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Strategies for Voltage Conversion Project Success

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SUMMARY

Large portions of the distribution grid are still operating at lower nominal voltages, but the drive to convert to higher classes (15kV and above) is going to be a central theme in the coming years for several reasons. Growing energy demands of electrification, greater emphasis on system reliability, and an increasing saturation of DERs on the system will all increase the pressure for these conversion efforts in the industry. Many utilities have already moved to standardizing the higher voltages for all new construction, but converting existing systems takes time to properly plan and implement. Similarly, managing the volume of work required to support these initiatives can stress existing processes, leading to stalled projects. Establishing processes that standardize and streamline portions of this conversion work to facilitate large-scale execution will be critical for electric utilities to support new grid load and an evolving market.

KEYWORDS

Voltage Conversion, GIS mapping, Load Flow Analysis, Python Script

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I. INTRODUCTION

With newer standards and a push to operate at higher nominal distribution voltages, most of the remaining 4kV infrastructure is found in areas that have not seen significant investment in improvements yet. As such, these circuits tend to have recurring reliability issues. While conversion of the system voltage in and of itself does not lead to greater reliability, the infrastructure investment required to upgrade the voltage results in rebuilt areas and adoption of new protection and reliability methods.

Even in 4kV areas where recent investment in system protection and reliability improvements have occurred, the nature of the 4kV system (and other lower nominal voltage classes) constrains efforts to modernize and limits the ability of circuits to support new load and support electrification goals. Demands placed on the distribution system are on the rise, attributable to increasing adoption of electric vehicles (EV) as well as proliferation of behind the meter generation in the form of rooftop solar and residential battery systems. Each of these represent consumer trends requiring increased capacity requirements as well as the ability to hold system voltage within compliance ranges in the presence of intermittent generation and load. Legacy, low nominal voltage distribution systems are ill equipped to meet these trends, and the long adhered to limits specified by ANSI may not be maintained in the face of new load and DER integration in 4kV distribution systems. [1] [2]

II. STANDARDIZATION

From the onset of streamlining conversions, several strategies need to be considered and implemented for use on projects. These include: method of isolating voltage classes through transformers; conductor selection standardization; construction conversion practice and limitations for multi-circuit poles.

Isolation Transformers

The use of isolation transformers to step down the new voltage class to the old voltage class is utilized to limit the number of circuit miles needing full conversion. However, leaving these segments at the older voltage class limits the ability of those sections to adopt new loads and support DER integration. Size limitations are inherent to these devices and limit their deployment on the system, with capacities typically not exceeding 500kVA per phase and requiring vehicle accessible locations due to their weight. Therefore, segmentation of the planning region into those areas requiring conversion to higher voltage classes and those where continued operation at the lower voltage class does not impede quality of service is key to developing a conversion plan throughout the conversion area. In conjunction with conversion, the cost of full conversion must be compared to the cost of deploying isolation transformer banks to develop a baseline cost where minimal areas are isolated.

When determining the areas to convert and which to maintain via the use of isolation transformers, it is important to take several factors into consideration. First, the location of circuit ties and how those are to function in the new configuration must be addressed. Two questions frequently arise with system flexibility and operability in mind, including “will existing ties be maintained thus requiring upgrades on adjacent circuits also operated at the lower nominal voltage?” and “will the tie be maintained through a set of isolation transformers?,” the latter of which brings its own set of challenges, as the power supported via the tie point is then limited to the size of the isolation transformer bank. The ability for

close transition switching on the tie point could also be impacted as the new isolation transformer might impose a new phase shift.
A second consideration is related to normally open points within circuits, especially in underground loops. Avoiding these instances and having both sides of the loop be similar voltage is preferred, but if this is not feasible due to circuit constraints, then the loss of that redundancy needs to be factored as well as the work needed to create the appropriate isolation between voltages. For similar scenarios involving overhead lines, creating a span of unenergized overhead conductor is a simple way to create isolation between dissimilar voltages and provide a layer of protection from inadvertent energization from the wrong voltage. To do so on the underground would likely require removal or abandonment of a section of cable, thus underground loops deserve additional review and scrutiny during the development of the conversion strategy.

Finally, with the extended lead times of transformers and the limited stock on hand for storm response, attempts should be made to have multiple sources with isolation transformers feeding into an area that is to remain at the lower voltage with a switching point in the middle of the load. The size of these redundant banks should consider an N-1 scenario of loss of a full bank while maintaining the ability to serve all the load through the remaining isolation transformers.

