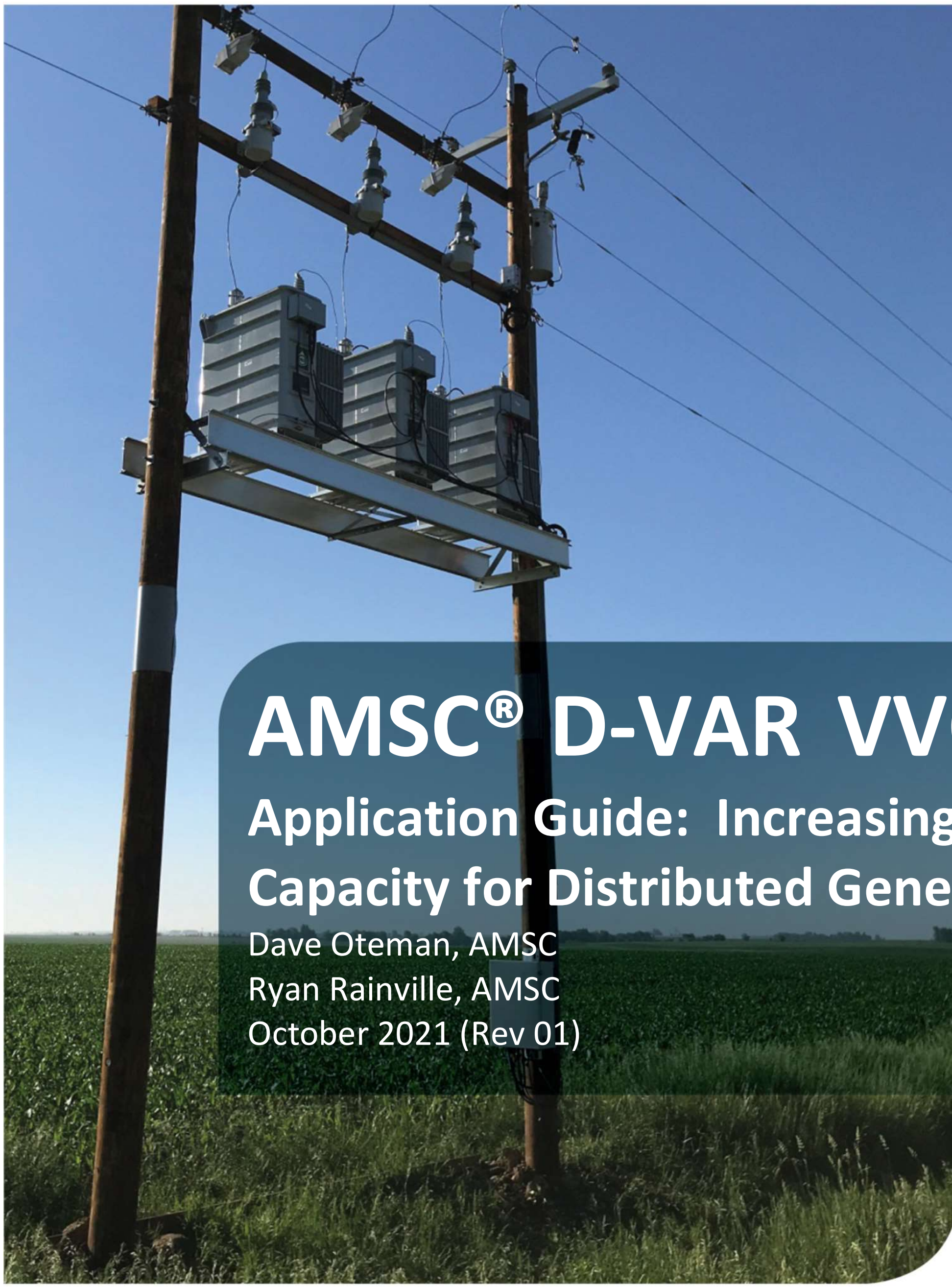

AMSC® D-VAR VVO®

Application Guide: Increasing Hosting Capacity for Distributed Generation

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October 2021 (Rev 01)

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Contents

1. Introduction

The D-VAR VVO® Distribution STATCOM is a high-performance distribution-class voltage regulation solution. Utilities and project developers employing the D-VAR VVO can eliminate common voltage constraints that occur on utility circuits and deliver an attractive stack of benefits to end-customers.

A summary of the value stack for utility applications of the D-VAR VVO Distribution STATCOM is provided in Figure 1.

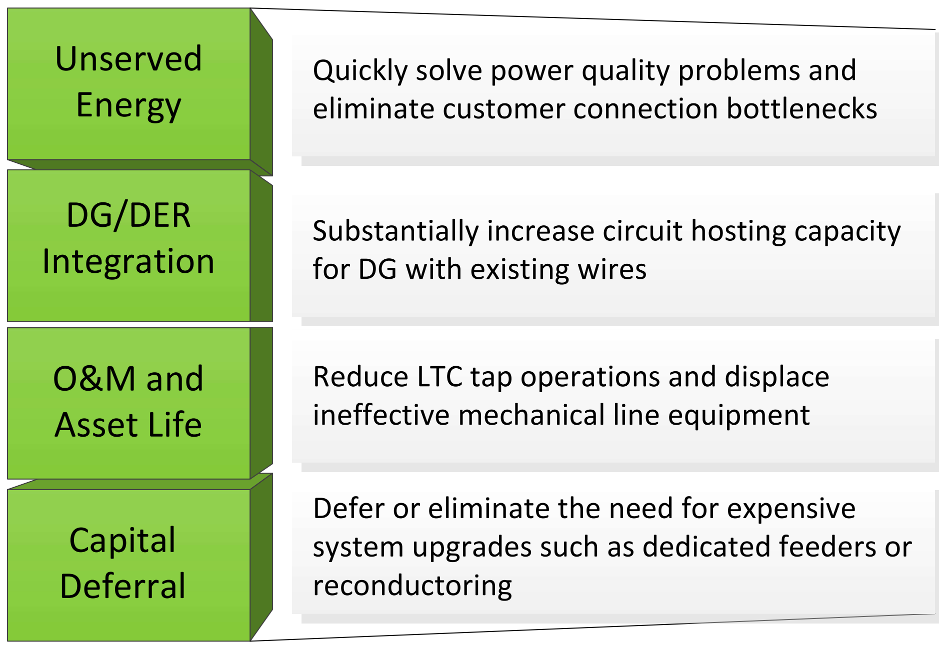

Figure 1. Value stack for D-VAR VVO applications.

This application guide focuses on mitigating system impacts from distributed energy resources (DER) which cost-effectively increases hosting capacity. A utility can realize all four of the benefits shown in Figure 1 when installing VVOs to increase hosting capacity.

This guide is intended for engineering managers, practicing engineers and project managers that have responsibility for designing and specifying solutions for DER/DG integration. After reading this application guide, readers should be able to:

- Understand how the D-VAR VVO can be used to solve power quality problems caused by intermittent DER
- Understand why the D-VAR VVO can be the most economical approach to solving issues related to DER
- Achieve sizing of D-VAR VVO necessary for hosting DER
- Understand the typical requirements for selecting a location for the D-VAR VVO

Utility scale (roughly 2,000kw to 10,000kW) photovoltaic solar plants are the focus of this application guide. The principles in the guide are also applicable to high penetrations of rooftop residential and commercial solar that aggregate to *Utility scale*. Likewise, the principles can be used to host wind turbines, run-of-river hydro, battery energy storage system, and more.

