Inductance Pulse Testing of Three Phase Inductors

by Mauricio Esguerra and Hubert Kreis

Three phase line inductors (also called reactors or chokes) help limit and control the load current as well as suppress current spikes and are widely used to protect variable-frequency drives and motors. They also mitigate the interference between multiple drives located next each other and reduce voltage notching. These inductors are normally built by winding three-legged laminated cores with constant cross-sectional area. The main parameter is the AC impedance at the rated current which is calculated from the inductance L as follows:

$$X_L = 2\pi f L \ ; \ f = 50 \ or \ 60 \ Hz \tag{1}$$

Conventional Inductance Test

The inductance of each leg of the reactor is measured by connecting the inductor to a variable high current 3-phase sinusoidal 50 or 60 Hz supply. The current *I* for all three coils is adjusted individually to be within the rated rms current range. The rms voltage across each coil can then be read. The amplitude inductance of each phase *k* is given by:

$$L_k = \frac{U_k}{2\pi f \cdot I_k}\ ;\ f = 50\ or\ 60\ Hz \tag{2}$$

The test setup requires three voltage and three current meters and is normally used only to test the inductance at a single current value. The difference between outer and middle coils (about 4 to 9%) is mostly neglected.

di/dt or Pulse Inductance Test

This test method is widely spread for the testing of single phase power chokes at high currents. It uses a rectangular voltage pulse applied to the component being tested. A current ramp is then created in the test component and its di/dt slew rate used to calculate a ***complete*** differential **i**nductance curve up to saturation, as follows:

$$L(I) = [U(I) - R_L \cdot I] \cdot \frac{dt}{di} \tag{3}$$

The compact and highly precise test instrument DPG10 by **ed-k**, allowing currents up to 1500 A is available in the market since 2005 and has been widely adopted as the industry standard for applications such as solar and UPS inverters; commutation, PFC, storage and line chokes for SMPS; rotor/stator inductance; etc. Thanks to its high current capability this testing method has complemented and even replaced conventional LCR sinus wave bridge methods in these applications.

Due to the big advantages of this testing device it has been often requested by both manufacturers and users to implement this method for three phase testing. It is in fact possible to use the single-phase device for 3-phase inductor testing if a number of points are taken in consideration:

1. Use the already implemented amplitude inductance function of the instrument
2. Connect the inductor coils in a skilful manner in order to obtain a magnetic flux distribution within the inductor as close as possible to the three-phase excitation used in the conventional inductance test
3. Calculate the equivalent inductance for the outer *and* middle coils

4. Correct the current axis for the equivalent rms current of the conventional inductance test
5. Correct for the frequency effects coming from the excitation with a rectangular pulse to show the equivalent value for 50 or 60 Hz sinusoidal excitation

Implementation and Results

In order to allow for automatic and reliable operation, **ed-k** has developed a three phase extension unit and corresponding software to consider the effects mentioned above. It yields an excellent correlation to conventional testing of inductors of different sizes and power ratings (s. Fig. 1-3: phase line reactors for motor drives with rated power 1.5, 3.0 and 15 kW). Notice that a test lasting only a few seconds yields also here a complete inductance vs. current characteristic. The same test using the conventional method mentioned above (usually with manual current adjustment) would take a substantially larger amount of time.

The basis of the software used to determine the equivalent inductance is based on a careful analysis of different factors:

- Analytical three phase magnetic circuit calculations
- Finite element magnetic field simulations (s. Fig. 4)
- Core material characteristics: permeability vs. flux density and permeability vs. frequency
- Magnetic response to a rectangular pulse
- Air gap effect on the magnetic circuit

It is important to note that both the material and air gap of the device under test are unknown. The corresponding information needed by the calculation algorithm is derived directly from the tested inductance vs. current curves.

As shown in Fig. 5, the test system is capable of testing at high maximum rms current values in dependence of the inductance value of the device under test. Virtually any inductor can be tested with enough margins to the inductance vs. current limit including even very large units up to a rated current of 1 kA.

The pulse testing method has another key advantage with respect to current waveform distortion due to magnetic saturation. As shown in Figs. 1 – 3 the inductance tested with the conventional method at high currents tend to be higher. This is a systematic error coming from a distorted current waveform with a high crest factor (Fig. 6): its equivalent sinusoidal (rms) waveform has a lower current value and according to eq. (2) yields an apparently higher inductance. There are no testing artifacts at any current value for the pulse test method due to a non-sinusoidal current signal. For this reason the inductance tested with this method at overload currents is as accurate a value as at rated current.

