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Communication Infrastructure Development to Support VVO: Lessons Learned from the Rhode Island Implementation

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SUMMARY

As part of modernizing the grid and reducing energy losses for its customers, National Grid is implementing Volt/VAR Optimization in different areas of the state of Rhode Island. There are currently 7 feeders capable of Volt/VAR Optimization and the results to date have shown over 3% in demand reductions. The plan in the state of Rhode Island is to expand VVO to 40 additional feeders in the next 4 years. National Grid is currently using a heuristic based system to achieve VVO where real-time system information is gathered from distributed sensors. Therefore, the role of reliable communications infrastructure in collecting this real-time information is critical. The following paper describes the infrastructure development and functionality of communication systems that allowed National Grid to enable VVO functionality in a number of projects. The paper also discusses the challenges associated with the deployment of these communication systems while comparing two different designs that were used to communicate with the VVO devices in the field. The first method involved setting up a private communication infrastructure operating in the unlicensed 5.8GHz frequency spectrum while the second one involved Verizon Wireless network and the use of cellular modems to communicate to field devices.

KEYWORDS

Wireless Communication, VVO, Smart Grid, Energy Efficiency, Cellular Radio, Mesh Networks

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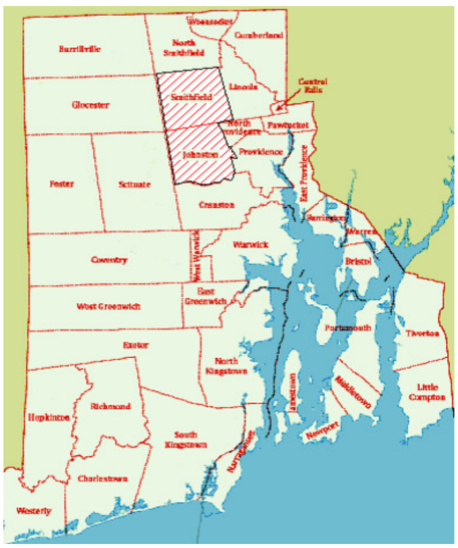
1. INTRODUCTION

VVO systems have the ability to significantly improve power quality, lower line losses and reduce peak demand. This is obtained by optimally managing voltage levels and reactive power along the distribution feeder and the substation. During the process, reducing the service voltage to customers but keeping it within defined limits results in less energy being consumed by end-use equipment. EPRI recognizes VVO as an effective mechanism to improve overall efficiency of the distribution system [1]. It is one of the most cost effective solutions to implement as the VVO system can leverage existing voltage and volt-ampere-reactive control equipment. National Grid decided to reap the benefits of this newer and available technology in seven feeders in RI. The first phase consisted of implementing VVO for Putnam Pike substation and its three feeders serving the Capital district of RI. The second phase involved Tower Hill substation and its four feeders serving the Coastal district of RI.



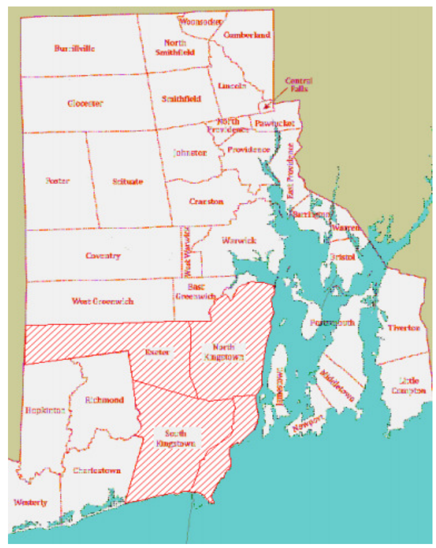


Figure 1a. Putnam Pike Region (Phase 1) **Figure 1b. Tower Hill Region (Phase 2)**

The table below summarizes the number and type of devices that were selected for Phase 1 and Phase 2:

Device Type	Putnam Pike	Tower Hill	Grand Total
Substation	1	1	2
Three Phase Capacitor Bank	21	19	40
Single Phase Distribution Line Regulators	15	12	27
Line Voltage Monitors	7	8	15
Grand Total	**44**	**40**	**84**

Through an RFP process, National Grid selected a VVO product which was intended to provide best-in-class energy efficiency. The system uses a heuristic based method and requires real-time data from three types of distribution devices (Voltage Regulators, Capacitors and Line Voltage Monitors). The ability to gather real-time data and issuing of commands to VVO control equipment requires an efficient communications scheme.

