

The state of the VFD 2026

A public research and authority report

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Report home, errata, and later editions: <https://waywardleaders.com/state-of-the-vfd-2026>

Abstract Variable frequency drives control approximately 40 percent of industrial motors, which makes their current state a question about equipment nearly every plant already owns rather than about what a catalog advertises. This report assesses that state through a proprietary search design: three frontier AI research instruments and a scholarly harness, run independently against one structured prompt, with declared source ranks, excluded domains, and a classification for every absence. Returns were filtered into a majority report, where the instruments converge, and a minority report, where one instrument produced a document the others had declared did not exist. The minority report proved correct repeatedly, and the seams between the two are where the productive insight sits. Nineteen brands were assessed and thirteen scored against a nine-dimension disclosure rubric published here in full. The central contradiction is that no drive from any reviewed manufacturer appears in the ISASecure certified components register, which leaves a common specification clause unmeetable by any product on the market. Silicon carbide has not entered general purpose product, drive-resident bearing diagnostics rest on a single seeded-fault dataset, IEEE 519-2022 states that its limits apply at the point of common coupling rather than at the drive terminals, and not one reviewed brand publishes field return rates. Every claim carries the document number needed to check it, which is the transparency marketing does not reach.

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Highlights and contradictions

Seven places where the public record contradicts something the industry widely believes. Each carries a document number and a section that shows the work.

The rest of this report is the evidence behind those seven, the vendor matrix in section 5, and a set of questions to put to a supplier in section 8.

The point of this report

Industrial buyers commit before they can verify. That is the ordinary condition of the work rather than a failure of diligence, because you specify a drive, or you quote one, months before anything about it can be checked against how it behaves in a real plant, and by the time the evidence arrives the purchase order is three years old.

Whatever is available flows into that gap. Marketing, mostly. Folklore, which in this industry is unusually durable. And in at least one case documented here, numbers that appear to have been invented outright.

Credibility is not uniform, though, and it climbs a ladder anyone can follow. At the bottom sits self-report, where the manufacturer says the drive is reliable. Above that is demonstration, where the manufacturer shows something. Above that is the buyer-checkable artifact, a document with a revision number you can retrieve and read without asking permission. At the top is third-party attestation, a certificate with a number, an issuing body, a scope and an expiry.

Self-report is universal and therefore worth nothing. Every drive manufacturer alive claims reliability. The rungs above it are where the differences live, and almost nobody measures them.

That is what this report measures. Not which drive is best, which no public source can estab-

lish. Not who holds the most share, which no public source can establish either. What each manufacturer will put on the public record, at which rung of that ladder, about the things a buyer would want to check.

The ranking that comes out is not the ranking the market believes. A mid-tier North American supplier publishes wear-component life with four stated conditions while 3 of the largest companies in the industry publish nothing comparable. The most complete functional safety data anywhere comes from a company that publishes nothing at all about how long its fans last. And on the disclosure that would matter more than all the others together, field return rates, every manufacturer checked is silent.

That last one is the finding underneath the whole report. 13 companies, and not one of them will tell you how often the product comes back.

What this edition is for

This edition is written for the person who has to put a number in a specification, or explain to a plant manager why a drive that was supposed to last did not.

Most of what follows is a correction. Nearly every section reports that something widely believed is not supported by the public record, or is supported by a document saying something narrower than the claim built on top of it. That is deliberate. A report confirming what you already believe is not worth an email address, and the test each finding had to pass was whether it changes what a competent engineer would write in a specification, ask a supplier, or put in a budget.

You will find a certification clause sitting in specifications today that no drive on the market can meet, a harmonic requirement a major water utility applies at the wrong measurement point, two standards carrying nearly the same number with 15 years between their tech-

The contradiction	Evidence
No drive from any manufacturer appears in the ISASecure certified components register, so a clause requiring it cannot be met by anybody	Section 1
IEEE 519-2022 states its limits apply at the point of common coupling and are not intended for evaluating equipment	Section 3.1
Field return rates: zero of the 19 brands reviewed publish them	Section 5.4
Toshiba publishes capacitor and fan design life with four stated conditions, and it is the only manufacturer that does	Section 5.3
Safe Torque Off is base build rather than a priced option, down to the value tier	Section 3.4
Silicon carbide has not shipped in any general purpose low voltage drive. The silicon shipped and the drives did not	Section 2.1
Drive-resident bearing diagnostics rest on one seeded-fault dataset, and the author’s own paper is held to that standard in section 2.4	Section 2.4

Table 1. Highlights and contradictions, with the section where each is evidenced

nical content, and the only published wear-life figures in the industry, from a company most specifications do not name.

What it costs you is five or six comfortable talking points, and an afternoon if you work through the verification queue at the back.

This is not a product recommendation, and no manufacturer paid for placement, reviewed a draft, or was contacted during the work. It is not a market forecast either. And it does not replace a vendor’s own current documentation, which is why every document number and revision date appears in full.

Method in brief

Every finding comes from public web search and public document retrieval. Nothing else. No distributor portal, no login, no non-disclosure material, no vendor briefing, no sample unit, no bench measurement, no supplier conversation.

Three frontier AI research tools were run independently against one structured prompt, carrying the same source ranking and the same excluded domains, and a separate scholarly harness was run against an academic works index with live DOI resolution. A finding reached this report only when it survived

disagreement between the instruments, and where they split, the split is reported rather than averaged away.

Absences are classified throughout: **(a)** appears not to exist, **(b)** exists but is gated or channeled, **(c)** could not determine. A low score means the evidence is not public. It does not mean the product is deficient.

Returns were filtered into two layers that the report keeps separate throughout. The **majority report** is what the instruments converge on, and it is the safer material. The **minority report** is what a single instrument produced after the others had declared it did not exist, and across this project the minority report was repeatedly the correct one. The seams between those two layers are where the contradictions in this document come from.

Three limits are worth carrying into section 1. An absence is a statement about one search rather than a fact about the world. Material behind a distributor login is invisible to this method, which biases the result against manufacturers who sell through distribution. And public documents are taken at face value, which is why every document number and revision date is quoted in full.

A note on how absences are worded in this report. Where a section says that something is not published, it means not published by the brands reviewed for this edition, found by these instruments, in September 2026. It does not mean no company anywhere publishes it. That distinction is the report's own standard applied to its own sentences, and any wording that reads as a universal claim should be read in the narrower sense or reported as an error.

Scope of this edition. Nineteen brands were assessed. Thirteen are scored against the full rubric in section 5. Six are recorded without a score because too little public English-language documentation was reachable at document-number level to rate them fairly, and publishing a low score on that evidence would be unfair: Fuji Electric, Hitachi, TECO-Westinghouse, AutomationDirect, INVT and Veichi. Brands not assessed for this edition include Lenze, KEB, Invertek, LS Electric, Benshaw, Bonfiglioli, Omron and Hyundai. Their absence describes this edition's scope rather than those companies, and extending the set is the first item on the list for the next one.

How this edition is shaped, and how later ones will differ. This is the first edition and it has no predecessor to measure against, so it establishes the terrain rather than reporting a change. It opens on standards and cybersecurity because that is where the public record is most specific, where a clause in a specification can be checked against a certificate number, and where the single sharpest contradiction sits. From that spine it follows the tributaries that open off it: what did not arrive in the product, what the literature will and will not support, what each manufacturer publishes and what it does not, and the places where an interesting number turned out to rest on nothing. A reader looking for one argument will not find one, because a census is not an argument.

Later editions are triggered rather than scheduled, so each will be shaped by whatever trig-

gered it. A drive entering the ISASecure register, a certificate number becoming public, a standards edition landing, or a block of the verification queue resolving: any of those gives the next edition a spine this one could not have, which is a delta measured against a published baseline. They should be shorter and narrower than this one, and they will be readable only because this edition did the wandering first.

When this is reissued. There is no fixed schedule, because the subject does not move on one. Standards editions are years apart, the certificates in section 5 run to 2030, and the market figure is published annually. This report is reissued when something material changes: a drive entering the ISASecure register, a certificate number becoming public, a new standards edition, a regulatory date arriving, or enough of the verification queue resolving to move the matrix. Every reissue carries its own date and names what changed and who corrected it.

The complete method, the AI involvement disclosure, the competing interests statement and the errors and omissions note are in **Appendix A**. The scoring rubric every matrix cell was scored against is in **Appendix B**. Corrections go to carl@waywardleaders.com.

1. Start here: the clause you cannot meet

No drive from any manufacturer appears in the ISASecure certified components register.

The public ISA/IEC 62443-4-2 certified component list was pulled on 14 September 2026. It carries roughly 80 entries, from ABB, Schneider, Honeywell, Emerson, Yokogawa, Hitachi, Toshiba Infrastructure Systems, Cisco and Johnson Controls. Every single one is a controller, a safety system, a switch, a firewall, an RTU, a gateway or a chiller controller.