2. Power Quality Impacts of DER

Figure 2 is based on EPRI DRIVE screening guidelines for hosting capacity [1, 2]. Most utility, state, or regional screening guidelines include these factors though the exact pass/fail criteria may differ.

Power System Criteria			
Thermal	**Power Quality / Voltage**	**Protection**	**Reliability/Safety**
Substation Transformer	**Sudden (fast) voltage change**	Relay reduction of reach	Unintentional Islanding
Primary Conductor	**Steady-state voltage**	Sympathetic tripping	**Operational flexibility**
	Voltage regulator impact	Element fault current	
	Load Tap Changer impact	Reverse power flow	
D-VAR VVO helps with the five power system criteria shown in green			

Figure 2: Power System Criteria for Distributed Generation Hosting Capacity

Of the four categories of violations, the most commonly occurring is a power quality/voltage violation. Regulations incentivizing DER often produce floods of interconnection applications that cannot be accommodated without system upgrades. This causes interconnection delays and disputes between utilities and developers that impede the expansion of renewable resources.

Reconductoring or building a dedicated circuit has traditionally been the most common tool to address interconnect constraints. While wire-based upgrades can address all three hosting constraints (protection, power quality/voltage and thermal), they are very costly and time-consuming upgrades for addressing voltage problems. The cost of a wire-based upgrade can exceed the combination of all other interconnection requirements, therefore, the ability to recoup a wire-based upgrade is challenging and varies greatly by local tariff structure.

Protection issues can typically be solved with low-cost improvements to relaying, and now voltage issues can be solved with AMSC's cost-effective D-VAR VVO STATCOM. Using VVO STATCOMs to address voltage issues defers wire-based upgrades until DER penetration approaches clear-cut ampacity limits and thereby maximizes the hosting capacity of existing wires[1].

3. Advantages of Distribution Class STATCOM

3.1 STATCOM Principle of Operation for Solar/DG

Solar facilities produce variable real power, causing upwards of 50 large power fluctuations on partly cloudy days [2]. These large power fluctuations can cause the following power quality issues:

- Excessive voltage rise > 105%
- Frequent and excessive voltage deviations > 3%
- Mis-operation and over-operation of existing line regulators and LTC's.

[1] Under certain tariffs, the VVO may be characterized as a non-wires alternative (NWA) with preferred treatment

Figure 3 and Figure 4 illustrate the principle of operation of a distribution STATCOM for solar and distributed generation applications.

The solar real power is in phase with the resistive portion of the feeder impedance. This results in large voltage swings across the resistive portion of the impedance as the variability in solar resource occurs due to cloud pass events.

The STATCOM technology produces precise reactive current in phase with the inductive portion of the impedance. To compensate for the voltage impacts of the variable solar power, the STATCOM technology automatically produces the precise amount of reactive current required to cancel the voltage impacts from the solar.

In practice, the STATCOM typically absorbs reactive power (inductive), producing operating power factors in the range of 0.95 to 0.85 lagging near the solar facility during periods of high solar production.

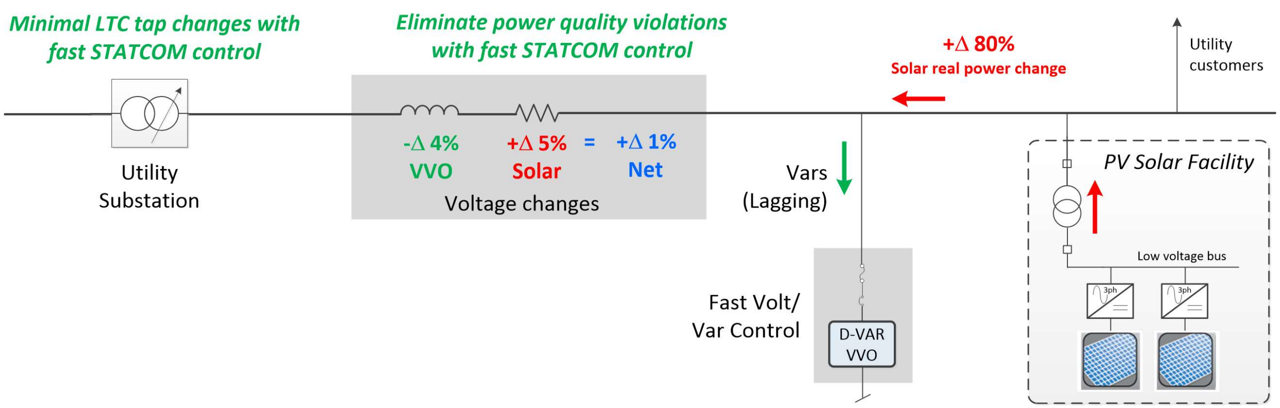

Figure 3. Single line diagram illustrating the principle of operation of the D-VAR VVO.

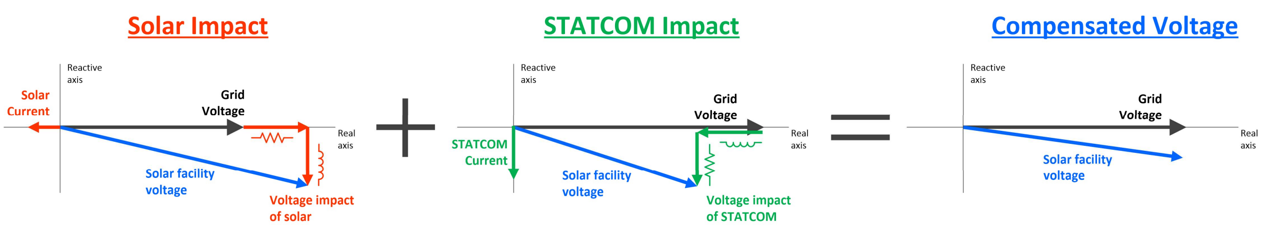

Figure 4. Electrical phasor diagram illustrating the D-VAR VVO principle of operation.

Waveform captures from a circuit experiencing reverse power flow due to solar are shown in Figure 5. The waveforms in the figure demonstrate the performance improvement of employing the D-VAR VVO STATCOM solution. The D-VAR VVO STATCOM is able to completely resolve the voltage violations caused by variable solar generation on the circuit.

