# AMSC® D-VAR VVO® Application Guide: Motor Starting Compensation


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*April 2021 (Rev 4)*

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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.

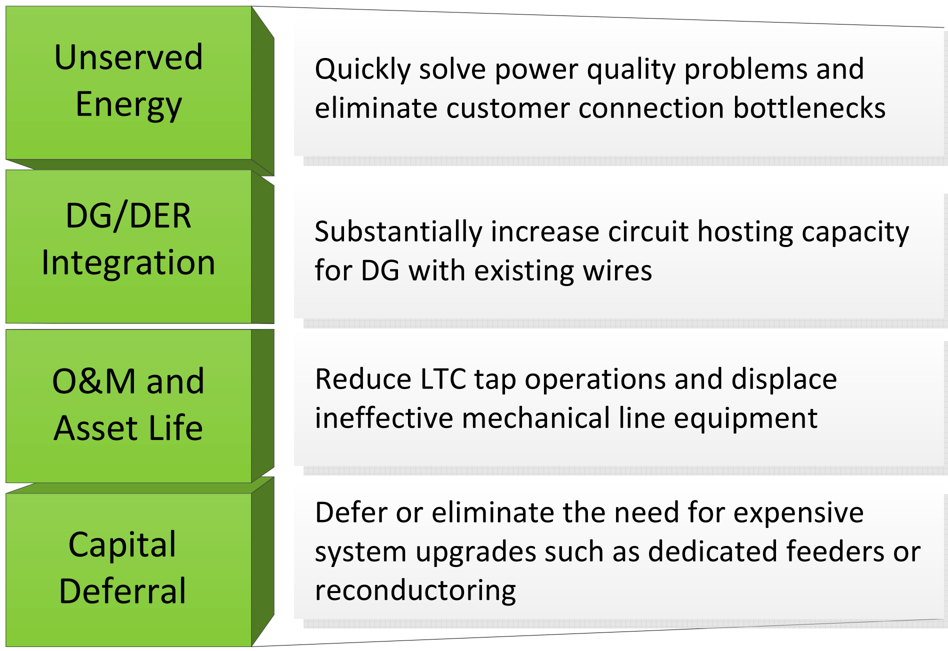


**Figure 1. Value stack for D-VAR VVO applications.**

This application guide focuses on solving common power quality problems that arise in motor starting applications. Applying the D-VAR VVO solution to these problems can achieve the *Unserved Energy* and *Capital Deferral* benefits defined in Figure 1.

Three phase, squirrel cage induction motors are the most common type used in a variety of industrial applications and are the focus of this guide. The term "motor" refers to this type of motor. Slip-ring, synchronous, and DC driven motors have unique uses for which the VVO may still provide benefit. AMSC's Planning & Applications group can be consulted for special applications.

After reading this application guide, practicing engineers should be able select a D-VAR VVO solution to address their motor starting application needs and learn the following:

- Understand how motor starting events cause power quality issues on the utility grid;
- Understand the limitations of conventional automation industry equipment for addressing power quality issues;
- Understand how and when the D-VAR VVO can be the most economical approach to solving issues related to motor start transients;
- Develop accurate sizing of D-VAR VVO's for motor start applications given typically-available data of motors;
- Selection of the appropriate control settings and identifying the practical siting considerations of the D-VAR VVO for motor starting applications.

# 2 Motor Starting Impacts on Utility Power Quality

## 2.1 Summary

Many power quality issues are due to the relative weakness of a distribution supply compared to the load served at a given location. This is an acute problem with large dynamic motor loads that can draw a sudden inrush of current within a few cycles. Likewise, power quality issues can arise from an aggregation of smaller motor loads in a weak portion of a circuit. Below is a list of example operations that can cause power quality problems:

- Irrigation pumping in agricultural areas
- Sawmills and woodchippers
- Quarries and crushing operations
- Pumping stations and processing plants in Oil & Gas fields
- Pumping operations for mining & chemical processing plants
- Grinding and pelletizing operations
- Large conveyors

When a motor is started from a standstill it will draw significant inrush current until the motor accelerates to running speed. The locked rotor power factor is approximately 20% causing high reactive power demand that must be sourced from the distribution supply. This predominantly reactive power can range from 3 to 10 kVA/HP with the vast majority of fielded motors near 6 KVA/HP.

Circuits fed from small power transformers or long medium voltage (MV) radials are especially susceptible to rapid voltage changes (RVC) caused by the starting motor's sudden demand for reactive power. Most utilities require limiting RVC measured at medium voltage to be 4% or less (and below 5% on the low voltage bus) for infrequent motor starts and may have a lower threshold for frequent motor starts. The severity, duration, and number of occurrences of RVC must be adequately limited to avoid power quality complaints from nearby customers.

## 2.2 Anticipating a Power Quality Problem

With the power system fault power known at the primary meter (i.e., at the medium voltage feed to a facility with the motor), a specific size motor can be assessed to determine if there will be a power quality issue.

The *maximum three phase short circuit current* indicates the amount of current that they utility can supply during a three phase bolted fault at a specific location. The *maximum three phase short circuit current* can be converted to *Fault Power* using the equation below.

$$Fault\ Power = (I_{SC\_3PH\_max})(V_{nominal\_LL})(\sqrt{3})$$

*Fault Power* can be used to compare the relative stiffness of two circuits with different operating voltages. It also provides an easier reference to the size of loads that are typically quantified in terms of MVA. Most distribution feeder circuits have fault power values declining from roughly 100 MVA (very stiff) near the substation to 10 MVA (very weak) near the end of the radial.

Figure 2 provides a convenient chart to determine the likelihood of a power quality problem due to motor starting. The chart applies for the most common motor locked rotor rating range of 5-7 kVA/HP. The only parameter required is the three-phase fault power at the primary meter serving the facility with the motor.   This parameter is readily available and is most-commonly obtained using one of two methods:

- The most recent facility arc flash study will have a 3ph fault power defined at the primary meter
- The local utility will be able to provide the fault power at the location – no study required

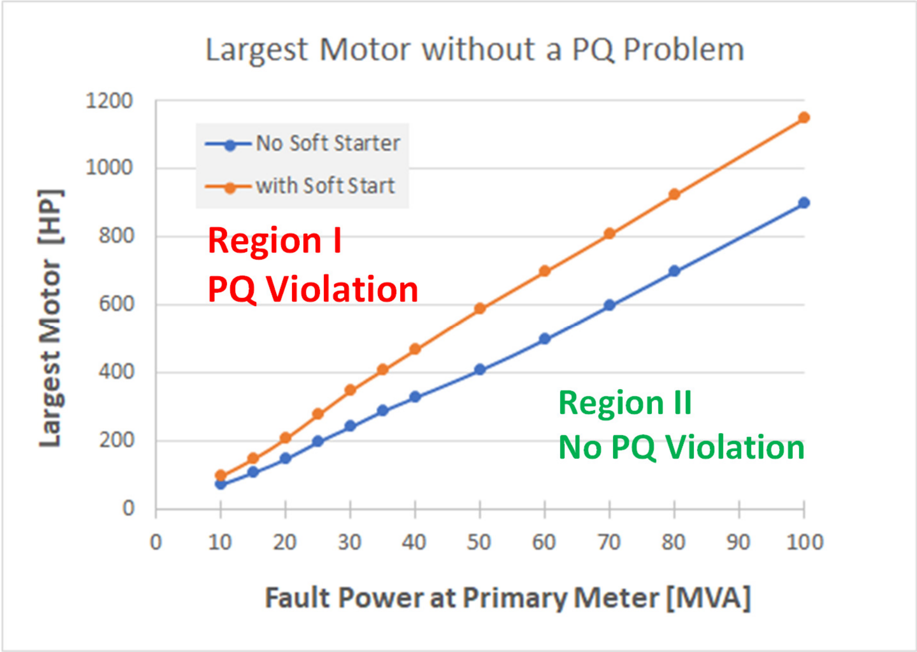


**Figure 2.  The largest motor that can be tolerated at a specific location on a distribution circuit.  The chart applies for locked rotor rating of 5-7 kVA/HP.**

In the region I above the curves, the corresponding motor sizes can be expected to result in a utility power quality problem and are excellent candidates for D-VAR VVO STATCOM solutions.  In the region II below the curves, the corresponding motor sizes can be expected to avoid a utility power quality violation.  The cost of a utility power quality problem can be debilitating.  Therefore, for motor sizes on the curve or very near the curves, AMSC recommends a more detailed analysis and a proactive approach to evaluate and manage a potential PQ problem.