Not one is a variable frequency drive.

That single fact reframes the entire cybersecurity conversation, and it has an immediate practical consequence. **A specification clause reading “component shall hold ISASecure CSA certification” is currently unmeetable by any drive on the market.** If that clause is in your standard specification today, it is either being waived quietly on every job or it is excluding every bidder.

A clause reading “component shall hold IEC 62443-4-2 certification” is different, and it is meetable, because certification and register entry are not the same artefact.

What exists, with numbers. ABB’s ACS880 holds certificate **968/CSP 1036.00/25**, issued by TÜV Rheinland on 4 July 2025 against IEC 62443-4-1:2018 and 62443-4-2:2019 at **Security Level Capability 1**, valid to 4 July 2030, with a published revision list tying it to UCU-based ACS880 variants in the V1.30.x and V1.31.x firmware families. Rockwell holds comparable TÜV Rheinland attestations in the same numbering scheme for PowerFlex 755T and 6000T.

What is claimed but not numbered. Danfoss announced VLT certification on 16 April 2026 and the certificate number never came out. Siemens publicly states that its next-generation SINAMICS drives are certified by UL Solutions to IEC 62443-4-2 at **SL-C 2**, which if it holds is the highest security level claimed by any drive anywhere, and the certificate number is not public. Eaton DX1 and Inovance make claims in the same posture.

two traps worth naming, because more than one instrument walked into both. Schneider holds genuine 62443-4-2 certificates, including **968/CSP 1017.00/24** for the ATS490 soft starter and one for a UPS network management card. Neither covers an Altivar drive. And Toshiba does appear in the ISASecure register, as **Toshiba Infrastructure Systems and Solutions Corporation**, for a distributed control system controller certified in 2017. That is a

different legal entity from Toshiba International Corporation, and it is not a drive.

What to write instead. Name the standard, the part, the security level capability, and require the certificate number and its scope statement in the submittal. A vendor holding a real certificate will hand you a PDF. A vendor holding a process certification under 62443-4-1 will hand you something that describes how it develops software, which is a genuinely different claim and one that says nothing about the product in your panel.

2. Five things that did not happen

2.1 Silicon carbide did not arrive in the drive you buy

Every general purpose low voltage range from ABB, Siemens and Danfoss remains silicon IGBT. Three independent instruments reached that conclusion separately.

The confusion is real and it has a clean explanation: **the silicon shipped and the drives did not.** The component layer moved hard and it moved on the record. onsemi announced EliteSiC SPM 31 intelligent power modules on 24 March 2025. Mitsubishi began sampling Full-SiC and Hybrid-SiC SLIMDIP modules on 22 April 2025. Those are real products with real dates. Trade coverage of a module launch reads almost identically to trade coverage of a drive launch, and 7 years of that has produced a widespread belief that the transition already happened in general purpose product.

Commercial silicon carbide drives do exist, and they are specialist. SmartD’s Clean Power VFD carries a dated datasheet, SDB-2-2375-A, 29 January 2026, 575 V, 105 kHz nominal and 210 kHz effective switching, 96 per cent efficiency, IE2, all figures manufacturer-stated. Inovance’s MD520HS is described as hybrid SiC in trade coverage dated 3 August 2026, from a single source, with no Inovance document located to confirm it.

No independent efficiency measurement of any commercially shipped silicon carbide low voltage drive exists. All four instruments agree, and the literature side is the more interesting confirmation: every silicon carbide inverter efficiency result published since 2018 is a laboratory prototype. No peer-reviewed paper evaluates a drive you can buy.

There is a specification consequence that almost nobody states. **Specifying silicon carbide and then leaving carrier frequency at the 2 kHz industrial default throws away most of the advantage you paid for**, and no 2026 catalog reviewed in this work forces a higher default. If you buy fast switching, you have to commission for it.

2.2 Gallium nitride is not in industrial drives at all

three instruments searched and found none. The gallium nitride that shipped in 2025 and 2026 is 400 to 600 W appliance and servo silicon: Navitas GaNSense motor drive integrated circuits shown at PCIM in May 2025, ST GANSPIN611 and GANSPIN612 in production from 24 November 2025, EPC integrated stages in mass production from 26 August 2026. These are not 400 V industrial frames and nobody in the component supply chain claims they are.

2.3 The active front end did not become the default

The evidence is the manufacturers' own catalog structure. Vendors still organize their ranges around six-pulse, low-harmonic and regenerative as different architectures with different prices, which is not what a portfolio looks like after a technology becomes standard.

The regulatory detail behind it is the sharpest supporting fact in the whole technical leg. **EU Regulation 2019/1781 exempts regenerative drives and drives below 10 percent current total harmonic distortion from the IE2 obligation.** Active front ends are therefore sold on

application requirement, not on efficiency regulation, and a sales conversation that implies otherwise has the causation backwards.

2.4 Drive-resident bearing and insulation diagnostics are not proven

This is the strongest convergence in the entire body of work. Every instrument reached it, emphatically.

The scholarly harness explains **why** in a way no web-searching tool could, because it followed citation chains rather than reading claims.

The condition monitoring literature is built on one dataset. The field is dominated by machine learning applied to the Case Western Reserve University bearing data: accelerometer vibration from a single test rig, with seeded faults, at known loads. A model reporting 99 percent accuracy against CWRU has not been shown to work on another motor, in another installation, with a naturally progressing fault. That is not a criticism of the researchers. It is a statement about what the field has and has not yet produced, and it explains directly why independent validation of drive-resident diagnostics cannot be found: the validation studies have not been done.

Bearing current behavior under fast switching traces to essentially one research group, working at Bristol and China University of Mining and Technology. The measurements are careful. They have not been independently reproduced. The link between faster switching and reduced bearing life is asserted from mechanism, and no accelerated life test or field return dataset supporting it has been published.

The 2 per-unit overvoltage at 40 feet with a 50 nanosecond rise time traces to one source nobody can retrieve. Following the chain leads to reference 9 of a 2021 paper, which could not be obtained. The figure is con-

sistent with transmission line theory. It is a citation chain rather than a measurement everyone repeated, and it is quoted in trade literature as though it were the latter.

No experimental head-to-head comparison exists of a diode bridge with a DC choke against a passive filter against an active front end, on the same drive, measuring total harmonic distortion and efficiency at multiple load points. The comparative claims in review paper introductions trace to sources that could not be verified.

What this means in practice: a drive that counts run hours, load and heatsink temperature and tells you about its own fans and capacitors is doing something real and useful. A drive that claims to tell you about your motor's bearings from current signature alone is making a claim the published evidence does not yet support. Treat the second as a research feature, not a maintenance strategy.

A note on the author's own work in this space, since it belongs in the same column as everybody else's. ORCA-VFD (Tolbert, 2026b) is a sensor-less remaining useful life method that reduces 41 raw drive parameters to eight signals available on nearly every commercial VFD, and it reports R^2 of 0.9991 against a 100,000 hour degradation trajectory. Read the next sentence before that number travels anywhere. The trajectory was synthesized. The monitored drive was a 7-year-old ABB ACS880 running a screw conveyor at 20 percent to 30 percent of motor full load current, and it did not reach failure during the 720 hour collection window. The paper's own abstract calls it a deployable proof of concept for sensor-less condition-based maintenance rather than a field-validated failure predictor, and names prospective validation against observed failures as the necessary next step.

What is validated against real field data in that paper is the discriminant analysis and the domain alignment: genuine field measurements

carry degradation texture in noise, drift and operational variability that physics simulation and fault injection do not, and aligning across those domains cut maximum mean discrepancy from 2.84 to 0.31. That is a real result. What is not validated is the failure prediction, because no failure occurred.

That is the standard this report applies to 13 manufacturers, applied to the author first. A vendor publishing exactly those figures with exactly those caveats would score well on this matrix, and nobody could use the result to claim the drive predicts bearing failure. The claim and the evidence have to travel together, and the discipline is easier to demand of somebody else.

2.5 Integrated motor drives are not new, and the number that matters is not published

The claim that motor-mounted and distributed drives arrived in the 2024 to 2026 window fails a simple chronology test. SEW documented MOVIMOT integrated motor-inverter gearmotors around 2010. Siemens announced the SINAMICS G115D, which combines motor, frequency converter and gearbox into one unit in motor-mounted and wall-mounted versions, on **2 November 2020**. A product cannot be a recent arrival if it shipped six years earlier, and that test is worth applying yourself to any "new for 2026" claim before it reaches a specification.

The useful question about integration is the one a maintenance planner asks and nobody answers. If the drive and the motor sit in one package, and they do not wear out at the same rate, what happens when the first one dies. That objection survives the chronology correction, so this work tried to verify it. The result is worth reporting in full, because the mechanism checks out and the number does not exist.

