TECHNICAL GUIDE

Mitigating Wildlife Impacts on Substations

Evidence, acceptance criteria, and reference details that support the *Field Guide: Mitigating Wildlife Impacts on Substations*

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INL thanks Brian McGowan, Scientias-Energy, for preparing the foundational technical report and for providing subject-matter input that informed this guidance. INL and Scientias-Energy also conducted targeted interviews with wildlife-mitigation product manufacturers specifically to inform this guide and incorporated anonymized themes and practical feedback from those discussions. Where relevant, the guide also reflects anonymized themes from utility conversations and interviews conducted across related INL work.

INL thanks the following organizations for their voluntary input: Bird Barrier America, Hubbell Power Systems, Kaddas Enterprises, Midsun, Powerline Sentry, TE Connectivity, Transguard.

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1. PURPOSE, AUDIENCE, AND HOW TO USE THIS TECHNICAL GUIDE

This Technical Guide supports the *Field Guide: Mitigating Wildlife Impacts on Substations* by providing (1) technical rationale and evidence, (2) a pass/fail acceptance standard tied to required photo documentation, (3) engineering guardrails and inspection/replacement triggers, and (4) lightweight templates that turn field observations into consistent closeout and clean, planned follow-up work packages.

This Technical Guide does not add field workload or assume crews have a full catalog of mitigation products on the truck. The Field Guide is the playbook for what crews can finish within normal operation and maintenance (O&M) windows, whereas this Technical Guide is the reference that keeps decisions consistent across crews, sites, and seasons—especially when a gap cannot be closed out in the same visit and must be escalated as a planned follow-up work package.

Purpose for Primary Users

- **Engineers:** Clearance and Protection Distance Required (PDR) sign-off, acceptance criteria, and documentation
- **Supervisors/Foremen:** Acceptance consistency, inspection triggers, and photo and documentation requirements
- **Reliability/Management:** Outage evidence anchors, seasonal timing triggers, key performance indicators (KPI) definitions, and reporting

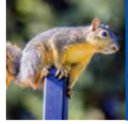
How to Use

- **What to do in the yard:** Use the Field Guide's SEPA-R + triage score to choose a Track and an Action Package, then follow the equipment quick-cards (see Field Guide Sections 3–6). For folding into O&M and metrics, see Field Guide Sections 7–8.
- **Is an action acceptable (closed out):** Use ***Section 4 (Acceptance Standard)*** and ***Appendix A, Photo Requirements and Product Reference Photos***.
- **When to schedule checks:** Use this guide's seasonality guidance and ***Section 3 (Evidence Snapshot)***.
- **When you cannot finish to acceptance with available parts/time/clearances:** Document the gap using the templates in Sections 7–8 so it becomes a clean, planned follow-up work package.
- **Standards/Program alignment:** Use ***"Appendix C", Standards Crosswalk***.

How this Guide was Built

This guide was developed as a companion to using the Field Guide first. Content is included only if it improves repeatability and durability, especially acceptance decisions, inspection and replacement triggers, and documentation discipline. Bulk reference material (templates and product photos) is attached in the appendices.

Use the Field Guide to plan and execute work, and use this Technical Guide to standardize acceptance, documentation, and follow-up so results are repeatable across crews, sites, and seasons. For the step-by-step workflow (Scope, Exclude, Protect, Audit, Repeat) and visit packages, see ***Field Guide, Section 4 (Action Packages by Track (Visit Actions))***.



2. SOURCES, METHODS, AND CONFIDENTIALITY

Inputs

This Technical Guide was developed from four inputs:

1. Scientias-Energy's technical report (background, mitigation concepts, equipment guidance, templates)
2. Vendor and utility interview notes (anonymized themes)
3. External literature and industry guidance
4. The Field Guide draft and internal review feedback.

Confidentiality and Limitations

Interview content is presented as themes, not endorsements, product performance claims, or attributable quotes. Key limitations include the following:

- **Cause coding drives trends:** Apparent increases can reflect better coding and fewer "unknowns," not more wildlife events.
- **Before/after data is often limited:** Utilities can lack clean baselines.
- **Execution quality dominates outcomes:** Coverage completeness, correct sizing and overlap, and basic maintenance determine durability.
- **Field constraints**: This guide does not assume crews can fully mitigate partially protected yards in one visit or with truck-stock. Where work cannot be completed to the acceptance standard due to parts, time, clearances, or equipment constraints, the correct outcome is to document the gap (photos + log) and escalate it as a planned retrofit rather than leave partial fixes.
- **No guaranteed outcomes**: The templates and KPIs support consistent implementation and tracking, but outcomes will vary by yard design, voltage/clearances, site conditions, and program maturity.

For these reasons, this guide emphasizes acceptance criteria, photos and documentation, and lightweight measurement templates rather than fixed outcome claims.

3. EVIDENCE SNAPSHOT AND INDUSTRY OBSERVATIONS

Evidence Snapshot

Table 1. Evidence snapshot (anchors used to justify focus, timing, and emphasis on application quality).

KEY EVIDENCE	WHAT IT SUPPORTS	SOURCE
Wildlife is a persistent contributor to outages; squirrels typically have the largest share	Scope priority (wildlife/ squirrels matter enough to justify structured mitigation)	• APPA data[1] • Vendor interviews (see Section 3 and *"Appendix B", Evidence Tables and Templates)* • Electric Power Research Institute[2]
Most distribution faults are momentary (~70–90%) and clear with recloser operation	Prioritize scenarios resulting in sustained outages and events rather than brief interruptions	Scientias-Energy
Seasonal peaks for squirrels: May to June and October to November	Timing of walkdowns / acceptance re-checks	APPA[3]
Wildlife outage shares remain high despite many mitigation products	Problem persistence is structural, not lack of products	Vendor interviews
Most substations are not fully protected; partial protection is common	Why "partial protection" persists and why structured approaches are needed	Vendor interviews
Installation and application quality (coverage completeness, sizing/ overlap, maintenance) is the primary differentiator	Why the program must emphasize acceptance criteria and re-checks	Vendor interviews

See Field Guide ***Executive Summary*** and ***Section 1 (Guide Overview)*** for the context behind these evidence anchors.

1 APPA. 2024. "What Causes Electrical Outages?" Last modified July 11, 2024.
2 EPRI. 2021. "Survey of Wildlife Protection Products." Technical Update, 3002021639.
3 Hofmann, A. 2017. "Defending Against Outages: Squirrel Tracker." APPA. Last modified July 26, 2017.