Conclusion

The new 3-phase testing system based on the proven DPG10 technology can not only rationalize factory qualification inductance testing. By virtue of the complete inductance curves it is also an efficient and highly precise engineering tool to both develop and select optimized components for various applications. This is especially the case if the inductance at overload currents, have to be considered.

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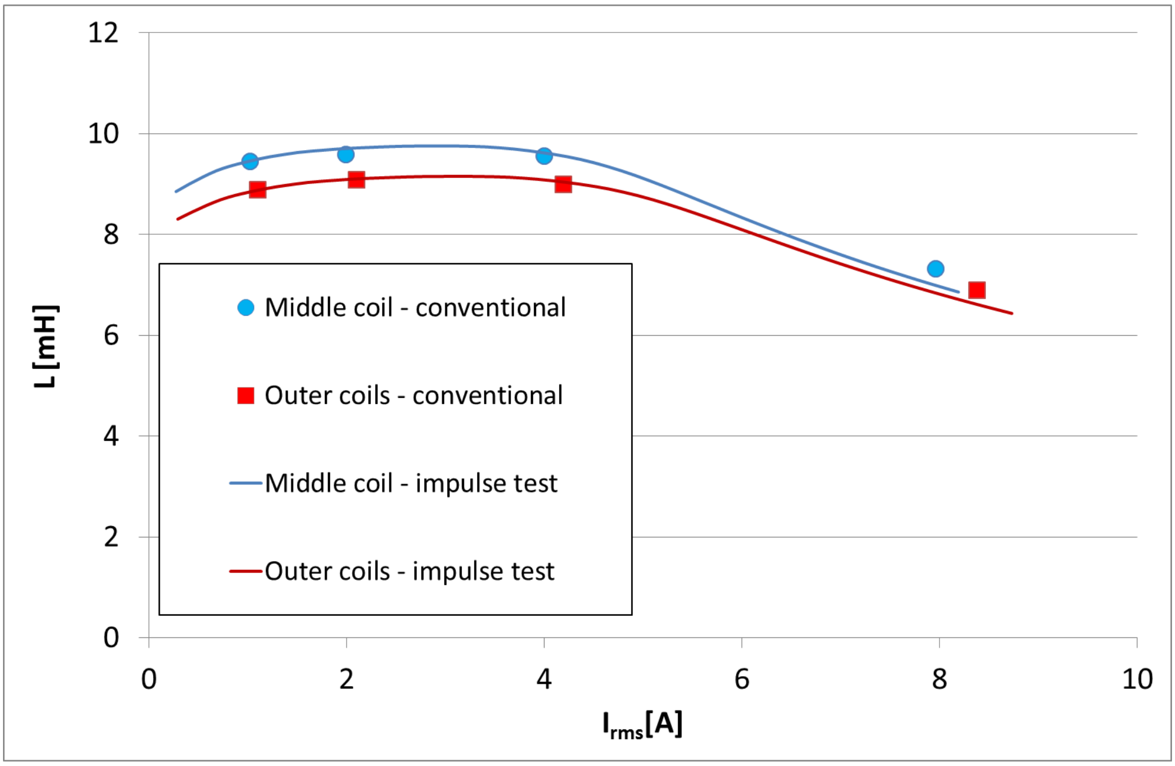

Fig. 1: Inductance of a 1.5 kW phase line reactor (I_{rated}=4 A)

