Pulsed Inductance Measurement on Magnetic Components from 0.1A to 10kA

Pulse measurement with IGBT power stages using the Power Choke Tester DPG10/20 series was presented in detail in the first and second parts of this series of articles on inductance measurement. The third part shows how the measurement principle can also be used to measure the inductance of 3-phase chokes with the help of a 3-Phase Extension Unit and what significant advantages it has over conventional measurement with mains voltage and mains current.

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Introduction

3-phase chokes are used in many applications such as output filters and input filters for frequency converters and commutation inductors for line-commutated converters. Normally, they are made of electrical steel sheets with three legs of the same cross-section. They are specified by their inductance and rated current at 50 or 60 Hz. Due to the asymmetrical, flat structure, the inductance of the two outer legs is usually lower than the inductance of the middle leg.

Conventional measuring method

In the conventional measuring method, the choke is connected to an adjustable 3-phase, sinusoidal, high-current, 50 or 60 Hz power supply in order to determine the inductance. The current is then adjusted to the rated RMS current for all three windings and the RMS voltage is then measured on each winding. The secant inductance (often called amplitude inductance) of each phase k can then be calculated according to the common alternating current theory with the following equation, neglecting the ohmic resistance:

$$L = \frac{Urms}{2\pi f * Irms}$$

Taking the ohmic resistance into account, this results in:

$$L = \frac{\left(\sqrt{\left(\frac{Urms}{Irms}\right)^2 - R^2}\right)}{2\pi f}$$

In addition to the 3-phase high-performance power supply, the test setup requires 3 RMS current meters and 3 RMS voltage meters. Normally, only one measurement is performed at the rated current. The difference between the middle leg and the two outer legs (3 - 9%) is mostly neglected.

Pulse measurement principle on 3-phase chokes

If the measuring pulse of the Power Choke Tester DPG10/20 series is only fed into one winding of a 3-phase choke, then completely different flux conditions are obtained in the core than with a 3-phase sinusoidal feed. The measurement result would be useless.

However, if a few points are considered, the pulse measurement method of the Power Choke Tester DPG10/20 series is also suitable for measuring the inductance of 3-phase chokes.

- The windings of the 3 legs must be interconnected in a suitable way so that a flux distribution in the core results that corresponds to that with the 3-phase sinusoidal current feed.
- For the independent characterisation of all three legs, several measurements must be carried out.
- All legs must have the same core cross-section.
- The secant (= amplitude) inductance measurement $L_{sec}(i)$ is to be used, from which the corresponding inductance of the middle and outer legs is to be calculated.
- In order to be able to scale the current axis with the corresponding RMS value, as is also specified in conventional measurement with 50/60 Hz mains voltage, a corresponding correction is required.
- Frequency effects due to excitation with a rectangular pulse not equal to 50 or 60 Hz must be corrected.

Figure 1: 3-Phase Extension Unit EXT1

In order to enable automatic and simple operation without manual reconnection of the windings, ed-k has developed special additional units for the Power Choke Tester DPG10/20 series: the 3-Phase Extension Units. In conjunction with sophisticated software algorithms, they provide a result that is equivalent to a conventional measurement with 3-phase sinusoidal voltages and currents. A correction to a reference frequency of 50 Hz or 60 Hz can be made if the pulse width has not corresponded to this frequency.

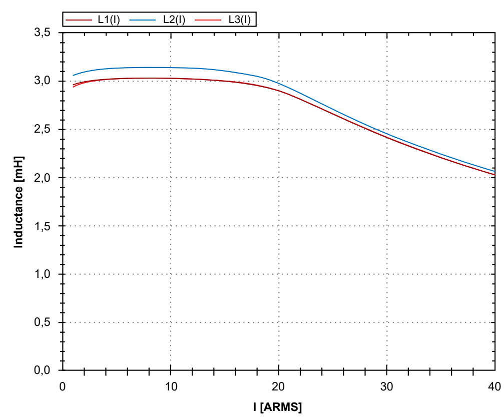

Figure 2: Inductance curves of a 3-phase inductor L1(I_{RMS}), L2(I_{RMS}) and L3(I_{RMS})

As opposed to conventional measurement, the measurement result not only provides the inductance at one measuring point, but a complete inductance curve $L1(I_{RMS})$, $L2(I_{RMS})$ and $L3(I_{RMS})$ for each individual winding of the 3-phase choke. Thus, the usually higher inductance of the middle leg can be seen immediately.