2. INITIAL COMMUNICATION SOLUTION

Phase 1: Use of Private RF Mesh Network to support VVO

National Grid conducted a separate RFP to select the provider of the communications system to build out a private network to support the VVO implementation. The RFP process evaluated the potential vendors on two basic criteria: Commercial (30%) & Technical (70%). After a careful evaluation, a vendor offering a mesh network based on the unlicensed 5.8GHz spectrum was chosen. The solution promised high data rates, low latency and flexibility in terms of communication protocols. The mesh network was intended to support communication for the VVO controls along the distribution feeders as well as the substations. Figure 2. shows the VVO field devices connecting to the RF Mesh Network.

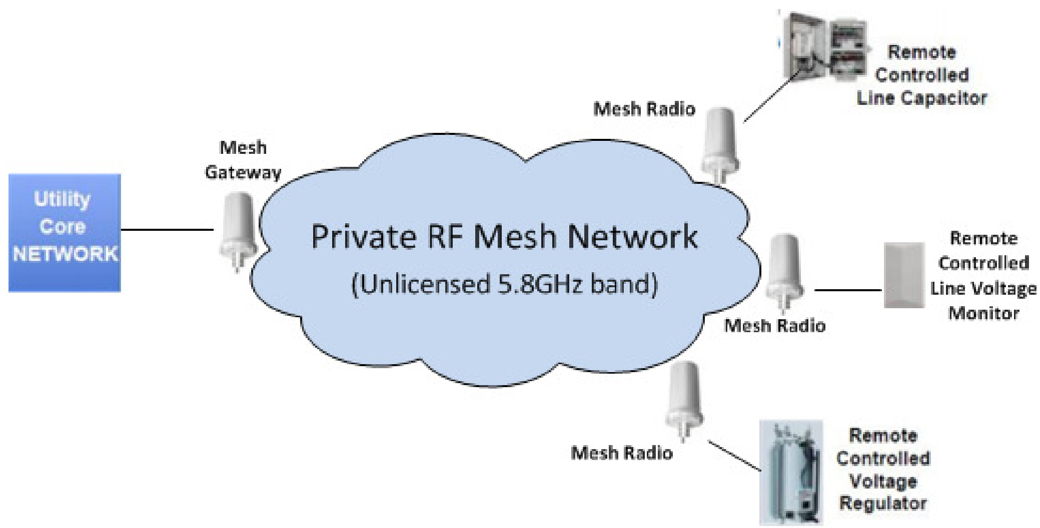


Figure 2. General diagram of the communications network using Private RF Mesh

Under this scheme, the data from the field devices is aggregated at the Mesh Gateway which provides backhaul connectivity to the Utility Core Network consisting of a data concentrator that retrieves information from the field and substation devices every 15 seconds. The data concentrator also provides a point of connection for National Grid's EMS system and the VVO server. This allows the capability of polling devices to operate the VVO scheme while increasing the control center operators' visibility of the distribution system.

The implementation of a private communication infrastructure provided several benefits, including:

- Cost: No recurring costs after the network design was completed as it was privately owned by National Grid
- Security: Field area network traffic was protected by the radio encrypting the data on the mesh using a native algorithm
- Operation: Fast polling and data rates offering near real-time gathering of data as required by the VVO system
- Management: Existance of a network management software package, which was instrumental in troubleshooting network problems as well as managing radio settings and firmware updates

3. CHALLENGES

Although the design presented several advantages, it also presented some particular challenges. National Grid owned most of the sites where the radios would be installed, however it was still an enormous challenge to field verify each site, have all the equiment installed and the antennas aligned for clear line of sight communications. The following points summarize the difficulties faced by National Grid in order to build a private communication network:

