ROOT CAUSE FAILURE ANALYSIS · CASE STUDY

"We're Rough on Motors Here": VFD Bearing Damage Hidden in Plain Sight

Six premature motor failures in seven weeks, explained away as normal. Teardowns, shaft-voltage measurements, and an installation survey traced them to VFD-induced electrical discharge machining.

SANITIZED CASE STUDY

SETTING	Multi-line food manufacturing plant with washdown production areas
POPULATION	136 motors fed by variable frequency drives (VFDs)
TRIGGER	6 motor failures in 7 weeks: 2 × 25 hp washdown inverter-duty motors and 4 × 3 hp motors, none older than three years
INVESTIGATOR	Apex Reliability Engineering principal, then the site Reliability Engineer
METHODS	Bearing teardown and failure-mode classification, oscilloscope shaft-voltage measurement, drive and cable installation survey, at-risk motor screening
INSTRUMENTS	Rigol DHO814 oscilloscope with a shaft-voltage probe

> **About this document.** Sanitized account of an actual investigation. Site, people, and identifying details removed; costs are approximate. Unlike the Apex Reliability Engineering sample reports, the technical findings here are real. Planning-level cost estimates are labeled as such.

Executive Summary

What happened, what the evidence showed, and why it matters to any plant running VFDs.

BOTTOM LINE

A cluster of premature motor failures was being explained away as normal for a washdown plant. The evidence said otherwise. Every drive-end bearing torn down showed **fluting**, the signature of VFD-induced electrical discharge machining (EDM). Shaft voltages of **21–34 V** were measured, and the installation survey found the conditions that produce them across the plant. The fixes are standard, inexpensive per motor, and small next to the **$90K** that the two 25 hp failures alone cost.

FAILURES IN 7 WEEKS	TEARDOWNS WITH FLUTING	SHAFT VOLTAGE MEASURED	COST, TWO 25 HP FAILURES	VFD MOTORS EXPOSED
6	**4 of 4**	**21–34 V**	**$90K**	**136**
2 × 25 hp, 4 × 3 hp; all under 3 years old	Drive-end bearings; grease blackened and viscous	On suspect motors, by oscilloscope	$30K replacement + $15K downtime, each	Installation gaps were plant-wide

WHAT THE INVESTIGATION FOUND

- CONFIRMED **Electrical bearing damage.** Drive-end fluting in all four teardowns, with degraded grease.
- CONFIRMED **Shaft voltage at damaging levels:** 21–34 V on suspect motors.
- CONFIRMED **Installation conditions known to drive bearing currents:** no direct motor-to-drive ground bond, unshielded runs over 100–140 ft, little drive filtering, and few motors with shaft grounding.
- SUPPORTED **Normalization of deviance.** Three stock explanations had kept the cluster from being investigated (Section 1).

WHAT WAS RECOMMENDED

1. **Bond each motor directly to its drive** with a dedicated ground conductor.
2. **Use shielded VFD cable**, prioritizing runs over 100 ft.
3. **Install shaft grounding rings** on at-risk motors.
4. **Add drive output filtering** (reactors or filters) on long runs.
5. **Work a red-flag list** of at-risk motors, ranked by known contributing factors (Section 4).

OUTCOME

NOT VERIFIED The investigator left the site before implementation could be confirmed, so this case reports findings and recommendations, not results.

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1 The Signal That Was Being Normalized

Normalization of deviance is what happens when repeated abnormal results stop looking abnormal. Each failure gets a plausible local explanation, and the pattern never gets examined.

TABLE 1.1 — THE TRIGGER CLUSTER

MOTORS	COUNT	SERVICE	AGE AT FAILURE	CONSEQUENCE
25 hp inverter-duty	2	Washdown production	Under 3 years	$30K replacement and about $15K downtime each; 5.5–7 h down
3 hp	4	Production, with redundancy	Under 3 years	Lower; redundant equipment limited downtime (not quantified)
Total	**6**	**Over 7 weeks**		**At least $90K**

TABLE 1.2 — WHAT PEOPLE SAID, AND WHAT THE EVIDENCE SHOWED

EXPLANATION IN CIRCULATION	WHAT THE EVIDENCE SHOWED	VERDICT
"We're rough on motors here."	Rough handling and overload leave mechanical damage patterns. The teardowns showed fluting, a regular washboard pattern produced by electrical discharge. These motors were also under three years old and rated inverter-duty.	NOT SUPPORTED
"It's a washdown facility, so the chemicals cause it."	Chemical and water ingress produce corrosion damage. Fluting is classified separately, as electrical erosion (ISO 15243:2017). Washdown was not ruled out as a co-factor, but it does not explain the damage found.	NOT SUPPORTED as primary cause
"We don't have that many motors fail, considering how many we have."	6 of 136 VFD motors (4.4%) failed in 7 weeks. If sustained, that pace is about 45 failures a year, or 33% of the fleet. The point is not a forecast; it is that the cluster was far outside normal background.	NOT SUPPORTED

WHY THIS MATTERS

Each explanation was plausible on its own, and that is what made them effective. None of them was tested. A single teardown, done early, would have redirected the conversation from "motors fail here" to "something is destroying our bearings."