Vendor Interviews and Implications

Across vendors, repeated themes were as follows:

- Squirrels are the most common wildlife driver of routine substation contact concerns (distribution and sub-transmission yards), even when the exact outage share varies by region and cause coding.
- Partial protection is common, leaving residual risk paths and repeat events.
- Fit and closure openings drive failures (gaps at interfaces, "daylight" at seams).
- Bushing and arrester covers are hard in practice (fit, closure integrity, durability).
- Degradation and displacement happen over time (ultraviolet [UV] aging, mechanical wear, storm, and wind shifts).
- Mitigation is often incident-driven and added after construction with limited budget.
- Utilities struggle to quantify what works, which slows scaling and business cases.

Implications include the following:

- **Primary control**: A clear pass/fail standard, required documentation/photos, re-check triggers

- **Timing lever**: Re-check around seasonal peaks and after storms and high winds to catch displacement, open seams, and degraded closures

- **Why this guide exists**: Make acceptance and follow-up consistent across crews, sites, and seasons (not to repeat the Field Guide). For instructions on "What to Do This Visit" (e.g., triage, track, packages, quick-cards), see ***Field Guide, Sections 3-6***.

Across sources, "equipment most at risk" shows up in two ways. Some sources emphasize common contact and bridge points (e.g., bushings, bus insulators, buswork interfaces). Others emphasize high-consequence assets that are frequently damaged or drive outage impact (e.g., breakers and switchgear, transformers, disconnects). This guide treats both ways as true, suggesting the prioritization of protection and acceptance around the interfaces where contact starts, while tracking outcomes at the assets where damage is most visible and costly. See ***"Appendix B" ("Table B-1. Vendor estimations of substation protection levels."*** and ***"Table B-2. Substation equipment most at risk (literature summary)."****)* for literature and vendor summaries that support this two-fold prioritization.

Where the right parts or clearances are not available to finish protection to acceptance, the correct action is to capture the gap and convert it into a planned work package (e.g., parts/kit/outage/engineering) rather than assume the crew can complete "full protection" in the same visit.

4. ACCEPTANCE STANDARD (PASS/FAIL) AND PHOTO DOCUMENTATION

Use this section to make closeout decisions consistent across crews, supervisors, and engineering reviewers. Field execution lives in the Field Guide (Section 4 and Section 6), while this section presents the pass/fail closeout standard.

If any check in *"Table 2. Acceptance checks (pass/fail)."* fails, (1) mark **Not Accepted**, (2) correct if feasible, and (3) re-check before leaving the yard. If the action cannot be corrected to pass/fail with available time/parts without creating new risk, then stop. Do not improvise, patch, or leave a failed/partially closed installation in place. Document the failure and create a planned retrofit work order that lists the missing parts, constraints (e.g., clearances/PDR/ mechanisms), and the required return scope.

A common closeout failure is caused by taping. Tape can be accepted only when it is a utility-approved high-performance insulation tape (heat-shrink is preferred where allowed and should be installed with sealed ends, no exposed metal at any interface, and not used to compensate for wrong sizing or damaged closures). If a form-fit part is not available in this window, treat an accepted tape solution as a temporary bridge and escalate the location for planned retrofit with form-fit parts.

Note that "pass/accepted" does not mean a yard is fully mitigated. It means the specific action(s) completed meet the pass/fail standard described in *"Table 2. Acceptance checks (pass/fail)."* and are documented well enough to verify later. Partial yard coverage can be acceptable; partial or failed installations are not.

This is the Technical Guide version of *Section 4 (Action Packages by Track (Visit Actions))* in the Field Guide, which provides acceptance checks to use every time.

Table 2. Acceptance checks (pass/fail).

CHECK	PASS (ACCEPTED)	FAIL (NOT ACCEPTED)
A. PDR, clearance, and creepage	Required clearances remain met after install; no "clearance theft"	Any reduced clearance that creates flashover risk
B. Interfaces closed and overlap	Continuous overlap at sheds, boots, bends, seams; no stretch gaps	"Daylight" at seams; exposed metal at any interface
C. Mechanisms free	Full travel verified (open, close, stroke); no binding; hinges/blades unobstructed Note: Pacific Gas and Electric Company (PG&E) requires verification after installations near switches: "OPERATE the switches to ensure free movement… from fully open to fully closed before energization.[4]	Any impeded travel or interference
D. Moisture and heat paths	No up-facing cups; drains clear; no pooling; ventilation/heat paths not blocked	Standing water, corrosion residue, algae or green residue; blocked vents
E. Closure integrity (latches, hinges, fasteners)	All latches closed; no missing or broken latch parts; no cracked or brittle polymer	Broken or missing latches; cover cracked, chalked, brittle; chewed edges that expose live parts
F. Material condition (tracking, erosion, melting)	No tracking or burn marks on covers or nearby hardware	Any tracking, burn marks, pits, melting, or arc damage
G. Displacement and fit stability	Cover or guard stable; no rotation/displacement; no wind-induced movement expected	Displaced guards, rotated covers, open seams, or loose guards
H. Wildlife use indicators	No hoarding or nesting evidence inside or under covers	Hoarding, nesting opportunity created by gaps or openings

4 PG&E. 2021. "Substation Animal Abatement Measures." Utility Procedure, TD-3350P-10, Rev. 7.

Common fail cues include the following:

- Daylight at seams
- Standing water and corrosion residue
- Displacement and rotation
- Tracking, burn, and melt.

If any fail cue is present and cannot be corrected to pass/fail immediately, treat the action as Not Accepted and escalate the event for planned retrofit. For every action, capture and link the minimum photo set (Appendix A1) as follows:

