Bode 100 - Application Note

Impedance Measurement of a Three-Phase Motor

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Table of Contents

Note: Basic procedures such as setting-up, adjusting and calibrating the Bode 100 are described in the Bode 100 user manual available at:
https://www.omicron-lab.com/downloads/vector-network-analysis/bode-100/

Note: All measurements in this application note have been performed using the Bode Analyzer Suite V3.51 Use this version or a newer version to perform the measurements shown in this document. You can download the latest version at
https://www.omicron-lab.com/downloads/vector-network-analysis/bode-100/

1 Executive Summary

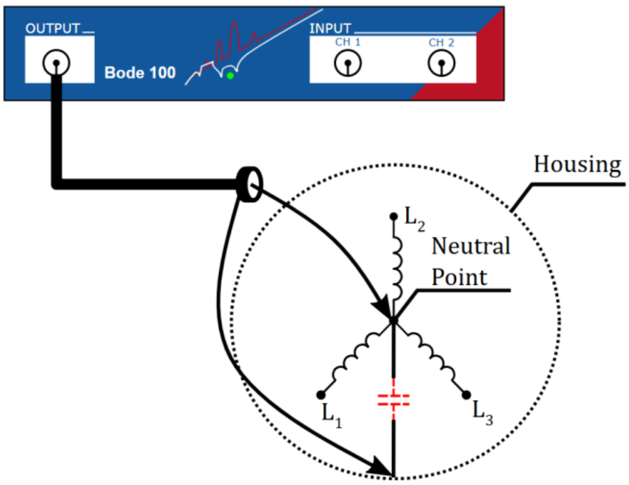
Understanding the impedance of a three-phase motor is crucial for ensuring optimal performance, efficiency, and safety. Measuring the impedance of the windings helps identify issues such as short circuits, insulation failures, and winding damage. Early detection of these problems allows for preventive maintenance, reducing the risk of unexpected motor failures.

Balanced winding impedance ensures that the motor operates efficiently, minimizing energy consumption and enhancing overall performance. Furthermore, the capacitance between the neutral and the motor housing is vital for ensuring electrical safety. Maintaining a low capacitance is essential for effective insulation, preventing current leaks, and safeguarding both the motor and its operations.

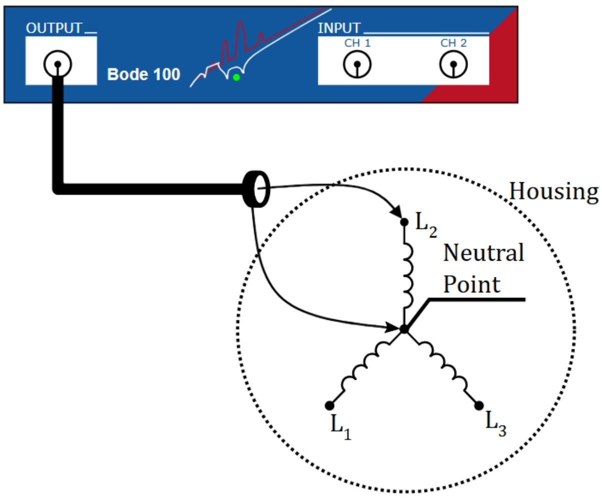
The scope of this application note is to provide a reliable setup for the impedance measurement with the Bode 100. This application note details the connection setup and the device setting of the Bode 100 necessary to perform the impedance measurement.

2 Measurement Tasks

The Device Under Test (DUT) for the measurement is a simple asynchronous three-phase motor. The One-Port method was selected since its impedance range is ideal for typical motor winding and housing capacitance impedance. In this application note, we measure the impedance between phase and neutral point as shown in Figure 1 a) or neutral to housing as shown in Figure 1 b).



b) Neutral N to Housing



a) Phase L2 to Neutral N

Figure 1: Different impedances of a three-phase motor in star configuration.