Reconductoring

When moving to a higher voltage class, thermal impacts are reduced as a consequence of the relationship of voltage and current to power delivered, meaning wire reconductoring is typically not needed. However, converting voltage classes is not done in a one-circuit to one-circuit manor - rather, circuits are typically reconfigured to supply the same area with “new,” albeit fewer distinct circuits due to the increased capacity found in the higher voltage class as shown in Figure 1. This system reconfiguration requires that new backbone paths are defined early in the planning process to enable efficient power delivery and flexibility throughout the footprint, requiring a careful review of wire size along said backbone paths. Laterals will likely require less attention unless the age of the wire necessitates replacement. For example, older solid copper conductors that has grown brittle over time should be identified and replaced with new wire adhering to utility standards.

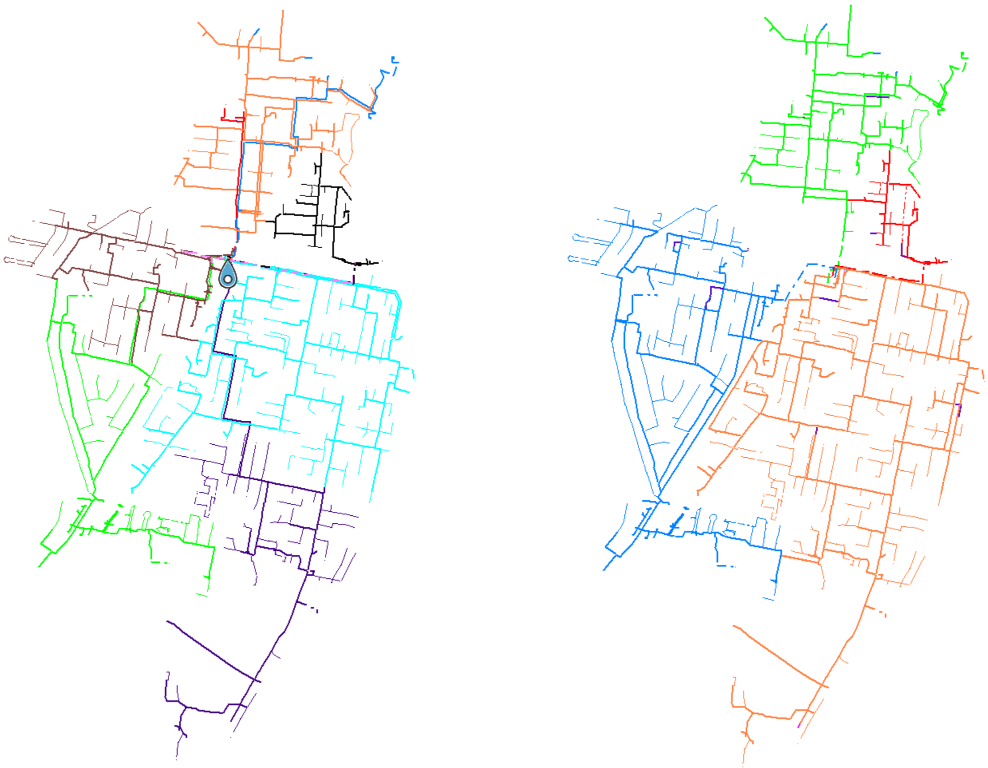

Figure 1. Area single lines before (left) and after (right) of a conversion area.

Conversion Sequencing

Conversion strategy also plays a factor in how you set up the circuit and sequence the work. Each decision will carry advantages and disadvantages. Existing system constraints as well as the location of both voltage class sources, or substations and feeder exits, impact the decision for which strategy is needed in each situation. Common strategies are summarized below.

- Rebuild – Upgrading existing circuit hardware to handle higher voltage class and utilization of dual rated voltage sensitive equipment. The conversion sequence moves sections of circuit at a time, the size of which depends on number of devices needing operation for the switch, outage window constraints, available number of crews and location of the two voltage sources.
- Overbuild – Installing new voltage class wire and equipment above existing system. Conversion is done a single device at a time, cutting over each from the lower circuit to the upper circuit.
- Segment Conversion – Similar to rebuild, however, segment conversion is utilized when the voltage source's location does not support the available crew and outage window to handle full conversion. Installation of temporary isolation transformers at the end of each conversion zone are moved incrementally down the line to slowly convert the area section by section.

Each strategy can be applied to a single project and often large conversion projects require that multiple solutions are leveraged. When new circuit configurations require rebuild of the existing system, especially the new backbone path, the method of conversion from above is driven by the location of both sources, new and old, as well as the conversion sequence steps and the interdependencies between conversion areas. Therefore, before making the determination that *rebuild* is the right strategy in an area as opposed to utilizing an *overbuild* strategy, the cutover sequence throughout the area must be reviewed carefully, maintaining both voltage sources while keeping true to the anticipated outage windows and crew size limitations.