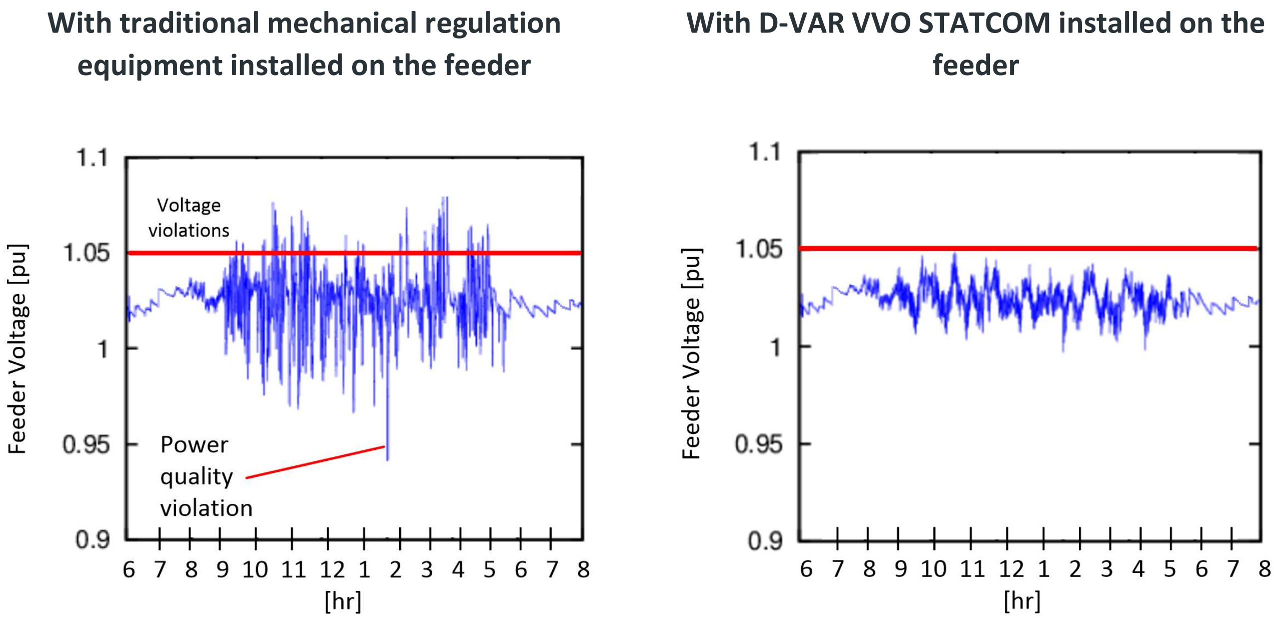

Figure 5. Distributed generation power quality improvement with D-VAR STATCOM.

3.2 STATCOM Ownership Considerations

The D-VAR VVO STATCOM is an apparatus-based tool that can be quickly installed on a distribution circuit to resolve/prevent voltage violations. It can be used by utilities to streamline interconnection of renewable resources into the distribution grid, reducing average interconnect times for solar and distributed generation facilities.

Mid-sized and large-sized utilities can deploy the D-VAR to free-up 100's of MW's of additional hosting capacity in their distribution systems ***with existing wires***.

Broad deployment of the D-VAR VVO can provide a substantial advantage for utilities and regulatory stakeholders that have set target dates for 100% renewable goals.

The D-Var VVO STATCOM can be owned by a utility or a facility operator. In many instances, utility ownership of the distribution STATCOM has advantages including:

- Utilities are large asset-owning companies that have both the incentive and the ability to recoup capital expenditures over a relatively long time horizon

- The D-VAR VVO ideally fits the traditional utility model of owning and operating distribution-class voltage regulation equipment
- Utilities possess the best engineering and operational expertise to take responsibility for the voltage management issues associated with distributed generation
- Solar developers can avoid taking on a non-core competency (voltage management) in their scope of project responsibility, and focus on what they do best – designing and constructing solar/DG facilities
- Utilities can maximize operational security by integrating D-VAR VVO with critical, utility-owned operational systems (e.g., ensuring proper operation of a voltage reduction system for emergency capacity as distributed generation continues to proliferate on the system)

3.3 D-VAR VVO Technology Advantages

The D-VAR VVO is purpose built for reliable, low-cost operation in medium voltage distribution systems and addresses the limitations of conventional mechanical utility equipment as illustrated in Figure 6. The advantages are achieved through the following technology design characteristics:

- Precise and continuous adjustment of Volt/Var output
- No routine maintenance due to a solid-state design with no moving parts
- Excellent safety, shunt-connected without the use of batteries
- Compact, distribution-class apparatus that can be installed in existing utility feeders
- 20-25 Yr service lifetime that is fully independent of load variability on the circuit, unlike mechanical equipment
- Extremely low operating losses (<1.25% of output typical)

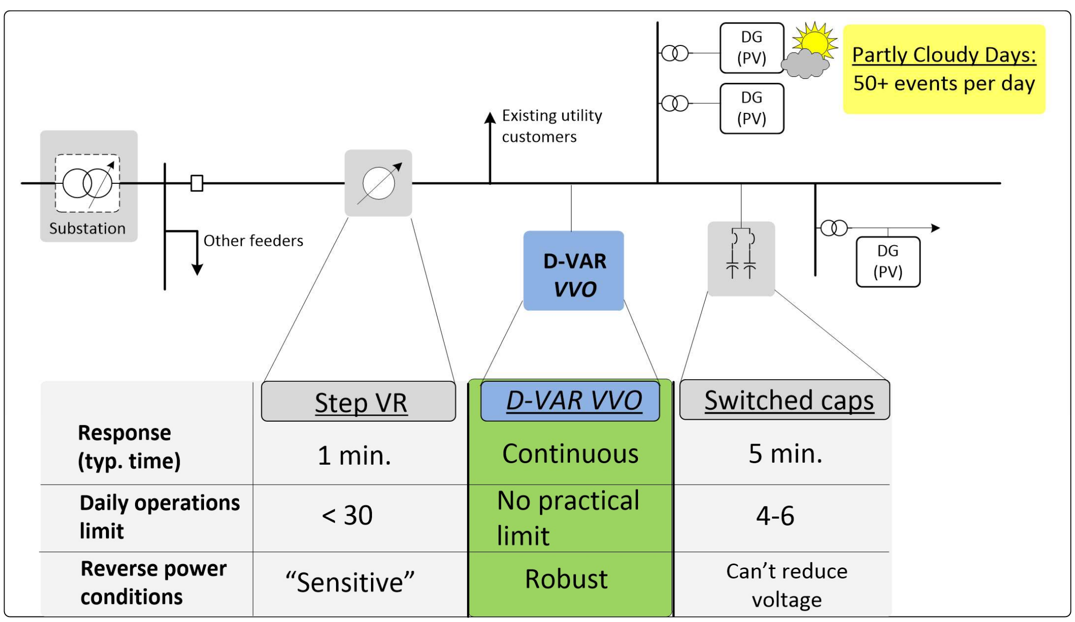

Figure 6. The advantage of power-electronics based D-VAR VVO for distributed generation.

4. D-VAR VVO Sizing Guidelines for DG applications

AMSC has developed sizing guidelines to help streamline engineering D-VAR VVO based solutions for the interconnect solar and DG facilities on existing feeders. The guidelines apply to the following most common cases:

- Case 1) Interconnecting single facilities on existing feeders
- Case 2) Interconnecting multiple facilities that cause violations when considered in aggregate
- Case 3) Meeting a constant power factor requirement at a solar/DG facility that may be enforced as part of an interconnect agreement.
- Case 4) Protecting substation LTC from excessive operations on circuits that must maximize DG

4.1 Single solar/DG facilities

The following guidelines ensure that:

1) Existing utility customers are protected from experiencing solar-related power quality issues including over voltages occurring during full solar output and voltage deviations occurring due to the variability of solar output
2) Upstream utility-owned line regulation apparatus and LTC apparatus are protected from excessive operation and premature asset wearout due to the variability of solar
3) The sizing guidelines are based on ensuring voltage deviations caused by the variability of solar are limited to <2%

The sizing tables Table 1 to Table 4 assume the following:

- The solar facility is operating at unity power factor
- The D-VAR VVO STATCOM is located near the solar facility point of interconnection (POI). The D-VAR VVO is recommended to be installed within 0.5 feeder-miles of the POI, and strictly within no more than 0.75 feeder-miles of the solar facility POI.

