LIEBERT® EXM™ UPS APPARENT OCCURRENCE OF HIGH THDI

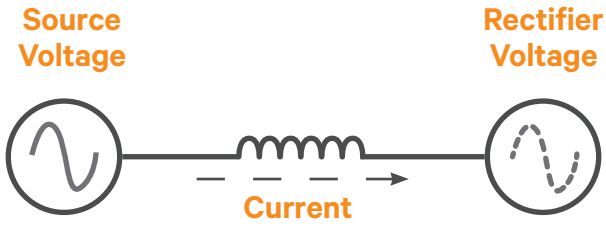
Discussion on EXM UPS THDi

The Issue - High THDi on EXM UPS

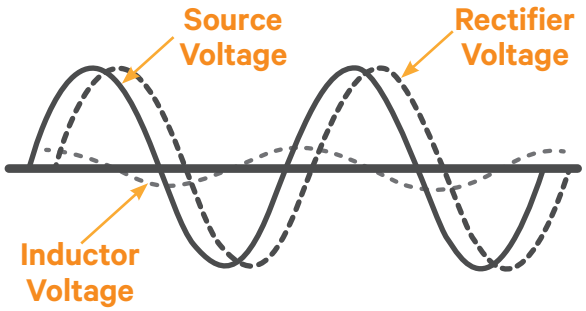
The Liebert® EXM™ UPS is specified to have an input current total harmonic distortion (THDi) of less than 5%. During initial production of the power modules, each rectifier module is tested with a controlled voltage power source to verify this specification. However, during final factory system testing, the THDi can be measured at greater than 5%. The purpose of this paper is to provide an explanation of why this can occur.

Background – Basic Rectifier Operation

First, a basic understanding of a typical active rectifier operation is useful. Although the details of any particular active rectifier control technique can be complex, a convenient way to think of its behavior is by considering the simplified electrical circuit below. This circuit consists of an inductor and two sine-wave voltage sources. One source represents the utility feed voltage and the other represents the voltage generated by the action of the PWM rectifier converter. An impedance is connected between the two sources. This is the input inductor of the rectifier.

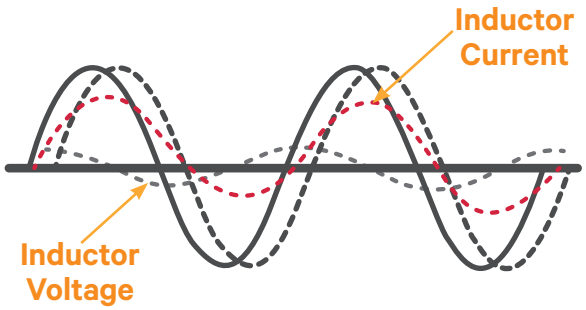


If the two voltages are equal amplitude and are in phase, then there is no voltage difference seen across the inductor and the current through the inductor is zero. If the rectifier creates a voltage which is slightly out of phase with the source voltage, then there will be a voltage developed across the inductor. At any point in the cycle, the voltage will be equal to the difference between the two sources. This results in a sine wave voltage which leads the source voltage by approximately 90 degrees.



The voltage across the inductor, and thus the current flow through the inductor, will be proportional to the phase angle difference between the two voltages. It can be seen then, that the rectifier can control the current through the inductor by adjusting the phase difference between its voltage and the source voltage.

Finally, note that since the current through an inductor lags the voltage by 90 degrees, the current is very close to being in phase with the input source voltage. This results in near unity power factor operation.



Next, let's determine how much inductor voltage is necessary to cause full load current to flow into the rectifier. Let's assume that full load current is 250 amps which would be approximately 200 KVA for a 480 volt system. Let's also assume the inductor is 50 uH which is equal to approximately .02 Ohms impedance at 60 Hz. So, it would take about 5 volts to cause 250 amps to flow (5 volts / .02 ohms = 250 amps). Note again that only a small phase difference between the source and rectifier voltage is necessary to create 5 volts difference across the inductor. Mathematically, the voltage is proportional to the sine of the phase difference angle times the input source voltage and is about 1 degree in this simplified example. This yields a very good input power factor.

Voltage Distortion - Effect on Rectifier Operation

Of course, the above simplified discussion assumes that the input source and the rectifier voltages are pure sine-waves. So what happens if this is not true? How does voltage distortion on the source or the rectifier voltage affect the input current to the rectifier?

First, let's consider the rectifier voltage. Being created by pulses of DC voltage (PWM), the voltage distortion is naturally high. However, since this is at a relatively high frequency, the effective impedance of the rectifier input inductor is large and only a small current flows through the inductor at the distortion frequencies. In addition, there is a high frequency trap filter located at the rectifier input. The net effect is that less than 5% distortion current flows from the source into the rectifier.

Now, let's consider a distorted source voltage. As an example let's assume 1% distortion at the 5th harmonic frequency (300 Hz). Since 1% of the phase to neutral voltage would be about 2.8 volts, this means that the amplitude of the distortion is more than half as much as the voltage created across the inductor to get 250 amps of 60 Hz fundamental current. However, since the frequency is 300 Hz, the impedance of the inductor is 5 times higher, so only about 28 amps flows (2.8 volts / .1 ohms = 28 amps). Still, this means that the input 5th harmonic current that flows in this example is 11% of the fundamental current.

This explains why when testing the EXM on voltage sources which contain lower order harmonic frequencies (5th, 7th, etc) there may be high input current THD. This will occur where the voltage source has non-linear loads operating on the same source. Non-linear loads typically create these low order harmonics. These include large phase controlled rectifiers which are common at the Liebert® test facility.

The EXM™ rectifier control contains some harmonic reduction for low order harmonics. This is in the form of a feed-forward signal of the source voltage into the reference voltage for the fundamental (60 Hz) input current control. Effectively, a portion of any source harmonic voltage is created in the rectifier voltage which tends to "cancel" the harmonic voltage difference seen across the input inductor. However, this harmonic compensation has limited effectiveness when the source harmonic content is much greater than 1%.

Reflective Harmonics – The True THDi Specification

Finally, it should be realized that what is primarily important in a rectifier system is the amount of reflective harmonics created by the rectifier. In other words, what harmonic currents are generated by the rectifier that could "reflect" a voltage distortion onto the source voltage due to the impedance of the source? In the discussion above, the low order harmonic currents are not reflective current harmonics generated by the rectifier causing source voltage harmonics, but are rather just the opposite. They are voltage harmonics generated by the source which create harmonic currents in the rectifier. The true measure of rectifier THDi performance is the reflective harmonics. These are less than 5% for the EXM UPS.

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