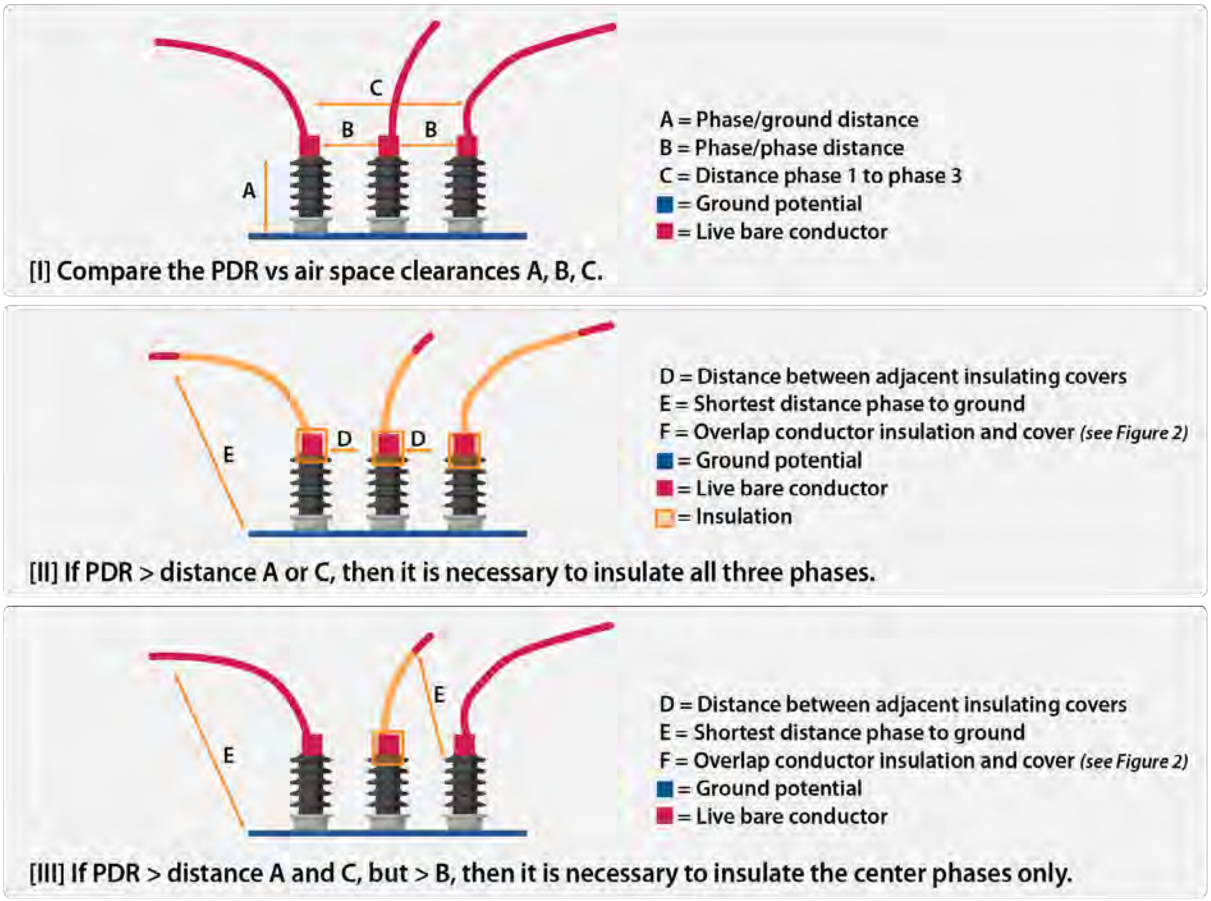
- Before wide
- Before close-ups (interfaces)
- After close-ups
- After wide.

Note: This guide does not provide pass/fail example photos. ***"Appendix A"*** provides required photo views, and ***Appendix A "Product Photos (Reference)"*** references photos of common mitigation products. If the required interfaces are not visible in the after photos, the action is not accepted for documentation purposes and must be re-photographed or escalated (planned return) so acceptance can be verified. Documentation is part of acceptance: if the interfaces are not visible in the after photos, closeout is not accepted for documentation.

5. ENGINEERING REFERENCE

Definitions

- **PDR (Protection Distance Required):** Maximum reach (or wingspan) of the target adult species +10% (e.g., Eastern gray squirrel reaches 53 cm × 1.1 = 58.3 cm). Figure 1 shows phase-to-ground spacing using the PDR concept to illustrate the minimum coverage distance mitigation must maintain. Use this as a quick visual reference for "how far coverage must extend." It is not a pass/fail example. Acceptance is still determined using Section 4.



▲ **Figure 1.** *Protection of phase-to-ground through PDR (Source: Scientias-Energy).*

- **Overlap "X" (insulation interfaces):** When multiple insulating components are used (e.g., bushing cover and conductor insulation), size for continuous overlap and stability (account for wind and movement). Figure 2 illustrates why continuous overlap is required when multiple installation elements are used (e.g., bushing cover and conductor insulation) at seams, bends, and interfaces.

Engineering Guardrails

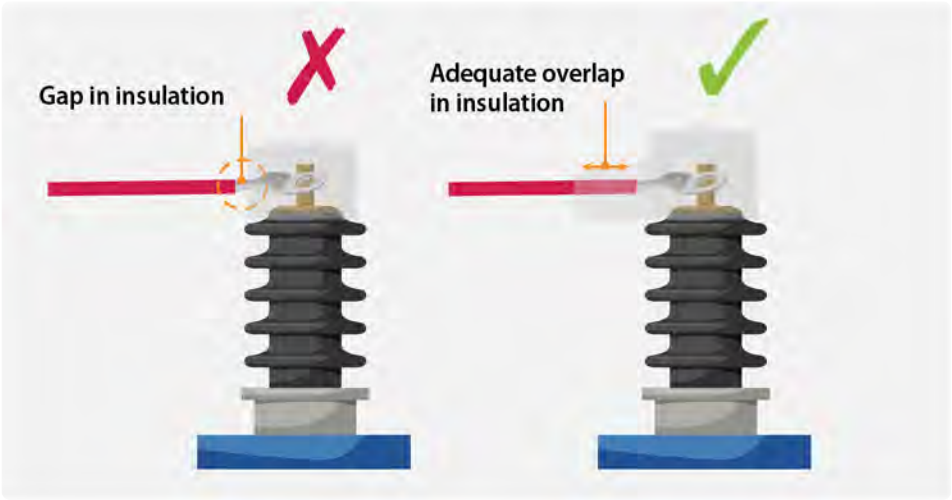


Figure 2. *Importance of overlap at insulation interfaces (Source: Scientias-Energy).*

This section acts as a gate between work that is field-feasible in a normal O&M window and work that must become a planned retrofit. Key engineering guardrails are listed in Table 3.

Plan a retrofit (stop and escalate) when any of the following are true:

- PDR/creepage after installation (e.g., tight geometry near grounded steel, unclear creepage path, borderline spacing) cannot be verified confidently.
- Correct sizing/parts are not available to achieve stable fit and closed interfaces.
- The installation would interfere with mechanisms, inspection access, thermography practice, or thermal/vent paths.
- The installation would prevent safety grounding access or would require adding grounding lugs or changing grounding points.
- The work requires switching, de-energization, or an outage window beyond the current scope.

Table 3. Key engineering guardrails.