## 2.3 Utility Power Quality Violation Example

An example of a utility power quality problem caused by motor start in a weak system is presented in this section. Figure 3 shows the real and reactive power demand when soft-starting a 350 HP motor. The point of interconnection with the utility is 12.47 kV, 11 MVA fault power.  The inrush of reactive current demand by the motor causes an 8.3% dip on the medium voltage. This will lead to noticeable flicker, rapid voltage change (RVC), and low voltage issues for electricity customers served within several miles of the motor.

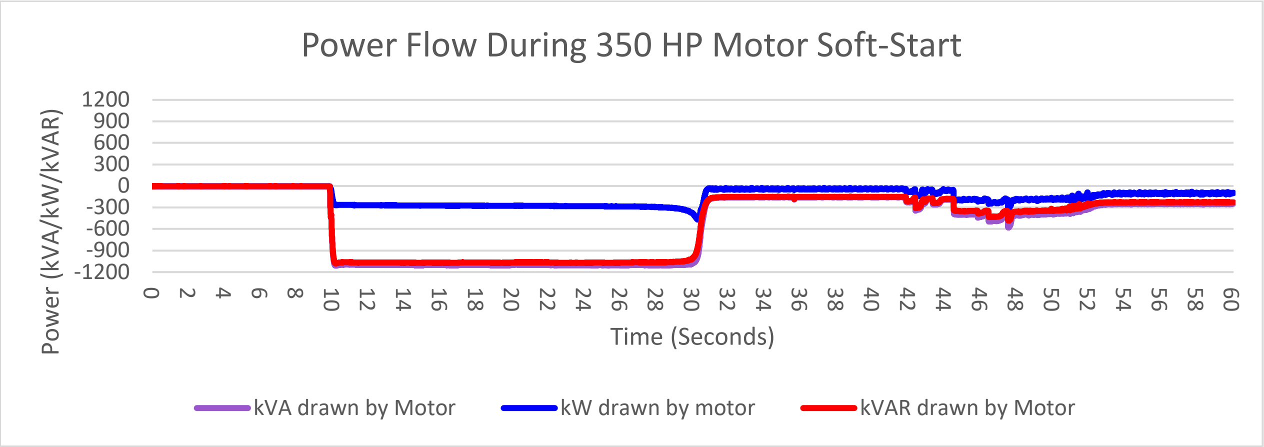


**Figure 3: Power Flow During 350 HP Motor Soft-Start**

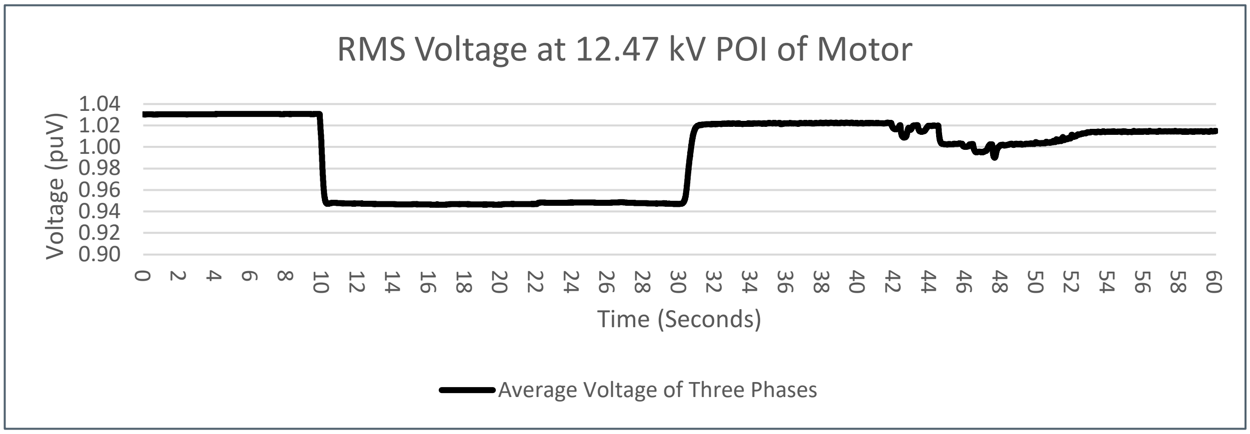


**Figure 4: Voltage During 350 HP Motor Soft-Start causing power quality issues.**

# 3 Motor Characteristics

The National Electric Manufacturers Association (NEMA) defines five major design types (A, B, C, D, and E). Each design type has a unique combination of torque, current, and efficiency as illustrated in Figure 5.

**Torque Characteristics**
**of NEMA A, B, C, D, & E Motors**

TYPICAL CHARACTERISTICS OF FIXED FREQUENCY SMALL AND MEDIUM MOTORS

| NEMA Motor | Locked Rotor Torque | Pull-Up Torque | Break Down Torque | Locked Rotor Current | Slip | Efficiency |
|---|---|---|---|---|---|---|
| A | 70-275 | 60-190 | 175-300 | n/a | 0.5-5% | medium or high |
| B | 70-275 | 65-190 | 175-300 | 600-700 | 0.5-5% | medium or high |
| C | 200-285 | 140-195 | 190-225 | 600-700 | 1-5% | medium |
| D | 275 | n/a | 275 | 600-700 | 5-8% | low |
| E | 75-190 | 60-140 | 160-200 | 800-1000 | 0.5-3% | high |

**Figure 5: NEMA Motor Design Use Cases and Torque Comparison**

NEMA Designs A and B are classified as general purpose and prolifically used. Thus, their motor characteristics set the basis for this guide. Design E is a higher efficiency variant, which can occasionally replace A and B motors. Since Design E has lower locked rotor torque and higher locked rotor current, it is more likely to require a VVO.

NEMA Designs C and D are typically applied when the process requires a flat torque vs speed capability. While not as common as Designs A and B, they are often applied when higher starting torque is required.

The starting torque of a squirrel cage induction motor is reduced by the square of voltage at its terminals. For example, a Design B motor with 1.5 pu locked rotor torque at 1.0 pu voltage would have 0.96 pu torque at 0.8 pu voltage [1.5*(0.8^2) = 0.96].

The starting current of a squirrel cage induction motor is reduced in proportion to the voltage at its terminals. A Design B motor with locked rotor current of 6.5 pu current would see it reduced to 5.2 pu current at 0.8 pu voltage [6*0.8 = 5.2]. Voltage dependency of this motor is summarized in Table 1.

**Table 1: Voltage dependency of Motor Starting Torque & Current for a Design B Motor**

| Voltage (PU of Operating Voltage) | Locked Rotor Torque (PU of Operating Torque) | Inrush Current (PU of Operating Current) |
|---|---|---|
| 1.00 | 1.50 | 6.50 |
| 0.90 | 1.22 | 5.85 |
| 0.80 | 0.96 | 5.20 |
| 0.70 | 0.74 | 4.55 |
| 0.60 | 0.54 | 3.90 |
| 0.50 | 0.38 | 3.25 |
| 0.40 | 0.24 | 2.60 |

The squared reduction in torque with voltage can prevent the use of soft starters on larger motors. These motors tend to have low locked rotor torque and would have difficulty starting at reduced voltages. Motor-driven loads have a torque speed characteristic that must be met or exceeded by the motor's available torque which can become problematic below approximately 0.8 puV.

