PQView application also provides reports that can be used for reliability improvement tasks such as vegetation management or asset conditions review. Figure 8 shows an example of a report displaying fault types per month for a group of feeders in the system.

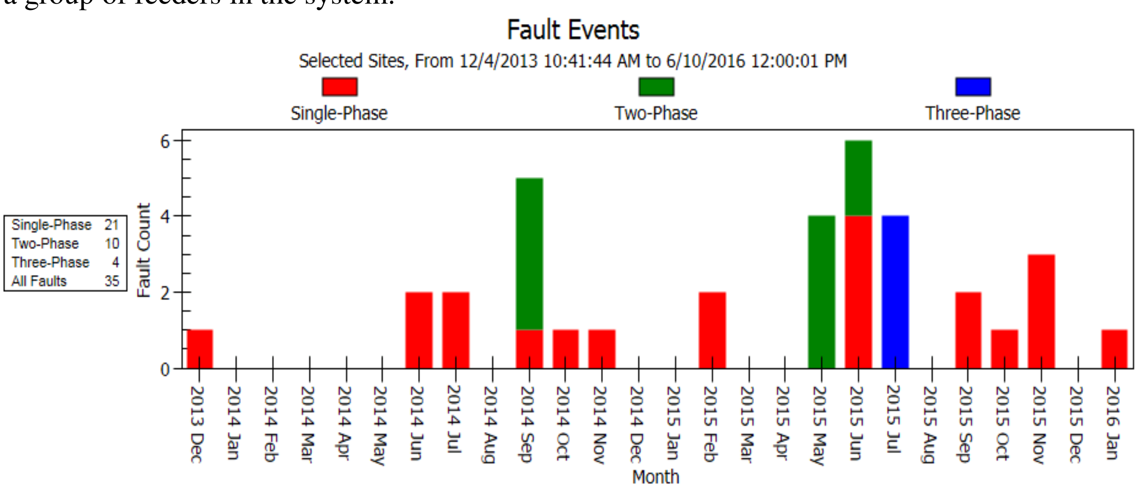

Figure 8 Report of type of faults per month in the area of interest

5. SUMMARY

The deployment of a Fault Localization system that can remotely identify potential locations where distribution faults originate has been presented.

The implementation makes use of a recently developed Smart Grid communication network, designed with enough flexibility to securely integrate wireless-based devices. By doing so, the project was able to be implemented quickly and at a significantly reduced cost.

In terms of accuracy, the comparison of potential fault locations against internal records shows some promissing results for the first feeders reviewed. As the testing and verification continues, minor moditications will be introduced to the algorithm to make it more accurate.

Given the flexibility that this system provides, it is expected that in the future feeders with performance problems will get a quick and simple monitoring equipment installation that will allow them to be easily integrated into a Fault Localization server. This will not only help with restoration time, but also with Fault Analysis to better understand what are the areas of that circuit that require more attention

The benefits that this implementation is expected to provide are the following:

- Ability to activate, at a very minimal cost, Fault Localization capabilities for any distribution feeder in National Grid's service territory where cellular communication is available
- Reduction in patrolling, troubleshooting and restoration time for customers, especially in areas served by underground circuits
- Enhancement of reliability review capabilities that can improve and simplify tasks such as vegetation management and asset condition review

As National Grid continues to moves forward towards the modernization efforts necessary to satisfy the increasing expectations of its customers, the success and experience gained by novel implementations like the one presented here, will continue to shape our path towards a modern and efficient grid. This is how National Grid is helping to create the future, one project at a time.

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