The mechanism asymmetry is documented and it is not subtle. A drive's service life is governed by consumable wear items, princi-

pally the DC bus electrolytic capacitors and the cooling fans. Toshiba publishes 10 years for both, at 40 °C average ambient, 65 percent relative humidity, 80 percent load factor or below, and 24 hour operation. KEB states that most manufacturers will admit a typical life expectancy of 7 to 12 years, and that fans and capacitors can begin to fail at about 5 years. A motor's service life is governed by bearings and winding insulation, running on L10 bearing life and thermal aging of the insulation system. Those are different physics with different drivers and different interventions. Re-grease a bearing on schedule and you extend it. Nothing you do on a Tuesday extends an electrolytic capacitor.

Danfoss published the clearest statement anyone in this industry has made about why the two numbers cannot be compared, and it deserves reading before any lifetime claim reaches a specification. Danfoss separates service life, the period the manufacturer expects the product to remain in service without catastrophic failure under reasonable standard conditions, from MTBF and MFOP, which it describes as predicted time between failures produced by hypothetical modelling. It then illustrates with two manufacturers both claiming 10 years of lifetime: one at 80 percent load, 5 days a week, 8 hours a day, the other at 100 percent load, 7 days a week, 24 hours a day. Identical claim, more than four times the operating hours behind it. The second illustration is sharper still, 1 manufacturer specifying fan exchange after 2 years and capacitor exchange after 3, against another stating that all components are specified for product lifetime. Those are Danfoss's illustrative examples rather than Danfoss product figures, and the point they make is the same one Toshiba's four stated conditions make: a lifetime number without its duty cycle is not a number.

Then the verification fails, and the failure is the finding. No manufacturer publishes field return rates for drives, established elsewhere in

this report across all 13 scored companies. The motor side does have data, and it is older and more contested than its reputation. The EPRI study dates to 1983, run by General Electric across 4,797 motors with 1,227 failures on 872 machines, 100 HP and larger, in utility service. IEEE surveys followed in 1985 covering 200 to 10,000 HP industrial and commercial installations, and in 1995 for petrochemical. Penrose, auditing what those studies actually reported, states that many of the statements attributed to them are either incomplete or entirely incorrect, and that facility-level maintenance variation rather than inherent motor reliability explains most of the difference in failure rates between sites. The EPRI breakdown he gives runs insulation to ground 18.5 percent, sleeve bearing 9.7 percent, ball bearing 4.9 percent, turn insulation 3.7 percent, rotor bar 3.5 percent, and unspecified or other 35.9 percent.

Hold that last figure next to the claim that bearings cause 41 percent of motor failures, which appears in very nearly every condition monitoring presentation ever given. The audit is a single source, it was not verified here against the primary studies, and it is flagged as a singleton for that reason. If it holds, the most-quoted statistic in predictive maintenance is a conflation of 2 separate studies with different populations, different horsepower ranges and different results. That is the same failure this report found in the capacitor life folklore and in the condition monitoring literature, and it should make anybody careful about a number they have repeated for years without reading its source.

What is published nowhere. No failure rate for an integrated motor-drive unit taken as a unit. No comparison of motor and drive failure rates across the same drive-fed population. No motor reliability study whose data post-dates widespread drive-fed operation, since every survey above predates it. The question a buyer of an integrated drive actually needs answered, whether the packaging costs more

in premature replacement than it saves in installation and wiring, has no public answer from anyone selling one.

Classified **(a)**, appears not to exist. It is also the single disclosure that would settle the integration argument, which may be why nobody has produced it.

3. The standards you are citing may not say what you think

3.1 IEEE 519 belongs at the point of common coupling

IEEE 519-2022 changed its wording more than its numbers, and the wording change is the one that matters to you.

Voltage limits are unchanged. Even-order current limits were relaxed: harmonics at or below the sixth are now limited to 50 percent of the tabulated odd limit, and above the sixth to the full limit, against a blanket 25 percent in the 2014 edition.

The change with money attached is the **explicit scope note stating that the limits apply at the point of common coupling and are not intended for the evaluation of equipment**. All three commercial instruments independently flagged the same thing: a specification that imposes IEEE 519 at the drive terminals was always a misapplication, and the standard now says so on its own face.

This is not theoretical. **American Water publishes a standard specification, section 26 29 23, revised 2021, stating that the VFD unit shall meet all IEEE 519 requirements for individual and total harmonic distortion.** That clause applies 519 to the unit, which the governing edition explicitly disowns. A major United States water utility's standing specification is therefore driving low-harmonic and active front end purchases against a test the standard says is not for that purpose.

If you have inherited a specification like that,

you are potentially buying filters, line reactors or an active front end that the standard does not require at that measurement point. Whether you still want them is an engineering decision about your own system impedance and your own transformer, and it should be made on that basis rather than on a misread clause.

3.2 “Complies with 61800-5-1” is not a specification

three numbers, three different documents, and a 15 year gap between two of them.

IEC 61800-5-1 Edition 3.0 is dated August 2022, with corrigenda in September 2023 and December 2025.

UL 61800-5-1 Edition 2 was ANSI-approved on 24 June 2022, and it is still rooted in the **2007** second edition of the IEC document. two standards with nearly the same number and nearly the same approval date, 15 years apart in technical content.

CSA C22.2 No. 61800-5-1:25 replaced CSA C22.2 No. 274 in June 2025.

A submittal that says “complies with 61800-5-1” without naming the edition and the certification scheme has told you nothing you can act on. Require the edition, the scheme, and the certificate or listing reference.

3.3 The stale standards problem, and why stale is not invalid

This one looks worse than it is, and the nuance is what makes it publishable rather than alarmist.

Eaton's PowerXL DG1 design guide, document **DG040001EB**, cites UL 508C and CSA C22.2 No. 274-13. Both are two editions dead. ABB, Rockwell, Mitsubishi and Fuji documents still cite CSA C22.2 No. 274 somewhere in current literature. Fuji's current FRENIC-GS product page cites UL 61800-5-1 Edition 1 and CSA

C22.2 No. 274.

But the CSA certification transition from No. 274 to No. 61800-5-1:25 runs to 1 September 2027. A 2026 manual citing No. 274 is stale disclosure, not an invalid listing. After September 2027 it becomes a genuinely different question, and that date belongs on your calendar rather than in an argument today.

On listing currency, the honest scoring is that **nobody leads**. Every vendor checked still cites the superseded CSA document somewhere.

3.4 Functional safety: Safe Torque Off is the baseline now

IEC 61800-5-2 is still the 2016 edition. No revision to plan around.

Safe Torque Off is the baseline and has reached the value tier of the market. AutomationDirect's DURApulse GS4, up to 300 HP, lists STO and 100 kA short circuit current rating as standard. Toshiba's AS3 puts STO on a detachable terminal strip. Control Techniques puts dual-channel STO at SIL 3 and PL e in every Unidrive M. **A specification that calls STO out as a priced option is reading a market that no longer exists.**

Safe Stop 1 is moving into base build on some families. Danfoss extended PROFIsafe and SS1-t across all iC7-Automation sizes on 30 January 2026. NORD integrated STO, SS1, SLS, SMS and SSM into NORDAC ON on 6 July 2026. Safely Limited Speed, Safe Direction and Safe Speed Monitor remain options on most general purpose frames, and they carry a commissioning test, which is a schedule item people forget to price.

The best function-by-function disclosure in the industry is Eaton's, for the DX1: STO at SIL 3, PL e, Category 4; SS1, SLS, SSM and SBC to SIL 3, PL e, Category 3; SS2, SOS and SDI at SIL 2, PL c. That granularity is what a safety verification actually needs, and almost

nobody else publishes it that way.

The best safety reliability data in the industry is ABB's, in document **3AXD10002751766 Rev A, dated 25 February 2026**. It gives PFH to two significant figures per frame size per option code, with PFDavg at two proof test intervals, diagnostic coverage, systematic capability, category, hardware fault tolerance, common cause factor, mission time, and a written statement of the demand assumption used in the calculation. One worked example: option +Q963, emergency stop with STO, frames R6 to R8, SIL 3, PL e, PFH 4.6E-08 per hour, PFDavg at a 2 year proof test interval 2.8E-04, DC at least 90 percent, HFT 1, CCF 80, mission time 20 years.

That is a document you can compute a SIL verification from. It is the standard the rest of the industry should be held to.

3.5 NEC 2026, with a caution

No change to Article 430 Part X was found by any instrument. That is the useful headline for drive installations.

The remaining detail comes with a real caveat, and the caveat is the point. One instrument produced a list of 2026 changes; another declined to quote final wording at all on the grounds that what it could verify was a second-draft NFPA record rather than adopted text. The second posture is the safer one for published work, and it is adopted here.