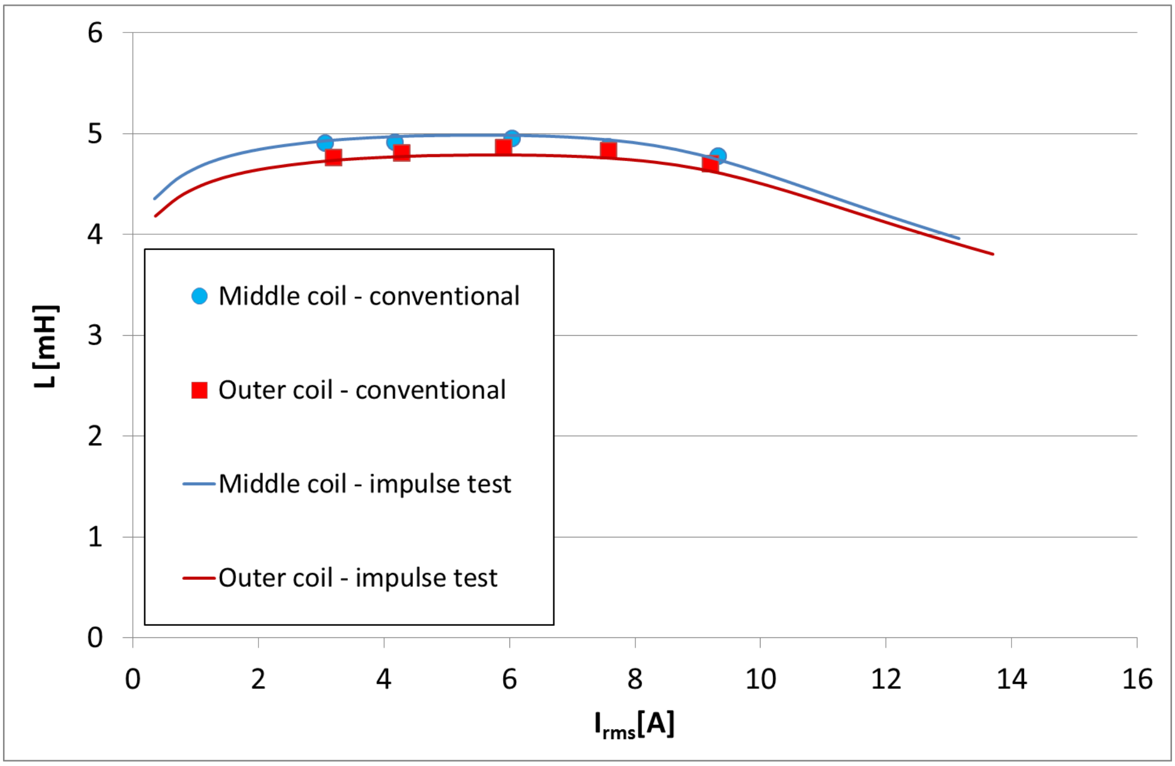

Fig. 2: Inductance of a 3 kW phase line reactor (I_{rated}=7 A)

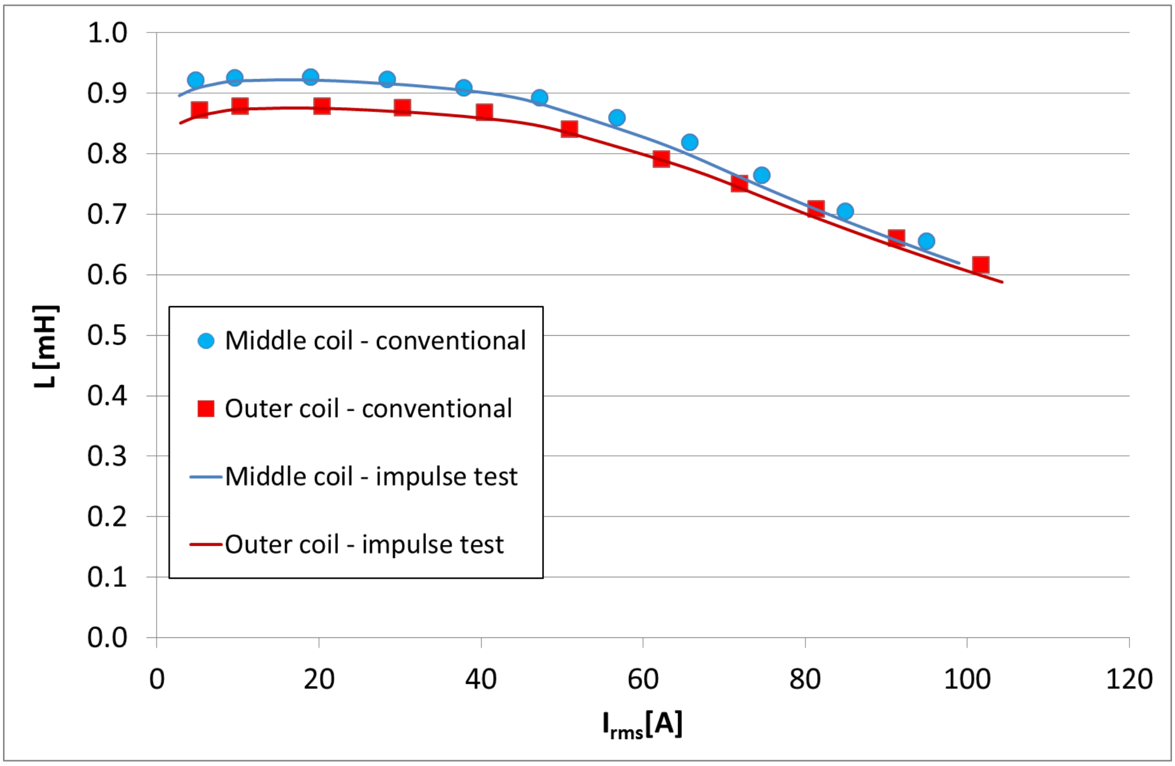

Fig. 3: Inductance of a 15 kW phase line reactor (I_{rated}=24 A)