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2 Investigation and Evidence

The investigation moved from the failed parts outward: what the bearings showed, what voltage was present, and what in the installation produced it.

FIGURE 2.1 — FLUTING ON A DRIVE-END BEARING INNER RACE (TEARDOWN PHOTO)



The evenly spaced transverse lines across the raceway are fluting: repeated electrical discharges between the rolling elements and race. Mechanical wear and corrosion do not produce this pattern.

INVESTIGATION SEQUENCE

1. **Failure history review:** establish the cluster.
2. **Four teardowns:** classify the damage mode.
3. **Shaft-voltage measurement:** confirm damaging voltage.
4. **Installation survey:** find what generates and routes bearing current.
5. **Red-flag screening:** rank at-risk motors.

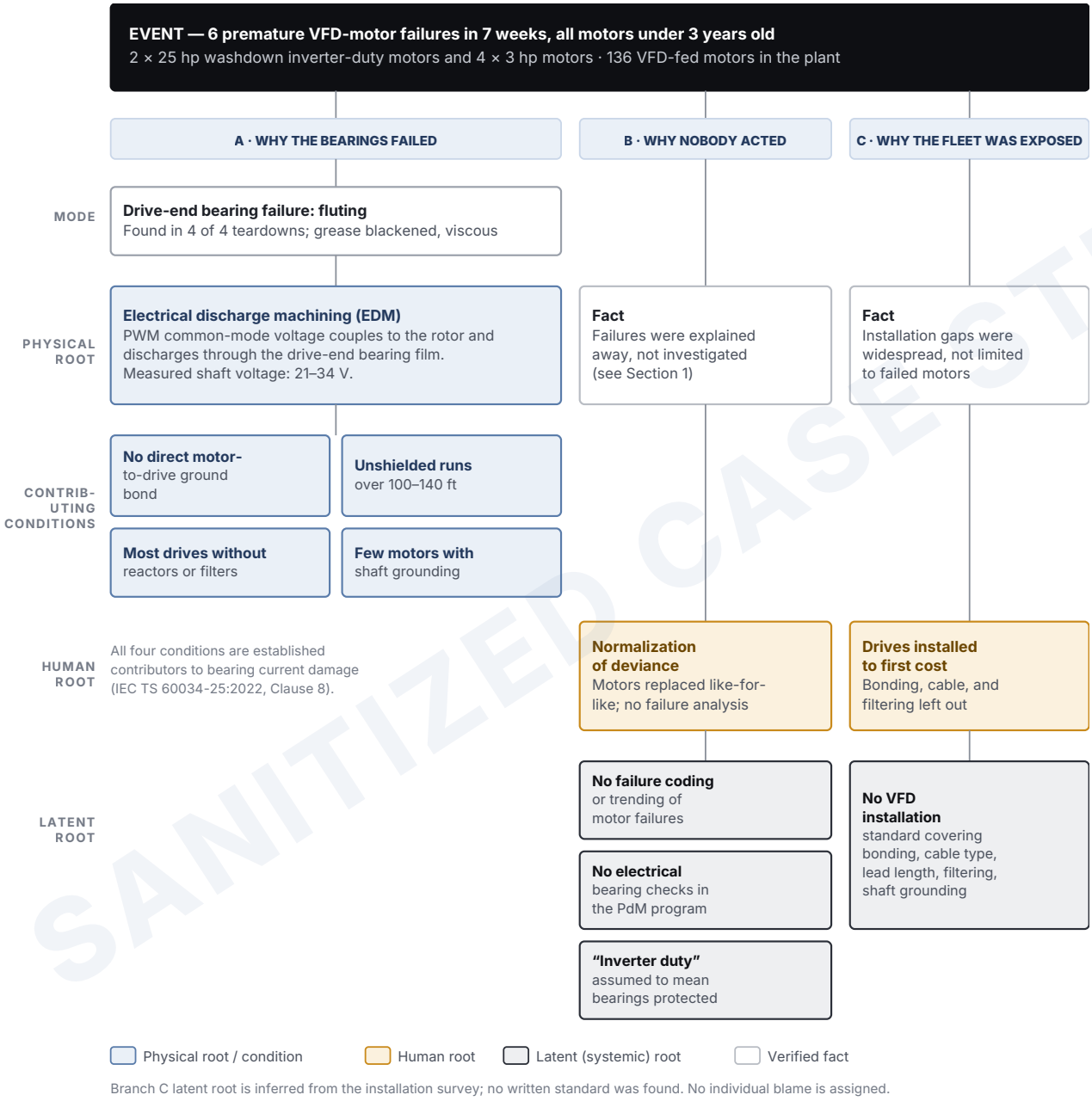
TABLE 2.1 — EVIDENCE REGISTER

ID	EVIDENCE	RESULT	STATUS
EV-01	Bearing teardowns (4 motors)	Drive-end (output shaft) bearings showed **fluting**, the washboard pattern of repeated electrical discharge (Figure 2.1)	CONFIRMED
EV-02	Drive-end grease condition	Blackened and highly viscous. Consistent with electrical degradation of the lubricant.	SUPPORTED
EV-03	Shaft voltage, suspect motors	**21–34 V**, measured with a Rigol DHO814 oscilloscope and shaft-voltage probe. Consistent with VFD-induced EDM. For context, NEMA MG 1 Part 31 cites 300 mV peak for bearing insulation on large motors (a different mechanism).	CONFIRMED
EV-04	Motor-to-drive grounding	Many VFDs had no direct ground bond to their motors	CONFIRMED
EV-05	Motor cable	Many unshielded runs from drive to motor exceeded 100 ft, and some exceeded 140 ft	CONFIRMED
EV-06	Drive filtering	Most drives had no reactors or filters	CONFIRMED
EV-07	Shaft grounding	Only a few motors in the plant had shaft grounding brushes	CONFIRMED
EV-08	Motor rating	The failed 25 hp motors were inverter-duty. That rating protects winding insulation, not bearings.	CONFIRMED

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3 Cause-and-Effect Logic Tree

The tree has three branches: why the bearings failed, why nobody acted on the pattern, and why the whole VFD fleet carried the same exposure.



Branch C latent root is inferred from the installation survey; no written standard was found. No individual blame is assigned.

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ROOT CAUSE STATEMENT

Physical: VFD common-mode voltage discharged through drive-end bearings (EDM), producing fluting and grease breakdown. **Contributing:** no direct motor-to-drive bonding, long unshielded runs, little drive filtering, and almost no shaft grounding. **Human:** failures were normalized and motors replaced like-for-like. **Latent:** no VFD installation standard, no failure coding or trending, no electrical bearing checks in PdM, and a belief that “inverter duty” meant protected bearings.