Reported, and to be checked against adopted text before it reaches a specification: a new 430.22(H); a new Table 430.251(C) and a revised Table 430.52(C)(1) addressing Design BE and CE motors; a new Article 120 consolidating load calculations; expanded arc flash labelling at 110.16; and 210.8(F) effective 1 September 2026.

The item worth keeping if it holds is an informational note at 210.8 recognizing **HF and HF+ marked ground fault circuit inter-**

rupters for high frequency leakage from electronic power conversion equipment. That is a real specification consequence, because Class A devices trip on 4 to 6 milliamps at line frequency and were never designed for the leakage spectrum a drive produces. If you have fought nuisance GFCI trips on drive-fed circuits, this is the code recognizing the problem.

3.6 Efficiency: nothing is tightening, and nobody should schedule around it

European Union. The IE2 minimum for drives under Regulation 2019/1781 has applied since 1 July 2021 and it stands. The review process runs from December 2024 into spring 2027. One instrument reports a Commission adoption aim of 2029; another reports a second stakeholder meeting on 24 September 2026. Both are single-source and both are worth watching. Neither supports a claim that a tightening is imminent.

United States. No federal VFD efficiency standard exists and none is in rulemaking. The Department of Energy Process Rule notice of proposed rulemaking of 7 July 2026 makes future standards procedurally harder to make, not easier.

India. IS 17123 Part 9 Section 1:2025 and Part 9 Section 2:2025 exist, aligned to IEC 61800-9, announced in a BIS bulletin dated 7 April 2025. A published standard is not a mandatory order, and no obligation was located.

China. Two documents, and neither instrument alone gives the true picture. **GB 30253-2024** is a mandatory permanent magnet synchronous motor standard in force from 1 October 2025 that reaches converter-fed machines. It is a motor rule, not a drive rule. **GB/T 12668.902-2021**, effective 1 October 2021, adopts the IEC 61800-9-2 method for drives but is a recommended GB/T rather than a mandatory GB. So China has a voluntary drive classification standard and a mandatory motor standard that catches converter-fed permanent magnet ma-

chines.

The motor side has the date that will actually bite you. The Department of Energy cutoff on 100 to 250 HP motors falls on **1 June 2027**, which is precisely the HP band where retrofits cluster.

And a related trap worth stating plainly, because it costs real money: **a NEMA Premium motor is an efficiency designation and says nothing about MG-1 Part 31 inverter-duty insulation withstand.** A high efficiency motor is not thereby inverter duty. Worse, **a like-for-like HP swap behind an installed drive is a commissioning event, not a drop-in**, because lower loss designs run different slip, different rated current and different thermal behavior. After 1 June 2027 that becomes routine in the exact band where it matters most.

One further item, flagged as unverified because it decides whether a job gets a filter. **The widely quoted pairing of “1,600 volt peak, 1 microsecond rise time” attributed to NEMA MG-1 Part 31 appears to be wrong on both counts.** The one microsecond figure belongs to machines above 600 volts, and Part 31 states a withstand as a function of rated voltage rather than a flat limit. The estimated error runs roughly 174 volts too generous on a 460 volt machine and roughly 260 volts too stingy on a 600 volt machine. This is a single-instrument finding and it is unverified. Check it against the current Part 31 text directly before you rely on either number. The literature offers no help: no paper since 2018 measures a silicon carbide drive output against Part 31 limits and reports pass or fail.

4. The one genuinely new legal obligation

In 3 years, the only new legal obligation placed on a drive is cybersecurity, and it is already live.

Regulation (EU) 2024/2847, the Cyber Resilience Act. In force 10 December 2024.

Chapter IV applying from 11 June 2026. **Article 14 reporting obligations live since 11 September 2026, and applying to products already on the market.** Full essential requirements and CE marking from 11 December 2027.

The reporting clock is specific: **24 hours for an early warning, 72 hours for full notification, 14 days for the final report.**

Read that middle line again. The reporting obligation reaches products already installed, not just new placements on the market. If you operate in the European Union, or buy from a manufacturer who does, the drives in your plant are already inside the scope of a regime that did not exist 3 years ago.

What this changes in procurement, concretely. The line item that appears next in tender documents is not a certification preference. It is CRA conformity and a named vulnerability contact, because that is a legal condition of sale rather than a nice-to-have. A manufacturer who cannot tell you today who receives a vulnerability report, and what happens in the following 24 hours, has a problem that is going to become your problem at handover.

Note the sequence, because it is unusual and worth understanding. **Certified product exists ahead of the demand for it.** No tender or standard specification requiring 62443-4-2 of a drive was located anywhere in this work, despite certified product existing since early 2025. The manufacturers built the certification before the market asked. The CRA is what turns that from marketing into a condition of sale.

5. The vendor disclosure matrix

5.1 What this measures, and the rule that makes it fair

Nobody can rank low voltage AC drive vendors on market share. No public share table

exists. Interact Analysis holds one for vendors above 1 percent and it sits behind the report price. Every “ABB leads with X percent” in circulation is quoting nothing.

So this ranks something else, something that turns out to matter more to you: **what a manufacturer will put in a public document with a revision number.** Certificates with numbers. Loss data at stated operating points. Safety reliability figures with stated assumptions. Condition monitoring descriptions that admit what is measured and what is modelled.

A low score means the evidence is not public. It does not mean the product is deficient. Rockwell’s engineering material sits in its literature library and its Product Compatibility and Download Center. Siemens routes through SIOS and the Industry Mall. Those are disclosure postures, not quality judgments. Every absence is classified (a), (b) or (c) as described at the front of this report.

three family scores, never summed. Compliance out of 12. Engineering evidence out of 9. Operator reality out of 6.

5.2 The matrix

What these integers are, and what they are not. They are ordinal scores, not measurements. They rank manufacturers against each other on how much a buyer can retrieve and read without asking permission, and they were assigned against the rubric published in Appendix B, which is where an argument with any cell should start. Treat the ordering as the finding and the integer as shorthand. Where a cell looks wrong, the notes column and section 9 name the documents the score rests on, and a correction lands on that cell.

Lighter treatment, insufficient evidence to score: Fuji Electric, Hitachi, TECO-Westinghouse, AutomationDirect, INVT, Veichi. Notes on each in section 5.7.

Vendor	Compliance /12	Engineering /9	Operator /6	Notes
ABB	9	8	4	Best certificate transparency, best safety data document in the industry
Toshiba TIC	5	8	6	Only manufacturer publishing wear component life with stated conditions
Danfoss	7	8	5	Best functional safety guides, hardware revision appendices
Rockwell	7	7	5	Only drive family besides ABB with a public certificate number
Siemens	7	7	3	Best loss-point data in the set. Software access the weakest cell
Eaton	5	6	3	Function-by-function safety disclosure, stale standards citations
Mitsubishi	5	6	4	Strong safety architecture, parameter copy to ordinary USB
Schneider	4	6	3	Certificate trail weaker than the marketing
Nidec / Control Techniques	4	5	4	Open legacy library, stale platform
Yaskawa	4	6	3	Concise conditioned performance data, software behind a request form
WEG	3	4	2	Firmware is channel-controlled and says so
Delta	3	3	2	STO certificate displayed as expired October 2024, no renewal located. Number in section 9
Inovance	3	3	2	SL2 certificate file exists, scope unresolved

Table 2. The vendor disclosure matrix. Family scores are reported separately and never summed

5.3 The contested cells, and how they resolved

four cells split between instruments. **Three resolved the same way, and the pattern is the most important methodological finding in the project.**

ABB's cybersecurity certificate. One instrument stated flatly that no drive 62443-4-2 product certificate existed for ABB, and said elsewhere that Rockwell's was the only one anywhere in the review. Two others independently produced certificate 968/CSP 1036.00/25, matching on holder (ABB Oy Drives, Helsinki), issuer, standards, security level, issue date and validity. **Resolved: the certificate exists.** And it is ACS880-specific.

ACS580, ACQ580 and ACS180 have no such certificate, and a separate medium voltage certificate, 968/CSP 1071.00/26, is not a low voltage ACS certificate.

Wear component life. two instruments declared an industry-wide vacuum, one of them in absolute terms: not a single vendor publishing cooling fan L10 hours or DC link capacitor design life at a named ambient on an open page. The third produced **Toshiba's AS3 Predictive Monitoring Product Guide, Rev. 11ESSENCE0824 (2024)**, which states a **10 year design life for the smoothing aluminium electrolytic capacitors; 10 year cooling fan life** for VFAS3-2004P to 2550P and 4004PC to 4132KPC; and **5 year main**

fan with 9 year inner-air fan for 4160KPC to 4280KPC. Reference conditions stated: **40 °C average ambient, 65 percent relative humidity, at or below 80 percent load factor, 24 hour operation per day. Resolved in favor of the document.** The vacuum is real across the majors. The one manufacturer filling it is a mid-tier North American supplier.