3 Measurement Setup

The impedance of the windings in the motor (L1-N, L2-N, L3-N) and the impedance between the neutral point and the housing were measured with the Bode 100 using the One-Port method. The Bode 100 One-Port setup can directly measure impedance/reflection at the output port. It uses the internal 50 Ω source impedance to derive the impedance connected at the output. The DUT must be connected directly to the output as shown in the following figure:

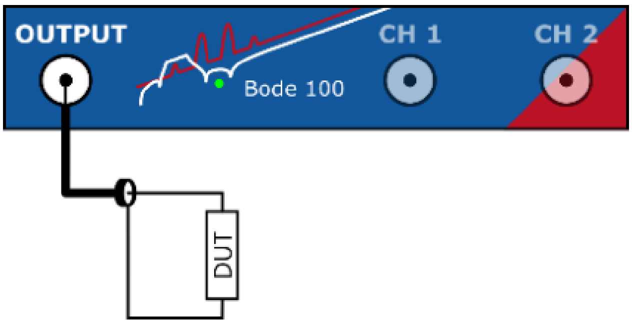


Figure 2: One-Port measurement setup.

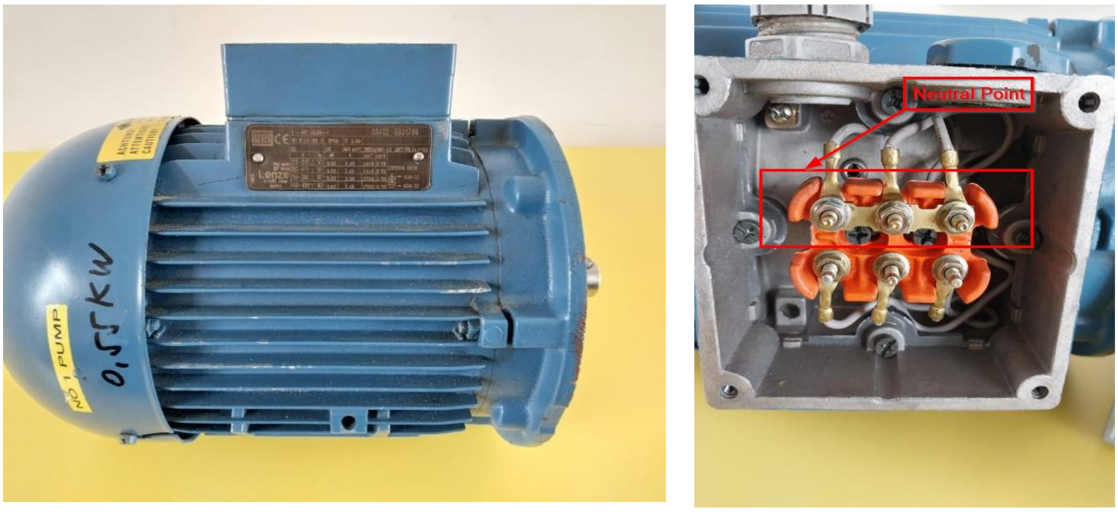
The DUT is connected to the Bode 100 housing (GND) via the BNC shield.

The optimum range for this measurement is ≈ 0.5 Ω to 10 kΩ. The Open/Short/Load calibration (preferably performed as User-Range calibration) was used in the measurement.

Please note that the two terminal connections are subject to contact resistance.

3.1 Device Under Test (DUT)

The DUT for the measurement was a three-phase motor with a start winding configuration. The motor’s terminal box facilitated the DUT’s measurement process.



a) Overview

b) Terminal box

Figure 3: Three-phase motor DUT

3.2 DUT Connection

At one end, a 50 Ω coaxial cable is connected to the output of the Bode 100, with a BNC socket adapter attached at the other end. The signal side is utilized for phase measurements, while the shield side is connected to the neutral point as shown in Figure 4.

a) Connect to the terminal box

b) BNC adapter and clips

Figure 4: DUT connection

3.3 Bode Analyzer Suite (BAS) Setup

The Bode Analyzer Suite (BAS) was set up to measure the frequency range from 10 Hz to 10 MHz to capture relevant impedance curve features of the three-phase motor. Three variables in BAS require adjustment depending on the measurement requirements: source level, number of points per measurement, and receiver bandwidth. Below are the criteria to consider when setting up these variables:

- **Source level:** The source level is the signal power output of the Bode 100. Multiple measurements with the same setup are performed to determine if the measurement results differ from the change in source level. Reduce the source level until the measurement does not change with the source level.
- **Number of Points:** The number of points in the BAS are the points measured at each measurement sweep.
- **Receiver Bandwidth:** Lowering the bandwidth will reduce noise and increase measurement time.