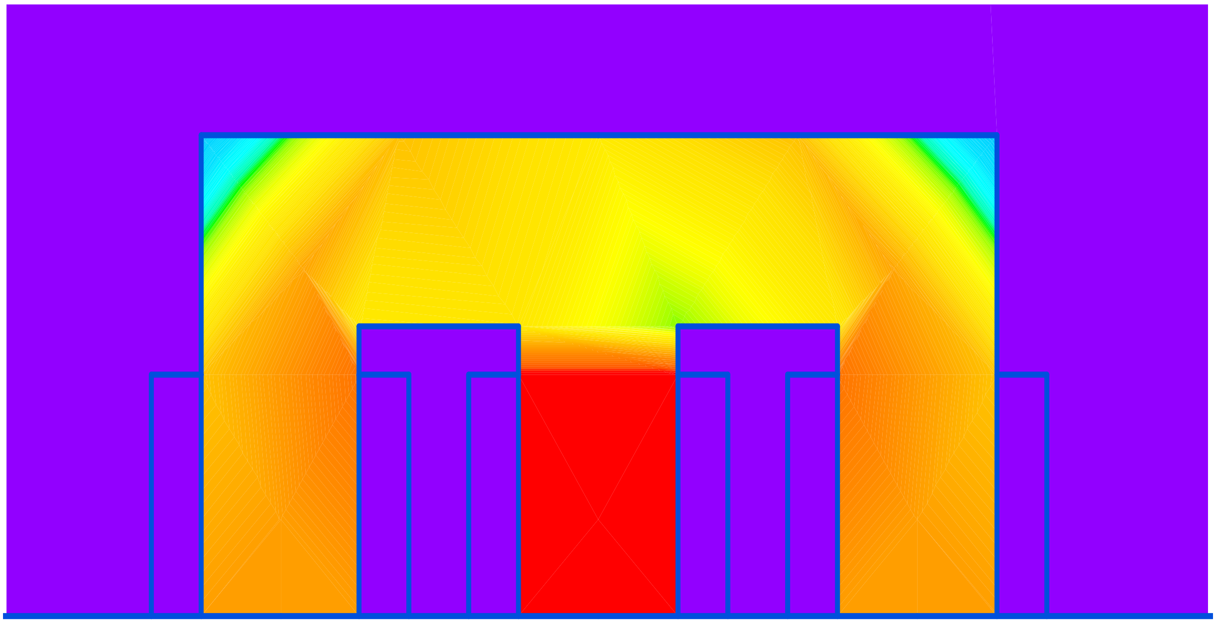

Fig. 4: Finite element simulation of a three phase inductor: flux density distribution

