Practical Application of the AMSC D-VAR VVO™ STATCOM

A Distribution Planner's Guide

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Document Revision History

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Introduction

The **AMSC D-VAR VVO™ STATCOM** is a dynamically adjustable resource for injecting or absorbing reactive current on distribution feeders. This provides a new tool for distribution planners to meet a variety of objectives to enhance distribution system operation:

1) Enhanced Voltage Regulation and Power Quality:
    a) Maintain a flat voltage profile across the feeder
    b) Avoid rapid voltage changes
    c) Stay within appropriate voltage range
    d) Replace harmonically resonating capacitors
2) Maximize the useful life of assets:
    a) Reduce LTC operations
    b) Eliminate mechanical equipment (e.g., switched capacitors and line regs)
    c) Defer or avoid large capital projects
        i) D-VAR VVO in lieu of reconductoring long circuits
        ii) D-VAR VVO in lieu of Substation relocation
3) Meet efficiency and renewable energy objectives:
    a) Reduce reactive demand at distribution substations
    b) Increase Distributed Energy Resource (DER) hosting capacity
    c) Eliminate bottlenecks in Conservation Voltage Reduction Schemes
    d) Enable use of circuit ties constrained by voltage stiffness

Installation & Ratings:

The VVO can directly connect to 15 kV class feeders and requires a step-up transformer for use on 25 kV and 35 kV class feeders. This application guide focuses on radial feeder applications. The VVO can also be applied in looped networks.

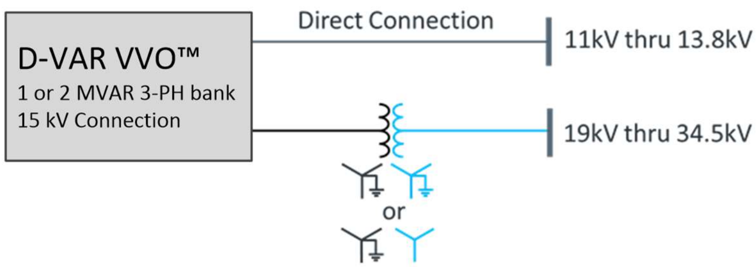

Figure 1: VVO connection options for distribution voltage classes

A three-phase VVO bank resembles a bank of overhead voltage regulators or stepdown transformers which allows for flexible placement along a feeder. The VVO can also be installed as a single phase unit which can be valuable on long, heavily loaded single phase lateral taps.

The D-VAR VVO is a shunt-connected solution. The shunt connection avoids inherent limitations of series regulating devices. These limitations include, and are not limited to:

- Thermal limitations to serving load growth
- Series failure modes causing outages or PQ issues
- Complexity and errors in proper control coordination

- Insertion of significant series impedance, thus further weakening a feeder

Figure 2 illustrates common installation standards for the VVO solution.

Figure 2: A typical three phase (left) and single phase (right) VVO installation

The nominal datasheet ratings of the D-VAR VVO are 1000 kVAR (333 kVAR/PH) and 2000 kVAR (667 kVAR/PH). More accurately, the VVO nameplate rating is based on current, e.g., 47 Amps for 1000 kVAR. Therefore, the reactive power the device produces depends on the operating voltage at the VVO terminals:

$$VVO\ kVAR\ Output = \frac{(VVO\ Amps)(LL\ Voltage)(\sqrt{3})}{3} = \frac{(47A)(12.47kV)(\sqrt{3})}{3} = 338\ kVAR/PH$$

Or at 13.8 kV:

$$VVO\ kVAR\ Output = \frac{(VVO\ Amps)(LL\ Voltage)(\sqrt{3})}{3} = \frac{(47A)(13.8kV)(\sqrt{3})}{3} = 375\ kVAR/PH$$

Understanding how the VVO impacts Voltage and Power Factor

A VVO's ability to move and regulate voltage depends upon the grid stiffness, measured in ***Fault Power*** and ***X/R ratio***. Fault Power, in MVA, can be calculated from the available maximum three phase short circuit current at a given location converted at operating voltage:

$$MVA_{SC} = \frac{I_{3LG\_SC} * kV_{LL_{operating}} * \sqrt{3}}{1000}$$

The X/R ratio is the positive sequence reactance over positive sequence resistance. On a distribution circuit this quickly becomes the cumulative X/R characteristic of the conductor being used and usually is between 0.5 and 4 on distribution circuits.

The VVO impacts voltage the most when Fault Power is low and X/R ratio is high as demonstrated in Figure 3. In general, the VVO is well suited to regulate voltage on downline portions of circuits where fault power is relatively low.

