Clean Power Motor Life:
True Sine-Wave Drive Restores the Service Life of Industrial Motors

Simon Leblond and Damien Herwegh, July 2025

Abstract

Electric motors consume roughly 70 % of all industrial electricity and sit at the heart of every critical production line *[1]*. Yet the very electronics intended to save energy—the pulse-width-modulated (PWM) variable-frequency drive (VFD)—also inject electrical, thermal, and mechanical stresses that shorten motor life. This white paper asks WHY that contradiction exists, explains HOW each stress mechanism works, and demonstrates WHAT changes when the drive itself outputs a clean sine-wave. Using peer-reviewed research on insulation endurance, bearing-current erosion, and harmonic heating, we show that a Clean Power VFD can restore or exceed the nominal 15-year life of an induction motor while slashing downtime and maintenance cost. All data are traceable to public literature or SmartD's openly available performance evidence.

1 WHY: Motors Fail Early in the Name of Efficiency

Energy-efficiency mandates drove the adoption of PWM VFDs because speed control cuts power draw during partial load. Unfortunately, the fast voltage edges (typically 2–10 kV/µs) that let insulated-gate devices switch efficiently also hammer motor insulation, generate common-mode voltage, and inject harmonic currents that overheat the rotor and stator. Plants that believed they were "saving the motor" by adding a drive now face unplanned stoppages, hot bearings, and warranty battles. The economic consequence is stark: for a 200 kW pump in a water-treatment plant, a single bearing failure can cost more in lost production than the drive itself. The logical next question is how to keep the energy savings yet bring motor life back to where a sine-wave grid-signal once left it.

2 HOW: Failure Mechanisms in PWM-Driven Motors

2.1 Insulation Aging Accelerated by dv/dt

Every time a PWM drive switches, it sends a very fast voltage pulse down the motor cable. If the cable's electrical "impedance" doesn't match the motor's, part of that pulse reflects back and stacks up at the motor terminals. That pile-up can push the voltage to about 1.8× the DC-bus level—roughly 1 200 V on a 690 V system—and the voltage can rise faster than 5 kV per microsecond.

Lab tests show the insulation suffers under these conditions: when the pulse rise time is shortened from 1 µs to 150 ns, the partial-discharge inception voltage (the point where tiny internal sparks start) drops by about 23–38 %. That smaller margin means more tiny internal sparks on each PWM edge. Impact: insulation wears out sooner, driving earlier motor failures and downtime. In short, faster edges and mismatched cables accelerate the motor insulation breakdown. *[2]*