Circuit consolidation

When encountering existing multi-circuit poles, efforts to consolidate should be attempted as this will simplify construction efforts when working these locations. When developing new higher voltage feeder boundaries, many times lower voltage feeders that share paths will be combined into a single circuit, unless customer or load redundancy requirements prevent it. As such, the ability to reduce existing multi-circuit overhead systems by transferring and combining load temporarily will allow the new system to take up less physical and vertical space.

III. MODELING

A robust, high-fidelity power flow model is foundational to the implementation of any well-informed capital project in the electric power system. Modern power flow platforms, when leveraged effectively, can yield information to engineers and planners to justify projects from both financial and operational perspectives. The development of a power flow model of the system under study is very often one of the first steps in the life cycle of a voltage conversion project.

Reflecting voltage conversion projects in power flow inherently requires modifying a significant volume of system assets, largely attributable to the change from a three-wire delta system to a four-wire, grounded wye system. Traditionally, capturing these modifications would require a distribution planning engineer to make these changes manually via the graphical user interface, or GUI. These changes may include adjusting transformer ratings, phase configurations, and windings, re-phasing and adding neutrals to cables and conductors, adjusting ratings of all overcurrent protective devices including reclosers, breakers, and fuses, and making other required adjustments to regulators and capacitor banks. This represents a monumental task – even for relatively small systems – requiring countless mouse clicks within the GUI and a high degree of tedium. There is additional risk of human error as the conversion is executed in the GUI as a result of fatigue and monotony.

Fortunately, most of the changes required to accurately reflect the converted system follow a pattern and a set of relatively consistent engineering rules. Additionally, today's power flow platforms grant engineers read/write capability to most of the relevant parameters within a particular asset class via database manipulation. It follows that logic can be written and executed to automate most of the required asset level changes while minimizing mouse clicks and GUI fatigue. The process flow for automation of this sort roughly follows the outline found within Figure 2 below.

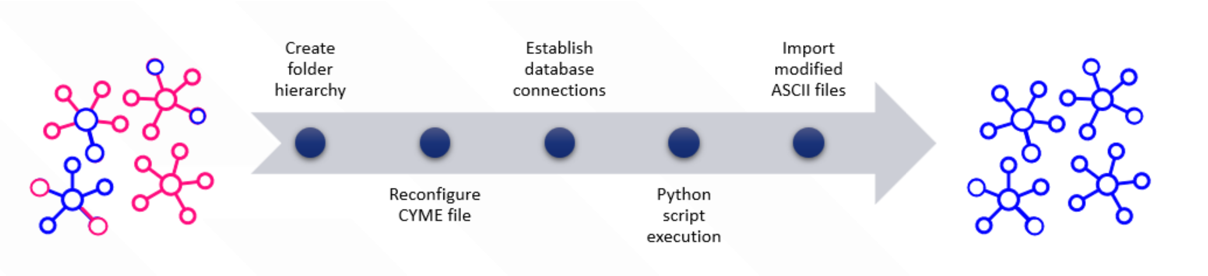

Figure 2. Process flow

In this example, a pair of Cyme database files containing the system under study were placed in a dedicated working location. A Python script was developed that accesses the raw, original database file to extract requisite information from each asset class impacted by the voltage conversion and writes said information to files compatible with the root database. The script then executes the pre-defined logic on these files, adjusting asset parameters (phasing, rated voltages, ratings, neutral wire, etc.) for the new system voltage level. Subsequently, these manipulated data files can be re-imported to the *new* model database which can then be accessed and evaluated in the more traditional fashion via the Cyme GUI.

In one example of utilizing this script, it can safely be assumed that *hours* of manually executed asset parameter adjustment were saved based on the footprint of the conversion. Table 1 below details the volume of assets for which parameters needed to be changed, and in lieu of an automation script, would have needed to be changed manually via the GUI.

Table 1. Circuit metrics

Asset Class	Element Quantity	Total Line Length, feet (where applicable)
Nodes	2,540	-
Source	10	-
Breaker	10	-
Overcurrent Relay	10	-
Cable	326	58,161
Overhead Conductor	1,606	234,004
Switches	48	-
Service Transformers	645	-
Spot Loads	645	-
Fuses	119	-
Capacitor Banks	10	-
Line Regulators	3	-

It should also be noted that conversion projects are carried out in the field in thoughtful stages, and conversion of the system in one fell swoop is rarely accomplished, as described in the preceding sections of this paper. Often, “pockets” of the original, lower nominal voltage will remain while customer equipment and utility assets are replaced in the field. Ensuring that system operation remains within compliance range through these stages of conversion can be validated in the power flow model. Careful manipulation of the automation script enables the various stages of the conversion to be reflected in power flow for this validation exercise. See Figure 3 below.

Figure 3. Stages of conversion

Finally, details of the reconfigured, converted system can be exported and ingested for utilization in other platforms, notably geospatial information systems, or GIS.