Danfoss condition monitoring. One instrument could not establish whether vibration monitoring requires an external accelerometer. Another found Danfoss stating that it does, that the drive accepts up to four channels of 4-20 milliamp channels, and distinguishing the calculated value used for bearing degradation from overall vibration used for imbalance, misalignment and looseness. **Resolved in favor of the document**, and it is the only full mark awarded on condition monitoring honesty.

Siemens SL-C 2. Asserted by one instrument, not found by two others, not confirmed independently. Resolved as **vendor-stated, third party named, number not public.** That scores 2, not 3, and not 0.

The pattern. Three of four contested cells resolved the same way: one instrument declared an absence and another produced the document. Across six weeks of this work the same thing has happened in every direction, with every tool taking a turn at being the one that was wrong.

The operating rule that falls out of it: a declared gap is a statement about one search, not about the world. It is why triangulation is worth the cost and why no single instrument's negative finding should reach print.

5.4 What the matrix shows

Disclosure does not track company size. Toshiba International, a mid-tier North American supplier, scores 8 on engineering evidence and a perfect 6 on operator reality, beating Siemens, Schneider and every Chinese en-

trant. Its AS3 page serves instruction manuals, extended manuals, communications files, the STO safety manual, a leakage current guide, an engineering specification at revision 9/25/2024, motor matching guidance, a start-up check sheet and the predictive monitoring guide, with no login.

The industry's best and worst quantitative disclosure sit in the same documents. ABB publishes 3AXD10002751766 Rev A with the full functional safety dataset described in section 3.4, and publishes nothing whatsoever about how long the fan lasts. **You can compute a SIL verification from ABB's public data. You cannot compute a maintenance budget from it.**

Almost none of the brands reviewed publishes MTBF, and that is to their credit. One exception was located, a Danfoss declaration from 2010 with method caveats and frame-size bands, correctly characterised as a dated vendor calculation rather than a field rate. Otherwise silence. Given that Telcordia, MIL-HDBK-217 and IEC 61709 produce materially different numbers for identical hardware, silence is more honest than a figure. If a vendor hands you an MTBF, your first question is which method, and your second is whether that method's number is comparable to the competitor's number, and the answer to the second is usually no.

Field return rates: not one of the brands reviewed publishes them. Classified (a) across the board on the evidence reviewed here: not found, not produced. It would be the single most valuable disclosure any drive manufacturer could make, and it is the one thing none of them will do.

Commissioning access is far more open than the trade folklore says, and this surprised every instrument. ABB's Drive Composer Entry is free. Rockwell's Connected Components Workbench Standard Edition is a free public download and 755TS firmware is publicly downloadable through PCDC. Dan-

foss MCT 10 Basic is free. Schneider's ATV600 firmware was publicly downloadable in May 2026. Mitsubishi's FR-A800 copies parameters to **ordinary USB memory**, not to a proprietary module. Keypad-only commissioning is universal. Parameter lists are in published firmware manuals at stated revisions.

two documented exceptions. **WEG states plainly that firmware cannot be downloaded through WPS and must be obtained from WEG or supplier technical support**, which is the clearest channel-control statement anyone makes, and it is at least honest. **Yaskawa's DriveWizard Industrial requires an online request form**. Siemens is structurally different rather than restrictive: Startdrive lives inside TIA Portal licensing rather than existing as a free standalone tool.

If you have been told that a given brand locks you out of your own drive, check it. In most cases in 2026 it is not true.

5.5 On shared platforms, and why the re-badge argument is a dead end

Two claims circulate constantly here and both get used as competitive ammunition: that AutomationDirect's DURApulse is a labeled Delta Electronics drive, and that Toshiba drives are rebadged Schneider. Neither was established in this work. One of them has a public record that surprises most of the people who repeat it.

Schneider Toshiba Inverter SAS was formed in 2000 at Pacy sur Eure in Normandy, Schneider 60 percent and Toshiba 40 percent, building general purpose inverters up to 630 kW and selling them under both badges. That is public, it is uncontroversial, and it puts Toshiba as the minority partner in a Schneider-controlled entity rather than the reverse. The entity is still active as Schneider Toshiba Inverter Europe SAS. Whether any particular current product came out of it is a separate question the public record does not settle, and the chronology test applies as it does everywhere: a venture

formed in 2000 establishes nothing about a platform launched two decades later.

Now the part worth more than the answer. Suppose it is all true. Suppose every shared-platform rumor in this industry checks out exactly as told. So what.

Shared manufacturing is ordinary. In any industry where a supplier sells at 3 levels, components, assemblies, and complete designs, the same hardware appears under several badges, and nobody in automotive or appliances or aerospace treats that as a scandal. A supplier who will sell you a module, or a subassembly, or a finished design with your name on it is running an ordinary business.

The logic also cuts both ways, which is what makes the argument a dead end. If a shared platform is inferior, it is inferior under every sticker on it, including the one being sold by whoever raised the point. If it is sound, it is sound under both. Learning that two drives share a board tells a buyer almost nothing about either one.

What differs between badges is everything this matrix actually measures, and 2026 is the year that stopped being arguable. Certification scope varies enormously between companies whose hardware may well overlap: ABB holds 968/CSP 1036.00/25 for the ACS880 and holds nothing comparable for the ACS580, while Schneider's genuine 62443-4-2 certificates cover a soft starter and a UPS card rather than any Altivar. Toshiba publishes capacitor and fan life with four stated conditions and several of the largest companies in the industry publish nothing comparable. Firmware downloads free and public from some, and is channel-controlled by others who say so plainly in their own documentation.

None of that is decided by who etched the board. It is decided by what the company chose to publish, certify, stock, support and stand behind: parts availability and lead time, docu-

mentation and firmware access, who answers the phone on a Saturday, how the warranty is administered, whether the commissioning software costs anything, how deep the spare stocking runs, and whether an application engineer will take the call. That is the ecosystem, it is what a badge actually sells, and by 2026 the distance between ecosystems is wider and far easier to verify than any distance between the boards.

So the rebadge question is the wrong question. The one that pays is narrower. What does this badge give me that the other one does not, in certification scope, documentation, parts and support. The matrix answers that, and answering it requires nobody to settle a rumor.

5.6 Best in class, by dimension

Rockwell deserves a separate note. It publishes the most sophisticated component remaining-life model in the set, estimating remaining life of IGBTs, fans and blowers, DC bus capacitors, circuit breakers, LCL capacitors and filters from temperature, air quality, airflow, voltage, runtime, cycles and drive size. That is a model driven by operating history, and it is genuinely useful. It is not a published L10 rating and it is not field reliability data, and nobody should relabel it as either.

5.7 The lighter vendors

Fuji Electric. FRENIC-GS launched 30 May 2024, a genuinely recent platform. Publishes component life monitoring with remaining-life indicators for main circuit capacitors, control capacitors and cooling fans, which is better than a simple alarm. Software via FeLibrary, so access is (b). Current product page still cites UL 61800-5-1 Edition 1 and CSA C22.2 No. 274.

Hitachi. One lead worth an hour of somebody's time: a repair shop technical compilation cites the Hitachi SJ300 and L300P service manual giving cooling fan life of approximately **35,000**

hours, about 4 years. Single source, primary document unverified. If it confirms, Hitachi joins Toshiba as the only manufacturers publishing a wear interval. Everything else (c).

TECO-Westinghouse. Publishes **list pricing** on its open manuals page, which no other vendor in this set does. A copy module instruction document exists, so parameter copy is supported and documented; whether the module is proprietary hardware is unresolved.

AutomationDirect. Transparent by business model, since it sells online. GSoft2 is a free download. GS30 documentation states **100 percent conformal coating to IEC 60721-3-3 class 3C2**, a specific environmental citation larger vendors omit. The recurring claim that DURApulse is a rebadged Delta Electronics product remains **not established**, and by the argument above it would not matter much if it were. Worth noting for provenance discipline rather than for competitive purposes: the loudest source is an excluded fabricator domain, and the folklore version traces to a 2019 forum post whose author links to Delta **Controls**, a Canadian building automation company, not Delta **Electronics** of Taiwan. AutomationDirect separately resells Toshiba and says so openly in its own AS3 literature.

INVT and Veichi. Recorded as unassessed rather than as poor disclosers. Neither instrument reached English technical documentation at document-number level. Publishing a low score for either would be unfair on this evidence.

6. What a drive will tell you about its own health

Strip out the marketing and there are three genuinely different things being sold under the heading of condition monitoring, and they are not interchangeable.