- The radios specified for VVO field devices had to be mounted on the primary space to get better line of sight. This required coordination between Overhead line crews and EMS personnel for installation and troubleshooting of the radios. This was particularly difficult to schedule for poles in the 23 kV lines where line crews require notification of work weeks in advance. During the peak demand season, this work would be delayed even further.
- The private network design had to be determined through field testing. This required utilizing two Overhead line crews with bucket trucks, Telecom Technicians and Police details to conduct RF surveys for most sites. Since multiple crews and groups needed to be engaged, this turned out to be cost prohibitive.
- Computer simulated RF propagation models did not accurately account for foliage. Due to time constraints, most of the sites were surveyed during fall and winter when there was little to no foliage on the trees. Although the surveyors left some buffer room for signal degradation due to leaves growing back, National Grid still had to revisit some of the sites due to poor signal strength. Just to re-align the antennas required multiple crews and co-ordination with other departments as described earlier.
- The private RF mesh system operated in the unlicensed 5.8 GHz spectrum. It was assumed initially that there was no interference at the proposed locations and this needed to be validated during RF testing. National Grid found interference with other radio systems at a number of sites that required migrating to a different frequency within the unlicensed band. In some cases, there were self-interference issues between the radios that had to be addressed as well.
- Due to the terrain and the limited number of field devices, the private network did not have enough mesh density for the wireless scheme to operate effectively. Some of the end points required a long chain of hops to reach the RF mesh network exposing it to multiple points of failure. This had to be resolved by adding more radios to the mesh.
- Some of the locations required replacing 40 ft. poles with 50 ft. poles to get better line of sight. Changing the poles also required co-ordination between multiple groups as some of the poles were owned by other utilities (Verizon). Another way to gain line of sight communication was to add radios to leased towers. There were several challenges associated with leasing third party tower sites and it was also cost prohibitive as any maintenance required hiring certified climbers. None of the National Grid crews were tower certified.

The challenges associated with the this initial network design proved to be considerably greater than originally anticipated. The Phase 1 of the project was running several weeks behind schedule. However, the work was in progress and Putnam Pike Substation and its three related feeders had to be completed. At that point, it was not possible to abandon the private communication plan.

With Phase 1 of the project coming to an end, National Grid analyzed the challenges associated with building out a private communication infrastructure and started looking at other communication solutions that might reduce the overall cost.

4. NEW COMMUNICATIONS SOLUTION

Phase 2: Use of Cellular Radios and Verizon Wireless Network to support VVO

Prior to its Rhode Island VVO project, National Grid had piloted another Smart Grid project in the city of Worcester. The company had built a private WiMAX network using the 3.6GHz unlicensed spectrum. The WiMAX network consisted of 12 base station sites providing communication to 135 field devices on distribution feeders in the city of Worcester. The challenges associated with building a private communication network were therefore not unknown to National Grid. There were certain sites in the Worcester Smart Grid where, due to terrain or geographical characteristics, the network provided poor communication capabilites. At the time, the WiMAX provider recommended the use of cellular service at these sites deemed as outliers for the WiMAX network. With the cellular networks in urban areas performing really well, National Grid was able to leverage this technology for other projects where control communication was required. The VVO project team decided to switch from the private RF network model to a cellular one connecting on Verizon Wireless network for Phase 2 of the VVO project involving Tower Hill.

The next step was to verify if the cellular network solution would work effectively with the VVO system. The VVO vendor had specifically asked for a communication scheme that would allow near real time gathering of data from the field devices. The service level agreement with the cellular provider mandated that polling over cellular network was to be done no faster than once every five minutes. This meant that the design could not have devices tie up a wireless channel consistently throughout the day as the VVO system required. National Grid and the cellular provider discussed the use of unsolicited messaging by the field devices which was deemed to be acceptable. Under this sceneario, If a field device had a change in any of the binary point status, it could dial back immediately and report it to the data concentrator. Similarly if a device had a change in analog quantity by a specified value (deadband), it was also allowed to dial back and report it to the data concentrator. The VVO provider worked with National Grid to define these deadbands for the analog quantities. The use of unsolicited messaging combined with the 5 minute event poll, allowed National Grid to design its communication solution to enable VVO for Tower Hill region using cellular radios as shown in Figure 3.

