



## Technical Paper

# Variable Frequency Drive DC Bus Voltage Degradation Due to Application of Passive Harmonic Filters with high insertion loss

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### Summary

The problem of leading power factor and generator compatibility as it relates to the application of passive harmonic filters has been well documented. Many manufacturers claim their passive harmonic filters are generator compatible based on lower capacitance. This design philosophy neglects the impact of insertion loss on the performance of the VFD. An evaluation of the application of passive harmonic filters applied to the input of Variable Frequency Drives (VFD) was performed by TCI engineering. The specific focus of the testing was the effect of passive harmonic filter design on the DC bus voltage of standard six-pulse drives.

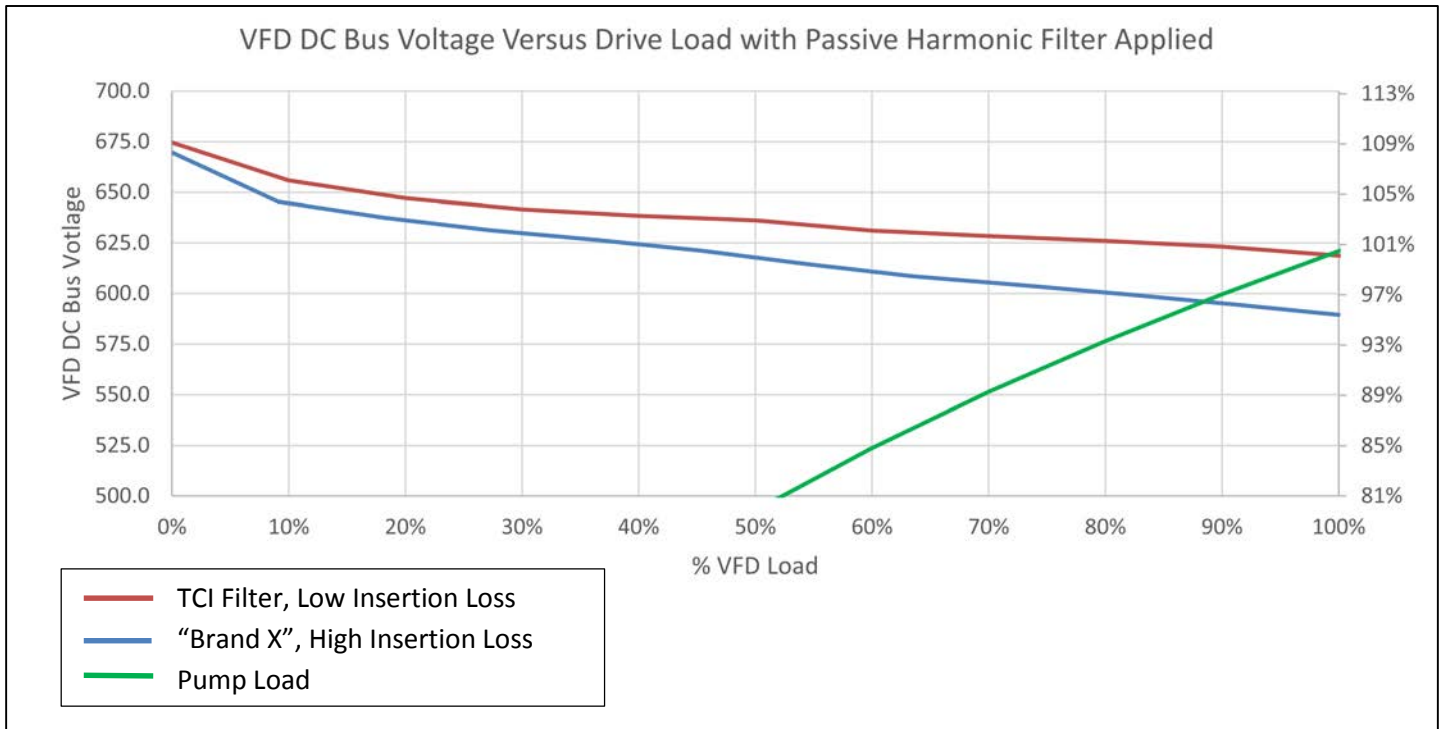
VFD drive voltage is a key factor in system design as the VFD bus voltage level directly relates to whether the drive can achieve rated shaft power out of the motor at full speed. Power lab testing with a motor dyne test setup compared the impact of a generator compatible (with high insertion losses) passive filter on VFD drive bus voltage against the impact of TCI's HarmonicGuard® and HarmonicShield™ filters (with low insertion losses) on VFD drive bus voltage.

