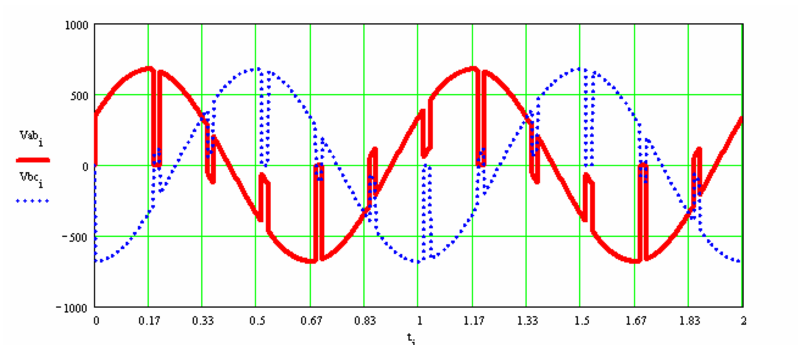
Application Note
CTAN #144

Application of Line Reactors and Isolation Transformers for AC and DC Drives

The installation of either line reactors or an isolation transformer between an AC power source and a drive provides several advantages that improve the reliability of a drive system.

SCR based converter/rectifiers:

For SCR based DC drives, and AC drives with SCR based front-end converters, a certain range of impedance in the AC power source is important. One of the effects that takes place in these drives is the commutation (or transfer) of current in SCRs, one to the next. In this process, temporarily (for a period of usually between 10μsec to 100's of μsec) two SCRs are in an "on" state at the same time, which effectively connects, or "shorts" two of the AC lines together. This event continues as long as it takes for the current, that had been flowing from a line through one SCR, to diminish to zero while another SCR, that has just been gated on, accepts all of that current.



The typical line to line voltage oscillograph measured at the power input of an SCR based converter showing the commutation notches.

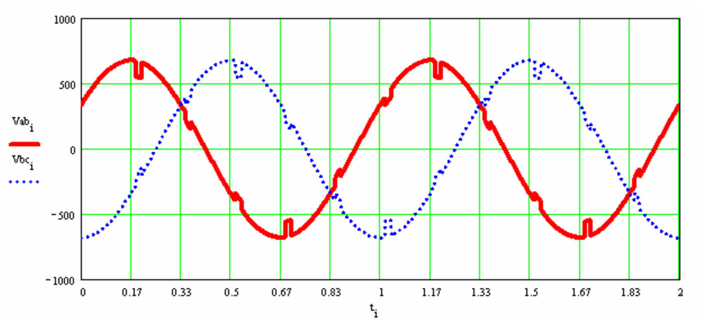
These effective line to line shorts produce rectangular shaped voltage pulses on the lines known as commutation notches. If the line impedance is very low, then the commutation notches will be very short in duration, which means that the rate of change of current (dI/dt) in the SCRs must be very high. In such a situation, inside an SCR, not all of the semiconductor material may have a chance to become conducting before the current becomes too high. This causes a "hot spot" that can degrade and finally cause the device to fail. Because of this, a level of impedance is crucial. A reasonable minimum level that this impedance should be is about ½%. I.e.: if the drive is at full current, then the voltage drop across the line inductance would be ½% of the line to neutral voltage. The inductance needed to cause that level of impedance would be:

$$\mathbf{L = \%Z \bullet V_{LL}^{2} / 100 \bullet P \bullet 2 \bullet \pi \bullet f_{line}} \text{ Henry}$$

where V_{LL} *is the line to line input voltage,* P *is the load power (watts),* f_{line} *would typically be 60Hz, and* **%Z** *would be ½ for ½% impedance.*

While having too little inductance can lead to deterioration and eventual failure of SCRs, if the line impedance is too high, then the commutation notches will become very wide causing considerable distortion of the sine wave. Such distortion can disrupt the operation of other equipment (connected at the same location) as well as interfering with the line synchronization of the drive initiating the distortion. When the synchronization becomes incorrect the drive can become unstable causing erratic high peaks of current which leads to even more distortion. A reasonable upper level for line impedance is about: %Z = 7%.

It should be noted that regardless of the total source impedance the amplitude of the commutation notches will always be same as is depicted in the graph above at a drive's input terminals. However, when line inductors are added between a drive and the line, and the line source impedance is relatively low as compared to the inductors, then on the line side of the inductors the size of the notches will be greatly reduced. This greatly decreases the possible interference that other equipment might experience if the inductors were not provided. The graph below shows the typical improvement that might be expected with the addition of line reactors.



