

Applications of Line and Load Reactors with Variable Frequency Drives

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Reactors can protect motors, variable frequency drives (VFDs) and other sensitive electrical equipment and increase their reliability and life span by absorbing the disturbances from the power line, preventing overvoltage trips, improving total power factor, and reducing nuisance tripping. Reactors can also help reduce the harmonics distortion of the power line by adding impedance to the utility grid.

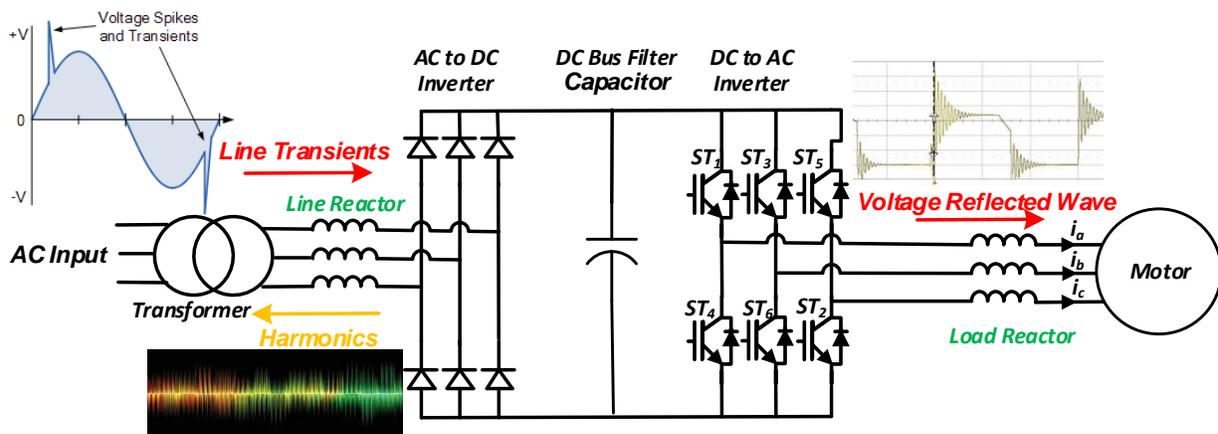


Figure 1: VFD and Motor System with Line and Load Reactors

I. What are Reactors?

Reactors are electro-magnetic devices, sometimes referred to as inductors, that are wired in series between electrical equipment in power systems. A reactor consists of a steel core which is constructed of electrical grade steel laminations and copper wound coils that form a magnetic field as current flows through it. This magnetic field limits the rate of change of the current, thus reducing harmonics and protecting the drive from power system surges and transients.

A reactor can be referred to as either a line reactor or a load reactor, depending on where it's installed. As shown in Figure 1, when a reactor is placed between the power system and the VFD, it is referred to as a line reactor. Line reactors can protect the entire VFD from power system surges

and transients. They also mitigate harmonic currents being drawn by the VFD. When a reactor is connected in series between the VFD and motors, it is referred to as a load reactor, which helps protect motors like an energy buffer.

II. Benefits of Line Reactors

Line reactors help protect VFDs from utility power line disturbances that may cause unexpected tripping or damage to the VFDs. They also help reduce the harmonics that the VFD generates back into the utility grid.

Line reactors should be used in the following circumstances:

1. Where the input voltage from the power line may contain disturbances such as surges, spikes, transients, etc.

- Where harmonic distortion is a concern. Refer to IEEE-519 [1] Harmonic Control in Power Systems.
- Where the supply line power capacity is much higher (10 times greater kVA rating) than the connected VFD system.

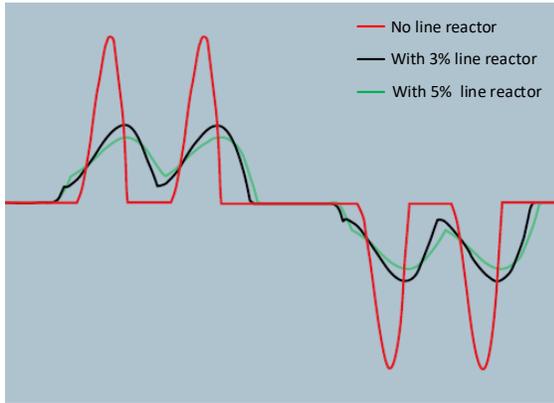


Figure 2. Line Current with and without Line Reactor

Minimizing Nuisance Overvoltage Trips Due to Line Transients

Utilities use capacitor banks in their distribution and transmission circuits primarily for voltage support and power factor correction. Energizing a capacitor bank creates a momentary short circuit during which energy is absorbed from the line to charge the capacitor. This is manifested in the voltage waveform as a sudden drop in voltage with a subsequent ringing effect, the magnitude and frequency of which depend on the system

parameters. The typical overvoltage magnitude is between 1.2-1.6 p.u. with a ringing frequency of 400-600 Hz. During the transient overvoltage event, the DC bus capacitor in the VFD attempts charging to the peak of the incoming transient line voltage, resulting in the VFD tripping off-line – showing an overvoltage fault code or in some cases even damaging the input diode front-end.