D-VAR VVO solutions for installation on the utility feeder are illustrated in the simplified single line diagram in Figure 7. The Appendix provides a summary of the method employed to create the tables.

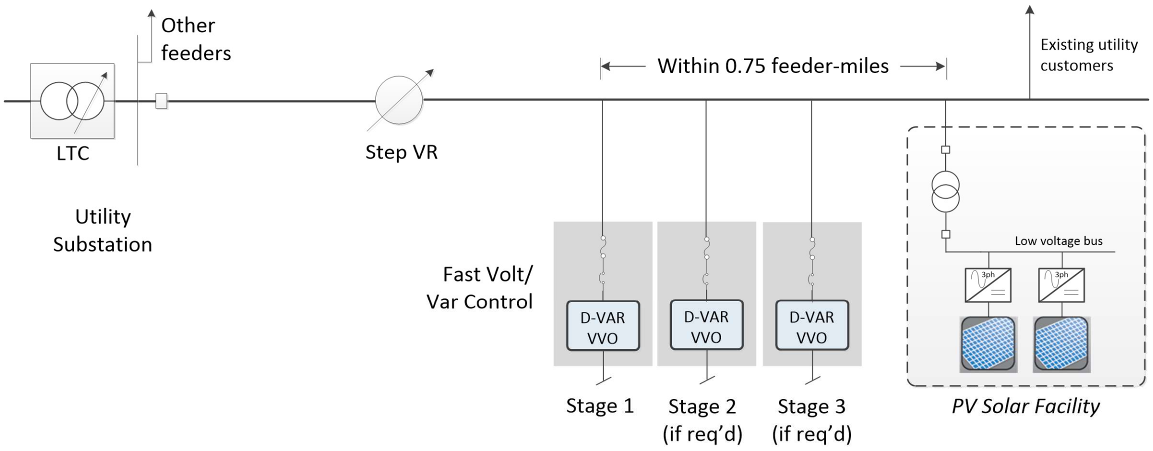

Figure 7. Single line diagram illustrating D-VAR VVO Solutions to resolve power quality issues caused by solar facilities on a distribution feeder.

Table 1. D-VAR VVO sizing table. Requirements to interconnect a specific size solar facility.

Table applies for distribution circuits with X/R = 1.

No VVO Required	(white)
1 VVO Required	(light green)
2 VVO Required	(medium green)
3 VVO Required	(dark green)
Interconnect not recommended	(grey)

		Number of VVO stages to prevent additional tapping of upstream devices due to solar variability (X/R=1)				
		Solar Plant Rating [MW]				
Fault Power at Solar Site [MVA]	**X/R**	**2**	**3**	**4**	**5**	**6**
20	1	2	3			
25	1	2	3			
30	1	2	3	3		
35	1	1	2	3		
40	1	1	2	3		
45	1	1	2	3		
50	1	1	2	3	3	

Table 2. D-VAR VVO sizing table. Requirements to interconnect a specific size solar facility.

Table applies for distribution circuits with X/R = 2.

		Number of VVO stages to resolve power quality issues (X/R=2)								
		Solar Facility Rating [MW]								
Fault Power at Solar Site [MVA]	X/R	2	3	4	5	6	7	8	9	10
20	2	1	1	2	2					
25	2	1	1	2	2	3				
30	2	1	1	2	2	3	3			
35	2	1	1	2	2	2	3	3		
40	2	1	1	1	2	2	3	3		
45	2	0	1	1	2	2	3	3		
50	2	0	1	1	2	2	3	3		
60	2	0	1	1	2	2	2	3	3	
70	2	0	0	1	1	2	2	3	3	
80	2	0	0	1	1	2	2	3	3	3
90	2	0	0	1	1	1	2	2	3	3
100	2	0	0	0	1	1	2	2	2	3
125	2	0	0	0	0	1	1	2	2	3

Table 3. D-VAR VVO sizing table. Requirements to interconnect a specific size solar facility.

Table applies for distribution circuits with X/R = 3.

		Number of VVO stages to resolve power quality issues (X/R = 3)								
		Solar Facility Rating [MW]								
Fault Power at Solar Site [MVA]	X/R	2	3	4	5	6	7	8	9	10
20	3	1	1	1	2					
25	3	1	1	1	2	2				
30	3	1	1	1	1	2	2			
35	3	0	1	1	1	2	2	2	3	
40	3	0	1	1	1	2	2	2	2	3
45	3	0	1	1	1	1	2	2	2	3
50	3	0	0	1	1	1	2	2	2	3
60	3	0	0	1	1	1	1	2	2	2
70	3	0	0	0	1	1	1	2	2	2
80	3	0	0	0	1	1	1	1	2	2
90	3	0	0	0	0	1	1	1	2	2
100	3	0	0	0	0	0	1	1	1	2
125	3	0	0	0	0	0	0	1	1	2

Table 4. D-VAR VVO sizing table. Requirements to interconnect a specific size solar facility.

Table applies for distribution circuits with X/R = 4.

		Number of VVO stages to resolve power quality issues (X/R = 4)								
		Solar Facility Rating [MW]								
Fault Power at Solar Site [MVA]	**X/R**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
20	4	1	1	1	1					
25	4	0	1	1	1	1				
30	4	0	1	1	1	1	2			
35	4	0	1	1	1	1	1	2	2	
40	4	0	0	1	1	1	1	2	2	2
45	4	0	0	1	1	1	1	1	2	2
50	4	0	0	0	1	1	1	1	2	2
60	4	0	0	0	1	1	1	1	1	2
70	4	0	0	0	0	1	1	1	1	1
80	4	0	0	0	0	0	1	1	1	1
90	4	0	0	0	0	0	0	1	1	1
100	4	0	0	0	0	0	0	1	1	1
125	4	0	0	0	0	0	0	0	0	1

4.2 Multiple solar/DG facilities in Aggregate

Addressing voltage violations caused by the aggregate effects of multiple solar installations is a common scenario encountered in practice. Multiple individual solar facilities may connect on a feeder circuit without requiring any individual mitigation. Over time, the aggregate amount of solar on the circuit may result in voltage violations. Figure 8 illustrates the situation of multiple facilities causing a violation.