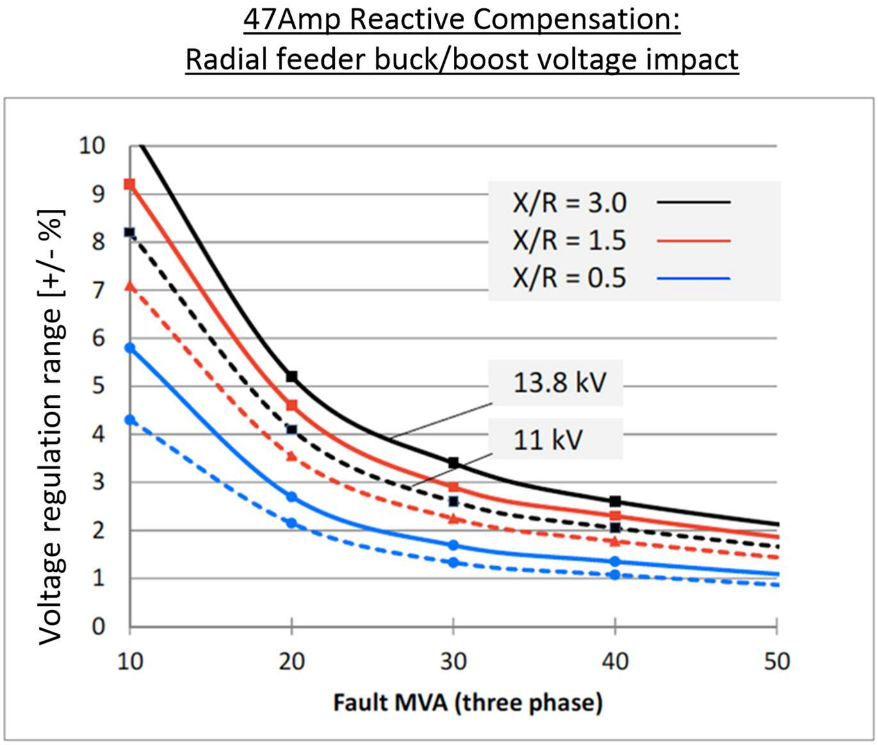

Figure 3: VVO estimated voltage boost at different Voltages, Fault MVAs, and X/R ratios (1000 kVAR device).

The VVO impacts voltage differently in comparison to conventional regulators and switched capacitors as shown in Figure 4. This will be further demonstrated in the application example.

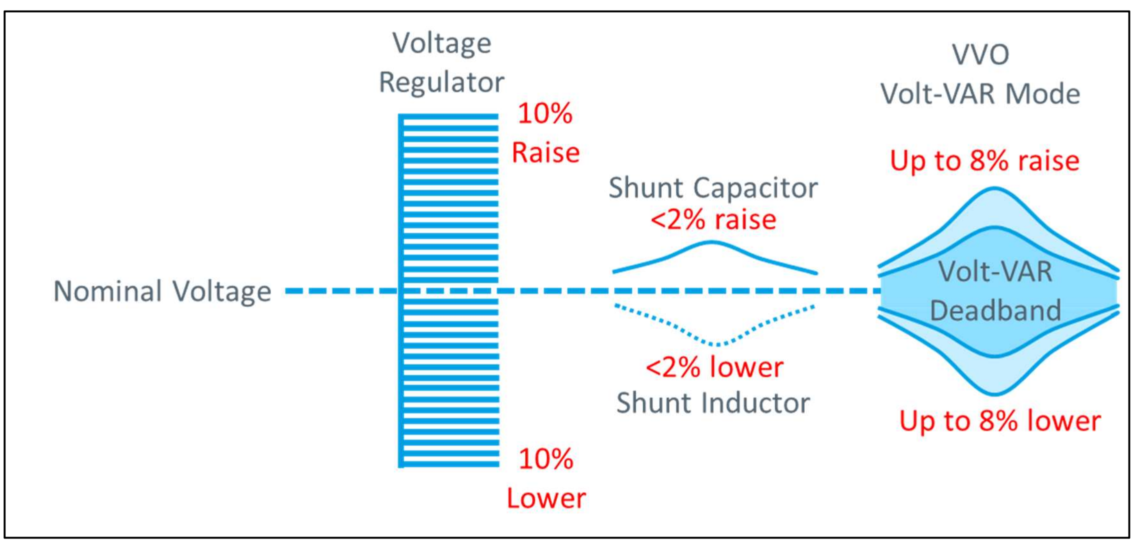

Figure 4: Comparison of Regulator, Capacitor, and VVO voltage impacts

Identifying Candidate Feeders for VVO:

In general, feeders that are not meeting the voltage management objectives listed in the introduction are candidates for the D-VAR VVO. The following are some identifiers:

