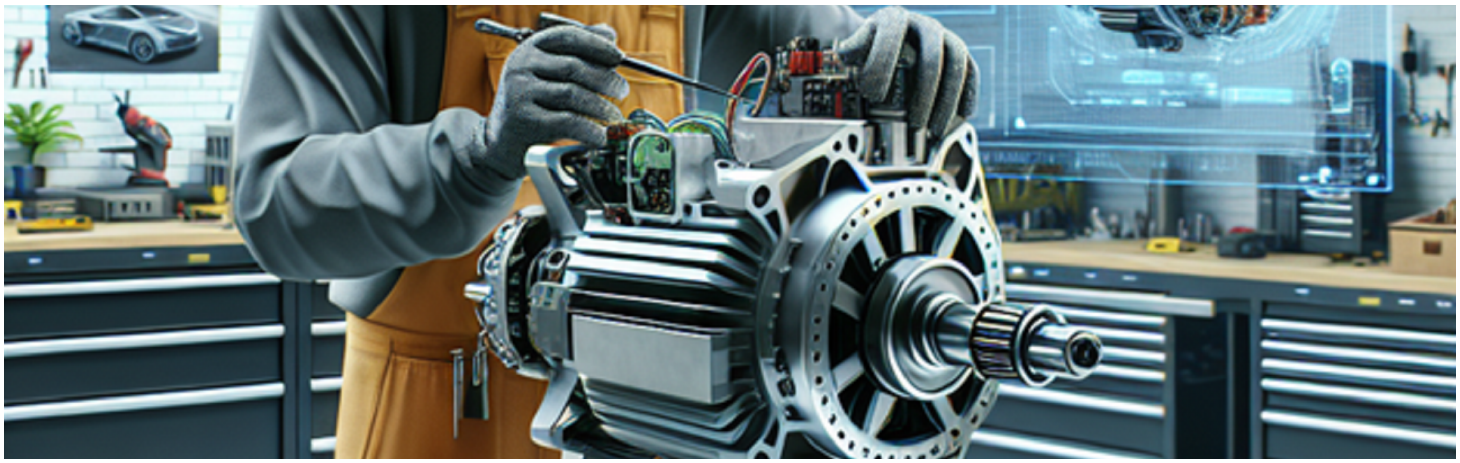

Written on 01 April 2025 3 minutes of reading

News

Fundamental Research

Sustainable mobility | Electrified Mobility

As the operating stresses to which they are exposed increase, so the conductors and insulation of new electrical machines for mobility are subject to ever greater risks of deterioration. To monitor winding aging, IFPEN offers a new strategy for on-line impedance frequency characterization, with no need for dedicated equipment.

Drawbacks of existing methods

With the arrival of new, ever faster and more efficient power electronics components, the trend for electric traction powertrains is **to increase switching frequencies**[1] **and supply voltages** [1]. As a result, electrical machine conductors and their insulators are subjected to **ever-increasing electrical stresses, with the associated risk of damage**. In order to protect these systems, and thereby reduce maintenance costs and times, **it is now essential** charge measurement [2], insulation resistance measurement [3] or inter-turn capacitance estimation [4] can be implemented. The main drawbacks of these methods are their cost, their off-line implementation and the difficulty of integrating them into a vehicle as standard. To address these issues, IFPEN offers a **new strategy for on-line impedance frequency characterization, without dedicated equipment, to monitor winding aging**
.

[1] Frequency at which the power is switched from on to off

A simplified characterization carried out during operation

Impedance measurement has been usually performed on a machine that is no longer operating and disconnected from its power source, using an impedance analyzer. Other approaches, either off-line or with coupling systems, involve exciting the winding with voltage pulses at a given frequency in order to reconstruct the Bode plot[2]of this impedance [5]. The main drawback of these methods is their invasive nature[3], and the need to have access to dedicated excitation/characterization systems.
The solution developed at IFPEN eliminates the need for a dedicated excitation system and allows **impedance characterization at any time** while the motor is running. The proposed idea is to use **the harmonic excitation of the windings** that is generated by the voltage inverter supply [6], to characterize their frequency response, using only current and voltage measurements at the machine terminals.