As an example, Figure 6 shows a motor with the same characteristics given in Table 1 and demonstrates that a conveyor served by this motor would stall if voltage were reduced to less than 0.80 puV. Therefore, even with a soft starter reducing voltage to 0.8pu, a substantial amount of inrush current will remain and therefore still cause a problematic voltage dip.

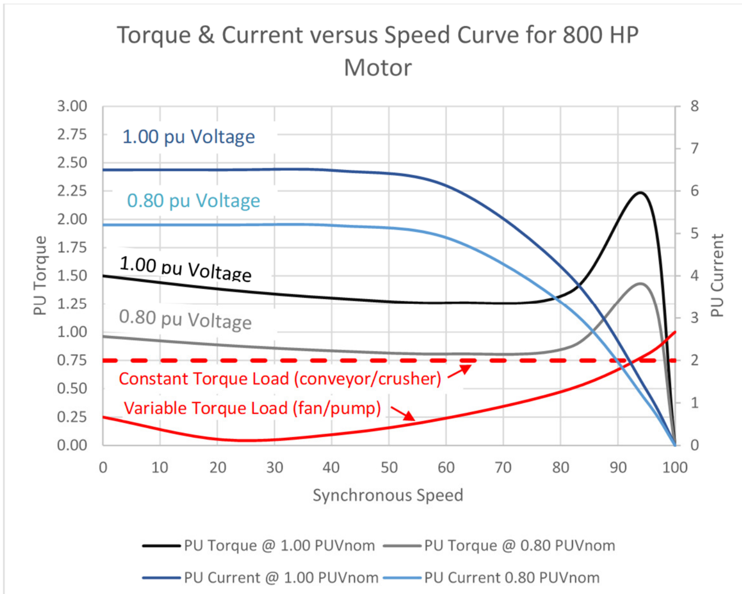


**Figure 6: Locked Rotor Torque & Current versus speed**

# 4 Motor Starting Methods and Power Quality

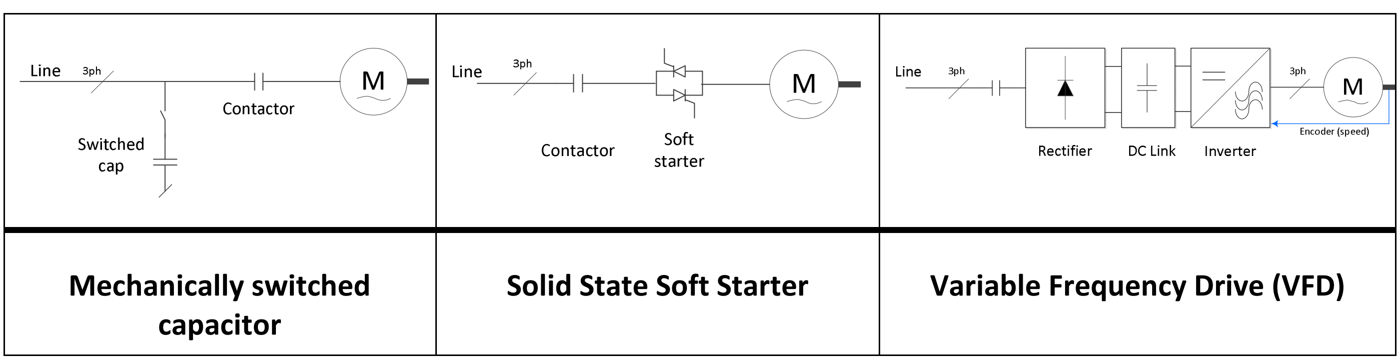


**Figure 7. Schematics of conventional motor starting methods.**

## 4.1 Mechanically Switched Capacitor

This is the simplest compensation approach. While switched caps can be used to compensate power factor during motor RUN conditions, mechanically switched caps are generally too slow and imprecise to adequately protect for motor starting inrush. For this reason, switched capacitors are rarely specified in modern installations.

## 4.2 Soft Starter

The primary purpose of soft starter is to reduce the mechanical stresses on the motor and driven load during start-up by reducing motor voltage. It reduces peak inrush current as a consequence but often not enough to avoid problematic voltage dips on the supply circuit. Soft starters can be electromechanical or solid state and in either case they operate on the principle of reducing voltage at the motor terminal during start-up. Soft starters can have drawbacks or limitations as noted below:

- *In practice, soft-starters are typically not set below 75% remaining voltage, and therefore, substantial inrush currents remain (still 4-5x rated current)*
- *Soft starters are typically selected based on mechanical process control criteria and therefore cannot typically ensure grid power quality issues are addressed*
- *A soft starter is only active during start-up or shut-down and therefore a soft starter cannot mitigate grid voltage transients that arise due to torque transients caused by the process*
- *Larger solid-state soft starters create high levels of grid THD (>30% THDi) that can require mitigation*
- *Some electromechanical soft starters are 'open-transition' which can cause motor-damaging current and torque transients*

## 4.3 Variable Frequency Drives

The primary purpose of variable frequency drives (VFD) is to provide speed control where the application requires it. A VFD can also provide controlled start-up and shutdown of the motor but it a costly solution when used only for this purpose.

Additional power quality shortcomings of a VFD include:

- *A VFD is selected based on motor control criteria and therefore may not address power quality issues at the site or on the medium voltage feeder*
- *A VFD is not capable of controlling grid voltage and therefore cannot be used to directly address grid power quality issues*
- *A standard VFD utilizes a six-pulse or twelve pulse-rectifier which are known to cause high current harmonics that often require additional filtering to mitigate*
- *A VFD is especially expensive if it must be outdoor rated*
- *A VFD is especially expensive if it serves a motor with terminal voltages of 3.3kV or 4.16kV*

## 4.4 Cost-Effectiveness of Distribution STATCOM

A STATCOM operates by rapidly and precisely providing the large reactive current/Var inrush required during motor starting events, so that the utility grid does not provide the Vars. This operation can substantially reduce the voltage dips and therefore address the associated power quality problems. The principle of operation is discussed in detail in Section 5.

The AMSC D-VAR VVO Distribution Class STATCOM addresses the power quality limitations of traditional devices by providing a dedicated tool that designers can apply directly on the utility medium voltage supply or feeder system. It is ideally suited to correcting power quality issues due to both motor starting transients *as well as* process transients that temporarily reduce the motor speed (such as a sawmill cutting lumber after the saw is started). VVO's can be used as a single mitigation solution or in conjunction with traditional motor starting devices such as soft starters. Figure 8 provides a summary of representative implementation costs of PQ mitigation solutions for motor starting.