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4 Red-Flag Screening and Recommendations

With 136 VFD motors exposed, the practical question was where to start. A red-flag list ranked motors by the established contributors to shaft voltage and bearing current, each with a recommendation.

TABLE 4.1 — SCREENING FACTORS USED FOR THE RED-FLAG LIST

FACTOR	WHY IT RAISES RISK
No direct motor-to-drive ground bond	High-frequency current lacks a low-impedance return path and finds one through the bearings and driven equipment
Unshielded cable, especially over 100–140 ft	Long, unshielded leads increase reflected-wave voltage and common-mode current, and give the current no defined return path
No drive output filtering	Nothing limits voltage rise time or common-mode content reaching the motor
No shaft grounding	Shaft voltage builds until it discharges through the bearing film
Failure history or measured shaft voltage	Direct evidence that damage is already happening
Criticality and redundancy	Sets the cost of a failure; the 25 hp washdown motors had no redundancy

TABLE 4.2 — RECOMMENDATIONS

RECOMMENDATION	WHAT IT DOES	PRIORITY
Direct motor-to-drive bonding	Gives high-frequency current a defined return path that bypasses the bearings	All red-flag motors
Shielded VFD cable	Contains and returns common-mode current; specified for new installs and replacements	Runs over 100 ft first
Shaft grounding rings	Bleeds shaft voltage to ground before it can discharge through the bearing	Red-flag motors; all new VFD motors
Drive output filtering (load reactor, dV/dt, or common-mode filter)	Reduces voltage stress and common-mode content on long leads	Long runs and critical motors
VFD installation standard	Makes bonding, cable type, maximum lead length, filtering, and shaft grounding the default	Before the next project
Failure coding and shaft-voltage checks	Lets the next cluster be seen early and gives PdM an electrical bearing check	Ongoing

Guidance basis: IEC TS 60034-25:2022, Clause 8 (bearing currents in converter-fed machines); NEMA MG 1 Part 31 (definite-purpose inverter-fed polyphase motors).

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5 The Financial Case

The plant's records could not support a reliable baseline failure rate, because motor failures were not coded. That gap is itself a finding. The case is therefore made as break-even: how much mitigation one avoided failure pays for.