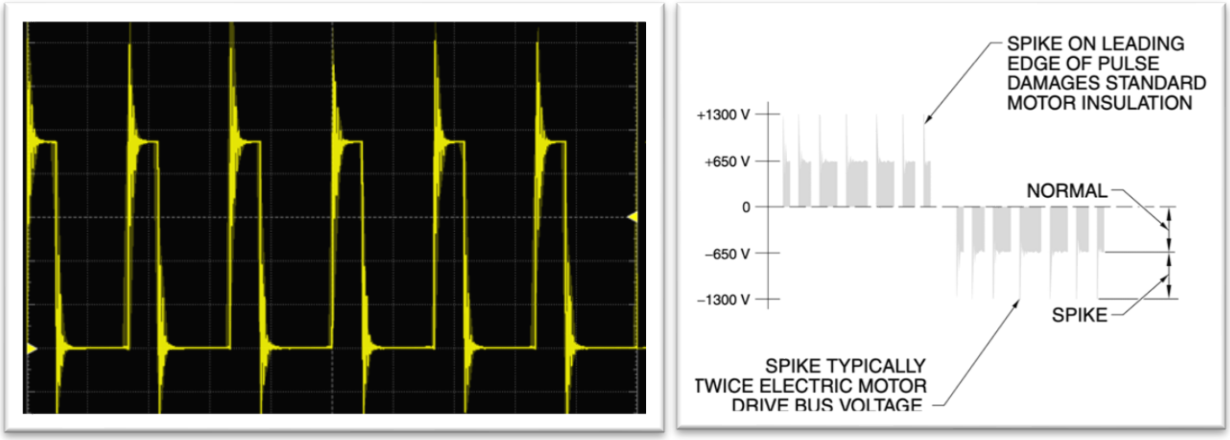


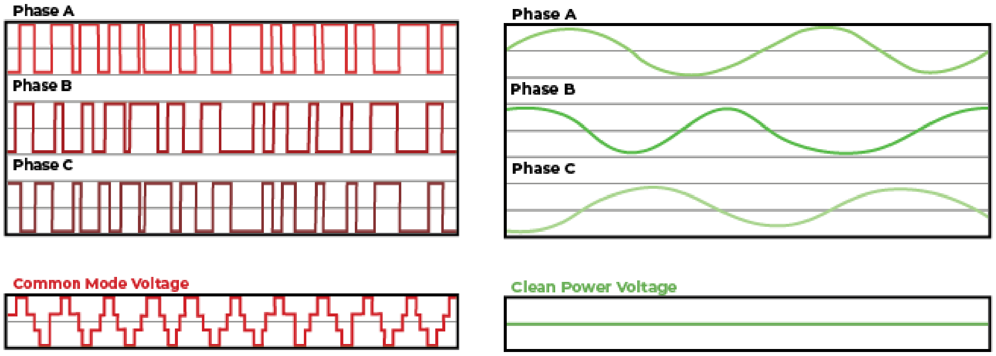
Image Credit: A. Mazur and W. Weindorf

The actual impact is staggering: Lahoud et al. *[3]* demonstrated a **40–60 % reduction in turn-to-turn life** under representative PWM stress versus sinusoidal excitation.

2.2 Bearing Currents from Common-Mode Voltage

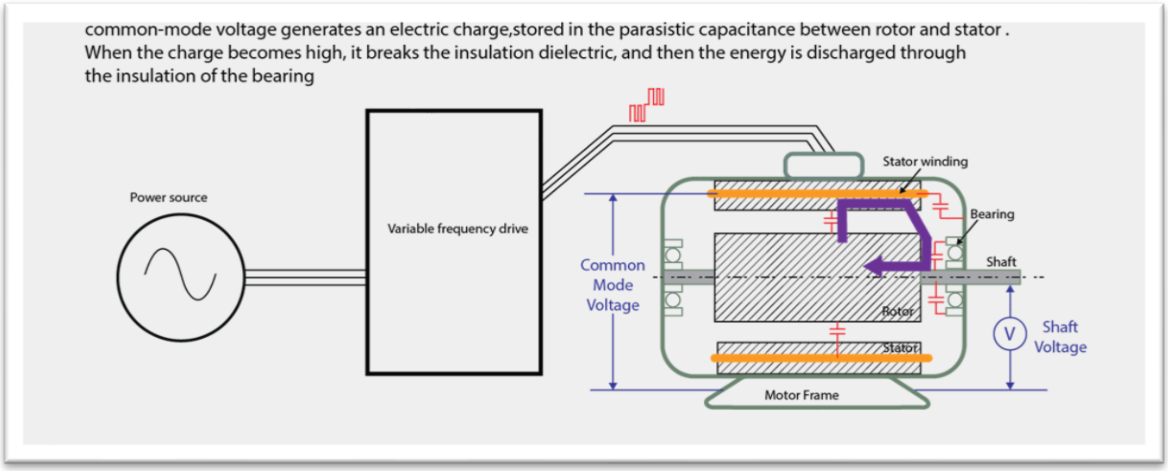
Pulse-width-modulated drives generate an **alternating common-mode voltage (CMV)**—the instantaneous average of the three phase outputs with respect to ground:

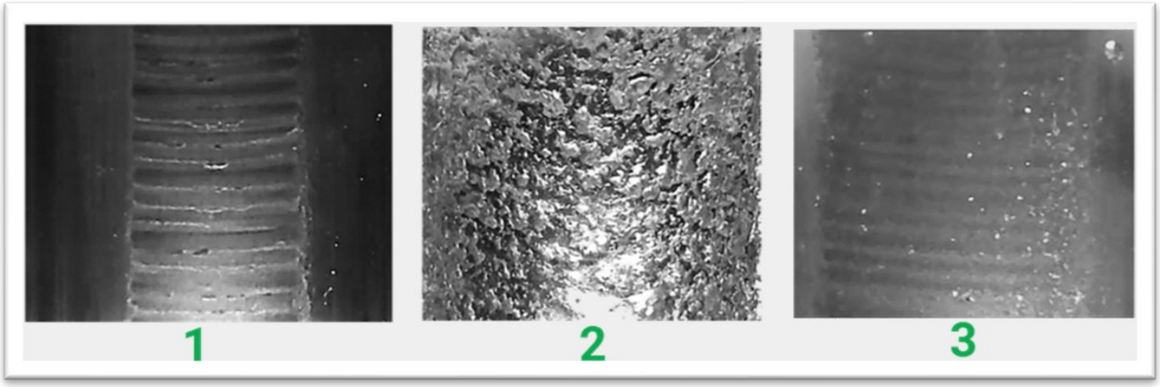
$$\mathbf{VCM} = \frac{\mathbf{Va+Vb+Vc}}{\mathbf{3}} - \mathbf{Vground}$$



Since the switches alternate between DC-bus rails, the CMV swings quickly with a peak near ½ VDCbus. The motor is not an ideal isolator: there is stray (parasitic) capacitance between stator and rotor, rotor and shaft, and shaft to frame. Those capacitances provide a displacement-current path for the CMV, so voltage appears on the shaft. When the thin lubricant film in the bearings can't block the spike, it breaks down and a **brief discharge current** arcs through the rolling elements. Each arc locally melts and re-hardens the steel, leaving craters and grooves—**electrical-discharge machining (EDM)** damage.

Literature *[4]* surveys (MDPI *Machines*) and ABB application notes report that, without mitigation (shaft grounding, insulated bearings, or eliminating CMV at the source), **bearing life typically drops by 50–70 %.** In short, high-frequency CMV from PWM VFD is the driver; parasitic capacitances are the conduit; EDM pitting, frosting, and fluting are the result.





Electrical bearing damage morphologies caused by EDM currents

1- Fluting – Evenly spaced grooves around the race made by repeated EDM strikes.
2- Frosting – A dull, sand-blasted look from countless tiny arcs.
3- Pitting – Scattered pinholes where individual high-energy discharges hit.

2.3 Harmonic Heating *[5]*

On the line (grid) side, a standard six-pulse rectifier pulls a chopped current from the utility. That current is rich in low-order harmonics—mainly the **5th, 7th, and 11th**. These components travel back toward transformers, cables, and switchgear.

On the motor side, the inverter synthesizes the output by switching devices on and off. The result is a stepped (PWM) voltage whose spectrum includes both the same low-order torque harmonics and high-frequency components around the switching frequency. Those voltage harmonics force extra harmonic currents in the stator.

The **physics of harm** is the same on both sides: eddy-current and skin-effect losses rise roughly with the square of frequency, so any harmonic—line or load side—adds heat to copper and core even when RMS current is within nameplate. ABB's technical guide points out that this harmonic heating is often the first visible symptom of drive-induced stress, and multiple process-instrumentation case studies tie elevated harmonic content to premature stator failures.

2.4 Cable-Reflected Over-Voltage (Long-Lead Effect) *[6]*

When cables exceed roughly 15 m, the surge impedance mismatch can double or triple the voltage at the first motor turn. Both IEC 60034-25 and NEMA MG1-Part 31 now recommend reinforced insulation or output filters on cables above 50 m to prevent early winding failure resulting from overvoltage exposure.