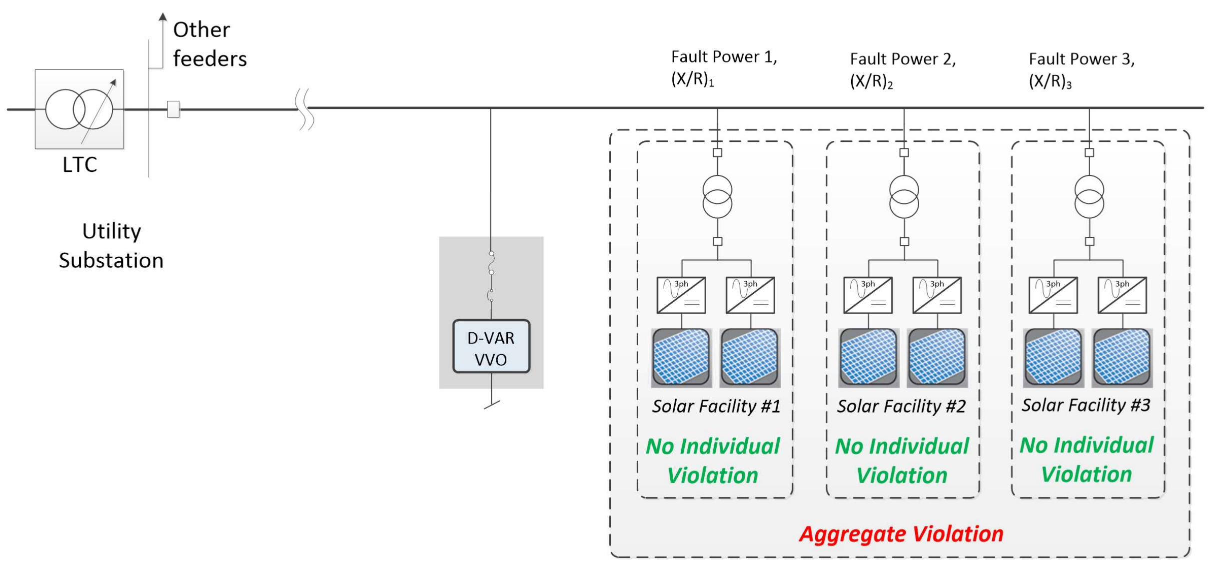

Figure 8. Single line illustrating a D-VAR VVO solution to address voltage violations caused by multiple facilities in aggregate.

4.2.1 Determining VVO Solutions for Multiple Facilities

An aggregate evaluation can be applied to multiple solar facilities fed by the *same utility feeder circuit*. The ratings in the single facility sizing tables in Section 4.1 can be used to represent an aggregate amount of solar, allowing multiple facilities to be accounted for as "one equivalent solar facility."

The fault power and X/R ratio of the aggregate solar can be estimated based on the capacity-weighted average fault powers of multiple individual solar facilities. The following summarizes a practical method to determine an equivalent single facility sizing for use with the D-VAR VVO sizing tables.

$FaultPower_{Agg}$	the equivalent fault power of the aggregation of multiple generating facilities
X/R_{Agg}	the equivalent X/R ratio of the aggregation of multiple generating facilities
C_{wn}	the weighted capacity of the nth generating facility
C_t	the total aggregate capacity of distributed generation on the feeder
C_n	the capacity of the nth generating facility

$$FaultPower_{Agg} = FaultPower_1 * C_{w1} + FaultPower_2 * C_{w2} + \cdots FaultPower_n * C_{wn}$$ **Equation 1**

$$\frac{X}{R}_{Agg} = \frac{X}{R}_1 * C_{w1} + \frac{X}{R}_2 * C_{w2} + \cdots \frac{X}{R}_n * C_{wn}$$ **Equation 2**

$$C_{w1} = \frac{C_1}{C_t}$$ **Equation 3**

$$C_{w2} = \frac{C_2}{C_t}$$ **Equation 4**

$$C_{wn} = \frac{C_n}{C_t}$$ **Equation 5**

$$C_t = C_1 + C_2 + \cdots C_n$$ **Equation 6**

4.2.2 Multiple facility Sizing Example

Consider a case with three solar facilities on a feeder, each with the same nameplate rating of 2MW. The facilities having a fault power of 80MVA, 70MVA, and 60MVA, respectively. The feeder has a characteristic X/R = 3.

Referencing Table 3, no VVO solution was required to address the first two 2MW solar facilities, however, the third 2MW solar facility resulted in a hosting capacity violation and requires a VVO solution to address the aggregate impacts of the 6MW of solar on the circuit.

The total capacity is determined:

$$C_t = 2\ MW +\ 2\ MW +\ 2MW$$

$$C_t = 6\ MW$$

The weighted capacities are determined by:

$$C_{w1} = \frac{2MW}{6MW}$$

$$C_{w1} = \frac{1}{3}$$

In this example, the weighted capacities C_{w2} and C_{w3} are each the same as C_{w1} because each plant size is the same size (2MW).

The aggregate fault power can now be determined:

$$FaultPower_{Agg} = 80MVA * 1/3 + 70MVA * 1/3 + 60MVA * 1/3$$

$$FaultPower_{Agg} = \frac{80MVA + 70MVA + 60MVA}{3}$$

$$\boldsymbol{FaultPower_{Agg} = 70\ \mathrm{MVA}}$$

The aggregate fault power of 70 MVA can be used to represent an equivalent single solar facility. Referring to Table 3, a single stage VVO is recommended to be able to fully resolve the power quality violations caused by the 6MW of aggregate solar on the distribution feeder.

4.3 DG Facilities with a power factor requirement

Certain utilities and system operators may require facilities to interconnect at a non-unity power factor. For significant non-unity power factor requirements (e.g. 0.8pf to 0.95pf), the D-VAR VVO solution can be attractive to quickly scale Dynamic Var capacity to meet the interconnect requirement.

The VVO sizing in Table 5 provides sizing reference for constant power factor applications. The table assumes the STATCOM is located behind the primary meter of the solar facility, as illustrated in the simplified single diagram in Figure 9.

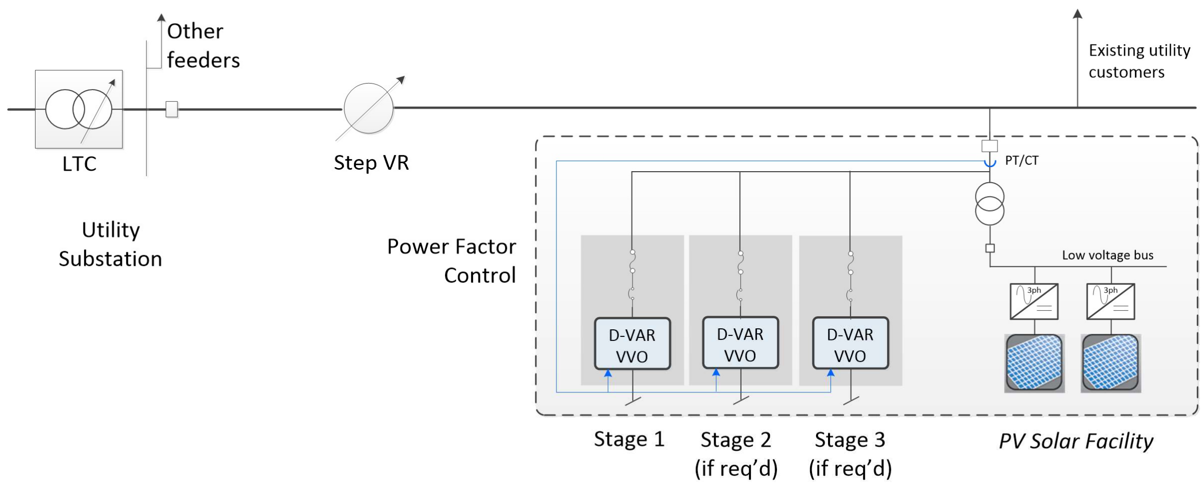

Figure 9. Single line diagram illustrating D-VAR VVO Solutions for solar facilities required to operate at non-unity power factor.

Table 5. D-VAR VVO sizing configurations to meet a constant power factor requirement at a solar facility.