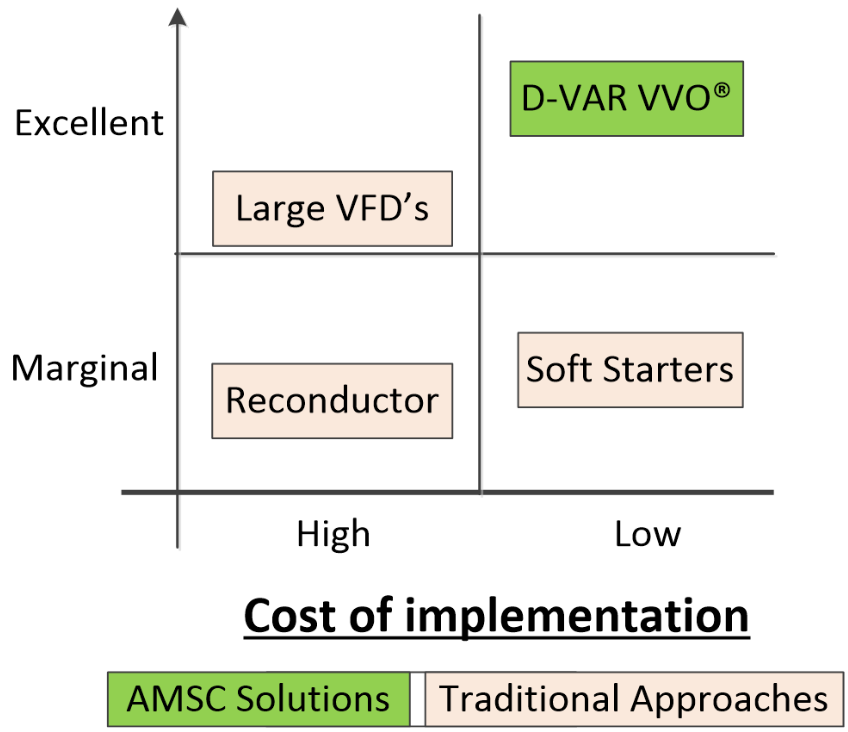


**Figure 8. Cost summary of motor start PQ mitigation options.**

Implementation cost encapsulates the true total project cost including labor and managing risks. The advantages of the VVO distribution-class STATCOM solution are summarized below:

- The solution can be quickly installed within an existing utility right-of way and avoids procurement of real estate or scarce plant space
- VVO's provide feeder-level protection for existing utility customers, allowing protection for multiple motors on a circuit or in a facility
- The solution provides 130% overload output for motor starting event, allowing minimized STATCOM nameplate ratings
- The solution is connected in shunt allowing live installation, no plant shut down, and excellent safety
- The VVO solution produces a sine wave output, eliminating the need for external harmonic filters
- The solution also provides other PQ improvements including power factor correction, reducing power factor penalties or freeing line capacity

# 5 Motor Starting Compensation with Distribution Class STATCOM

## 5.1 Principle of Operation

The VVO can be thought of as cancelling the reactive current demand of a connected motor, or motors. Direct On-line and soft-started motors draw mostly reactive current so the VVO is cancelling the vast majority of the associated voltage drop. An illustration of how the VVO current injection changes the net flow of current that needs to be supplied through the medium voltage circuit is provided in Figure 9 and Figure 10.

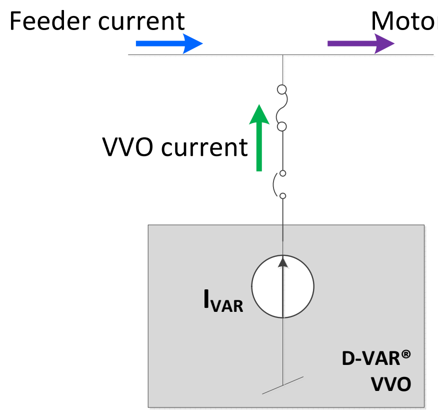


**Figure 9. Circuit diagram showing the currents in a motor starting application.**

Figure 11 demonstrates this using power flows for the same soft-started 350 HP motor introduced in Figure 3. Here, a VVO has been added that completely supplies the motor's reactive power demand (most of the motor current) leaving the substation to supply the small real power demand (net current). Figure 12 shows the small real power motor load results in less than a two percent voltage dip during VVO-mitigated motor start; well within the power quality standards for rapid voltage change events.

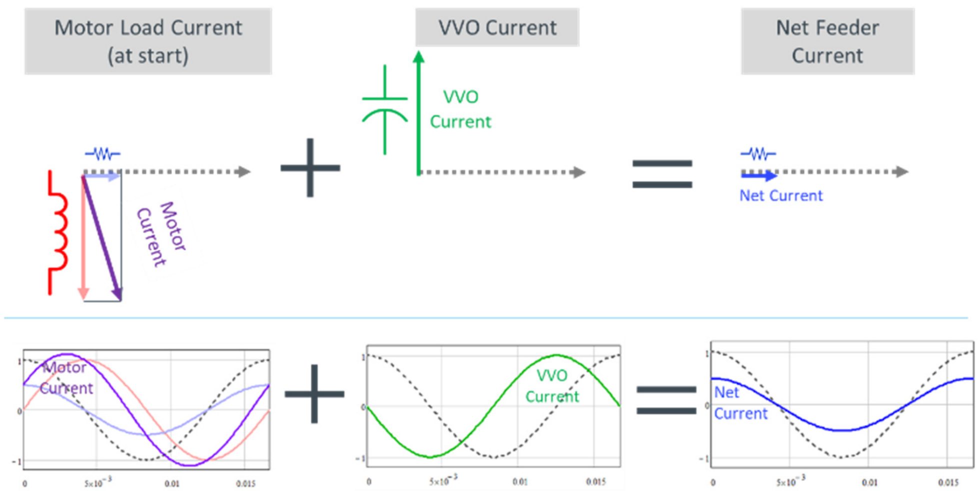


**Figure 10: VVO Reactive Current 'Cancellation' during Motor Start.**

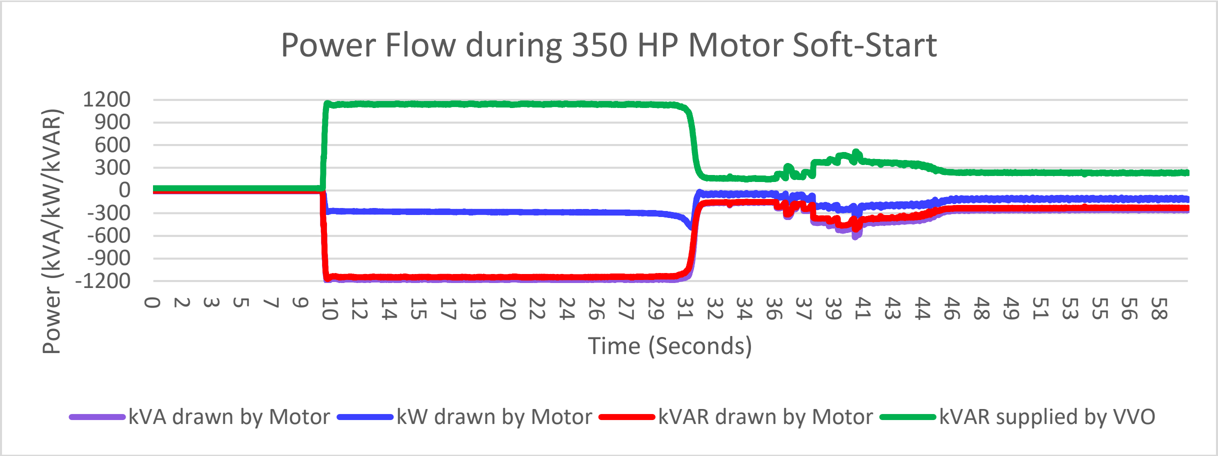


**Figure 11: Reactive Power Flow During 350 HP Motor Soft-Start with VVO.**

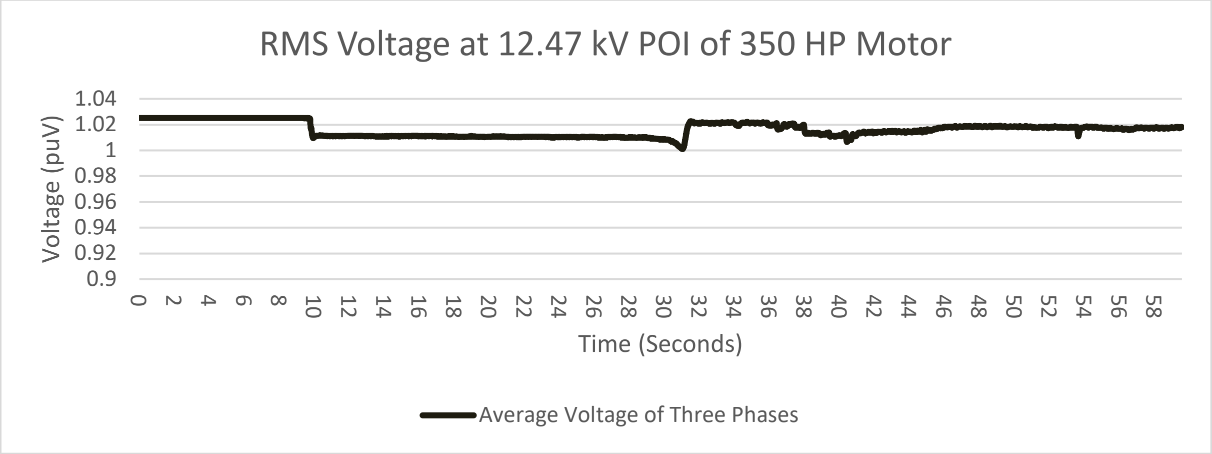


**Figure 12: Voltage During 350 HP Motor Soft-Start with VVO.**

Soft starters prolong the period of time the motor spends in a locked rotor state. This is evident in the example above where the 350 HP motor took a full 20 seconds to achieve running speed with the auto-transformer soft-starter set to 75% voltage. In this example, the soft starter could not be tapped to a lower voltage without driving the motor into thermal overload.