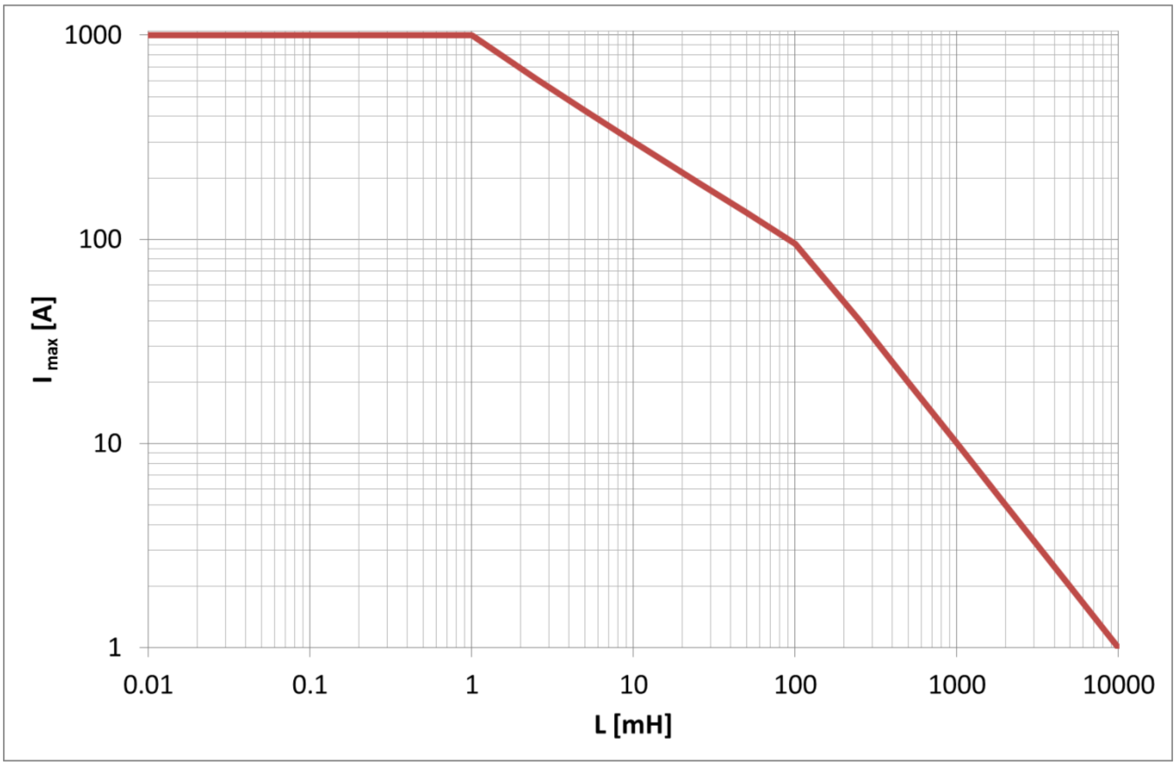

Fig. 5: Maximum rms current vs. three phase inductance for the pulse test
(DPG10-1500A/E with three phase extension unit)

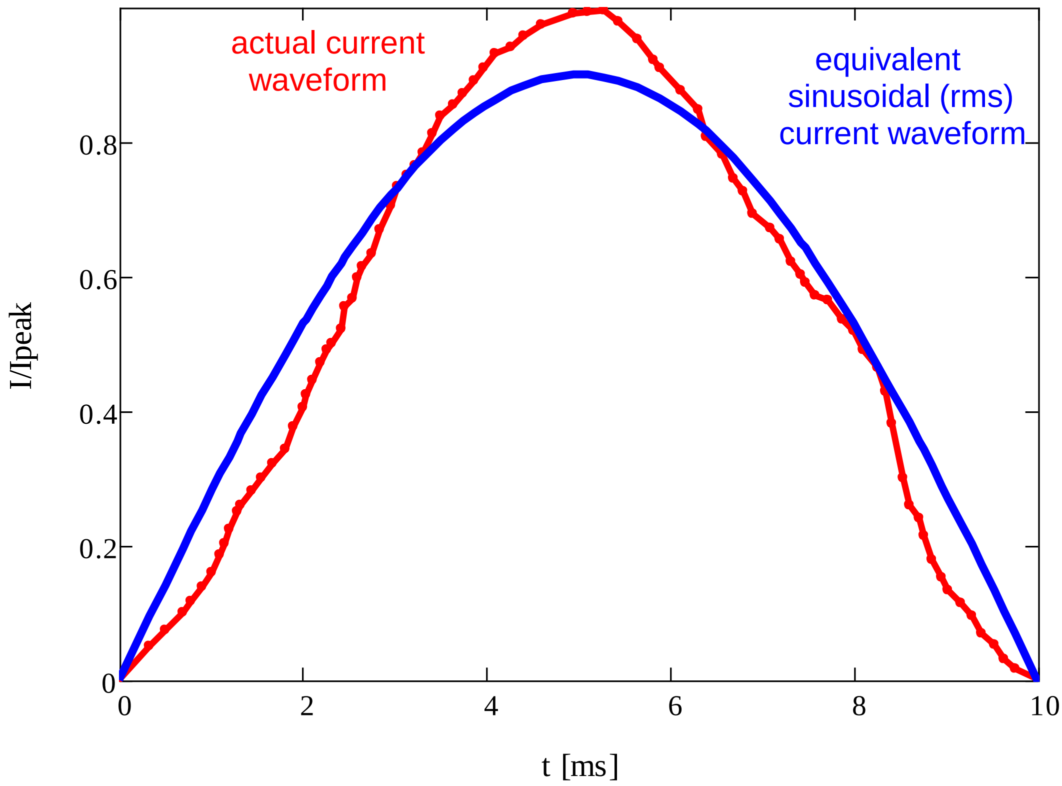

Fig. 6: distorted current waveform (conventional test) and equivalent sinusoidal waveform