No VVO Required	
1 VVO Required	
2 VVO Required	
3 VVO Required	
VVO Not Recommended	

		Number of VVO stages to meet power factor requirement								
		Solar Power Rating [MW]								
Power Factor	**Rating [MVA/MW]**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1	0	0	0	0	0	0	0	0	0
0.95	1.06	1	1	2	2	2	3	3	3	
0.9	1.11	1	2	2	3	3				
0.875	1.15	2	2	3	3					
0.85	1.18	2	2	3						
0.825	1.22	2	2	3						
0.8	1.25	2	2	3						

4.4 Protecting Substation LTC's from excessive operations

Table 1 to Table 4 provide the VVO sizing guidelines for solar applications. The tables illustrate that feeders requiring the maximum level of solar/DG interconnection require a 3 stage VVO solution installed near the solar facilities. The maximum inductive Var flow caused by the 3 stage VVO solution (up to 3MVAR) causes additional voltage drop across the utility substation transformer reactance. Because the Vars are adjusted dynamically in response to the variable solar resource, excessive LTC tapping can result. This phenomena can be compensated with a single VVO installed at the secondary of the LTC near the head of the feeder or in the substation. Refer to Figure 10. The VVO at the head of the feeder should also be configured in Volt/Var mode.

An additional VVO at the feeder head ***__is not__*** required with single stage or two stage VVO solutions.

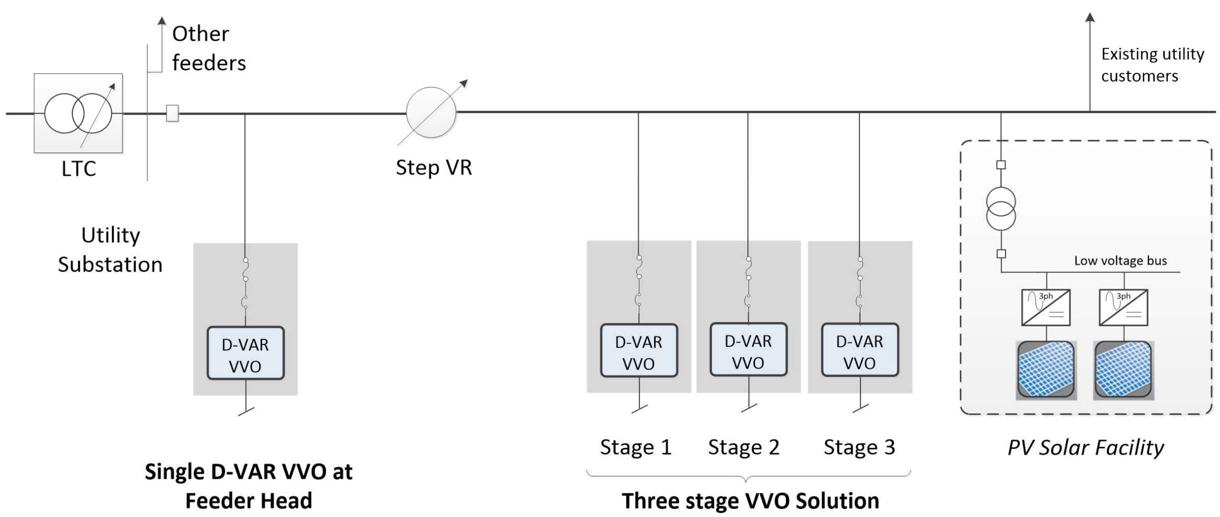

Figure 10. Single line diagram illustrating a three stage D-VAR VVO solution with the recommended single D-VAR VVO installed near the head of the feeder.

5. D-VAR VVO Location and System Integration Considerations

This section provides guidelines for locating STATCOMs on utility distribution circuits for solar and DG applications.

5.1 Considering existing line regulators

In general, use of the D-VAR VVO simplifies the control settings of line regulators on the feeder. This is because the VVO responds continuously and precisely to compensate for the solar variability. The line regulator settings can be set to respond to gross diurnal (ie, daily) changes in feeder loading. This is a significant operating advantage because mechanical line regulator technology is not capable of, nor is it reliable for, compensating solar variability.

Locate D-VAR VVO solutions in the last 1/3 of the voltage regulation zone, or greater than 2 miles downline of the line regulator as shown in Figure 11.

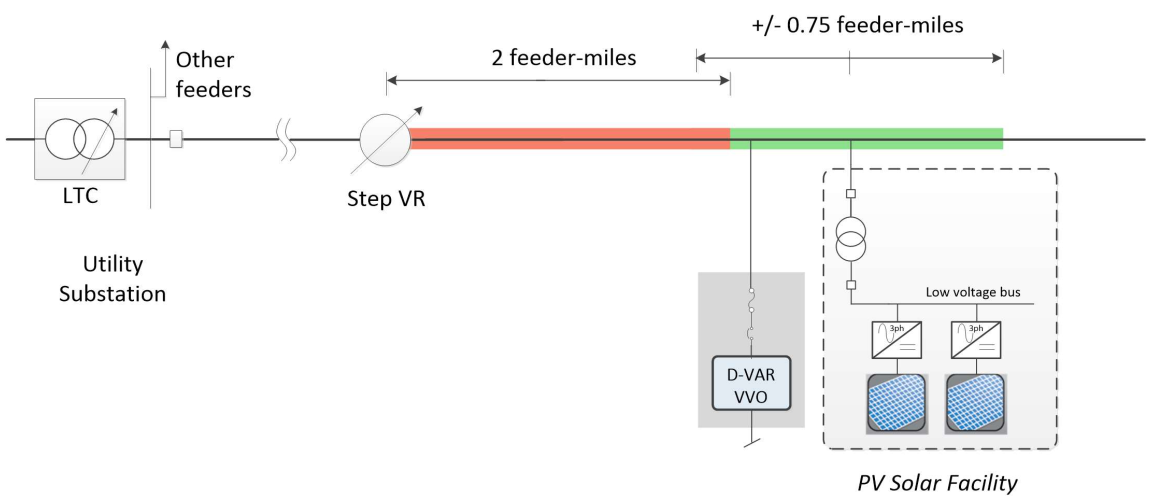

Figure 11. Single line diagram illustrating D-VAR VVO placement guidelines relative to line voltage regulators. The highlighted green region is the valid area to install a VVO solution.

Recommended control settings for the line regulator (pertains to one line regulator only) located ***upstream*** of the VVO solution are provided in Table 6 below.

Table 6. Recommended setting for the line regulator upstream of a D-VAR VVO.

Line Regulator Control Setting	Recommended Setting with D-VAR VVO	Rationale
Mode	Cogeneration	The upstream line regulator will see reverse power conditions from DG. The VVO mitigates over voltages due to the DG on the "load side" of the line regulator. Therefore, the line regulator should use the Cogeneration Mode to control the load side during both reverse and forward power conditions.
Voltage Target	123V - 125V	The VVO has fast Volt/Var control that continuously responds to voltage variations caused by DG. The upstream regulator Voltage Target should be set to manage maximum forward-power conditions. The Voltage Target can typically be set in the range of 123V - 125V with the VVO installed. The voltage target should not exceed 125V.
Bandwidth	1.5V - 3V	The VVO has a fast Volt/Var control that continuously responds to voltage variations caused by DG, limiting voltage variations measured at the line regulator. This protects the upstream line regulator or LTC from over tapping. Line regulator bandwidth should be set in the range of 2V - 3V. LTC bandwidth should be set to no less than 1.5V.
Time Delay	Same setting as prior to DG facility	The relatively slow regulator control "sees" the VVO as a load because the VVO is a shunt-connected device that only processes reactive power. Therefore, there are no timing coordination requirements. The regulator time delay setting should remain the same.
Line Drop Compensation	Disable	The VVO has fast Volt/Var control that continuously responds to voltage variations caused by fluctuations in both DG and load. Therefore, line drop compensation is not recommended for the regulator upstream of the VVO and should be disabled.
Voltage Limiter	Enable	The voltage limiter function should remain enabled. Large load rejections may still occur and the voltage limiter can help reduce the maximum voltage after a load rejection event.