As demonstrated in the waveforms of Figure 11, the VVO is capable of providing overload reactive current up to 130% of rated current. The VVO can provide overload in 60 second periods up to 5 times per hour. This temporary overload output capability is a key feature making the technology cost-effective for motor starting applications where locked rotor transients can last up to 30 seconds.

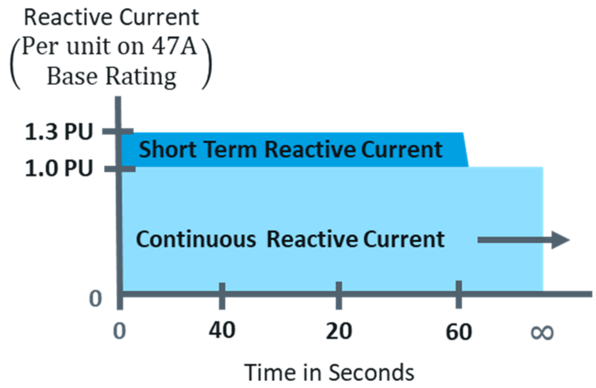


**Figure 13: VVO Reactive Current Capability.**

## 5.2 Hybrid Solutions for Increasing Dynamic Var Capacity

The D-VAR VVO STATCOM solutions can be cost-effectively expanded via hybrid configurations. In a hybrid configuration, a shunt, fixed capacitor is installed on the load side of the STATCOM to expand the dynamic Var rating. Figure 14 below illustrates the hybrid principle of operation.

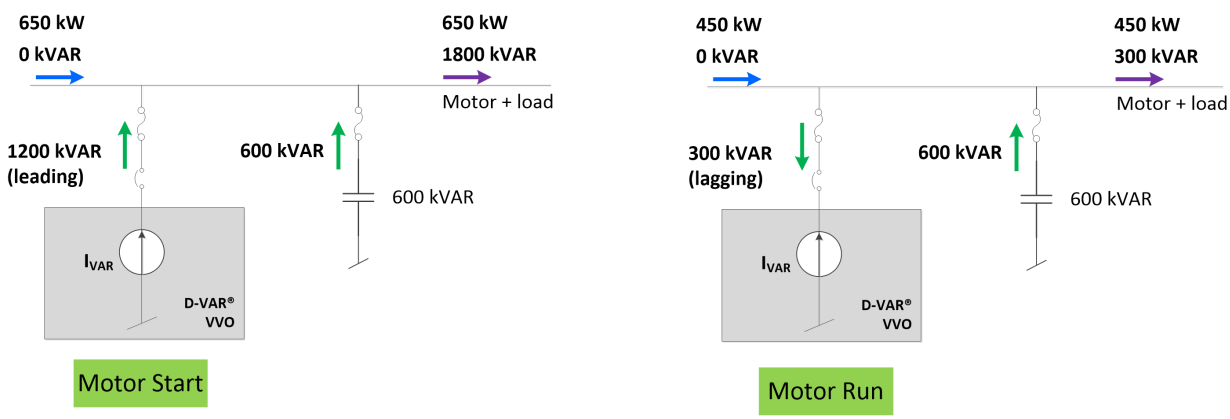


**Figure 14. A hybrid solution of a VVO with a fixed capacitor, achieving a dynamic Var capacity of 2000 kVAR at a feeder voltage of 13.8kV.**

The VVO controller regulates the STATCOM output to achieve zero net Vars on the feeder. With a fixed shunt capacitor located between the VVO and load, this configuration allows the total ***capacitive dynamic Var capacity*** to be expanded by the Var rating of the fixed capacitor. The VVO control supports hybrid solutions with a fixed capacitor nominal rating of 600kVAr per VVO. For proper control operation, it is essential that the capacitor is located electrically ***between the VVO and the load***.

## 5.3 D-VAR VVO Motor Start Performance Examples

Below are some other examples of motor starts mitigated by the VVO. Only the first 500 milliseconds of each start are captured and shown to illustrate the dynamic performance. The VVO continues to provide support beyond that time while the motor reaches running speed.

Figure 15 shows one of three co-located 1000 HP compressor motors starting with a VVO in parallel with a 600 kVAR capacitor. The motors are located a few miles from the distribution substation with a fault power of 64 MVA and X/R ratio above 3. After an initial inrush current of 3,700 kVAR the compressor draws approximately 2000 kVAR until the motor reaches running speed in 7 seconds. The hybrid VVO supplies approximately 2,000 kVAR and limits the voltage dip to just 2.1% for this start and the subsequent start of two additional 1000 HP motors.

Figure 16 shows a 200 HP motor started across the line on a weak 12.47 kV system (fault power = 16.6 MVA, X/R = 2.85). A single VVO supplies all the reactive power required by the motor and limits voltage dip to less than 2%.