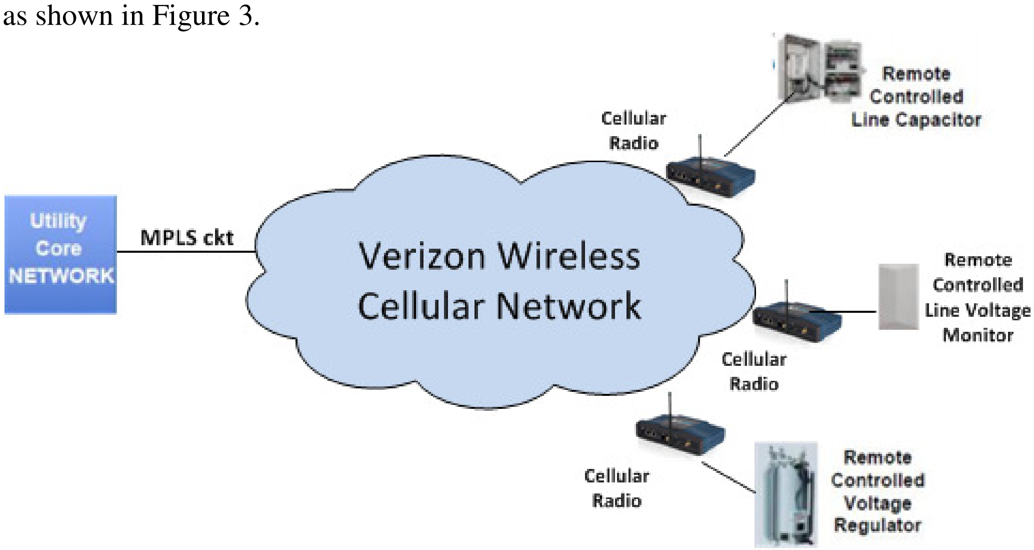


Figure 3. General diagram of the communications network using cellular network

The cellular platform offered several advantages over building a private communication system. The field verification for cell coverage was quick and easy.

Some of the general advantages of this implementation are:

- Cost: The deployment of the cellular system in Phase 2 took a fraction of the time compared to building the private communication network in Phase 1. Even with the monthly recurring costs associated with each cell modem connecting to VZW network, the network design proved to be cost effective. The cellular radios were mounted in the control cabinets on utility poles roughly 10' high from the ground. Therefore, the installation did not require Overhead line crews or any special alignment procedures. The ease of installation and deployment were the primary factors behind the cost savings.
- Security: The cellular radios offered device level security and prevented access to unauthorized local or remote users. The wireless security was supoorted by the VZW cloud on which they had reserved an exclusive address space for National Grid cellular devices. The wireless cloud connected to the physical location of the servers via a secure MPLS circuit.
- Operation: Since the VVO system did not require high data rates, we could use cellular service at sites where higher 4G LTE speeds were not available. In the Tower Hill region we did not experience any problems with cell coverage and all of the sites indicated a good RSSI level connecting to the cell towers.
- Management: After carefully testing firmware and configuration and locking it down with the radio vendor, the need for device management was eliminated. The network management software was not a necessity as it was in the case of a private mesh network. The radio vendor does offer a network manager and it is something National Grid is considering and may utilize at a later date.

Some of the the disadvantages of using cellular service are the monthly recurring charges related to each cell modem that is deployed on the service provider's network and the difficulty to troubleshoot network related problems (the service provider has to be contacted to resolve operational problems). In some instances, there have been interruptions in communication over the cellular network. These telemetry failures in some cases have lasted long enough to cause the VVO system to disengage. Energy conservation is best achieved when the VVO system has complete visibility of the field controls. These communication problems are present in all wireless solutions and National Grid believes that the advatanges provided with the cellular solution still outweigh the mentioned disadvantages when compared to the RF mesh deign implemented in Phase 1.

5. VVO ANALYSIS

National Grid has obtained a detailed operational analysis of the VVO scheme for a period of 6 months beginning on April 1st , 2016 and ending on September 30th, 2016. The Measurement & Verification (M&V) process was conducted only on Phase 1 (Putnam Pike region) as Phase 2 had not been completed at that point. The M&V was performed utilizing filtered time series where the VVO system was turned on for a period of one day and off for the next day. This accounted for collecting data based on similar temperatures and customer load. The graph below shows greater than 3% reduction in demand when Conservation

Voltage Reduction (CVR) is enabled on one of the feeders. An estimate of the energy conserved is 2871 kWh/day which is enough electricity to power over 80 homes.