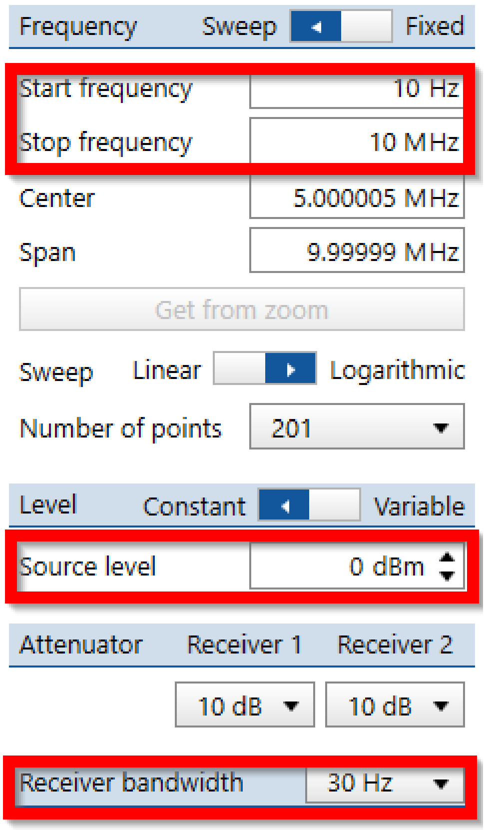
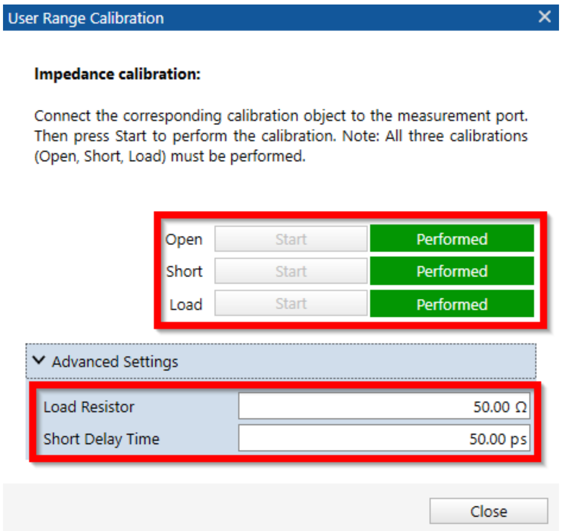


Figure 5: BAS settings for Three-phase motor impedance measurement.

3.4 Calibration

Calibrating the measurement setup before conducting any measurements is essential. We recommend performing a User-Range impedance calibration to ensure accurate results. The Open-Short-Load calibration is particularly effective in eliminating parasitic errors of the cable, such as setup inductance and capacitance.



a) Calibration window


b) Open connection


c) Short connection


d) Load connection

Figure 6: Impedance calibration

Note that the BNC to Clip adapter was not included in the calibration. However, the capacitance of the adapter with clips is estimated to be in the single pF region and the inductance will be significantly smaller than the winding inductance. Therefore, it is estimated that the error from the adapter can be ignored.

4 Results

The impedance results for each phase (Figure 7 and Figure 14) show characteristic inductive behavior. As expected, the impedance magnitude is lower at frequencies below 1kHz. However, at frequencies between 1kHz and 10kHz, the magnitude increases considerably, displaying inductive behavior. This indicates that at high frequencies, the motor's windings exhibit greater opposition to the flow of alternating current, which effectively increases the inductance magnitude. Also, shows the measured phase of the impedance of the motor.