IV. GIS WORK FLOW

The ability to represent system improvements made during the initial engineering process is a significant challenge that is necessary not only for overall project organization but also for work order development. The duration and longevity of voltage conversion projects necessitates a concise way to organize the conditions and considerations that went into the project team's decisions that can be updated and maintained throughout the project's duration.

A master overview map that shows as a one-line the extents of the circuit being converted can be an invaluable tool for the project team. These maps should show, at a high-level, the modifications being done to the circuit. Examples include reconductoring directives, circuit reconfigurations, recloser installations, and any special considerations that need to be documented to provide continuity or context to the decisions made by the engineering team.

Overview maps are also a key tool in determining the overall conversion sequence for the project. Considerations such as isolation points and converted voltage source paths are easier to manage when laid out in the context of the rest of the circuit, and the general work occurring in the vicinity.

A common pitfall with these maps is that they are static objects that represent the project at the time they were created, and without rigid documentation and change management processes in place, they can become outdated and obsolete quickly. If the project team lacks confidence in these maps, confusion and duplication of effort can occur and ultimately a clear direction or update needs to be given by the project leadership team to bring everyone to the same baseline.

The utilization of GIS data and web-based maps such as those in ArcGIS Online can facilitate a significant improvement in the collaboration and overall workflow for a voltage conversion project team. Engineers developing pre-conversion scopes of work are able to see conductor, pole, transformer, and other equipment details in the broader context of the conversion scope of work, as well as in relation to other existing conditions such as property and right-of-way lines. Project reviewers are then also able to see the latest data that the scoping engineers and modeling team worked off of to develop their sketches and scopes of work. This one stop approach to project organization naturally leads to efficiencies in the reduction of confusion and review cycles, but also allows for greater confidence in the decisions made throughout the project life cycle.

Furthermore, with some configurations and a regimentation of process, it's possible to utilize the GIS data, web-map, and power flow model to develop the sketches directly, thus saving the project team’s time both in the development stage, as well as during any revisions that may be required in the future.

There are several ways to organize and manage a voltage conversion project throughout its lifecycle. The utilization of tools like overview maps and GIS based web-maps are essential for maintaining order and confidence in the directions and decisions that ultimately culminate in the produced scopes of work that are issued to the field for construction.

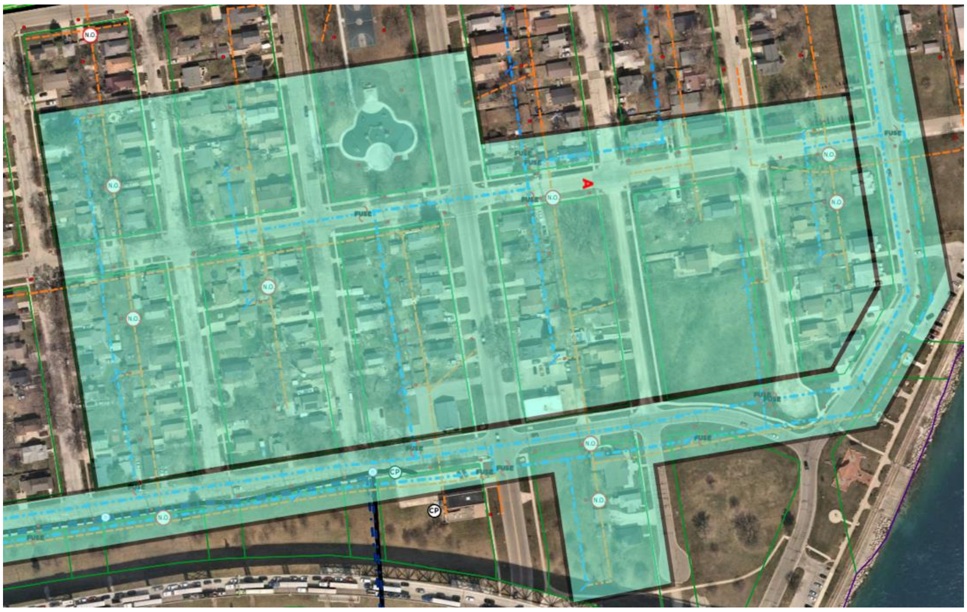

Figure 4. Example of a GIS based work order area

V. **Conclusion**

System voltage conversions are becoming increasingly necessary to support the modernization of the electric grid and tend to be the most complex projects to tackle. Many issues can slow a conversion project down: determining a final configuration while keeping existing configuration functional; dealing with outage constraints; and crew size limitations. By setting up initial engineering and construction standards, deploying software scripting, and leveraging information in a GIS platform, you can streamline and manage these conversion projects more thoroughly and efficiently.

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