TOPIC	RULE OR THRESHOLD
Creepage and clearance	Do not encapsulate a bushing in a way that shorts creepage distance (flashover, tracking risk)
Grounding and safety grounding access	Do not install covers in a way that prevents installing safety grounds. Maintain sufficient exposed bare conductor or install grounding lugs, where required (PG&E).[5]
Gaps and open seams (interface control)	Treat the first bend and any open seam as primary failure points; overlap fully
Cover openings (secondary wildlife risks)	Keep openings small enough to prevent bird encroachment (<10 mm) and squirrel hoarding (<5 mm), where applicable. Electric Power Research Institute (EPRI) note: Some bushing covers include jumper ports or drain holes; these can be effective for squirrels but problematic for birds that probe holes – so control opening size and placement accordingly.[6] PG&E note: "REMOVE inactive nests within substation equipment" and "BLOCK OR SEAL locations commonly used for building nests."[7]
"Too small" cover	For bulge and pressure on internal live parts, replace the smaller cover with a larger cover.
"Too large" cover	For excess wind movement and exposure risk, replace the larger cover with a more compact/stable cover.
Latch integrity	Broken or missing latch parts are replacement-level; investigate cause (e.g., force and UV).

Figure 3 provides a simple visual reminder that mitigation parts should fit tight and be stable, with enough coverage and overlap to stay closed at interfaces, bends, and seams over time. It is not a pass/fail photo example, but rather it is a sizing concept to reinforce the "right size, right fit, no gaps" principle.

In alignment with IEEE 1264, when selecting and applying mitigation, consider whether the method introduces added risk and verify electrical clearances

5 PG&E. 2021. "Substation Animal Abatement Measures." Utility Procedure, TD-3350P-10, Rev. 7.

6 EPRI. 2021. "Survey of Wildlife Protection Products." Technical Update, 3002021639.

7 PG&E. 2021. "Substation Animal Abatement Measures." Utility Procedure, TD-3350P-10, Rev. 7.

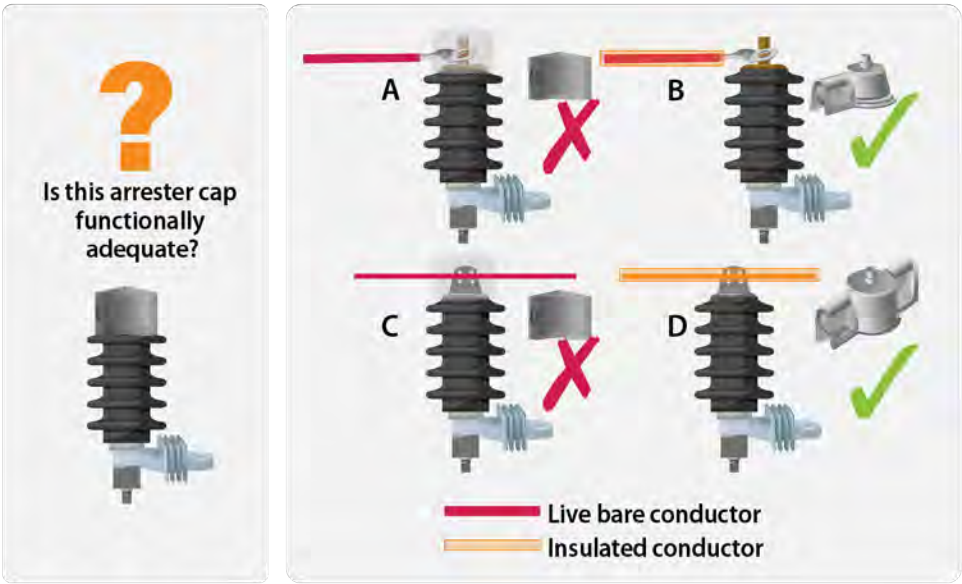


Figure 3. *Arrester wildlife mitigation (profile arrester caps, Kaddas).*

remain satisfied after installation.[8] Also, specify materials accordingly where wildfire risk is a concern. IEEE 1264 notes that if a non-flame-retardant guard is involved in a flashover, it can ignite/melt and drip flaming material.[9]

See *__"Appendix B" ("Table B-2. Substation equipment most at risk (literature summary)."__* for common product issue modes and the corresponding corrective controls (e.g., selection and sizing, UV and mechanical degradation, displacement, tracking).

8 IEEE Std 1264-2022. 20222. "IEEE Guide for Animal Mitigation for Electric Power Supply Substations."
9 IEEE Std 1264-2022. 2022. "IEEE Guide for Animal Mitigation for Electric Power Supply Substations."

6. COMMISSIONING, INSPECTION, AND REPLACEMENT STANDARD

Commissioning (closeout checks after any installation)

Commissioning is the closeout step that makes installations durable. It is required after any protection installation, correction, replacement, or removal, regardless of whether the work was completed as a quick win, a repair of a legacy installation, or a larger planned retrofit.

For each action completed during a visit, make a clear closeout decision:

- **Accepted**: All applicable acceptance checks pass (Section 4, Table 2), and the required after photos show key interfaces (Appendix A-1).
- **Not accepted – fix now**: Correct during visit with time and parts available, then re-check.
- **Not accepted – escalate (planned retrofit):** If you cannot correct to pass/fail with available parts/time without introducing new risk, stop. Do not improvise, patch, or leave partial fixes. Document the failure mode and create a planned retrofit work order that lists the missing parts, clearance/PDR constraints, mechanism/thermal constraints, and the required return scope.

At closeout, verify the following:

- **Coverage**: PDR is fully insulated; no gaps at interfaces or bends
- **Closures**: Latches closed; no cracks, missing parts, or bulging (bulging usually indicates undersized parts)
- **Fit (where applicable**): Bushing and arrester covers properly encapsulate the top shed per product design.

IEEE 1656 indicates that protective devices should not degrade dielectric performance and should minimize outage risk when wildlife interacts with energized equipment – so closeout checks are the control that keeps mitigation from becoming a new failure mode.[10]

Inspection Triggers (When to Re-Check)

Inspections are the method by which to keep installations “healthy” over time. The goal is to re-check protection when displacement, degradation, or new wildlife paths are most likely to occur.

10 IEEE Std 1656-2010. 2010. “IEEE Guide for Testing the Electrical, Mechanical, and Durability Performance of Wildlife Protective Devices on Overhead Distribution Lines.”