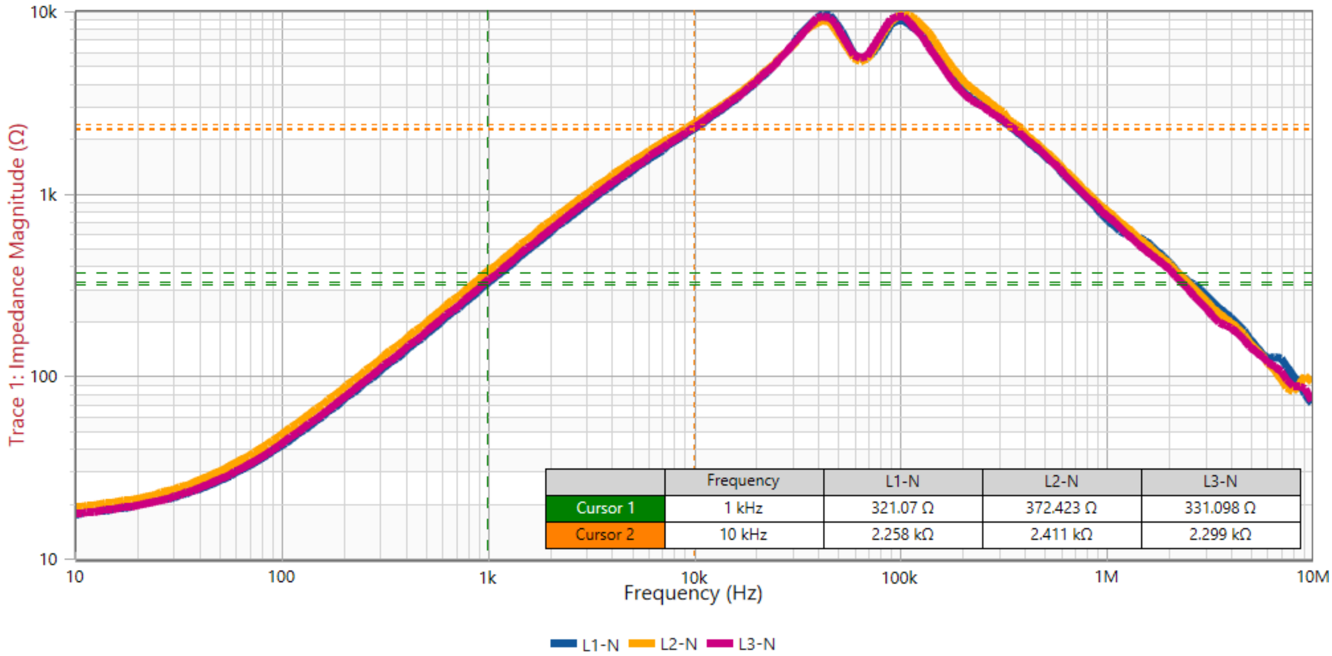


Figure 7 Impedance Magnitude of the motor phases