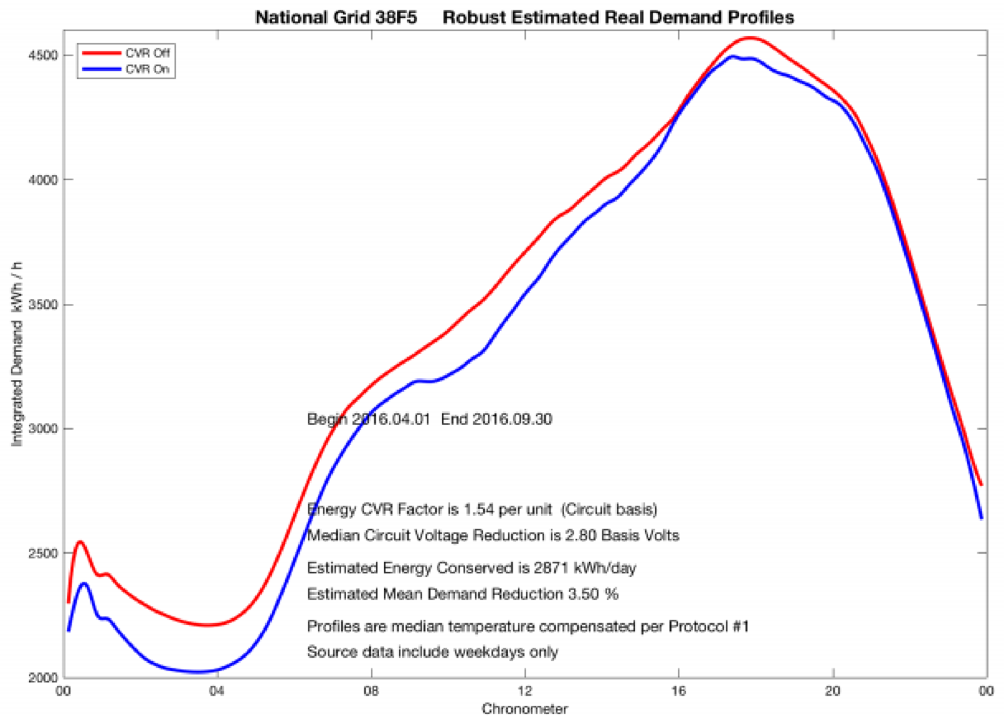


Figure 4. Demand Reduction comparison over a period of 24 hrs

The analysis for Phase 2 of the project which uses cellular communications is under way. At this time, there is not enough data from that M&V study to be included in this report.

6. SUMMARY

National Grid's VVO project has demonstrated the benefits associated to this technology. The company is considering expanding the original pilot's foot print to include 40 more feeders in RI the next 4 years as well as deploying it as part of the NY REV demo project. The Measurement & Verification data from Phase 2 will allow National Grid to compare the performance of the two different communication schemes. The faster event polling rate available in the private network allows real time gathering of data from the field devices. The cellular scheme utilizes the 5 minute event poll along with the unsolicited messaging from the controls to provide near real time information to the VVO server. The ease of deployment of cellular scheme and the costs involved make cellular service a favorable option to consider regarding future expansion of VVO.

The advanced capacitor controls and voltage regulator controls used by National Grid are capable of providing energy reductions without the need of a centralized VVO/ CVR system. National Grid could optimally program and co-ordinate these controls to gain significant benefits in energy reduction. The benefit of a centralized VVO system in that case may reflect a value well below 3% in demand reduction. In any case, the role of communications in co-ordinating between the controls and gathering data from devices is crucial to optimizing energy conservation.

National Grid continues to tirelessly work towards a future where energy resources are used more efficiently while providing a high quality of service. The learnings from projects like the one presented in this paper will help to shape the way that the future grid will look like. This is how National Grid is helping to create the future, one project at a time.

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