1) Long feeders with two or more stages of regulation or low ampacity conductor
2) Distribution circuits supplied from weak 23 kV or 34.5 kV subtransmission or small power transformers with less than 10 MVA base rating
3) Feeders with high penetration of variable renewables like wind and solar
4) Feeders with load growth concentrated near the end of the main line
5) Line regulators experiencing maximum boost or excessive tap changes
6) Problems managing power factor on the circuit using only discrete capacitor sizes
7) Regional undergrounding that requires voltage bucking due to cable capacitance

Practical Application Example of the VVO

Consider as an example, a 100 KM long 25 kV feeder with 2.5 MVA of load at 92% power factor distributed evenly across its length. The combined load draws approximately 1000 kVAR supplied from the substation. The conductor is capable of carrying 385 Amps and has an X1/R1 ratio of 1.26. The Fault power (voltage stiffness) is 178 MVA at the substation but quickly drops off down the feeder as the cumulative conductor impedance increases. The voltage begins at 1.00 per unit at the substation but quickly decreases as the distributed loads cause voltage drop.

Without any mitigation, the voltage profile across the feeder would follow the unacceptable yellow profile shown in Figure 5.

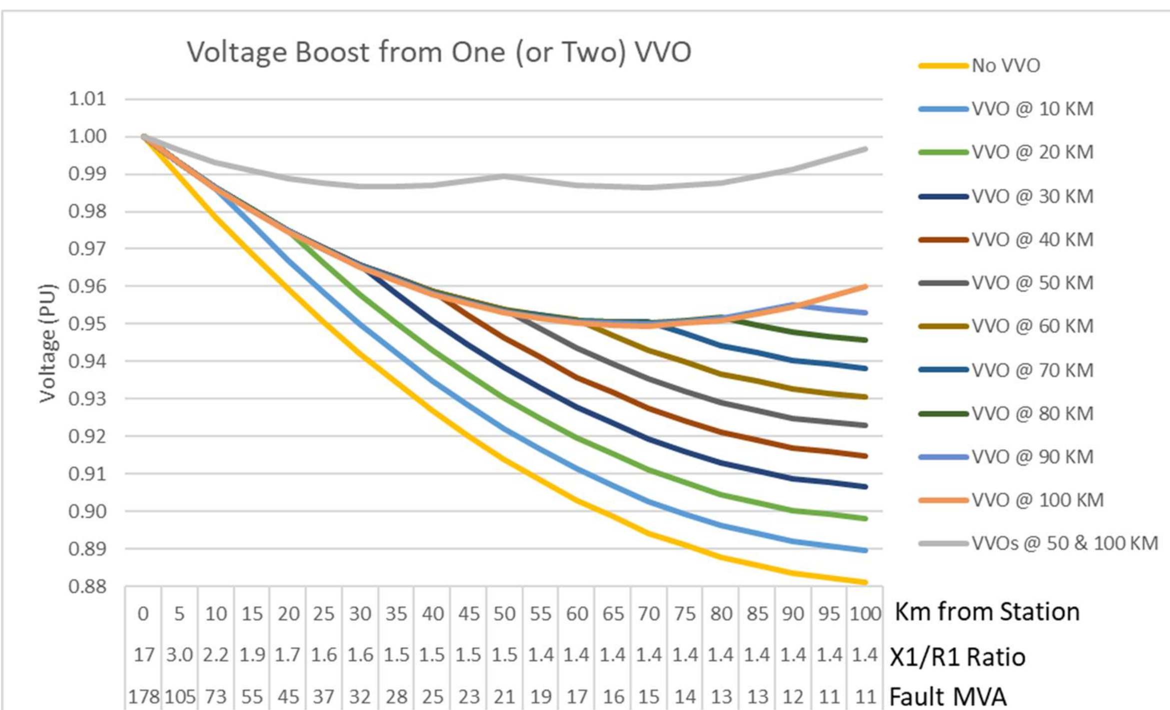

Figure 5: Resulting voltage profile with VVO at various locations

Now assume one 1000 kVAR VVO (capable of +/- 1000 kVAR) is available to address the voltage drop problem and can be located anywhere on the circuit.

If the VVO is placed near the 10 KM mark where fault power is still high, then it provides only a small voltage boost and doesn't adequately address the downstream voltage drop. Power factor measured at the feeder breaker is near unity.

If the VVO is placed near the 100 KM mark where fault power is low, then it provides a substantial ~8% voltage boost (also has the ability to buck voltage by 8%). Power factor measured at the feeder breaker is near unity.

A second VVO could be installed in the middle of the feeder to act as a 'tent pole' supporting voltage in the middle of the circuit, as shown in the grey profile. The power factor measured at the feeder breaker would be leading.

Attempting to address the same voltage drop problem with a conventional line regulator results in the blue profile in Figure 6, with the regulator located half-way down the circuit. This would not address all of the low voltage on the feeder and would require fourteen tap raises on the regulator. Power factor measured at the feeder breaker would be a poor 92% lagging.