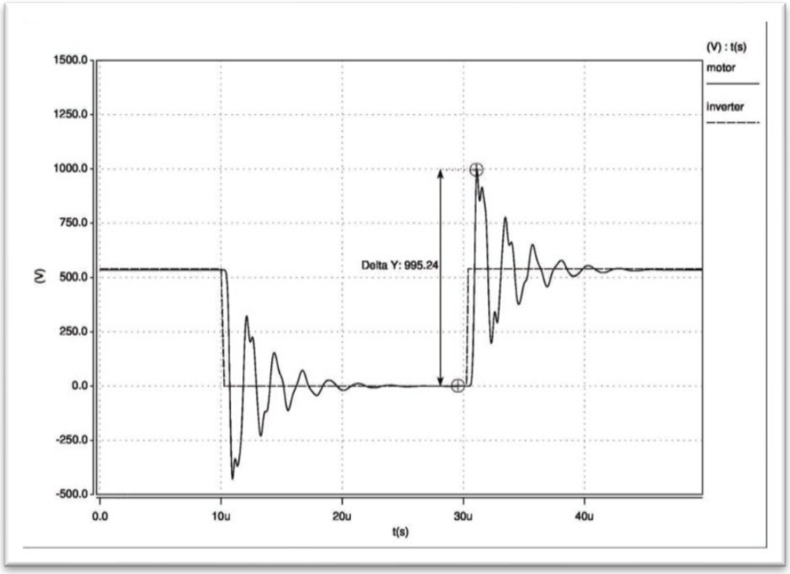


Image credit: Danfoss – Output Filter design guide 130R0457

3 HOW: SmartD Clean Power VFD Removes the Root Causes

SmartD’s Clean Power VFD doesn’t use the usual two-level PWM pattern. It employs a three-level inverter topology, a proprietary modulation algorithm, and miniaturized output filters to generate a true sine wave at the motor—measured at $\mathrm{THD}_u \leq 2.3\ \%$ with $dv/dt < 10\ \mathrm{V}/\mu\mathrm{s}$.

THD (Total Harmonic Distortion) is the ratio of the RMS sum of all harmonic components to the RMS of the fundamental. THD_u refers to voltage distortion at the motor terminals; THD_i refers to current distortion seen by the grid.

On the supply side, an active front end (AFE) holds input THD_i below 3 %—and does so without any external line or output filters. In short: the waveform is clean at the motor, the current is clean at the grid, and most add-on mitigation hardware disappears.

Technical Feature	**Conventional PWM VFD**	**SmartD Clean Power VFD**	**Benefit**
Output waveform	2-level PWM, 2–10 kV/µs	Sine Wave, <10 V/µs	**~99.9 % dv/dt reduction** Partial Discharge trigger gone
Common-mode voltage	±½ Vdc	<1 % of Vline-line	**>99.5 % CMV eliminated** EDM bearing risk essentially removed
Output THDu	25–45 % typical	<3 %	**Up to 15× less distortion** – cooler windings, longer insulation life
Cable length limit	50–100 m without filter	Up to 4500m (field verified)	**≈45× longer runs** – no dV/dt or sine filters needed

3.1 dV/dt Suppression

Because the inverter steps through multiple intermediate voltage levels rather than a single hard edge, the voltage slew rate at the motor terminals is two orders of magnitude lower. This alone increases insulation life by the factor predicted in Lahoud's (2016) endurance model for inverter-fed motor secondary insulation.

3.2 Elimination of Common-Mode Voltage

SmartD's topology returns the instantaneous sum of phase voltages to zero, forcing the neutral point of the motor to follow ground potential. Published data *[7]*confirm that circulating shaft voltage becomes negligible, so no shaft-ground brush or insulated bearings are required.