Re-check triggers at the following frequencies (use any that apply):

- **Annually** (visual condition check)
- **After storms/high winds** (displacement, broken parts, drainage issues, nests)
- **Seasonal fault peaks** (default: late spring and fall; try using local history)
- **After any re-entry** where covers were removed or reinstalled
- **When a "planned retrofit" gap remains open**, re-check the documented gap on the next scheduled yard visit to keep the backlog current.

Many utilities report failures tied to material degradation and installation issues. EPRI notes training and repeatable practice can reduce implementation failures, supporting the annual and post-storm re-check triggers in this guide.[11]

Inspection Checklist and Corrective Actions

Use this checklist during any re-check trigger *(Section 6, Inspection Triggers)* and during routine walkdowns. If any condition listed in Table 4 is present, the mitigation at that location is not accepted until it is corrected to the acceptance standard (Section 4) or escalated as a planned retrofit.

Table 4. Inspection conditions (not accepted).

CONDITION	ACTION
Cracks, chalking, brittle polymer (UV aging)	Replace
Missing or broken latches, clips, fasteners	Refit, repair, or replace
Tracking, burn marks, pits, melting, or arc damage on covers or nearby hardware	Replace; investigate cause
Displaced guards, rotated covers, open seams (daylight at interfaces)	Refit or replace; restore overlap
Standing water, corrosion, algae/green residue inside covers	Correct drainage; clean/dry as needed
Hoarding or insect nesting inside covers (bees, wasps) or evidence of wildlife use that creates contact risk	Remove, clean, reinstate per safety
Any exposed live metal intended to be covered	Restore coverage; re-check acceptance

After corrections, re-run acceptance checks and log date/location, action, pass/fail, and photo link in the work system. If any condition cannot be corrected to pass/fail, stop and escalate the condition to a planned retrofit with photos and a note on parts and scope. All new material-related failures should be reported to engineering though appropriate channels.

11 EPRI. 2021. "Survey of Wildlife Protection Products." Technical Update, 3002021639.

Replacement Criteria

Replacement is required whenever a protection component cannot reliably meet the acceptance standard (Section 4). Do not "patch" failed protection as a durable solution. If the component in the current visit cannot be replaced with available time and parts, document the condition and escalate it as a planned retrofit rather than a partial fix.

Replace (do not patch) the component if the following conditions are met:

- Closure hardware is damaged beyond repair.
- Polymer insulation is cracked, embrittled, UV degraded.
- Wildlife damage exposes live parts or defeats closure.
- Tracking, burn, arc damage is present.

Escalate the condition as a planned retrofit when replacement cannot be closed out to acceptance such as in the following scenarios:

- Correct part size or model is not available.
- PDR/creepage cannot be confidently maintained after replacement.
- Mechanism, inspection, or grounding access constraints require engineering review or a different design.
- The work requires an outage window beyond the current scope.

A replacement is only complete when it is accepted (pass/fail checks met) and documented with the minimum photo set ***(Appendix A, "Photo Set (Close-Out and Inspection)".*** If acceptance cannot be met in the same visit, close out the condition as "Not Accepted – Escalate (Planned Retrofit)" and attach photos and a one-line log that specifies what is needed.

Required Photos

The minimum photo set (per action) is as follows:

- **Before**: Wide and key interfaces
- **After**: Key interfaces and wide.

Store photos where supervisors and engineering can retrieve them (linked in the work order). For the field photo workflow and how crews should capture photos during visits, see Field Guide ***Section 3 (Photos)*** and ***Section 7 (Photo Protocol).***

7. DATA CAPTURE, KEY PERFORMANCE INDICATORS, AND RCFA TEMPLATES

For how these KPIs are used by managers and how to use them programmatically, see the ***Field Guide, Section 8 (Measuring Effect and Building the Business Case)***. Some utilities are moving toward predictive maintenance concepts to help preserve system function and to prioritize failure modes and preventative tasks accordingly.[12] These KPIs are meant to be a normal extension of mainstream substation asset management.

Key Performance Indicators

The goal is to keep KPIs (listed in Table 5) simple enough to maintain them within existing systems, while still showing whether (1) wildlife events are dropping, (2) installations are holding, (3) quality/acceptance is consistent, and (4) documented gaps are being turned into planned work and closed out over time.

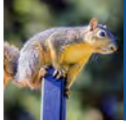
Table 5. T5 KPIs (definitions and calculation).

KPI	DEFINITION	CALCULATION	TARGET/FLAG
KPI-1	Wildlife/squirrel-coded sustained events per 90 days (yard)	Count of wildlife-coded sustained events in last 90 days	Track trend (down is good)
KPI-2	Re-trip ≤30 days after a wildlife-coded event (device)	Yes/No per event	Target: No re-trip ≤30 days
KPI-3	Photo-acceptance coverage	Actions with acceptable after photos divided by the total actions	Target: 100%
KPI-4	Planned retrofit backlog	Count of gaps where Acceptance = N (Planned Retrofit) that are still open.	Updated weekly or monthly
KPI-5	Backlog burn-down	Count of planned retrofit items closed	Monthly roll up

Together, KPI-1 and KPI-2 show reliability impact; KPI-3 shows field execution quality and documentation discipline; and KPI-4 and KPI-5 show whether the program is converting gaps into planned work while reducing wildlife risk in yards.

Avoid false "worsening" in tracked data. Track wildlife-coded sustained events and "unknowns" with clear wildlife signatures so improved cause coding does not look like a new increase in events.

12 United States Department of Agriculture. 2001. "Design Guide for Rural Substations." Rural Utilities Service Bulletin 1724E-300.



KPI-3 Rule: What Counts as a Accepted Photo

For KPI-3, count an action only if the after photos clearly show the following:

- Required interfaces (seams, bends, overlaps, latches, clearances as applicable)
- Final condition is well enough to confirm acceptance.

8. TEMPLATES AND COMPARISON WINDOWS

Action Record

Use one line per action taken (or gap documented). This record is meant to fit inside existing work management systems (or a simple spreadsheet) without creating a new process. If an item cannot be closed out in the same visit, log it as a planned follow-up and attach photos.

An example of what the record fields will look like is as follows:

Date | Yard | Device/Area | Track (monitor, quick wins, targeted protect) | Action type (exclude, protect, audit, correct, replace, inspect) | Action taken (plain language) | Acceptance (Y/N) | Photo link (before, interfaces, and after) | Follow-up needed (parts/kit/outage/engineering/procurement)

Field-side logging expectations are summarized in the Field Guide, in Section 8.

Root Cause Failure Analysis Mini-Template

Use this mini-template when a wildlife event occurs, a near-miss is found, or a mitigation action fails acceptance. The goal is to quickly separate what happened from why it happened and to distinguish constraints that require planned retrofit from issues that can be fixed with better execution or maintenance.