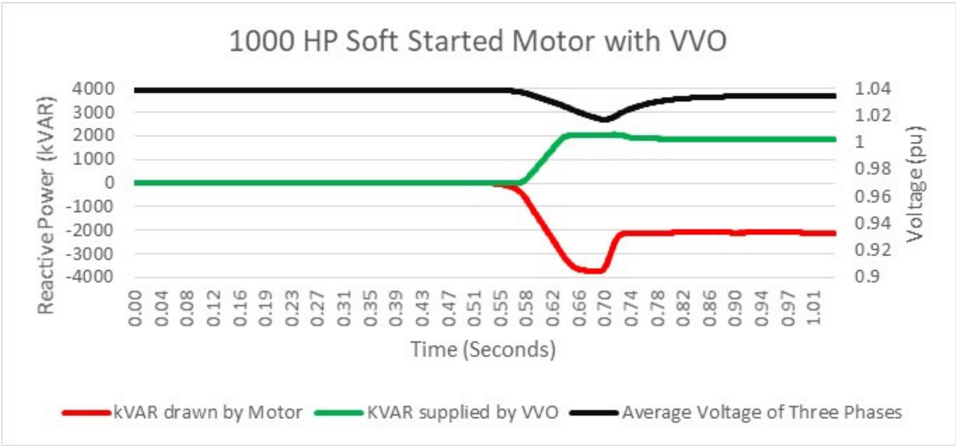


**Figure 15: 1000 HP Motor Start with VVO & Fixed Capacitor**

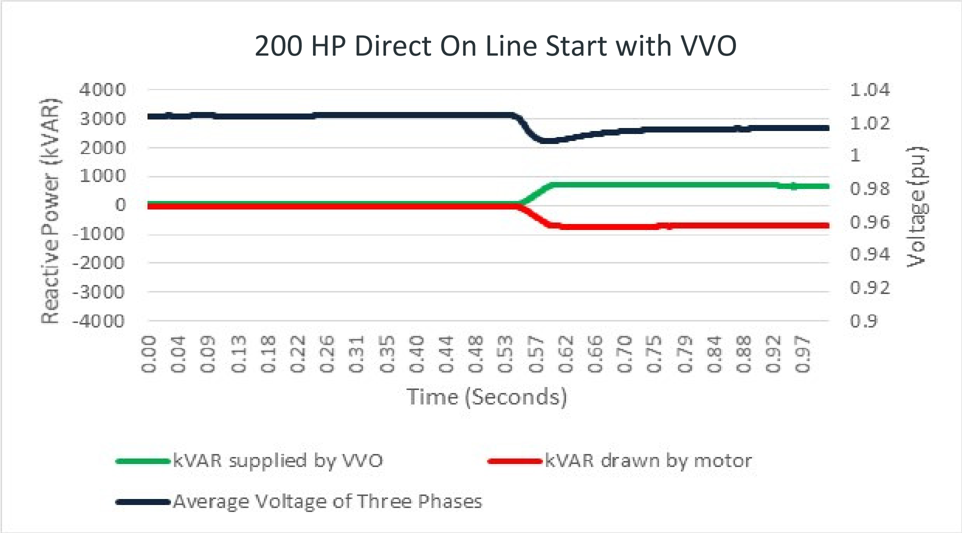


**Figure 16: 200 HP direct on-line start with VVO**

## 5.4 Transformer Voltage Drop Considerations

Because the D-VAR VVO STATCOM dynamically maintains the medium voltage bus, the voltages throughout affected facilities is also improved during motor starting events. In practice, motor ratings are a fraction of the facility transformer rating and additional reinforcements are typically ***not*** required to ensure acceptable voltage at the motor bus. To determine the *transformer* voltage drop during a motor start event, the table below can be used as a guide.

**Table 2. Transformer voltage drops during motor start events.**

| Ratio of motor to main transformer nameplate rating (kW/kVA) | Transformer voltage drop [%] (typical DOL motor) | Transformer voltage drop [%] (typical Soft Start motor) |
|---|---|---|
| 0.1 | 3.13 | 2.35 |
| 0.2 | 6.07 | 4.55 |
| 0.3 | 8.83 | 6.62 |
| 0.4 | 11.43 | 8.57 |
| 0.5 | 13.88 | 10.41 |
| 0.6 | 16.19 | 12.15 |
| 0.7 | 18.39 | 13.79 |

The scenarios highlighted in green generally require no secondary reinforcements. The scenarios in orange should be evaluated, and in most cases should ***not*** require additional reinforcements. The red scenarios can result in issues such as protective relay tripping, and would likely require additional reinforcements such as increased transformer rating.

For motor buses with other loads on the same bus, practical field experience has shown that occasional, short duration low voltages on the secondary bus due to motor starting events are generally acceptable to 90% remaining voltage. If the other loads are sensitive, they should be moved to another transformer at the facility so that they will be protected by the VVO as shown in Figure 17 below.

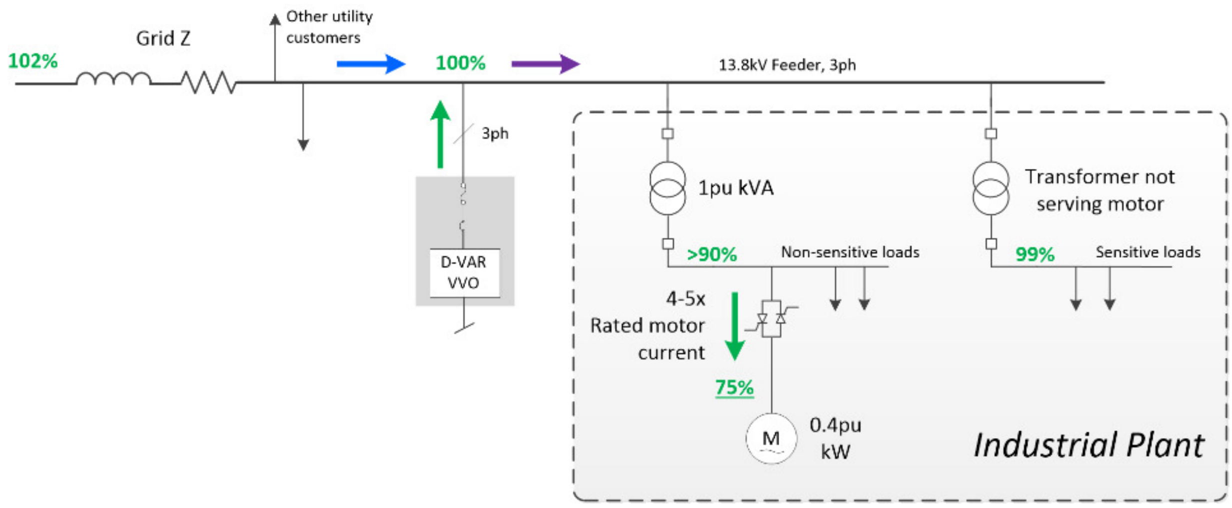


**Figure 17. Representative voltages in a VVO motor starting application.**

## 5.5 Application Circuit Examples

The D-VAR VVO is offered in several configurations to allow engineers to cost-effectively size a solution to the application requirements. The following figures provide circuit single line diagrams of several example configurations.

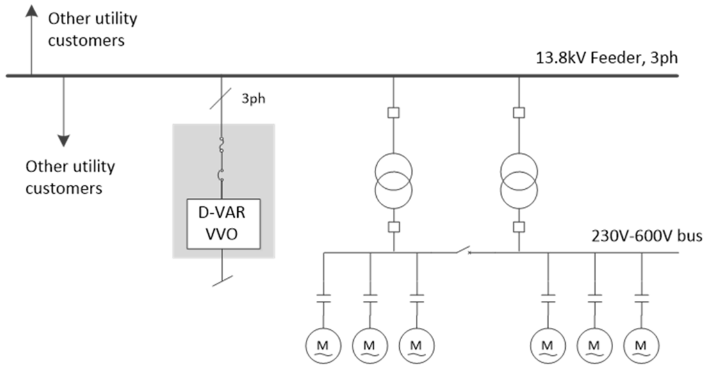


**Figure 18. Application Example: A single D-VAR VVO protecting a feeder from the power quality issues caused by multiple DOL started motors. The D-VAR VVO in this circuit provides up to 1.43 MVAR of dynamic reactive motor starting support including the 130% overload rating of the device.**

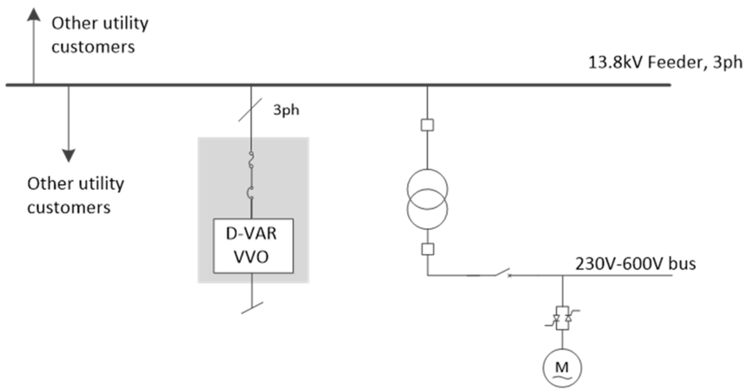


**Figure 19. Application Example: A single D-VAR VVO protecting a feeder from power quality issues caused by a single large motor with a soft starter (e.g. 450 HP motor with soft starter). The D-VAR VVO in this circuit provides up to 1.43 MVAR of dynamic reactive support including the 130% overload rating of the device.**