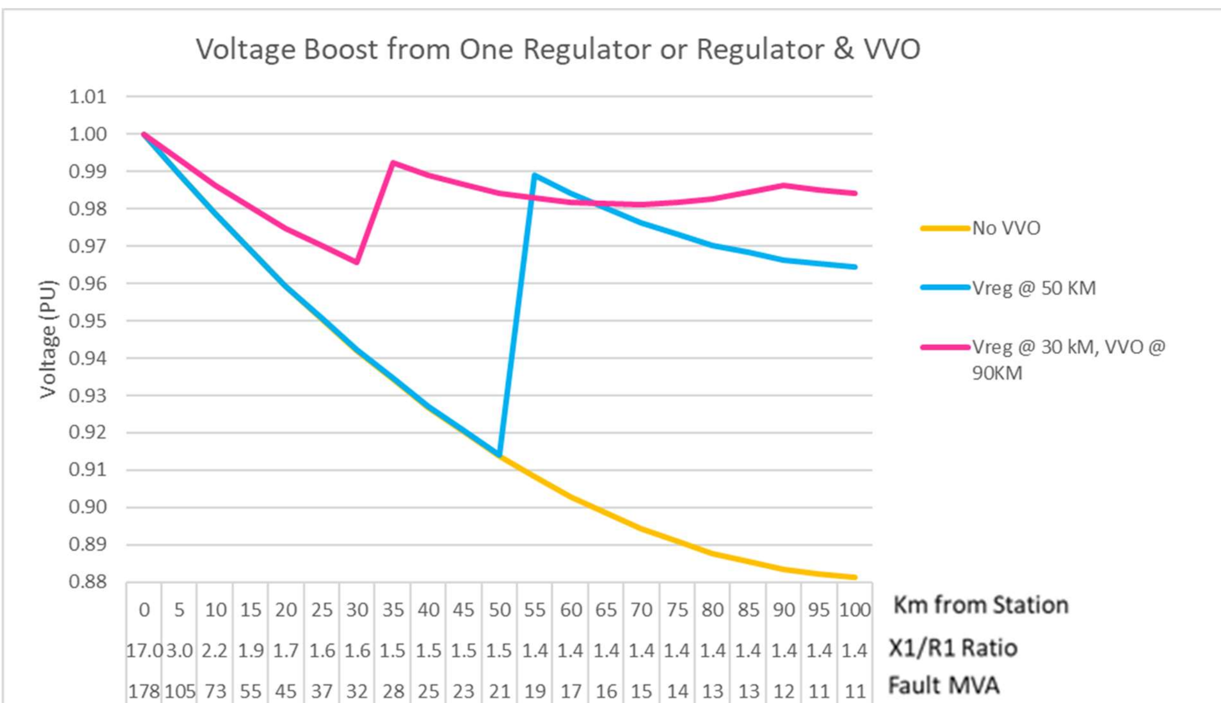

Figure 6: Resulting voltage profile with Regulator or Regulator and VVO

Instead, a solution based on one line regulator and one VVO offers the best solution achieving both a flat voltage profile along the feeder, and a power factor near unity at the feeder breaker (the pink profile in Figure 6). In this arrangement the regulator only needs to move up 5 tap positions and will experience fewer tap changes as the VVO dynamically adjusts to maintain voltage as the loading varies. This dynamic adjustment, combined with the shunt connection allows for intrinsic coordination, i.e., there are no coordination considerations between the VVO and upstream regulators.

Real distribution feeders are not as simple as the example provided. For instance, real feeders may have:

- A mixture of conductors with various impedances
- Unevenly distributed load and/or generation
- Regulators and capacitors already installed at non-optimal locations

The general principles demonstrated in the example above are still helpful. The D-VAR VVO placement strategies can be summarized as follows:

1) Consider using *only* VVOs and fixed capacitors for voltage regulation on lightly- loaded rural feeders.
2) If two or more regulators are in series, consider replacing the second line regulator or any additional downstream regulators with VVOs. Alternatively, consider placing a VVO approximately 2/3rds of the way into a second regulation zone (replacing or supplementing capacitors located nearby).
3) Rather than focusing on conductor types, evaluate fault power to identify VVO locations. In general, VVOs can have a meaningful impact on voltage where three phase fault power is below 50 MVA (refer to Figure 3).
4) Design the total capacitor and VVO capacity to roughly equal the maximum reactive power demand on the circuit. For instance, a circuit that peaks at 12,000 kVA @ 94% PF will require approximately 4,000 kVAR in compensation which can be provided from two 900 kVAR capacitors and two three-phase VVO units distributed across the feeder.
5) Consider placing a VVO near any variable generation that is causing increased regulator or capacitor switching or persistent high voltage. In many of these cases, the regulator or capacitor can be eliminated.

QUESTIONS?

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