An example of what the minimum fields selected would look like is as follows:

Date | Yard | Device/Area | Event type (outage, sustained trip, near-miss, or inspection finding) | Evidence (chew, hoarding, nest, carcass, tracking, burn, unknown) | Suspected fault path (bridge, access, contact point) | Current yard state (null, partial, full) | Track used | Action taken (if any) | Acceptance (Y/N) | Photo link

For the one-line Root Cause Failure Analysis (RCFA) log version, see ***Field Guide, Section 8 (One-Line RCFA Log)***.

Before/After Comparison Window

Use a consistent comparison window so seasonality and coding changes do not distort results. Track both reliability outcomes and whether documented gaps are being closed through planned retrofit over time. Recommended windows are as follows:

- Baseline: 12 months prior to the first loop visit at that yard
- After-period: 6–12 months after the first loop visit
- Seasonality: Whenever possible, compare the same seasons year-over-year.

See ***Field Guide, Section 8 (Measuring Effect and Building the Business Case (KPID and Dollars))*** for the before/after guidance used in the field workflow.

Appendix A

Photo Requirements and Product Reference Photos

Photo Set (Close-Out and Inspection)

Photos are part of acceptance and are also the justification for escalating an action into a clean, planned retrofit work package. Capture and link the photo set for every action and for every documented gap.

Take these four photos for every action:

1. **Before-wide:** Show device and nearby equipment (provides context for location in the yard)
2. **Before close-ups:** 2-4 close-ups of critical interfaces (e.g., seams, bends, overlaps, latches, clearances)
3. **After close-ups:** Same interfaces after the fix/installation
4. **After-wide:** Same wide view showing final condition and clearances

Photo quality rules are as follows:

- Interfaces must be visible and in focus (no glare blocking seams and latches).
- If the required interfaces are not visible, the action is not accepted for documentation (counts against KPI-3).

Store the photos by linking the photo set in the work order/work management system.

Product Photos (Reference)

ARRESTER CAP/COVER

(also known as surge arrester cap/cover or lightning arrester cap/cover)

Purpose: Insulate the live arrester connection and leave enough overlap space so the connected conductor insulation and cap act as one insulated assembly.

Potential issues: Low-profile or undersized caps can limit overlap and leave an exposed live gap.

Other points: Size to the arrester, connection, and conductor; poor sizing is a common failure driver.

Image courtesy of Hubbell Power Systems

BUSHING COVER

(also known as insulator cover or insulator cap)

Purpose: Insulate the live bushing, insulator, and arrester connection and provide enough overlap with conductor insulation to insulate the full assembly.

Potential issues: Too large, vibration, movement, re-opening; too small, pressing and opening over time or poor overlap; poor materials, UV embrittlement, tracking, puncture; latches/hinges can fail (sometimes "patched" with tape or ties – treat as not accepted and replace with a correctly sized cover that closes without tape).

Other points: Good designs are re-enterable and can be opened and closed repeatedly without damage or needing tape/ties.

Image courtesy of TE Connectivity

CONDUCTOR INSULATION – COLD APPLIED TAPE

(also known as silicone tape, self-fusing tape, self-amalgamating tape, insulating tape)

Purpose: Versatile way to insulate complex geometry or as an impromptu alternative when standard components are unavailable.

Potential issues: Installer-sensitive; needs consistent ~2/3 overlap; limited shelf life (heat storage can degrade); sharp edges can split; over-stretching/out-of-date tape can reduce adhesion/performance.

Other points: For primary insulation in which molded parts are unavailable, use only utility-approved tape. For tape or covers, Pacific Gas and Electric Company says they "must cover all exposed metal, and never cover sight glass, or more than the first skirt."[13] When a tape-based primary insulation solution is necessary, heat-shrink is generally preferred over cold-applied tape (no shelf-life concern), provided heat application is allowed and safe for the location.

Image courtesy of Midsun Group

13 PG&E. 2021. "Substation Animal Abatement Measures." Utility Procedure, TD-3350P-10, Rev. 7.

CONDUCTOR INSULATION – HEAT SHRINK TAPE

(also known as heat shrink insulation)

Purpose: Versatile insulation for complex geometry or quick field application.

Potential issues: Installer-sensitive; needs consistent ~2/3 overlap; sharp edges can split during recovery; requires heat gun/open flame (may be restricted in enclosed areas).

Other points: No shelf-life concern like silicone tape.

Image courtesy of TE Connectivity

CONDUCTOR INSULATION

Wrap-around flexible (also known as line hose or insulating hose)

Purpose: Retrofit flexible silicone insulation for straight sections and smooth bends.

Potential issues: Must be fixed in place to prevent movement (silicone tape preferred; UV-resistant ties often used but not recommended); not for sharp bends as it can buckle and expose live elements.

Other points: Some vendors provide install tools for longer lengths; do not stretch onto oversized substrates as it can reduce puncture strength.

Image courtesy of TE Connectivity; Midsun Group

INSULATING SHEET OR BARRIER BOARD

(also known as insulating barrier)

Purpose: Flexible or rigid sheet insulation; rigid boards can act as phase-separation walls.

Potential issues: Too loose; vibration, movement, re-opening; too tight or small; stress and splitting over time; latches can fail or be lost during re-entry; rigid board may need extra fixings.

Other points: Flexible sheet is a versatile add-on to tapes for impromptu alternative solutions (bushings, bus connections, bus); typically held with compatible silicone grommets.

Image courtesy of Midsun Group

BUS SECTION INSULATION

Wrap-around bus bar insulation (also known as: bus bar cover; bus wrap)

Purpose: Insulate bus bar in multiple geometries (round, square, rectangular, L-shaped, flat).

Potential issues: Fewer suppliers for larger and custom bus cross-sections.

Other points: More relevant when higher-yard coverage is needed (larger wildlife/birds in scope).

Image courtesy of Hubbell Power Systems

ANIMAL GUARD

(also known as squirrel guard)

Purpose: Increase phase-to-ground distance an animal must bridge to cause a fault.

Potential issues: Overlapping tips should be offset (tracking risk); not effective for snakes; horizontal installs can become small-bird nesting surfaces.

Other points: Typically installed on grounded side between sheds (e.g., 1st to 2nd or 2nd to 3rd); many designs can be installed live with a hot stick, specify if required.

Image courtesy of Hubbell Power Systems

CUSTOM COVER

Purpose: Custom-fit covers using standard cover materials and designs for special/low-volume geometries common in substations.