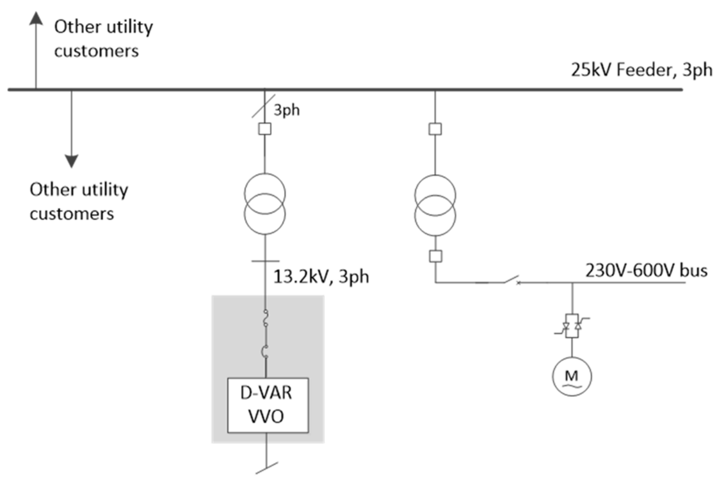


**Figure 20. A D-VAR VVO with a step-up transformer protecting a 25kV class distribution feeder. The D-VAR VVO in this circuit provides up to 1.3 MVAR of dynamic reactive motor starting support including the 130% overload rating of the device.**

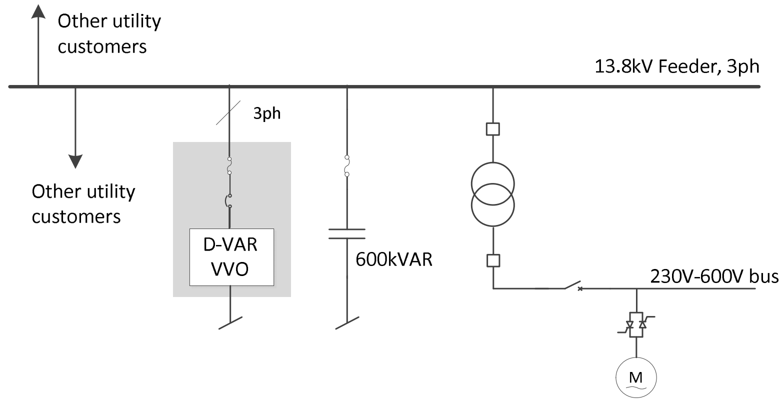


**Figure 21. A D-VAR VVO hybrid configuration. The D-VAR VVO solution provides up to 2 MVAr of dynamic reactive motor starting support including the 130% overload rating of the device and the fixed capacitor. D-VAR VVO control automatically absorbs 600kVAr in order to offset the 600kVAr fixed capacitor bank during normal operation (i.e., when the motor is *not* starting).**

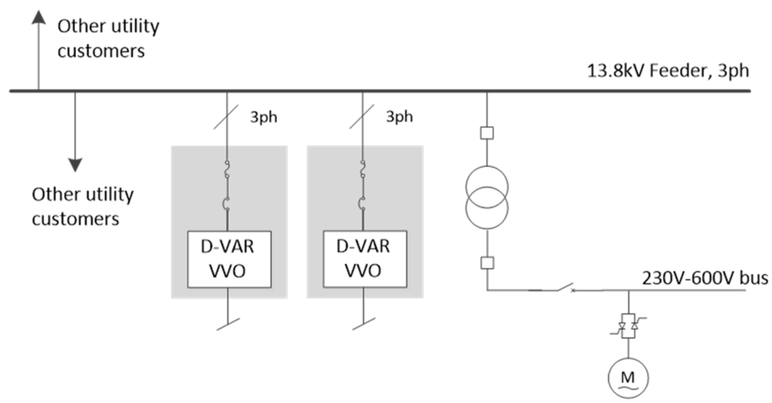


**Figure 22. Application Example: Two D-VAR VVO's connected in parallel to compensate power quality issues caused by a very large (e.g. 1000HP) motor with a soft starter. The D-VAR VVO solution in this circuit provides up to 2.85MVAr of dynamic reactive support including the 130% overload rating of the device.**

# 6 Sizing Guidelines for Motor Start Compensation

## 6.1 Standard VVO Configurations

The VVO operates by providing motor Vars at the VVO interconnection point which has the effect of reducing the apparent size of the motor. VVO-based solutions are powerful enough to provide mitigation up to motor ratings of approximately 1500 HP. Table 3 (motors without soft starters) and Table 4 (motors with soft starters) can be used as a quick reference to determine a suitable VVO mitigation solution based on the concept of apparent motor size.

**Table 3: Apparent Motor Size using VVO solutions – Motors with no Soft Starter. Locked rotor 5-7 kVA/HP.**

| Actual Motor Size [HP] | Apparent Motor Size with Solution [HP] | | | |
|---|---|---|---|---|
| | 1 VVO | 1 VVO 600 kVAR Capacitor | 2 VVO | 2 VVO 2x600 kVAR Capacitor |
| 100 | 0 | 0 | 0 | 0 |
| 200 | 0 | 0 | 0 | 0 |
| 350 | 55 | 0 | 0 | 0 |
| 400 | 105 | 0 | 0 | 0 |
| 500 | 205 | 71 | 0 | 0 |
| 600 | 305 | 171 | 10 | 0 |
| 700 | 405 | 271 | 110 | 0 |
| 800 | 505 | 371 | 210 | 0 |
| 900 | 605 | 471 | 310 | 42 |
| 1000 | 705 | 571 | 410 | 142 |
| 1100 | 805 | 671 | 510 | 242 |
| 1200 | 905 | 771 | 610 | 342 |
| 1300 | 1005 | 871 | 710 | 442 |
| 1400 | 1105 | 971 | 810 | 542 |
| 1500 | 1205 | 1071 | 910 | 642 |

**Table 4: Apparent Motor Size using VVO solutions – Motors with Soft Starter. Locked rotor 5-7 kVA/HP.**

| Actual Motor Size [HP] | Apparent Motor Size with Solution - w. 75% Soft Starter [HP] | | | |
|---|---|---|---|---|
| | 1 VVO | 1 VVO 600 kVAR Capacitor | 2 VVO | 2 VVO 2x600 kVAR Capacitor |
| 100 | 0 | 0 | 0 | 0 |
| 200 | 0 | 0 | 0 | 0 |
| 350 | 0 | 0 | 0 | 0 |
| 400 | 0 | 0 | 0 | 0 |
| 500 | 98 | 0 | 0 | 0 |
| 600 | 198 | 0 | 0 | 0 |
| 700 | 298 | 115 | 0 | 0 |
| 800 | 398 | 215 | 0 | 0 |
| 900 | 498 | 315 | 96 | 0 |
| 1000 | 598 | 415 | 196 | 0 |
| 1100 | 698 | 515 | 296 | 0 |
| 1200 | 798 | 615 | 396 | 0 |
| 1300 | 898 | 715 | 496 | 130 |
| 1400 | 998 | 815 | 596 | 230 |
| 1500 | 1098 | 915 | 696 | 330 |

The configurations in the highlighted green cells can be expected to achieve performance of 4% or less voltage dips on the feeder. In a majority of practical installations, the highlighted configurations can achieve voltage dip performance of 3% change on the feeder. A significant consideration is locked rotor kVA/HP rating of the motor. The tables address the most common locked rotor ratings range of 5-7 kVA/HP. For motors with very high kVA-HP ratings above this range, a detailed study is recommended.

The appendix provides a reference chart for allowable motor starting voltage dip magnitudes that multiple utilities in North America have applied when addressing motor starting PQ issues. For infrequent starting events (e.g., 2x per hour or less), which represent a majority of applications, a performance of up to 4% change in voltage on the *medium voltage feeder* is generally acceptable. While there is no ubiquitous standard specifically for motor starting events, the IEEE-1453 standard for rapid voltage change (RVC) can also be used as a guideline for determining target voltage dip levels.