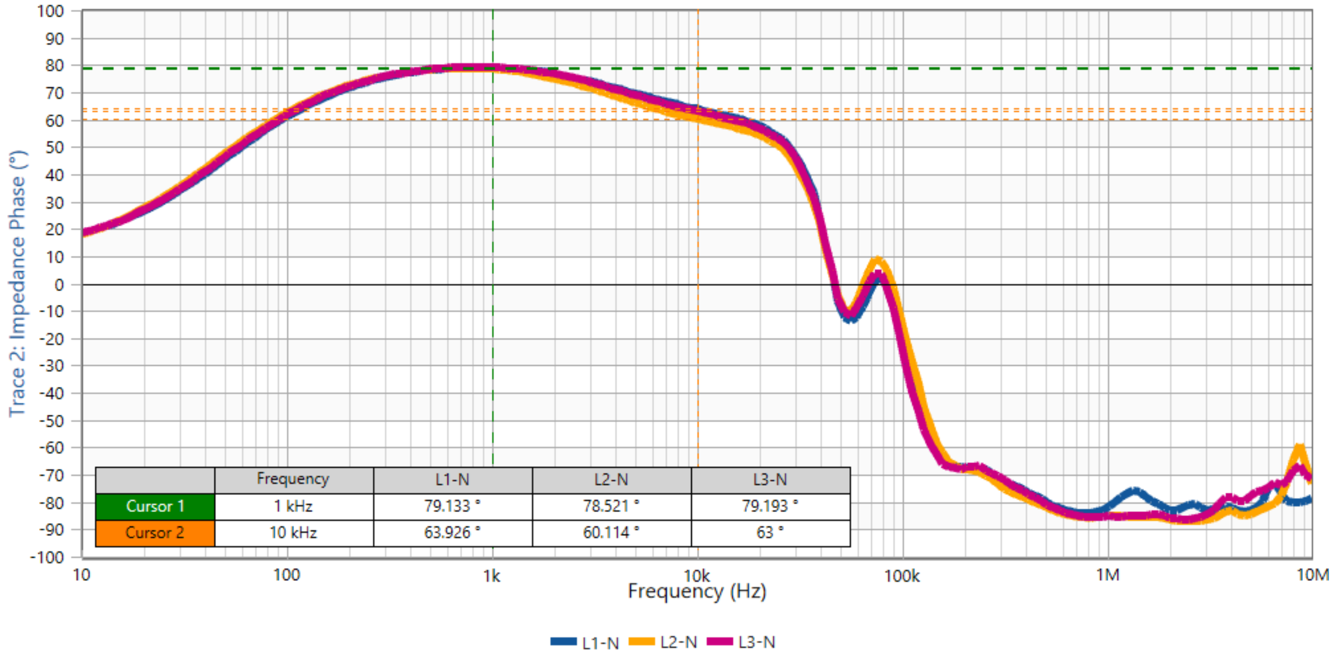
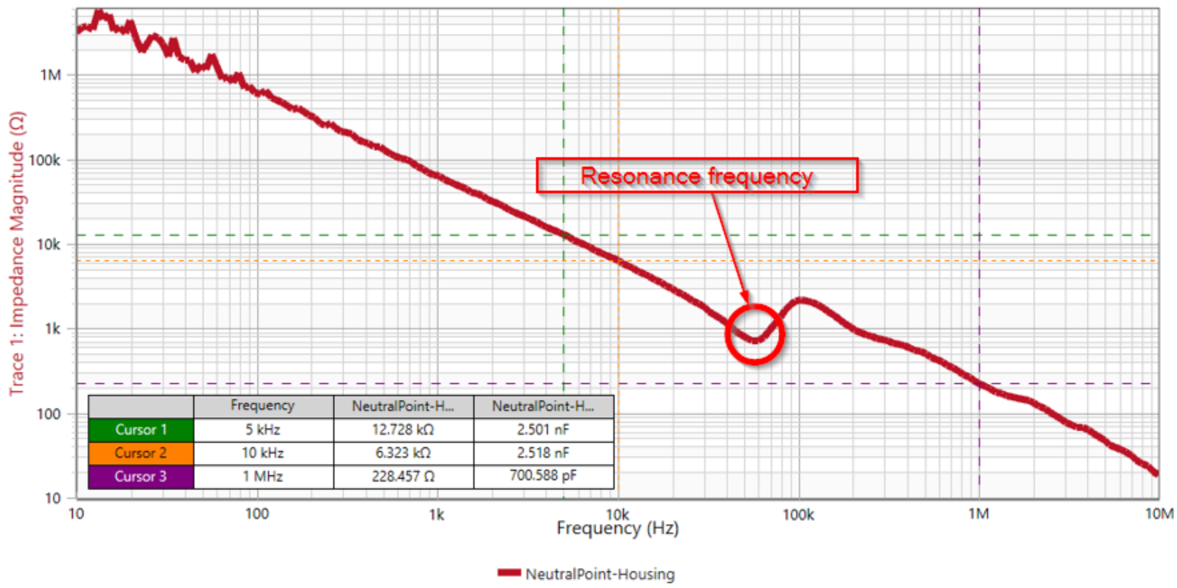