Line reactors provide two main functions that help minimize the effect of capacitor switching transients on VFDs [2]: First, the line reactor impedance provides a voltage drop that reduces the DC bus voltage, thereby providing a greater margin for overvoltage trip. Further, reactors limit the magnitude and the rate of the surge current charging the capacitor. The performance of surge current limitation of a typical line reactor is shown in Figure 2. For most cases, 3% impedance line reactors based on the drive kVA rating should be adequate to reduce power line transient voltages.

Reducing Input Line Current Harmonics from VFDs

While VFDs provide great advantages in energy savings and increased efficiency, they are the #1 cause of electrical power system pollution. The input current waveform of VFDs with diode bridge rectifier is characterized by a two-pulse

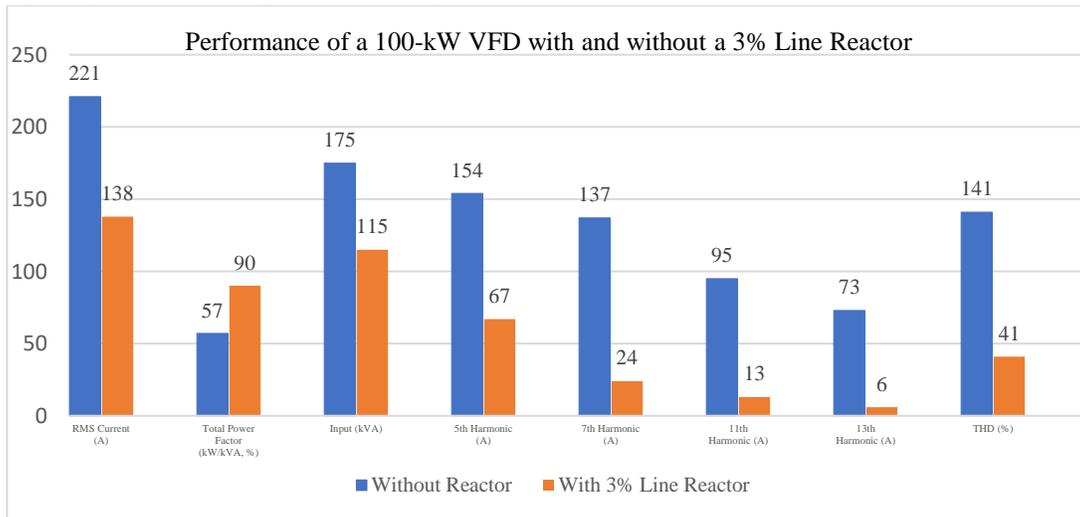


Figure 3. Performance of a 100-kW VFD without and with a 3% Reactor

current waveshape in each half cycle. Each pulse is related to the charging of the DC bus capacitor to the peak incoming voltage. The result is a non-sinusoidal current flow with a total harmonic distortion (THD) of typically 90-150% with a harmonic content that is predominantly 5th, 7th, 11th, and 13th harmonics as shown in Figure 3. The application of a line reactor causes the discontinuous current to become continuous. The main reason is that with line reactors, the voltage at the VFD terminals becomes flat-topped, and the charging time for the DC bus capacitor increases, thereby increasing the current pulse width while decreasing its peak amplitude. The use of 5% impedance line reactors can eliminate about 65% of the current THD, which will help to comply with the IEEE 519 Standard and reduce motor operating temperature and noise.

Improving VFD Power Factor and Reducing Line Losses

VFDs typically have a poor power factor (0.6-0.65). However, this does not mean that VFDs have a high reactive power demand. VFDs do not have any reactive power demand as the reactive power is supplied from the DC bus capacitor. The high kVA demand from VFDs, which related to poor factor is due to the harmonic content in the current waveshape. Reducing the harmonics either by a reactor or by an appropriate harmonic filter leads to an improvement of the power factor. As explained in the previous section, use of line reactors reduces the harmonic currents, which causes a reduction of total rms current and the kVA demand of the drive. Since the line reactor does not change the fundamental component of the current, the kW input required remains the same, dictated by load requirements. This means that the ratio of kW/kVA defined as “power factor” will be improved.

Minimizing Line-Side Overload Protector Trips During Unsymmetrical Voltage Sags

A large majority of faults in utility power systems are single line-to-ground faults. During such faults, the voltage at the drive terminals is highly unbalanced. This momentary unbalance in the

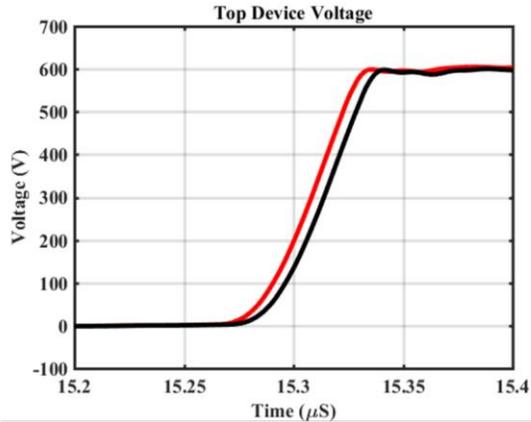
supply voltage causes high current on one of the phases on the line side of the VFD. For VFDs that are connected close to a transformer allowing a high available short-circuit current, the peak current may reach 200% to 250% of the rated line current, causing trip of the line-side overload protector (fuse, circuit breaker, etc.) during the sag. Application of line reactors reduces the available fault current at the drive terminals and minimizes the chance of overload protector operation during un-symmetrical voltage sags.