A counter. Run hours, fan hours, power cycles. Every modern drive does this. Useful, uncon-

Dimension	Leader	Evidence
Cybersecurity certificate	ABB	968/CSP 1036.00/25 with security level, dates, validity, firmware revision list, and honest treatment of which option modules are not independently certified
Efficiency documentation	Siemens	G120X generated data sheets publish IEC 61800-9-2 converter losses at standardized operating points, not merely the IE class
Functional safety functions	Eaton	DX1 published function by function with SIL, PL and Category for each
Listing currency	no leader	Every brand checked still cites CSA No. 274 somewhere
Documentation depth	ABB and Toshiba	Revision-controlled PDFs, no login, document numbers visible
Reliability data	ABB for safety, Toshiba for wear life	No reviewed brand does both
Performance data	Toshiba	150% for 1 minute heavy duty and 120% for 1 minute normal duty, plus 180% for 2 seconds and 135% for 2 seconds; closed loop 0.01% at 1000:1, open loop 0.1% at 60:1; derating curves by frame against ambient and carrier; 1% per 100 m above 1000 m
Condition monitoring honesty	Danfoss and Toshiba	Danfoss names the 4-20 mA sensor requirement; Toshiba states it processes run time, load, temperature and output current and requires no external sensor
Commissioning access	Toshiba and AutomationDirect	Open manuals, register map, keypad transfer application note, free software

Table 3. Best in class by dimension, with the evidence each ranking rests on

troversial, and it tells you nothing you could not have written on a clipboard.

A wear model. The drive watches its own operating history, heatsink temperature, load factor and cycling, and estimates remaining life of its own components. Rockwell's is the most elaborate. Fuji publishes remaining-life indicators. Toshiba's AS3 processes run time, load, temperature and output current and requires no external sensor. **This is real, it is about the drive rather than the machine, and it is worth having.** Its accuracy against field

returns is unpublished, because none of the brands reviewed publishes field returns.

A machine diagnostic. The drive claims to tell you something about the motor, the bearings, the coupling or the driven load. **Here the ground gets soft.** Danfoss is the most honest about it: vibration monitoring requires external sensors on up to four channels of 4-20 milliamp channels, and the calculated bearing degradation value is distinguished from overall vibration used for imbalance, misalignment and looseness. That is a drive being a data acquisition

platform for sensors you install, which is a perfectly good thing to be, and it is not the same as a drive inferring bearing condition from current alone.

Buy the second. Be careful with the third.

Ask which of the three you are being sold, and ask what external hardware the answer requires. The published evidence for current-signature bearing diagnostics, as set out in section 2.4, does not yet support a maintenance decision.

And one number to carry around. **Toshiba's published wear life is roughly half the number in circulation.** The most-repeated figure on the open internet asserts that most drive manufacturers rate their products for 100,000 hours or more of powered operation at rated load and ambient, citing no manufacturer at all. Toshiba's document, from an actual manufacturer, says 10 years, with four stated conditions attached. **The vacuum is being filled by fabricated numbers**, and the real one is less flattering and far more useful.

7. The regulatory calendar

Dates that will change a specification, a budget or a purchase order.

Nothing on that list is a technology transition. All of it is regulatory, and all of it is on the record with a date, which is more than can be said for the silicon carbide timeline.

8. 15 questions to put to a vendor

Each one has a right answer that exists in a document, and each one separates a manufacturer who has the document from one who has a brochure.

1. Which edition of IEC or UL 61800-5-1 is this product listed to, under which scheme, and what is the listing reference?
2. Does your literature still cite CSA C22.2

No. 274, and what is your plan before 1 September 2027?

3. Do you hold an IEC 62443-4-2 product certificate, or a 62443-4-1 process certificate? Those are different. Which is it?
4. If you hold 4-2, what is the certificate number, the security level capability, the issuing body, the expiry, and the exact product and firmware scope?
5. Who receives a vulnerability report about this product, and what happens in the first 24 hours?
6. Are you placing this product on the EU market, and what is your CRA conformity position for 11 December 2027?
7. Publish or send me the PFH, PFDavg, diagnostic coverage, hardware fault tolerance, common cause factor and mission time for the safety option I am buying, at my frame size.
8. What is the design life of the DC link capacitors and the cooling fans, at what ambient, what humidity, what load factor and what daily run time?
9. What is your field return rate for this family?
10. If you give me an MTBF, which method produced it, and against which standard?
11. Does condition monitoring on this drive require any external sensor, and on which input?
12. What does the bearing diagnostic actually measure, and what has it been validated against outside your own laboratory?
13. Can I download the commissioning software and the firmware without a distributor account?
14. Is Safe Torque Off standard or priced, and which additional safety functions require a commissioning test?

Date	What happens
24 September 2026	Second EU ecodesign stakeholder meeting reported. Single source. Watch, do not plan
11 September 2026	Already live. CRA Article 14 reporting applies, including to products already on the market
1 June 2027	DOE efficiency cutoff on 100 to 250 HP motors. The retrofit band
Spring 2027	EU ecodesign review process concludes. Commission adoption aim reported as 2029
1 September 2027	CSA certification transition from C22.2 No. 274 ends. Stale citations stop being merely stale
11 December 2027	CRA full essential requirements and CE marking apply

Table 4. The regulatory calendar

15. At what carrier frequency are your published loss and derating figures stated, and what happens to them at the setting I will actually run?

Questions 9 and 12 will mostly go unanswered. Ask them anyway. The answers, and the refusals, tell you more about a supplier than the specification sheet does.

9. How to check this document

Nothing in here is asking for trust. The verification queue below is ordered by the cost of being wrong, and every item is one download away.

- **NEMA MG-1 Part 31.** The correction to the 1,600 volt and 1 microsecond figures. Single instrument, unverified, and it is the number that decides whether a job gets a filter. Read the current Part 31 text.

- **The ISASecure register.** Pull it yourself and date the retrieval. The claim that no drive appears in it opens this report and it should be checked on the day you act on it, not quoted from 14 September 2026.
- **Toshiba AS3 Predictive Monitoring Product Guide, Rev. 11ESSENCE0824.** The wear-life numbers are the most quotable figures in this report and they rest on one instrument's reading.
- **ABB 3AXD10002751766 Rev A** and certificate **968/CSP 1036.00/25**. Both are quoted in this report and both are public.
- **NEC 2026** Article 430 and 210.8 details, against adopted text rather than a draft record.
- **Siemens SL-C 2 certificate number**, still not public after three instruments and two research legs.

- **Danfoss VLT 62443-4-2 certificate number.** Announced 16 April 2026, number never came out.
- **Inovance certificate file “IEC62443-4-2 SL2-CBSCY 092835 0419 Rev.00”.** Pull it and confirm whether the scope covers a drive. If it does, Inovance holds the highest security level in the set.
- **Delta STO certificate 01/205/5429.04/19,** displayed as expired 23 October

2024. Confirm whether a renewal exists before repeating the lapse.

- **Eaton DG040001EB** standards citations, quoted directly.
- **The Penrose audit of the EPRI and IEEE motor reliability studies,** and the origin of the “bearings cause 41 percent of motor failures” figure. Single source, unverified against the primary studies, and it contradicts a number that has been repeated in this industry for 40 years. Pull the EPRI 1983 report and the IEEE 1985 and 1995 surveys before quoting either version.
- **Siemens SINAMICS G115D announcement date,** given here as 2 November 2020 from the Siemens press release. An earlier draft of this work carried July 2023, which was wrong.
- **Hitachi SJ300 and L300P service manual** fan life figure.
- **Inovance MD520HS.** two instruments have it from the same single trade article. Needs an Inovance document.
- **BS EN IEC 61800-9-2:2025+A1:2026.** A single catalog sighting with an unconfirmed publication date. Do not cite it.

If you check one of these and find this report wrong, that is the system working as designed.

The classification scheme exists so a correction lands on one cell instead of discrediting the table, and a correction that shows a document exists behind a login proves the central thesis rather than refuting it: the data was there, and it was not public.

Abbreviations

Appendix A: Method, AI Involvement, and Authorship

The Question Behind the Census

Every drive brand a buyer can specify in North America publishes something, and several publish a great deal, yet no one appears to have read all of it against a single set of questions, scored it against a single scheme, and placed the result where anyone could check it. That absence defines the project. The work is a census of disclosure, recording what each manufacturer currently available to a North American buyer has committed to the public record, read the same way, scored against the same criteria, with every absence classified rather than assumed. Questions about which drive performs best in service fall outside what the public record can settle, and this report does not attempt them.