Testing showed that applications using a passive filter sold as generator compatible but with high insertion losses resulted in degradation of the VFD drive bus voltage. This is of concern because lower DC bus voltage prevents the VFD from achieving rated power at rated speed. Additionally, lower DC bus voltage can lead to drive output voltage distortion or “flat topping” which lowers motor efficiency. Passive harmonic filters designed for lower insertion loss using lower inductance and higher tuned circuit capacitance, such as TCI's HarmonicGuard® and HarmonicShield™ filters, avoid application issues associated with lower VFD DC bus voltage, See Figures 1 and 2.

### Background

Passive harmonic filters are commonly applied to the input of six pulse rectifier input VFDs as an economical means to meet IEEE-519-2014 source harmonic requirements. Passive harmonic filters primarily consist of a series line reactor and a shunt LC tuned circuit. The shunt circuit is tuned near the 5th harmonic and is connected on the load side of the line reactor. The tuned circuit provides the majority of the harmonic current required by the VFD so that the resulting line current supplied by the source has harmonic current levels that fall below limits set by IEEE-519-2014 specifications.

The primary purpose of the series line reactor in a harmonic filter is to provide broadband filtering of the drive harmonics and to isolate the filter tuned circuit from the upstream source. Without the source decoupling provided by the line reactor, the tuned circuit could attract harmonic currents from source background voltage distortion or other nearby system nonlinear loads in addition to the downstream drive load. This additional harmonic current could potentially overload the tuned circuit.



**Figure 1** – VFD DC Bus Voltage versus Load for “Brand X” and TCI Passive Harmonic Filters Applied to the Input of the VFD

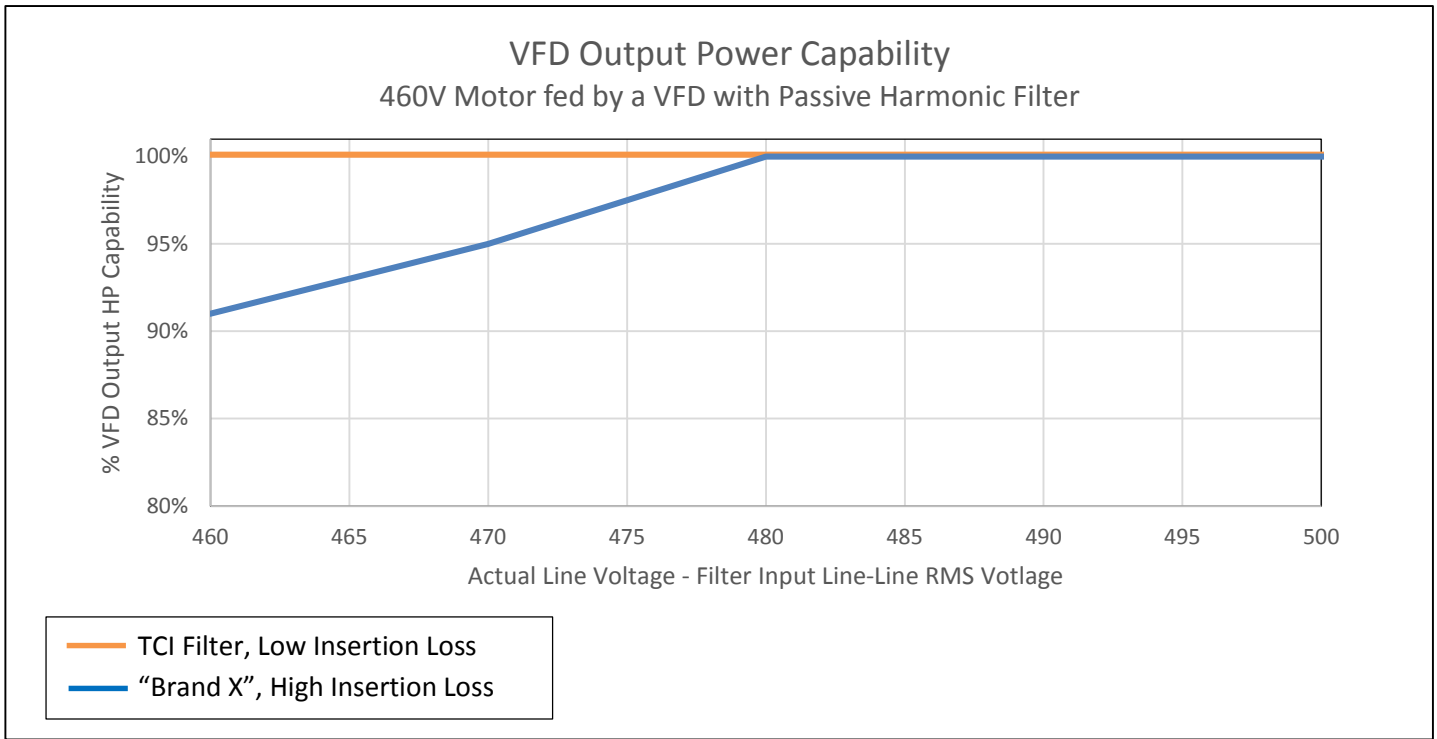
The selection of the series line reactor impedance as well as the tuned circuit inductor and capacitor values is critical to the filter performance, as measured by the input current total harmonic distortion. These design parameters can also impact the input power factor and the voltage drop across the filter.