5.2 Considering utility switched capacitor banks

When installing D-VAR VVO solutions for solar hosting and DG applications, the following guidelines are recommended for switched capacitor banks:

- ***Behind-the-meter, customer-owned switched capacitor banks***
  - Should remain in service and do not need to be considered when installing D-VAR VVO solutions on the feeder

- ***Upstream utility-owned switched capacitor banks***
  - Upstream switched capacitor banks *located on feeders* with D-VAR VVO should be placed in the voltage control mode. This configuration is necessary to avoid the cap bank responding to the lagging power factor necessary to mitigate solar impacts
  - Capacitor banks in the upstream utility substation can operate in a Var control mode and can compensate power factor at the substation

- ***Nearby utility-owned switched capacitors***
  - If a nearby switched capacitor is rated at 600kVAR or less, the capacitor bank is no longer required and can be removed from service
  - During circuit loading conditions, the D-VAR VVO can replace the functionality of the removed switched capacitor bank

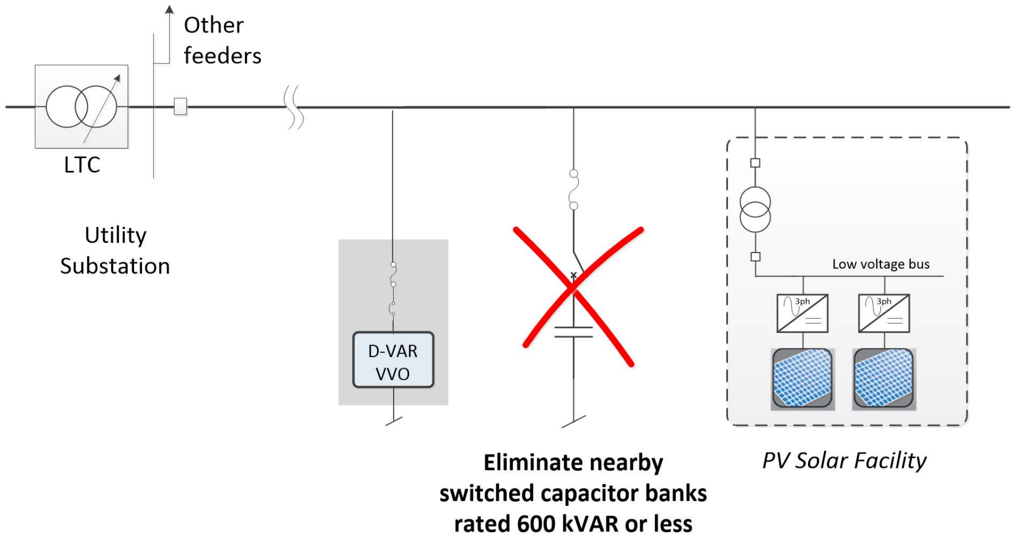

Figure 12. Eliminate nearby switched capacitor banks rated at 600kVAR or less.

5.3 Considering existing reclosers and protection zones

Locate D-VAR VVO within the same protection zones as the solar facilities that the D-VAR is intended to mitigate, as shown in Figure 13. This practice is essential to avoid the VVO becoming unavailable due to a reclose event while the solar facility continues to operate.

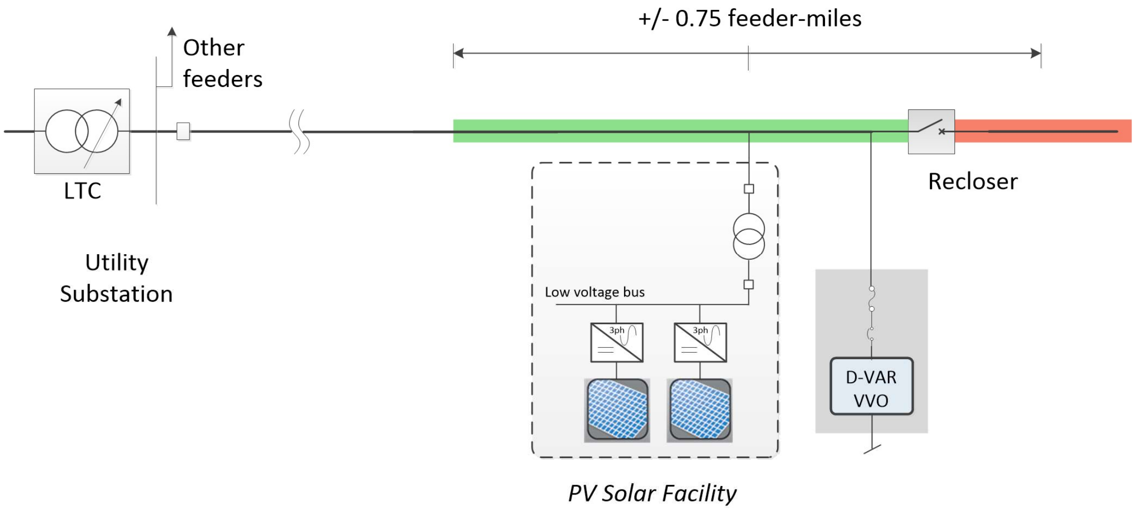

Figure 13. Single line diagram illustrating D-VAR VVO placement guidelines relative to line reclosers. The highlighted green region is the valid area to install a VVO solution.

5.4 Considering integration with DERMS solutions

The D-VAR VVO can be readily integrated with existing Volt/Var & Distributed Energy Resource Management Systems (DERMS) via the D-VAR VVO SCADA communications link. The following recommendations apply:

- Rely on the fast (i.e., sub-cycle response) and precise Volt/Var control action of the D-VAR VVO to compensate for the variability of DER
- Use the centralized DERMS control system, with typical update intervals of 5-15 minutes, to adjust Volt/Var settings via SCADA communications
- When the nominal voltage set point to the D-VAR VVO is updated via SCADA, the D-VAR VVO automatically adjusts the remainder of the Volt/Var curve set points
- The D-VAR VVO responds to set point updates with smooth transition behavior, i.e., there is no need to stop the D-VAR VVO to change Volt/Var set points

5.5 D-VAR VVO fault current contribution

Fault current contribution of the D-VAR VVO is a consideration when reviewing protection settings and coordination on the circuit:

- The VVO contributes up to 63A of reactive current per stage when the power system voltage measured at the VVO is greater than 0.5pu (>=0.5pu)
- The VVO inhibits operation when the power system voltage drops below 0.5pu (<0.5pu) remaining. Practically, this means that for faults electrically near the D-VAR VVO, the VVO does not contribute fault current
- Fault current contributed by a D-VAR VVO solution of up to Qty=3 VVO stages is typically a negligible contribution to the available fault current at any point on the circuit

6. Guidelines for Volt/VAR Settings

AMSC has developed guidelines to configure the Volt/Var settings of the STATCOM for solar and DG applications. The guidelines below can be referenced as default initial settings. Performance of the D-VAR VVO can be monitored via the remote monitoring system or utility SCADA interface to the D-Var VVO. Minor adjustments to the initial Volt/Var settings are not uncommon and can be made via SCADA.