TABLE 5.1 — KNOWN COST OF THE TRIGGER CLUSTER

ITEM	PER 25 HP FAILURE	TWO FAILURES
Motor replacement	$30,000	$60,000
Downtime (5.5–7 h)	$15,000	$30,000
Total	**$45,000**	**$90,000**

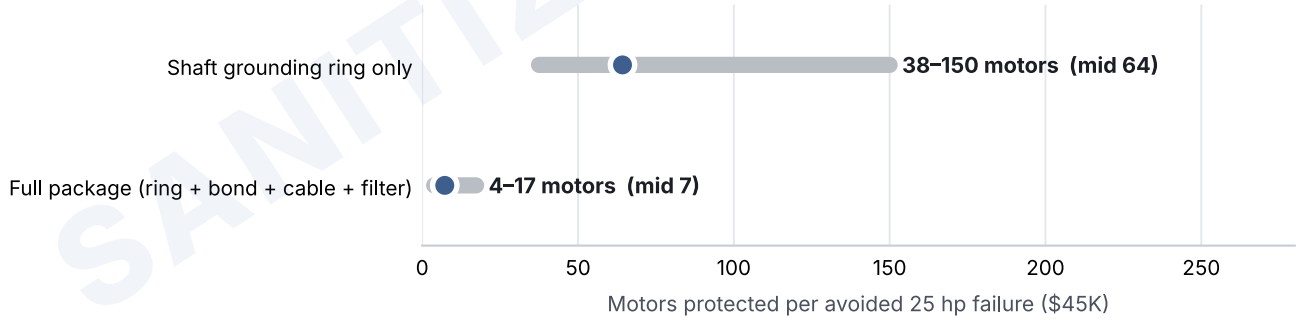
The four 3 hp failures are excluded. Redundancy kept their cost lower, and it was not quantified.

TABLE 5.2 — MITIGATION COST PER MOTOR (PLANNING-LEVEL ESTIMATES, NOT FROM THE INVESTIGATION)

MEASURE	LOW	MID	HIGH
Shaft grounding ring, installed	$300	$700	$1,200
Motor-to-drive bonding correction	$200	$500	$1,000
Shielded VFD cable re-pull (100–150 ft)	$1,500	$3,500	$6,000
Output reactor or filter	$600	$1,500	$3,500
Full package, one motor	**$2,600**	**$6,200**	**$11,700**

ESTIMATE Typical small-to-mid-size motor and drive pricing, including labor. Validate with quotes; cable cost varies most with run length and routing.

FIGURE 5.1 — MOTORS PROTECTED BY THE COST OF ONE AVOIDED 25 HP FAILURE



BREAK-EVEN IN PLAIN TERMS

One avoided 25 hp failure ($45,000) pays for the full package on 4–17 motors, or shaft grounding rings on 38–150. Rings for all 136 VFD motors would cost an estimated $41K–$163K, in the same range as the $90K the two 25 hp failures cost in seven weeks.

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6 Outcome, Limitations, and Lessons

This case reports what the evidence showed and what was recommended. It does not claim results that were never verified.

TABLE 6.1 — LIMITATIONS

GAP	EFFECT ON CONCLUSIONS
Implementation and results not verified; the investigator left the site first	No post-mitigation failure rate or shaft-voltage data is claimed
Four motors torn down, out of six failures	The damage mode is confirmed for those four. The other two are attributed by shared conditions, not physical evidence.
Grease condition assessed visually, not by lab analysis	Electrical degradation of the grease is graded Supported, not Confirmed
Washdown exposure not ruled out as a co-factor	It does not explain fluting, but it may shorten bearing life further
No coded failure history	No baseline failure rate, so the financial case is made as break-even

WHAT THIS CASE SHOWS

FOR PLANT LEADERSHIP

A cluster of failures is a signal, even when every individual failure has a convenient explanation. Ask for one teardown before accepting “that's normal here.”

FOR MAINTENANCE MANAGERS

“Inverter duty” protects windings, not bearings. If your VFD installations lack bonding, shielded cable, or shaft grounding, check your drive-end bearings and measure shaft voltage before the next failure.

FOR FINANCE

The two 25 hp failures alone cost about as much as protecting every VFD motor in the plant with shaft grounding rings. Prevention here is a small, one-time cost per motor.

TABLE 6.2 — STANDARDS AND REFERENCES

REFERENCE	TITLE AND USE
IEC TS 60034-25:2022	Rotating electrical machines — Part 25: AC electrical machines used in power drive systems — Application guide. Clause 8: bearing currents and prevention.
NEMA MG 1, Part 31	Definite-purpose inverter-fed polyphase motors. Shaft voltage and bearing current guidance.
ISO 15243:2017	Rolling bearings — Damage and failures — Terms, characteristics and causes. Classification of fluting as electrical erosion.

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