Potential issues: Longer lead time; trial fits and careful measuring take more time.

Other points: Custom-cover capability is effectively required for complete protection; it is a limiting factor for many vendors.

Image courtesy of Hubbell Power Systems

CUTOUT COVER

Purpose: Insulate live components on a fuse cutout without interfering with moving elements during operation.

Potential issues: Too tight, interferes or leaves energized parts exposed; too loose, movement in wind and can create nesting space; should not compromise creepage distance.

Other points: Requires careful selection/dimensioning; failures often come from using what is available instead of the correct cover.

Image courtesy of Hubbell Power Systems

Equipment References Photos

Insulating bus sections (reference example). Figure A-1 is included to show where bus sections commonly present contact as well as bridge risk and what continuous coverage looks like along straight runs and through transitions.

Use this as an orientation reference for where to focus close-up photos (e.g., interfaces, seams, overlaps, and bends). It is not an acceptance example. Final acceptance is based on the Section 4 of the Technical Guide and the required photo views in Appendix A-1. For device-specific "Protect First, Do, Avoid, Accept" guidance, see Field Guide, Section 6 (on equipment quick-cards).

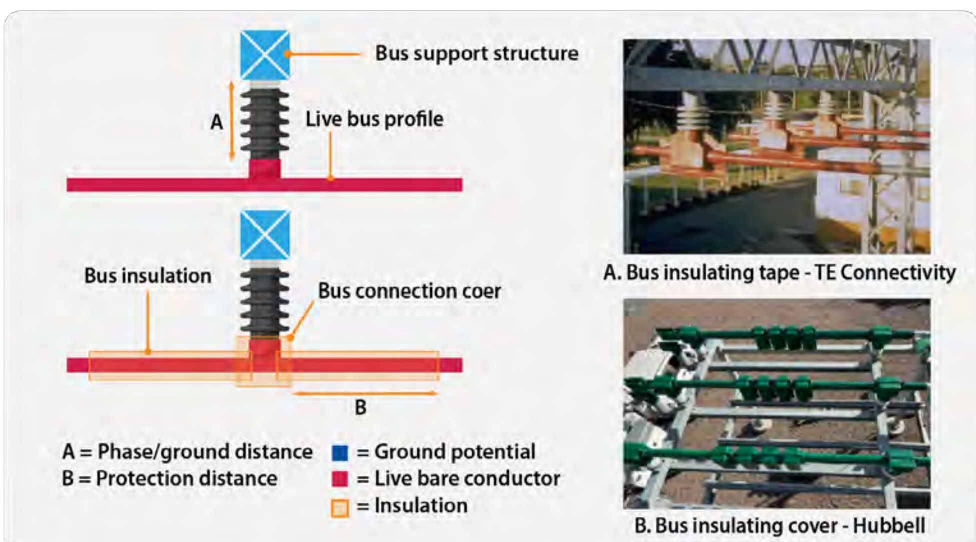


Figure A-1. *Insulating bus sections.*

Appendix B

Evidence Tables and Templates

Substation Protection Levels

This appendix contains evidence tables used to justify prioritization and timing. All vendor content is anonymized and presented as interview themes—not measured performance data, endorsements, nor comparable "rankings" across vendors.

Utilities commonly describe three broad protection states: null (no protection), partial (scattered or aging installs), and full (broad coverage). Interviews and published sources consistently indicate that a partial state is the dominant state across many fleets, often because protection is added incident-by-incident, installs age out or shift, budgets are constrained, and staged inventory varies by district.

This "partial protection majority" is the reason the Field Guide is written as a triage-and-escalation playbook rather than a "fully-mitigate-in-one-visit" checklist. Work that can be finished to acceptance in a normal visit should be closed out to a consistent standard. Work that cannot be completed due to parts, time, clearances/PDR, mechanisms, thermal/vent limits, or outage-window needs should be documented as a planned follow-up work package.

In practice, improving reliability at partially protected yards depends on two parallel actions: (1) closing accepted work to a consistent standard, and (2) converting remaining gaps into planned retrofit work packages that can be kitted, scheduled, funded, and burned down over time (KPI-4 and KPI-5).

"Table B-1. Vendor estimations of substation protection levels." indicates anonymized vendor interview estimates on the percent of substations fully, partially, and not protected. Levels of protection are defined here as follows:

- **Protected >95%** = Mitigation covers nearly all at-risk equipment/paths in the yard.
- **Partial protection** = Some at-risk equipment is mitigated, but not all.
- **Little/no mitigation** = Minimal/No installed protection exists.

Table B-1. Vendor estimations of substation protection levels.

	Vendor A	Vendor B	Vendor C	Vendor D	Vendor E	Vendor F	Vendor G
% stations protected >95%	<5%	2%	<7.5%	10–20%	<5%	<5%	–
% stations with partial protection	~20%	8%	<15%	50–60%	95%	55–65%	35–39%
% or stations with little or no wildlife mitigation	~75%	90%	<77.5%	30%	0%	30–40%	60–64%

The estimated levels of substation protection help justify why the field and technical guides emphasize repeatable closeout standards over product selection.

In the ***Field Guide, Section 4 (Packages by Yard State)***, the classification of null, partial, and full determines what package emphasis to use. In the Technical Guide, these states help determine whether an item is field-feasible to close-out to acceptance on the same visit or should be logged as "Not Accepted – Escalate," and plan a follow up.

Equipment Risk by Squirrels

Squirrels have a significant impact on distribution substations in North America. ***"Table B-2. Substation equipment most at risk (literature summary)."*** summarizes what multiple published sources identify as equipment commonly impacted by squirrels. Some sources include both substations and overhead line equipment.

Table B-2. Substation equipment most at risk (literature summary).

Source	Equipment most at risk	Note
(NRECA, 1996)	Transformers, poles mounted equipment, and arresters	This report covers OHL and stations.
(1264, 2022)	Bushings and bus insulators	Mentions power transformers, capacitors, breakers, reclosers, surge arresters, voltage and current transformers, regulators, switchgear, potheads, switches, bushings, insulators, and bus conductors.
(Bernstein, 1999)	Breakers and reclosers, power transformers, and bus conductors	—

Source	Equipment most at risk	Note
(Enck, 1989)	Bus work and circuit breakers	Mentions transformers, capacitors, disconnects, fuses.
(Sangster, 1995)	Fuses	Other equipment damaged includes insulators, arresters, bushings, regulators, transformers, switches, and switchgear.