The project originates in the author’s own research on this equipment. Tolbert (2026b) reported that among published predictive maintenance studies for VFD and motor systems, only 10.15 percent validate their approaches against genuine operational data from functioning industrial equipment, while the remainder rely on laboratory test stands, simulated signals, or artificially injected faults, and that laboratory-validated models deployed into the field reach false-positive rates approaching 30 percent. That finding concerns the scholarly literature. The question motivating the present work is whether the manufacturer literature exhibits the same structure, and the sections that follow answer that it does: claims circu-

late widely, retrievable evidence standing behind them is scarce, and the distance between the two is where a specifying engineer absorbs the cost.

The Instruments

three frontier models were run independently against a CASINO search design, the author's structured research prompt format, which specifies the scope areas, a source ranking from R1 through R5, an absence classification, a set of excluded domains, and a requirement that each return declare its own source ranks. Several open-weight models were run separately through a scholarly harness against an academic works index with live DOI resolution, an instrument that produced provenance findings the web-searching tools could not, among them the observation that the condition monitoring literature rests substantially on a single seeded-fault dataset. Author time on design, adjudication, structuring, and correction totaled approximately 20 hours.

Instrument selection was itself a research decision, and it narrowed the field deliberately. Gemini, Copilot, Perplexity, and comparable retrieval-weighted assistants were excluded following informal comparison trials the author conducted across prior projects. The reason is structural rather than a judgment of general capability. A tool optimized to synthesize an answer from ranked retrieval will produce an answer whenever ranked retrieval returns anything, and the present task depends on distinguishing three outcomes that such a tool tends to collapse into one: a document that appears not to exist, a document that exists behind a channel, and a determination that could not be made. An assistant asked whether a given manufacturer publishes cooling fan life will generally answer the question, and will less often report that the question has no public answer, which is precisely the report the absence classification requires. The exclusion rests on the author's own trials rather than on controlled

benchmarking, no such benchmark was conducted for this work, and a reader reaching a different conclusion about those tools is disagreeing with a judgment rather than with a measurement.

Disclosure of AI Involvement

The disclosure literature has converged on the position that generative AI cannot hold authorship and that its contribution is therefore reported at the level of the task rather than declared in aggregate. Miessler (2023) proposed an AI Influence Level scale running from 0, human created with no AI involvement, through 5, AI created with little human involvement, with the label shifting from human created to AI created at level 3; Tolbert (2026a) adapted that scale for doctoral and graduate work. Suchikova et al. (2025) reasoned from a different starting point toward a compatible conclusion, proposing a delegation taxonomy in which the human specifies which discrete tasks were delegated instead of assigning a single global rating, and Wahle et al. (2023) built the same principle into a reporting card that separates methodology from writing and presentation. This report follows that convergence, since a single AIL figure would misdescribe work whose components were produced at different levels, and the aggregate would conceal precisely the distribution a reader needs.

Two features of that distribution warrant comment. Retrieval carries no AIL value because document location sits outside what the scale was constructed to measure. A literature review is not designated AI created for having run its search through Scopus, and the operative questions are whether the retrieved item was read, whether the claim traces to it, and whether an independent reader can verify the trace. Every document number, certificate number, and revision date in this report is published so that the third question has an answer available to anyone who wants one.

The prose sits at level 3, where the scale shifts its label from human created to AI created and treats that shift as a change in authorship rather than a gradation of degree. The standard Tolbert (2026a) applies to doctoral writing is stricter than what was applied here, and the looser setting follows from what the work consists of, since the contribution lies in which documents were sought, how they were scored, which were excluded, and what the scoring passed over. Readers are entitled to that figure and to whatever weight they elect to place on it.

The Applicationist Contribution

The claim available here is narrower than the one commonly advanced on behalf of domain expertise, and its narrowness is what renders it defensible. The instruments demonstrated substantial competence with the subject matter, locating a TUV Rheinland certificate that two other instruments had independently declared nonexistent, an ABB functional safety document giving PFH by frame size and option code, a Toshiba wear-life table carrying four stated reference conditions, and a Japanese product page bearing on a rebadging question trade folklore has never settled. Several of those retrievals exceeded what a competent engineer would accomplish in comparable time.

What the instruments could not supply were the criteria. No search index contains the judgment that MTBF figures computed under Telcordia, MIL-HDBK-217, and IEC 61709 are not comparable to one another, and that silence on MTBF therefore constitutes a more honest disclosure than a number would. None contains the knowledge that specification writers routinely apply IEEE 519 at the drive terminals, which is what renders the 2022 scope note the most consequential finding in the technical leg. None weighs a missing fan life figure against a missing certificate according to which reader bears the cost of the omission. This is the appli-

cationist contribution, the work of a practitioner who applies theory rather than generating it, and it operates at the level of what ought to be measured rather than what can be found.

The clearest evidence of that contribution in this project is also the least flattering to it. The first pass followed documentation density rather than market presence, producing a technical leg weighted toward Danfoss, Vacon, Mitsubishi, and Toshiba while omitting Rockwell entirely, in both legs. No instrument identified the omission. The author identified it in a single sentence, because 27 brands of hands-on career history had established what the return should have contained and had not.

Positionality, Competing Interests, and the Limits of Adversarial Design

No non-disclosure agreement, non-compete, or privileged commercial information was employed in this work, and none was required, since every source cited is public and named. The author's situation nonetheless bears on the reading, and it is stated here rather than left for discovery. Thirty years in industrial controls and reliability, including hands-on work with 27 drive brands, supplies the criteria organizing this report and supplies whatever bias those criteria carry. The author is Senior Application Engineer and Director of Marketing at Malloy Electric, a distributor and service organization that carries **ABB, Toshiba, Fuji and SEW**. Two of those, ABB and Toshiba, hold the highest scores in this matrix, which makes this the disclosure that matters most in the document, and it is stated here rather than left for a reader to discover. Fuji appears only among the unscored lighter brands and SEW appears only in a chronology. Wayward Leaders LLC published and gates this report, and the commercial return on that gating is an email address.

Three things bound that conflict, and a reader should test all three rather than take any of them on assurance. The scores measure what

each manufacturer chose to publish, which the author did not control and cannot influence, and every cell traces to a document number that anyone can pull. The rubric that produced the scores is published in full as Appendix B, so a reader who suspects the nine dimensions were chosen to flatter a carried line can check that suspicion against the criteria directly. And the matrix is not uniformly kind to either brand: ABB scores 4 of 6 on operator reality and publishes nothing whatever about wear component life, while Toshiba scores 5 of 12 on compliance, the weakest showing among the top five. A scheme built to favor those two would not have produced those cells.

The interpretive stance taken here holds that rigor arises from making situatedness explicit and reflexively examined rather than from purifying interpretation of it. A practitioner carrying 30 years and 27 brands holds preferences, and a document denying as much would forfeit its credibility in the first paragraph. The productive question concerns what the design does about those preferences, and the answer divides along a line worth stating precisely.

Three instruments ran independently, without shared memory and without access to the author's priors, so that what the search returned was not conditioned on what the author expected it to return. They disagreed with one another and, on several cells, with him. A negative finding from any single instrument was treated throughout as a statement about one search rather than as a fact about the world, which addresses the specific failure to which a confident practitioner is most exposed. Evidence of that adversarial function appears in the document itself, where four cells on which the instruments disagreed are described in section 5.3 with the disagreement intact, and three of them resolved against the instrument that had declared an absence.

The design offers no comparable protection against the scheme. The author specified the

nine dimensions, and three instruments applying those nine dimensions inherit whatever the dimensions value and whatever they pass over. Adversarial retrieval interrogates the evidence standing behind a cell, and it has nothing to say about whether the cell warranted existence in the first place. A reader who concludes that the wrong properties were measured raises an objection this method cannot answer from inside itself, which is the reason the scoring scheme is published in full rather than summarized.

Errors, Omissions, and Why They Constitute Part of the Finding

This report contains omissions, and their presence carries more information than their absence would. The search design triangulates three independent frontier instruments against a scholarly harness running on an academic works index, declares its source ranks, excludes known-bad domains, and classifies every absence rather than assuming one. A routine of that construction, run against this subject, still returns gaps. Those gaps describe the state of the public record more than they describe a deficiency in the method, and the distinction governs how a reader should treat any particular missing cell.

Three categories of omission are anticipated here, and none of the three is correctable by searching harder. Material held behind a channel constitutes the largest. A manufacturer's reliability data residing in a distributor portal remains invisible to every instrument employed in this work regardless of how the prompt is written, which is the reason such cells carry the (b) classification rather than the (a). The second category comprises material that exists publicly and was not reached, since retrieval is probabilistic across instruments. The contested cells documented earlier demonstrate the mechanism from inside this project, where three of four resolved when one instrument produced a document that two others had independently declared nonexistent. That same failure op-

erates at the boundary of the search, where no instrument produced the document and no disagreement flagged its absence, and those omissions are undetectable from within the design. The third category is instrument selection itself. The exclusion of retrieval-weighted assistants described above removes whatever those tools would have contributed, plausibly including documents the retained instruments did not reach, and that exclusion was a judgment made for stated reasons rather than a neutral act.