Figure 8 Impedance Phase of the motor phases

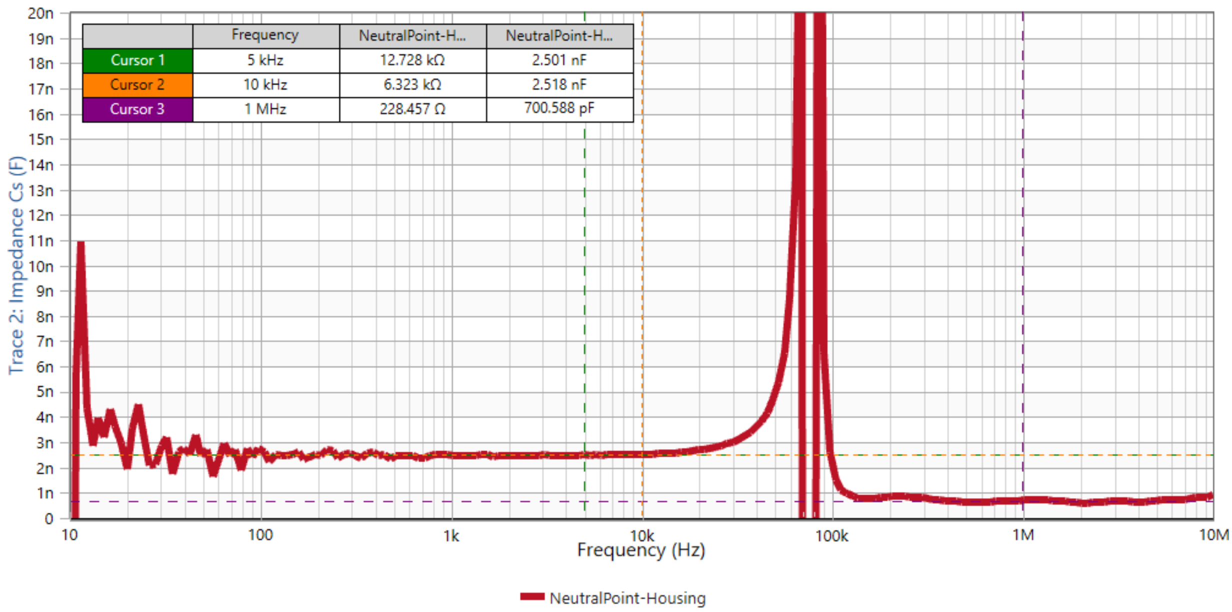
At roughly 50 kHz, the impedance shows a resonance frequency and changes from inductive to capacitive behavior because of parasitic capacitance in the winding. Above 100 kHz, the winding shows purely capacitive behavior.

The capacitance between the neutral point and the motor's housing can vary depending on the motor's specific design and construction. Up to the resonance frequency of the windings, approximately 55 kHz, a single capacitance predominates in the measurement. As shown in Figure 10, the capacitance is approximately 2.5nF between 5 kHz and 10kHz. Around the resonance frequency, a simple single capacitor cannot model the measured behavior. Figure 9 illustrates that at higher frequencies, around 1 MHz, the capacitance is roughly 0.7nF.



	Frequency	NeutralPoint-H...	NeutralPoint-H...
Cursor 1	5 kHz	12.728 kΩ	2.501 nF
Cursor 2	10 kHz	6.323 kΩ	2.518 nF
Cursor 3	1 MHz	228.457 Ω	700.588 pF

Figure 9 Impedance measurement between neutral point and Housing



	Frequency	NeutralPoint-H...	NeutralPoint-H...
Cursor 1	5 kHz	12.728 kΩ	2.501 nF
Cursor 2	10 kHz	6.323 kΩ	2.518 nF
Cursor 3	1 MHz	228.457 Ω	700.588 pF

Figure 10 Capacitive impedance between the neutral point and Housing

5 Conclusion

In this document we have shown that the Bode 100 is perfectly suitable to measure the impedance response of motor windings from 1 Hz up to 50 MHz. A simple One-Port measurement method is suitable for this application. Connection can be made by a simple BNC to 4 mm adapter with crocodile clips. The parasitics of the adapter do not impact the measurement significantly up to several MHz.

- The results indicate that the methodology used to determine the status of the motor windings is effective.
- The insulation capacitance of the motor was measured.
- The procedures employes to assess the condition of a motor, as demonstrated in the application note, are reliable.

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