6.1 Recommended settings for downline feeder application

The following settings can be considered as recommended initial defaults for D-VAR VVO distributed generation applications, refer to Figure 14 A for a graphic representation of the settings:

- Positive sequence mode is recommended to address applications with large three phase facilities
- Independent phase mode is recommended to address residential solar applications where significant single phase DER may be connected on a lateral, or when significant voltage unbalance may pre-exist on the circuit

- Vtarget = Vnom (nominal circuit voltage with the solar plant at zero output)
- Symmetrical curve
- Deadband = +/-0.5%
- Droop = 2.5%/1pu

6.2 Recommended settings for feeder head application

As discussed in Section 4.4, in applications that require maximizing solar/DG on a feeder, a single VVO stage should be installed at the head of the feeder (in addition to the Qty=3 downline VVO stages). The following recommended default settings for feeder head VVO's are designed to protect LTC's from excessive operation. Refer to Figure 14 B for a graphical representation of the Volt/Var settings:

- Independent phase mode is recommended to address applications at the feeder head
- Vtarget = LTC target voltage (nominal LTC voltage setting)
- Symmetrical curve
- Deadband = +/-0.25%
- Droop = 1.5%/1pu

A. Default curve for applications requiring the VVO installed on downline feeder locations

B. Default curve for applications requiring VVO installed at the head of the feeder

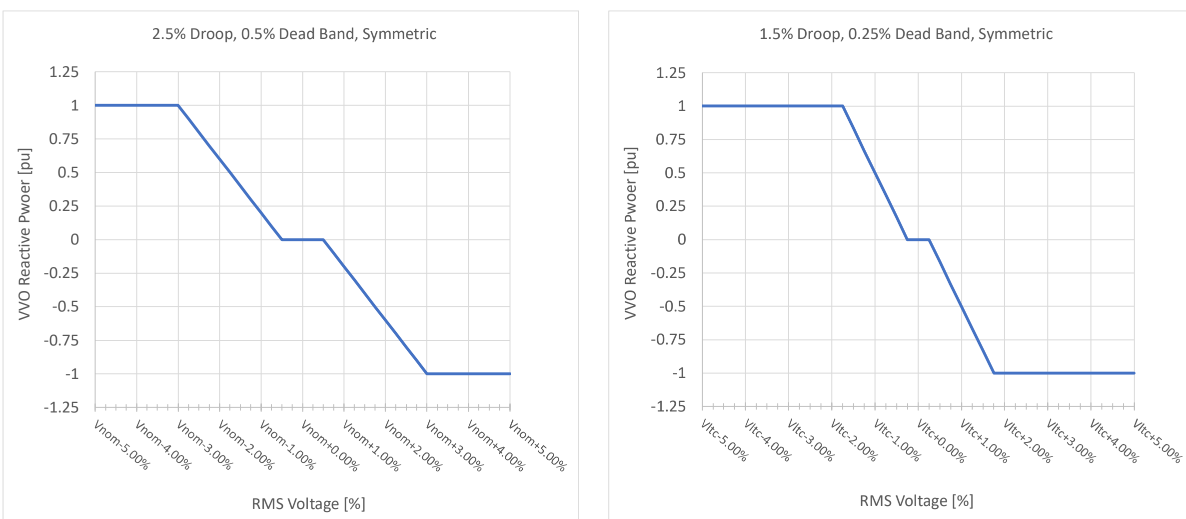

Figure 14. D-VAR VVO default Volt/Var curves for solar/DG applications.

6.3 Volt/Var Setting Tools

AMSC has also developed tools and an application note for the calculation of Volt/Var curves given system configurations and system parameters. Please contact the AMSC applications engineering team for additional information.

7. Summary Tips

7.1 Tips for understanding the advantages of D-VAR VVO for Distributed Generation

- Power quality and voltage issues are the most ***commonly-occurring hosting capacity violations*** for distributed generation facilities
- A properly-sized D-VAR VVO solution ***fully addresses all power quality and voltage violations*** that can be caused by distributed generation facilities
- D-VAR VVO enables utilities to achieve a substantial ***increase of hosting capacity with existing wires***
- With the broader use of VVO's across the utility distribution system, ***100's of MW of additional distributed generation capacity*** can be freed-up in a typical mid-sized utility territory
- Utilities can significantly ***reduce average facility interconnect times*** with the D-VAR VVO
- D-VAR VVO is an ***inherently safe***, shunt-connected device that does not rely on batteries
- D-VAR VVO requires ***no routine maintenance***

7.2 Tips for applying D-VAR VVO Solutions

- Use AMSC's reference tables to quickly and accurately size solutions for solar and distributed generation applications
- A single D-VAR VVO can add typically between 2-4MW of solar or distributed generation, depending on the properties of the distribution circuit
- D-VAR VVO solutions can be applied to *increase* distribution feeder hosting capacities. Depending on the circuit type and voltage class, achieving up to an additional ~10 MW on a feeder is feasible (in addition to the native hosting capacity of that feeder)
- Up to three parallel VVO systems can be connected near the same electrical point of interconnect to support larger distributed generation facilities
- A single VVO at the feeder head is recommended when maximizing hosting capacity on the feeder (i.e., when qty=3 downline VVO's are required) in order to protect the LTC from excessive tapping

D-VAR VVO®

Helping utilities enhance service quality at the:

- **Right time** – Systems available with a standard lead time
- **Right size** - Sizes are tailored to distribution needs
- **Right location** – Distribution-class apparatus can be installed anywhere that it needs to be
- **Right certainty** – The performance certainty of utility-grade and utility-owned equipment

=

- **Right value** – Multiple customer benefits enable attractive capital deployment

8. D-VAR VVO Application Support

Website: https://www.amsc.com/gridtec/distributed-generation-solutions/#dvarvvo

Related downloadable resources:

- D-VAR VVO Variable Generation Application Brochure
- Case Study: Accelerating Renewables by Integrating Solar Plants into Distribution Circuits
- D-VAR VVO Modeling guides for Cyme, Synergi, and Milsoft
- Practical application of the D-VAR VVO STATCOM

9. Works Cited

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10. Appendix

The VVO solutions in Section 4 are based on ensuring a 1.5% voltage variation for a sudden loss of solar output due to cloud pass events. A cloud pass event causes a maximum of 80% loss in solar in practice. The following method is applied to determine the VVO size:

The percent change in voltage due to a distributed generation (DG) facility change in output ΔP_{DG} and a STATCOM change in output ΔQ_S is determined by:

$$\Delta|V| \cong \frac{\Delta P_{DG}}{V} * R + \frac{\Delta Q_S}{V} * X \qquad \text{Equation 7}$$

Equation can be rearranged to determine the reactive power required to compensate the sudden loss of solar:

$$\Delta Q_S \cong \frac{V}{X}\Delta|V| + \frac{\Delta P_{DG}}{X/R} \qquad \text{Equation 8}$$

Applying ΔV = 1.5% and ΔP_{DG} = 80%, the STATCOM size can be determined for a known circuit fault power MVA and circuit X/R ratio.