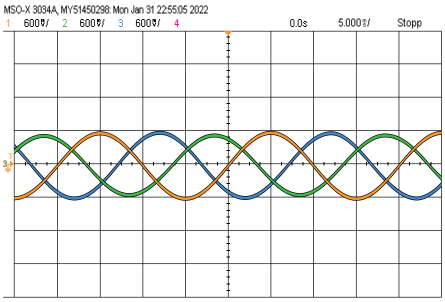

Figure 3: Current waveforms in the linear range CH1-CH3: 20A/div

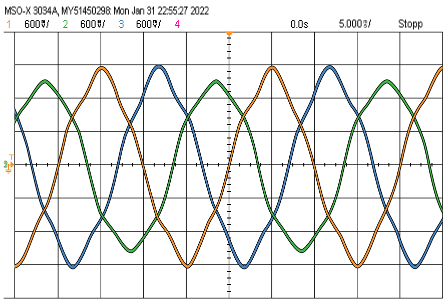

Figure 4: Distorted current waveforms in the non-linear range CH1-CH3: 20A/div

It is worth noting that only 4 measuring pulses are necessary for this.

Advantages of the pulse measurement principle

Compared to conventional measurement, the pulse measurement principle has decisive advantages.

Conventional measurement only provides correct results in the linear range. Due to the extremely non-linear behaviour of the core materials (saturation), the currents and/or the voltages are distorted and no longer sinusoidal. This is especially true for iron-based core materials, which have a much lower permeability at both very small and large magnetic field strengths H than in the normal working range. If sinusoidal currents are applied to the 3-phase inductors, a non-sinusoidal voltage results on the test specimen. Conversely, non-sinusoidal currents result if a sinusoidal voltage is applied.

In practice, neither sinusoidal currents nor sinusoidal voltages result. The normally round sine peaks become pointed. In extreme cases, there may even be steep, needle-shaped pulses on the peaks. The measured variables feature considerable harmonic contents.

The above equations come from the common alternating current theory and are valid only for linear conditions. They are therefore no longer permitted for the calculation of the inductance in the non-linear range (saturation)!

Another problem of conventional measurement is the RMS value measurement of voltage and current. In RMS value measurement, by definition, the measured variable is evaluated quadratically and integrated over a period (same heating of an ohmic resistance as a direct current with the same value). The RMS value measurement of distorted measured variables containing harmonics therefore provides a result that obviously has nothing to do with the physical relationships of magnetism.

For these two reasons, therefore, conventional measurement systematically provides incorrect measurement results with non-linear conditions. Due to the principle, however, the pulse measurement method also provides correct measurement curves $Lk(I_{RMS})$ even with non-linear conditions. Each inductance determined at overload currents is just as accurate as at the rated current!

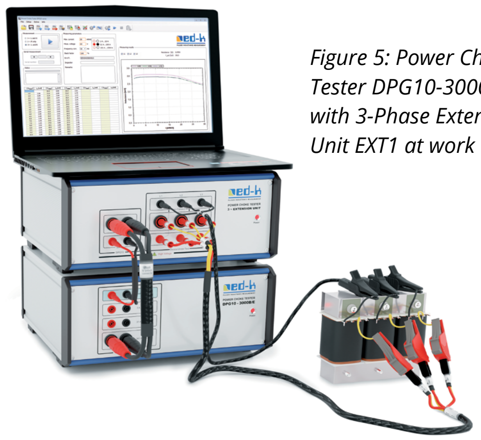

Figure 5: Power Choke Tester DPG10-3000B/E with 3-Phase Extension Unit EXT1 at work

Another significant advantage of the pulse measurement method is that the measurement can be carried out more easily and very much faster than the conventional measurement. With the help of the 3-Phase Extension Unit, the measurement curves $L(I_{RMS})$ for all 3 legs are already available after about 5 secs.

Even in the case of measurements in the overload range with measurement currents that are significantly larger than the rated current, the measurement result is not influenced by thermal effects, as the short measuring pulses do not cause any heating.

Safety

In order to characterise inductive power components under real operating conditions, the Power Choke Tester DPG10 series must operate with high voltages and currents. A very large pulse energy must be available for large components.

In order to be able to guarantee maximum safety for the user and compliance with all safety-relevant regulations and standards at all times, the DPG10/20 series is based on a comprehensive, sophisticated safety concept. It includes extensive safety and monitoring circuits. All safety-relevant circuit parts such as charging circuit, discharge circuit and monitoring circuits are subjected to a self-test after switching on the device. If the self-test fails, the device is placed in an energy-free, safe state within <100 ms.

The device is similarly placed in an energy-free, safe state within milliseconds if a monitoring circuit detects a fault. Particularly critical monitoring circuits are redundantly implemented. Of course, the DPG10/20 series also meets the EN 61010 safety standard, which also includes the safety requirements under fault conditions.

For inductance testing in series production, the DPG10/20 series has a safety lock interface, to which a safety contact of a protective cover or a light curtain can be connected. If the safety contact is interrupted, measuring pulses are immediately blocked and the outputs are switched off within milliseconds.

Summary

The 3-phase test system based on the proven DPG10 technology can not only rationalize inductance testing in series production. Due to the complete inductance curves, it is also an efficient and high-precision engineering tool that can be used for the development and selection of optimised components for various applications. This is the case in particular when the inductance must be taken into account for overload currents, as the conventional measuring method with mains voltages and mains currents in the non-linear range provides inherently incorrect results.

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