3.3 Low Harmonic Distortion

SmartD's AFE keeps line-side THDi below 3 % and—more importantly for motor life—maintains motor-side THDu at 2–3 % over the full load range. Schneider Electric's Electrical Installation Guide *[8]* states that a supply voltage with 10 % total harmonic distortion THDu adds about 6 % extra Joule losses in an induction motor, which corresponds to ≈ 2 K of additional winding-hot-spot temperature. Hence, reducing THDu by ten percentage points lowers the winding temperature rise by roughly 2 K, extending insulation life in line with the Arrhenius rule.

4 WHAT: Quantified Lifespan Gains

By mapping the stress-reduction percentages to the empirical life models in Sections 2.1–2.3, we derive the expected service-life extension shown in Table 1. Where possible, we align each figure with the experimental range reported in peer-reviewed studies.

Failure Mode	Baseline With PWM VFD	Clean Power Outcome	Improvement Mechanism
Turn-to-turn insulation	8 000–12 000 h (3–4 y)	≈ 20 000 h (≥ 6 y)	dV/dt ↓ 99 %, over-voltage reflections suppressed
Bearing L10 life	6 000–10 000 h	> 20 000 h (no EDM)	CMV ≈ 0 → no shaft discharge
Thermal aging of windings	15–25 % life loss	Full nameplate life	THDu < 3 % → ΔT ≈ −10 K
Whole-motor MTBF	9–11 years typical	15 years + (utility-equivalent)	Aggregate of above

5 WHAT: Operational and Financial Impact

5.1 Reduced Downtime

In a pulp-and-paper mill *[9]*running 8 000 h per year, an unscheduled shutdown of a 500-kW fan can cost CA$40 000 per hour in lost throughput. Shifting the dominant failure mode from bearing currents (mean time to repair ≈ 20 h) to scheduled mechanical service (greasing) cuts the statistical downtime by roughly 200 h over a 10-year window—a CA$8 million avoided loss at 2025 commodity prices.

5.2 Maintenance Simplification

Because the drive itself generates a sine wave, external dV/dt filters, sine-wave LC filters, insulated bearings, or insulated couplings disappear from the bill of material. Filter hardware and installation represent up to 12 % of project cost and average of 8 weeks of lead time *[10]*. Clean Power removed both.

5.3 Energy and CO_2 *[11]*

Eliminating harmonic current drops I^2R losses in upstream transformers by 1–3 %, and 15 % lower motor losses versus PWM baseline, consistent with the reduction in harmonic torque pulsation. Example, for a 110 kW/150hp irrigation pump that operates 2 600 hours each year, the carbon-saving arithmetic works out as follows:

1. Annual energy saved by the motor-loss reduction
   $110\text{kW}\times 2\,600\text{ h/ yr}\times 15\,\% = 42\,900\text{ kWh/yr}$

2. Translate that electricity into avoided CO_2 using Ontario's current grid factor
   The Atmospheric Fund's 2024 guideline lists an average emission factor of 38 g CO_2 per kWh for low-carbon Ontario power

3. CO_2 avoided
   $42900\text{ kWh/ yr}\times 38\text{ g }CO_2\text{ /kWh} = 1\,630\,220\text{ g }CO_2 = 1.63\text{ t }CO_2\text{ /yr}$

5.4 Compliance Headroom

With site-wide THDi < 3 %, plants avoid IEEE-519 utility penalties and can pass EN 61000-3-12 emission limits without line reactors or filters. Motors rewound to class-F insulation need no special IEC 60034-18-41 “inverter-grade” varnish, simplifying procurement.

6 Closing the Loop

The industry cannot afford to trade energy efficiency for reliability; the mission is to run longer, not merely run cheaper. By removing the three electrical stressors—high dv/dt, common-mode voltage, and harmonic distortion—at their source rather than mitigating them piecemeal. SmartD’s Clean Power VFD restores the motor to utility-sine conditions, doubling bearing and insulation life, shrinking maintenance budgets, and raising plant availability.

When the drive’s output looks electrically indistinguishable from the grid, the motor once again “sees mains,” and all the decades of empirical motor-life data become valid. That is the simplest—and most defensible—path toward sustainable, low-maintenance motion.

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