A reader who locates a document this report treats as absent has therefore not refuted it, and a correction demonstrating that data sits behind a distributor login corroborates the central argument rather than undermining it, since the information existed and was not public. Corrections are welcome at carl@waywardleaders.com, and any subsequent edition will name what was corrected and who corrected it.

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Appendix B: The scoring rubric

Published in full so that any cell in the matrix can be argued with. Nine dimensions in three families, each scored 0 to 3. Family A totals 12, Family B totals 9, Family C totals 6. The families are reported separately and never summed, because adding incommensurate dimensions manufactures a precision that is not there. A vendor can be strong on compliance and weak on operator access, and showing that is more useful than averaging it away.

Family A: Compliance and certification (12)

A1. Product cybersecurity certification. 3 = IEC 62443-4-2 product certificate with the number public, SL-C stated, and revision scope identified. 2 = certified with the body named, number not public. 1 = 62443-4-1 process certification only. 0 = intent statements or nothing.

A2. Efficiency documentation. 3 = IE class per IEC 61800-9-2 with loss data at the standard's operating points plus IES power drive system data, publicly accessible. 2 = IE class and loss data, no PDS data. 1 = IE2 compliance asserted, loss data not findable. 0 = nothing public.

A3. Functional safety functions. 3 = STO and SS1 in the base build of the general

purpose family, SIL and PL stated against IEC 61800-5-2:2016, extended functions documented with option codes. 2 = STO base, SS1 by documented option. 1 = STO by option. 0 = not documented.

A4. Product safety listing currency. 3 = cited at edition, meaning IEC 61800-5-1 Ed 3.0 (2022), UL 61800-5-1 Ed 2 (2022), CSA C22.2 No. 61800-5-1:25. 2 = cited with editions partial. 1 = asserted without edition, or still citing the withdrawn CSA C22.2 No. 274. 0 = not findable.

Family B: Engineering evidence (9)

B1. Technical documentation depth. Publicly accessible without a login, at a stated revision. 3 = application guides at revision, harmonic data, cable length and dV/dt guidance with numbers, EMC category by configuration. 2 = most of that, some behind registration. 1 = datasheets and marketing only, engineering material behind a login or distributor channel. 0 = little public technical material.

B2. Reliability data published. Raw MTBF is deliberately excluded from the score. Published drive MTBF is calculated per Telcordia, MIL-HDBK-217 or IEC 61709 at a vendor-chosen temperature and load, and the same hardware yields numbers a factor of three apart by method. It is recorded where found, with its method and assumptions, and not scored. What is scored is the set of quantities the standards define identically for everyone. 3 = safety manual published with PFH, SFF, HFT, mission time and proof test interval for each claimed function, **and** wear component life at a stated ambient, meaning cooling fan L10 and DC link capacitor design life. 2 = safety reliability figures published, wear component life absent or qualitative only. 1 = SIL or PL claimed with no published PFH or SFF, or wear life stated without conditions. 0 = neither published. Recorded separately and unscored: stated design life, warranty term, and any published field return

or failure rate data.

B3. Performance data published. Figures are comparable only when their conditions are stated, so the score is for stating them. 3 = overload capability given by duty class with percentage, duration and duty cycle; derating curves published for ambient, altitude and carrier frequency; speed and torque control accuracy with the control mode and feedback arrangement named. 2 = overload and derating published, control accuracy absent or unconditioned. 1 = headline figures with no stated conditions. 0 = not published. A manufacturer quoting 200 percent overload without a duration scores 1.

Family C: Operator reality (6)

C1. Condition monitoring honesty. 3 = states per function which quantity is measured, which is modeled, and whether an external sensor is required. 2 = partial. 1 = capability claimed, physical basis not stated. 0 = marketing language only. This dimension inverts the usual reading. A manufacturer stating that its vibration monitoring requires accelerometers on 4 to 20 mA inputs scores high, because admitting the sensor requirement is disclosure. The low scores belong to anyone claiming bearing detection without saying what is measured.

C2. Commissioning and service access. 3 = complete parameter list published publicly; commissioning software free and downloadable without a login or service contract; firmware downloadable on the same terms; parameter backup and restore possible with the drive's own keypad or free software and no proprietary dongle; programming manual separate from the hardware manual, at a revision. 2 = most of that with one item behind registration. 1 = software or firmware requires a distributor relationship or paid account, or the parameter list exists only in gated documentation. 0 = little accessible without a channel relationship.

The rule that governs every cell

A low score means the evidence is not public. It does not mean the product is deficient. Rockwell's engineering material lives largely in its literature library and PCDC rather than on crawlable pages. Siemens routes through SIOS and the Industry Mall. Those are disclosure postures rather than quality judgments, and without this rule the matrix would be unfair in a way a manufacturer could correctly object to.

Term	Meaning
AFE	Active front end
CRA	Cyber Resilience Act, Regulation (EU) 2024/2847
CSA	Canadian Standards Association
DC	Diagnostic coverage
FLA	Full load amperes
GaN	Gallium nitride
HFT	Hardware fault tolerance
HTSUS	Harmonized Tariff Schedule of the United States
IE2	Efficiency class for converters under IEC 61800-9-2
ISASecure	Conformance scheme operated by the ISA Security Compliance Institute
L10	Bearing life at 10 percent failure probability
MTBF	Mean time between failures
PCC	Point of common coupling
PFDavg	Average probability of dangerous failure on demand
PFH	Probability of dangerous failure per hour
PL	Performance level under ISO 13849
RUL	Remaining useful life
SCCR	Short circuit current rating
SFF	Safe failure fraction
SiC	Silicon carbide
SIL	Safety integrity level
SL-C	Security level capability under IEC 62443-4-2
SS1	Safe stop 1
STO	Safe torque off
THDi	Total harmonic current distortion
VFD	Variable frequency drive

Table 5. AI involvement by component, scored against the AI Influence Level scale

Component	AIL	Description
Research question and motivation	0	Author
CASINO design, scope areas, source ranking, excluded domains	0 to 1	Author, written and revised by hand
The nine-dimension scoring scheme	2	Author specified the dimensions and expanded them from cybersecurity alone to nine covering performance, published reliability figures, and usability; wording drafted with AI
Choice of deliverable form	0	Author. A scored matrix rather than a narrative
Retrieval and document location	not applicable	Instrumentation rather than authorship. See below
Conflict adjudication between instruments	2 to 3	Author set the standing rule that conflicts resolve on evidence and are never averaged; individual cells adjudicated with AI and reviewed
Vendor coverage and scope correction	0	Author. Identified a documentation-density bias in both legs that had overweighted several brands and omitted Rockwell entirely
Prose of this report	3	AI created, human full structure. The author supplied the structure, the argument, and the corrections; the sentences were drafted by the tool
Verification queue and published caveats	2	Author's standard, AI assembled

Table 6. Detail

About the author



Carl Lee Tolbert, PhD, CMRP, is a researcher and methodologist whose work bridges organizational leadership and industrial practice. He is Lecturer and Methodologist in the DBA program at Truett McConnell University, where he guides doctoral candidates through research design, instrument development, analysis, and defense, with additional faculty appointments at the University of Sioux Falls and Columbia International University.

He is an affiliated researcher with the Institute for Globally Distributed Open Research and Education, a peer reviewer for several MDPI journals, and is completing a Master of Arts in Technology and Society at the University of Chicago, examining how artificial intelligence reproduces the Enlightenment's quest for perfection.

His doctoral research was a hermeneutic study of industrial distribution drawing on interviews with more than 200 industrial leaders, and a follow-up study measured grit in more than 400 United States industrial maintenance workers, finding perseverance significantly above general-population norms and identifying newly promoted leaders as the highest burnout risk. He is the author of more than 20 peer-reviewed articles and chapters across leadership, organizational behavior, and applied engineering, and his books include *The 10 Immutable Laws of the Industrial Distribution Specialist* and *Before the First Fault*, a field treatment of variable frequency drive installation and reliability. His technical scholarship includes the ORCA research portfolio on drive reliability and remaining-useful-life estimation.

He holds a PhD in Organizational Leadership and the Certified Maintenance and Reliability Professional credential, and he is President of Wayward Leaders LLC in Sioux Falls, South Dakota.

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This report online: <https://waywardleaders.com/state-of-the-vfd-2026>

Courses and dates: <https://waywardleaders.com/training>

Field notes and fault references: <https://waywardleaders.com/field-notes>

Corrections to this report: carl@waywardleaders.com



Courses and dates

Compiled 14 September 2026 from public sources only. No manufacturer paid for placement, reviewed a draft, or was contacted during this work.