When minimizing the voltage dip as much as possible is mandatory (e.g., applications with frequent events requiring <3%), additional analysis such as load flow modeling is recommended in order to determine the best solution.

## 6.2 Sizing Guidelines for Load Flow Analysis

Most load flow software packages provide a "Motor Start – Maximum Size" analysis. This analysis determines the largest HP motor that can be interconnected at any given point on the circuit without creating problematic voltage dips. If the proposed motor exceeds the maximum allowable size determined by the load flow software then Table 3 can be used to estimate if a VVO solution can 'shrink' the motor to an acceptable size. This can subsequently be validated using more detailed load flow analysis.

# 7 Control Settings and Siting Considerations

## 7.1 Feeder Var Mode

In most motor starting applications, the Feeder Var control mode is the appropriate mode to effectively mitigate motor start power quality issues. The Feeder Var mode requires medium voltage line post sensors on the *load side* of the STATCOM. In this mode, the STATCOM directly controls the medium voltage load Vars such that the net Vars on the "source" side of the STATCOM are dynamically maintained to zero.

It is recommended to install the STATCOM near the problematic motor load, either on a lateral feeding the load center or at the medium voltage PoI of the motor load center. As a rule of thumb, the STATCOM should be placed within 0.5 feeder-miles of the problematic load. Because Feeder Var mode requires a line sensor, the STATCOM electrical point of interconnect *must be between the feeder substation and the corresponding motor load.*

Some specific advantages of the Feeder Var mode include:

- There are no control-related settings: True plug 'n play operation
- The device does not act on voltage, and therefore there are no operational considerations with the utility voltage regulation system

For applications that require the highest precision and fastest response, feeder Var mode is recommended. With proper solution sizing, the performance of VVO can ***achieve performance of <2% change in voltage on the utility feeder.***

## 7.2 Volt/Var Mode

In some cases, it is most appropriate to address motor starting applications using the Volt/Var control mode. The Volt/Var can be appropriate for applications that have one or more of the following requirements:

- The STATCOM application requires mitigating other issues in addition to motor start events (e.g., mitigating voltage sags due to power system events as well as motor start events)

- The STATCOM cannot be located electrically between the load and feeder substation due to siting constraints
- The problematic voltage dip events are relatively infrequent (e.g., a few times per day), and therefore do not require the maximum possible mitigation performance

It is recommended that the electrical point of interconnection is near the motor load (target within 0.5 feeder-miles of the motor). The following control settings are typically effective defaults for motor start applications that require the Volt/Var mode:

- Target voltage: 100% of nominal circuit voltage *at the VVO insertion point*
- Dead band: +/- 1.5% of nominal
- Droop curve: 2.5% voltage change per full output

In Volt/Var mode, properly sized solutions can achieve performance of ***<4% change in voltage on the utility feeder***. In many cases this performance can adequately addresses the PQ issues. If very high precision response is required or it is essential to reduce the voltage dip as much as possible, Volt/Var mode is not recommended and Feeder Var mode should be used instead.

In either mode, the basic principle of operation is the same as discussed in this application guide and the 130% overload output of the device is available in either mode.

For applications that require three or more D-VAR VVO's connected in parallel at the same site, please consult with AMSC solutions engineering prior to determining the control settings.

# 8 Summary Tips For Deploying Successful Solutions

The purpose of this concluding section is to recap the key points in this application guide. Below is a reference list to help when solving power quality issues due to motor starting events:

***Tips for understanding the motor starting power quality problem:***

- Induction motors inherently consume a large amount of Vars when starting from a line, typically consuming 5-7 per unit of the motor's continuous HP rating:
  - Locked rotor VA is a physical property of the induction machine and is listed as a nameplate rating
- The large step increase in VArs during starting can cause a corresponding large and problematic voltage dip on the medium voltage distribution feeder
- Motor starting PQ issues are a reactive power problem, not a real power problem (typically 85%+ of the starting current is Vars)
- Use AMSC's "largest motor chart" to quickly assess risk of a PQ problem (fault power)
- Reduced voltage starting methods have limited effectiveness to address power quality; in practice, typical Var reductions are in the range of 20-30%

***Tips for applying distribution class STATCOM to motor starting:***

- A medium voltage, shunt-connected STATCOM fully addresses motor starting power quality issues by providing dynamic Vars near the culprit motor(s)
- Distribution class STATCOM power electronics technology allows for flexible and precise location within existing utility feeder right-of-way
- The one-minute overload rating of a STATCOM can be used when specifying motor starting applications

  - Motor starting events are less than 30 seconds
- AMSC's D-VAR VVO distribution STATCOM can be scaled from 1.4 MVar up to 4 MVar at a single point of interconnection to address motors up to 1500HP
- The hybrid configuration (a fixed capacitor between the STATCOM and the motor) is a simple and cost-effective approach for achieving increased dynamic Var ratings without additional power electronics capacity
- AMSC provides proven reference sizing tables, appropriate for most applications.  Use these to select cost-effective STATCOM configuration up to 1500HP motors
- Very large motors up to tens of thousands of horsepower can be addressed with larger, substation class STATCOMs that are available with nameplate ratings of several MVAR
- AMSC provides application engineering expertise to help enable fast and certain deployment of STATCOM solutions

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# D-VAR VVO®

*Enhancing electrical service quality at the:*

- **Right time** – Systems typically in stock or low standard lead times
- **Right size** -  1MVAR to 4MVAR installations are tailored to distribution needs
- **Right location** – Compact, distribution-class apparatus can be installed where it needs to be
- **Right certainty** – High performance shunt device removes project risks

**=**

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

# D-VAR VVO® Applications Support

Contact AMSC applications at:

NetworkPlanning@amsc.com

Product Page with resources:

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

Check the product page for updates to our application resources.

# 9 Appendix

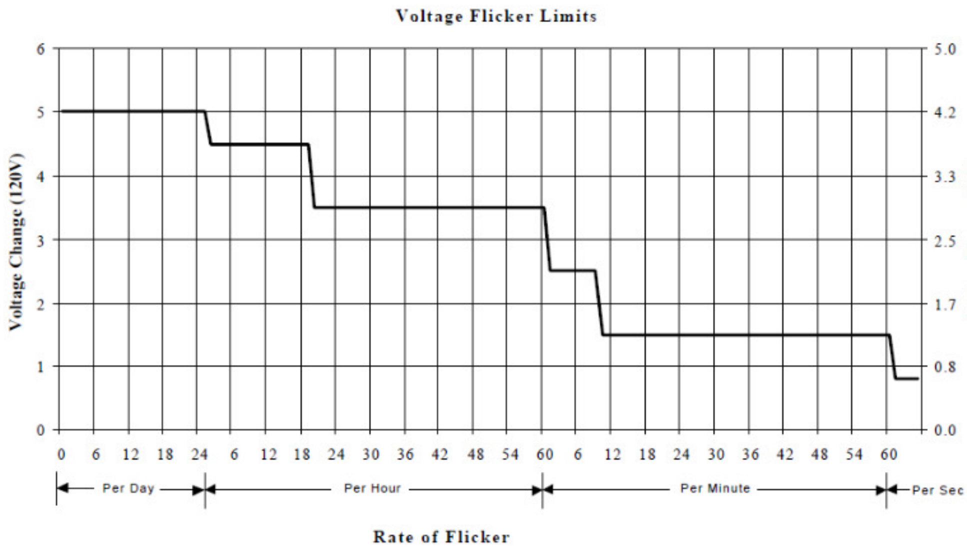


**Figure 23. Representative Utility guideline used for voltage changes caused by motor starting.**

**Revisions**

R01 - Initial Release Sept 2020 (RR, DGO)

R02 – Added section on hybrid Oct 2020 (DGO)

R03 – Added section 8 Jan 2021 (DGO, RR)

R04 – Added chart in section 2.2 April 2021 (DGO)