The typical oscillograph of line to line voltages on the line side of reactors connected to a drive, showing considerably reduced notch depth.

Beyond controlling the characteristics of the commutation notches, line impedance helps to protect a drive from incoming line disturbances. Most drives have both MOVs between the input line connections and R-C "snubbers" across each SCR. The MOVs are usually chosen to begin conducting between about 900 and 1200V (for a drive operating on 480Vac). In the event of a line voltage transient, the inductive impedance ahead of the drive limits the surge current though MOVs. The greater the impedance, the larger the transient can be without exceeding a MOV's energy absorption capacity.

The RCs are in the circuitry to try to restrict the rate of change of voltage across SCRs. Unfortunately SCRs can be gated on erroneously by very fast voltage transients from the power system. In combination with any inductive impedance ahead of the drive's power input, the RCs form a low pass filter that limits the rate of change of voltage (dV/dt), thereby preventing false gating. Once again the higher the impedance, the greater the filtering.

AC drives with diode rectifiers:

AC drives with diode rectifier front-end converters are not susceptible to the false gating and commutation problems as described above, however the existence of sufficient line impedance ahead of a drive is still important. Rectifier diodes are susceptible to failure due to over-voltage surges and high frequency disturbances, which can be limited or attenuated by line impedance. Unlike phase controlled converters that can limit their output current, a diode rectifier that is connected to a capacitor bank can experience very high currents in the event of a line surge in voltage. Larger drives usually have DC bus inductors that help limit surge currents, however for all such drives the presence of a reasonable level of the line impedance increases the level of line surge they can stand before damage will occur.

Line inductors cause AC current sharing in a common DC bus system:

AC drive systems are often designed with their cap banks connected to a common DC bus so that some of the drives in the system can regenerate. In such a system, where it is desirable to feed all the drives from a common AC supply, the application of line inductors (3% for example) can be used to cause the AC current going into each drive to be shared amongst all the drives in proportion to the size of each drive. To do this the value of the inductances must be strategically chosen so that they are all inversely proportional to power rating of each drive – or so that the percent impedance relative to the size of each drive is the same. The equation for inductance given above can be used to find the values.

Isolation transformer provide greater benefits:

Isolation transformers offer more protection for a drive. Being isolated, primary to secondary, they inherently exclude high transient voltages with respect to earth from being impressed on a drive. Also typical isolation transformers are built with laminated iron cores that have fairly low eddy current, and hysteresis losses at 50 or 60Hz. However those losses become much more significant at higher frequencies. From the standpoint of drive protection, the fact that the transformers provide poor transfer of power (because of the losses) at high frequencies, is fortunate; voltage transients and high frequency disturbances or harmonics cannot pass without considerable attenuation, in either direction through a transformer.

Another advantage of an isolation transformer is that in the event of a high voltage surge being applied to the primary, the iron core will saturate. Because this occurs, its primary impedance becomes very low, limiting the voltage the transient can attain. More importantly, once the iron is saturated, the magnetic flux cannot grow in magnitude, hence the secondary output voltage is limited. There is some coupling, primary to secondary, outside of the iron core, but this coupling is poor. The fact that the decreased primary impedance has lessened (or clamped) the transient, means that the transient seen at the secondary will be limited.

Conclusion and design recommendations:

Ever since electronic drives have come into being, a large number have probably been connected directly to high capacity plant power distribution systems and have functioned properly for years. In many of those cases the power system may be very well controlled, having sufficient stray impedance in the wiring or have heavy loading of the characteristics that inherently prevent high voltage and high frequency disturbances. Nevertheless, from a general reliability standpoint the probability of failure is reduced when drives are fed power through an isolation transformer or to a lesser degree, line reactors.

For multidrive systems, and even those with a large number of drives, a single isolation transformer may feed the entire system. However we recommend, for the design of such systems, no more than five drives of similar size be fed by a single isolation transformer without individual line reactors being added ahead of each drive. Generally 3% reactors are sufficient for this purpose.

To obtain additional information and help selecting an Isolation Transformer or Line Reactor, simply click on the Transformer or Line Reactor links below.

ISOLATION TRANSFORMERS

Line Reactors

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