III. Benefits of Load Reactors

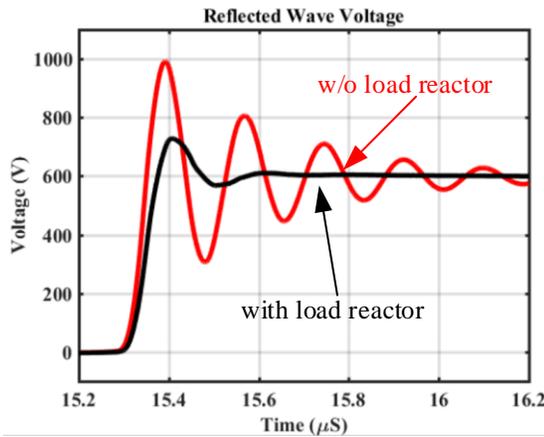
Load reactors (also called an output reactors) are installed after the VFD to protect the motor. They can increase load inductance and reduce the effect of reflected waves. If a load reactor is used at the output, it should be located as close to the VFD as possible.

Reducing the Effect of Reflected Wave

Load reactors are used to protect the motor when long wires between the VFD and motor are required. The VFD generates a high frequency (such as 16 kHz) PWM output by turning on and off the switching components like MOSFETs and IGBTs. The output voltage rise time is short, and usually less than a few microseconds. These short rise times combined with long wires between the drive and motor can produce voltage reflections, also called reflected waves [3], that have high peak voltages as shown in Figure 4. The resulting voltage can exceed the motor’s peak voltage rating where insulation breakdown occurs. Generally, a load reactor should be used if the motor wiring extends over 100 ft., but this value can vary depending on the motor. If a motor meets the NEMA MG-1 Part 31 standard [4], it is possible to have as much as 300 ft of cabling without a load reactor. If it does not meet the standard, the maximum cable length should be 100 ft. For any motor, if the distance is between 300 to 500 ft., a load reactor should be used. If the distance is over 500 ft. then a special type of filter called a dV/dt filter (low-pass filter) should be used.



(a)



(b)

Figure 4 Switching Waveforms and Motor Load Voltage with and without Load Reactor

Increasing Load Inductance

Applying a reactor at the output of a drive is sometimes necessary. If the motor has a “low leakage inductance” a reactor can help bring the total load inductance back up to a level that the drive can handle. In the days of the “Bipolar transistor” drive, carrier frequencies rarely exceeded 1.5Khz. This meant that the transistor’s “on time” was much longer. This allowed current to ramp up higher, limited by the load or motor inductance. The result of a low inductance motor was huge ripple current that sometimes ran into the current limit of the drive causing poor performance or tripping. For the most part, the higher carrier frequencies and correspondingly lower ripple current of today’s IGBT (Isolated Gate Bipolar Transistor) drives have eliminated the need to add inductance to the load.

IV. Reactors Percent Impedance: 3% or 5%

Line and load reactors are classified by their percent impedance (denoted as percent IZ or %IZ), which is the voltage drop due to impedance, at the rated current, expressed as a percent of rated voltage. The most common line reactors have either 3% or 5% impedance. Reactors with 3% impedance are enough for most solid-state applications in North America. They absorb normal line spikes and motor current surges and can prevent most nuisance line tripping of circuit protection devices. When higher line disturbances are present, 5% impedance reactors may be needed. If an application is installed in a location outside North America, or if IEEE 519 compliance is required, a higher impedance reactor is generally recommended. If the aim is to diminish noise from the motor or to extend motor life, higher impedance reactors can be used to reduce harmonics even further. This additional performance typically comes at a higher cost than 3% impedance versions. When multiple motors are controlled by a single drive, a single load reactor can be placed between the VFD and the motors, simplifying the system layout and reducing cost.

Though using line and load reactors can protect the VFD systems, and increase the reliability and robustness, users should be aware of some side-effects such as adding cost and weight, requiring space, generating heat and reducing efficiency.

References

- [1] IEEE 519-2014 - IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems
- [2] When reliability counts: Reactors and filters for all industries and applications, Siemens
- [3] Analysis of Reflected Wave Phenomenon on Wide Bandgap Device Switching Performance, A. Sathyanarayanan, 2017
- [4] NEMA Standard Publication MG 1-2016 Motors and Generators, National Electrical Manufacturers Association