The voltage drop across the filter is critical for maintaining adequate VFD DC bus voltage and output power capability in all (generator and non-generator) applications. The issue addressed in this paper shows that passive harmonic filters which are not optimized to balance insertion loss, as well as THD and power factor, can cause a loss of horsepower at full load. VFDs with insufficient bus voltage may not be able to provide required voltage to drive current into the motor at rated speed or may be forced to transition to a non-optimal distorted “flat-top” output voltage which results in a loss of motor efficiency.

## Test Setup

A motor dyne test setup was used during the evaluation. The motor dyne consisted of two 100Hp motors with their shafts directly coupled together. One motor acted as the speed reference motor and was set to operate at rated motor speed driven by a regen VFD. The second motor acted as the variable torque motor driven by a standard commercial drive with a six pulse rectifier input. The torque command of this motor was adjusted to load the passive harmonic filter and VFD at various load operating points.

The source impedance of the passive filter and torque VFD load was set to 1.5% impedance at 75Hp. The ABB ACS800 75Hp 480V VFD connected to the load terminals of the passive filter had an internal 3% AC reactor. The 1.5% source impedance and 3% drive load impedance operating point selection was guided by the conditions specified in the application manuals from tested passive filter manufacturers.



**Figure 2** – VFD Output Power Capability as a function of input ac voltage for different passive filters.

The 75Hp passive filter under test was connected at the input of the drive controlling the variable torque motor. AC data was collected using calibrated power quality meters on the input and output of the passive harmonic filter. The VFD DC bus voltage was recorded using a calibrated digital multi-meter directly connected to the drive DC bus power terminals.

## Test Data

Figure 1 shows the VFD DC bus voltage from no load (drive idle) to rated load at full motor speed. To account for minor variations in the source RMS voltage level the plot data is normalized to 460V RMS line to line at the filter input. As can be seen from the plot data the low tuned circuit capacitance passive filter results in approximately 25VDC less bus voltage being available to the drive at full load.

A corresponding pump load curve (proportional to shaft speed squared) is overlaid on the plot. This curve shows that the reduction in VFD DC bus voltage caused by the application of the non-optimized harmonic filter could potentially limit the shaft power of the motor below its full rating or cause the drive to transition to a flat topped, trapezoidal output voltage waveform that would

degrade system efficiency and increase motor heating due to motor voltage distortion. For example, comparing the degraded drive bus voltage curve from the non-optimized passive filter versus the pump load curve, a 75Hp motor would start to see the adverse effects of lower drive bus voltage around 68Hp.

Viewed another way, Figure 2 shows the output power capability of a VFD equipped with a passive harmonic filter as a function of input ac line voltage for a 460V motor. The graph illustrates that with TCI’s HarmonicShield filter, the VFD dc bus voltage is maintained at 460V ac to the motor, which provides 100% of rated horsepower when 460V or greater voltage is supplied to the filter. With filters from other manufacturers a minimum of 480V must be supplied to the filter in order to achieve 100% motor voltage and output power. At 460V input voltage, the motor voltage must be reduced due to lower dc bus voltage. The output power is limited to approximated 91% of rated horsepower.

The application of the TCI HarmonicShield passive filter avoids these application issues by having a lower line impedance and sufficient tuned circuit capacitance to maintain the VFD input voltage at a nominal 480V.

## Conclusion

Power lab testing with actual motor loads shows that application of harmonic filters with insufficient tuned circuit capacitance and higher line impedance can result in insufficient DC bus voltage being available at the drive. Under full load conditions at rated speed, the lack of available DC bus voltage can limit the maximum shaft power that can be achieved from the motor or require the drive to transition into a non-sinusoidal output which degrades system efficiency.

Passive harmonic filters manufacturers that claim their filters are 'generator compatible' based on lower capacitance alone ignore the impact the necessary increase in inductance has on the DC bus voltage. Optimum passive harmonic filter design considers all aspects of filter performance; THD, power factor, and insertion loss. Only TCI's HarmonicGuard® series and new HarmonicShield™ filters are designed to ensure that you get total performance.

For more information on generator compatibility, see TCI's technical paper "Generator Compatibility of Passive Filters" (<http://www.transcoil.com/Public/Documents/TechnicalPapers/Generator-Compatibility-Passive-Filters.pdf>)



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