[2] Frequency representation of a system response
[3] Methods that affect the operation of a machine

Winding frequency response identification method

The characterization process consists in measuring the voltages at the motor terminals, as well as the current circulating in each of its phases (Figure 1(a)). A frequency analysis of these signals is then performed (Figure 1(b)). The idea then is to look for frequency components whose amplitudes exceed a fixed threshold[4]. For each of these dominant frequencies, the impedance is then calculated using Ohm's law (Figure 1(c)).
The next step is simply to concatenate the raw impedance characteristics from voltage and current thresholding (Figure 1(d)). Finally, the data is cleaned **to retain only those frequencies around multiples of the switching frequency**, which are the only ones actually excited (Figure 1(e)).

[4] Threshold whose behavior is inversely related to frequency

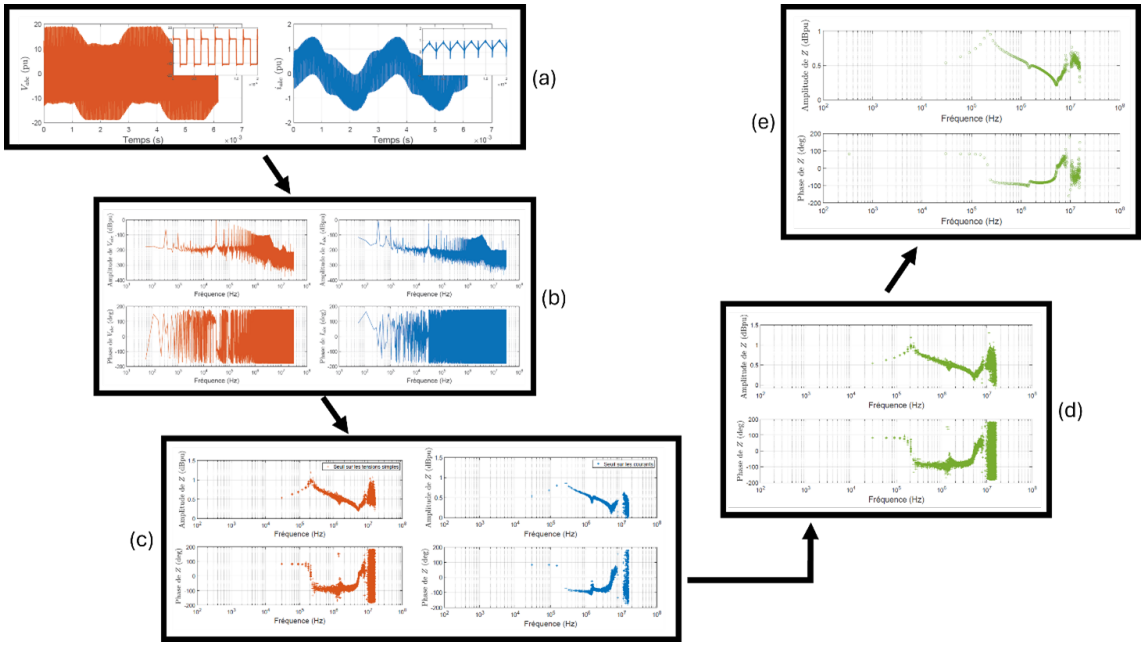

Figure 1: Measured voltages and currents (a); frequency content of voltages and currents signals (b); raw impedance characteristics resulting from voltage and current thresholding (c); complete raw impedance characteristic (d); cleaned impedance characteristic (e)

An approach with numerous advantages

This method offers the following benefits:

- Since the harmonic excitation is naturally performed via the voltage inverter, the method has no effect on either machine operation or aging.
- No measurement cables or mounting adapters are required, eliminating the need for prior calibration and making impedance measurement even more reliable.
- **Aging can be monitored at any time**, without removing the machine from its operating environment, allowing early identification of insulation degradation in the windings.

Condition-based maintenance of electrical machines

It has been shown that the evolution of the Bode plot of the impedance of electrical machine windings is directly related to the condition of the insulators [7,8]. The first parallel resonance frequency is directly linked to **the inter-turn capacitance**, and therefore to **the insulation quality of the windings** . Thanks to the precise evaluation of this resonance throughout motor operation, the proposed method will make it possible to monitor **the evolution of the windings' condition**. In a condition-based maintenance[5] strategy, such monitoring can therefore be used to estimate the RUL[6] of the winding, and thus be able to guarantee the best performance and availability rate of the system.

[5] Preventive maintenance based on equipment condition
[6] Remaining Useful Life

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Scientific contacts: Jérémy Creux, Najla Haje Obeid

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