Literature sources often mix two ideas: (1) where squirrels most often make contact and bridge (interfaces like bushings and bus insulation) and (2) what equipment is ultimately damaged or counted in outage reporting such as breakers, transformers, etc. Use ***"Table B-2. Substation equipment most at risk (literature summary)."*** to support prioritization and scope—not as a definitive ranking. If local outage history/cause codes, equipment failure patterns, site conditions, or species patterns indicate a different ordering, follow that local prioritization. Otherwise, use ***"Table B-2. Substation equipment most at risk (literature summary)."*** as a guide to support prioritization and scope.

"Table B-3. Substation equipment most at risk (vendor interviews)." summarizes what vendors most frequently identified as the "top" substation equipment categories in which squirrel-related issues show up. It reflects vendor experience and call patterns rather than measured fleet-wide rates.

Table B-3. Substation equipment most at risk (vendor interviews).

	Vendor A	Vendor B	Vendor C	Vendor D	Vendor E	Vendor F	Vendor G
No. 1	Switchgear	Breakers	Disconnects	Transformer	No clear answer	Transformers	Transformer
No. 2	Breakers	Disconnects	Transformers	Disconnects		Capacitor banks	Busbar
No. 3	Transformers	Potential transformers, voltage trans-formers	Switches	Switches		Switches	Switchgear
Others	Conductors and connections	N/A	Bus support insulators	Bus support insulators		N/A	Arresters

Vendor responses tend to emphasize the assets on which damage is visible and for which mitigation products are commonly applied (e.g., breakers, switchgear, transformers, disconnects). Several vendors also point to interfaces and support insulation (e.g., bus support insulators, conductors, and connections) as recurring contact points.

Practical Takeaway of ***"Table B-1. Vendor estimations of substation protection levels."*** and ***"Table B-2. Substation equipment most at risk (literature summary)."*** for this Guide.

Taken together, the tables support a two-layer approach:

1. **Protect and verify the interfaces** where contact typically begins (e.g., bushings, bus insulation and support insulators, conductors and connections).

2. **Track outcomes at high-consequence assets** (e.g., breakers, switchgear, transformers, disconnects) using consistent acceptance, inspection triggers, and basic key performance indicators.

These takeaways support the purposes of the Technical Guide in emphasizing (1) a pass/fail acceptance standard, (2) required closeout photos that show interfaces clearly, and (3) inspection and replacement triggers that catch displacement and degradation early.

Interview Themes Mapped to Technical Guide Requirements

"Table B-4. What we heard and where it shows up in this Technical Guide." translates repeated vendor and utility themes into the specific acceptance checks, engineering guardrails, inspection triggers, and documentation rules used in this Technical Guide. Themes are anonymized and presented as patterns, not endorsements.

Table B-4. What we heard and where it shows up in this Technical Guide.

REPEATED VENDOR RESPONSES	GUIDE LOCATION
Open seams and daylight at interfaces drive repeat events	Section 4, Table 2, Acceptance Check B; Section 6.3, ***Inspection Checklist and Corrective Actions***
Fit and closure issues are common (wrong size, poor overlap)	Section 5.2, ***Engineering Guardrails***; Section 4, Table 2, Acceptance Checks B, E, and G
Latches and closures fail or get patched	Section 4, Table 2, Acceptance Check E; Section 6.4, ***Replacement Criteria***
Ultraviolet aging and degradation over time	Section 6.3, ***Inspection Checklist and Corrective Actions***, Table 4; Section 6.4, ***Replacement Criteria***
Displacement after wind/storms causes re-opening	Section 6.2, ***Inspection Triggers (When to Re-Check***; Section 4, Table 2, Acceptance Check G
Water traps and blocked vents show up under covers	Section 4, Table 2, Acceptance Check D; Section 6.3, ***Inspection Checklist and Corrective Actions***

REPEATED VENDOR RESPONSES	GUIDE LOCATION
Tracking, burn, or melt indicates escalating risk	Section 4, Table 2, Acceptance Check F; Section 6.3, ***Inspection Checklist and Corrective Actions***; Section 6.4, ***Replacement Criteria***
Wildlife hoarding or nesting inside covers	Section 4, Table 2, Acceptance Check H; Section 6.3, ***Inspection Checklist and Corrective Actions***
Utilities struggle to prove effectiveness with clean data	Section 7, ***Data Capture, Key Performance Indicators, and Root Cause Failure Analysis [RH1.1]Templates***; Section 8, ***Templates and Comparison Windows***

If a yard continues to experience events after mitigation work, use this crosswalk to identify the most likely control for tightening (e.g., fit and overlap, closure integrity, displacement, drainage, material condition, or documentation discipline). The goal is to turn repeat issues into consistent, repeatable checks—not to expand scope or add new product requirements.

Common Product Issue Modes and What to Do About Them

"Table B-5. Common product issue modes (why mitigation does not hold)." summarizes recurring issue modes reported across vendor experience and industry observations—most commonly poor product selection and sizing, followed by ultraviolet (UV) or mechanical degradation, displacement (wind/storms), and tracking and thermal damage.

Use ***"Table B-5. Common product issue modes (why mitigation does not hold)."*** to reinforce what to check (e.g., fit, overlap, closures, material condition) and what to change (e.g., part selection, install method, and re-check triggers) when events repeat.

Table B-5. Common product issue modes (why mitigation does not hold).

No.	Vendor A	Vendor B	Vendor C	Vendor D	Vendor E	Vendor F	Vendor G
1	UV or mechanical breakage	Product selection	Product selection	Product selection	Product selection	Product selection	UV or mechanical breakage
2	Displacement Wind	UV or mechanical breakage	Nesting interference	Displacement Wind	Ignition /Melting	No clear answer	Ignition /Melting
3	No clear answer	Tracking	Tracking	UV degradation	Squirrel hoarding in covers	No clear answer	Basic electrical functioning
4	Product selection	—	—	Nesting interference	—	Fire ignition	Product selection

These issue modes map directly to the Technical Guide controls:

- **Acceptance (Section 4):** Seam and overlap, closure integrity, material condition, displacement, moisture, and vent paths
- **Engineering guardrails (Section 5):** Too small/too large, overlap, and “do not create a new hazard”
- **Inspection and replacement (Section 6):** Post-storm checks, UV aging, tracking and arc damage, and no patch fixes.

Program Prioritization Overlay

(Reliability Index and Strategic Importance Index)

This overlay is provided for program managers, supervisors, planners, and reliability teams. It is not intended to be calculated by crews during a yard visit. Crews should use the Field Guide's visit-level triage score and tracks. The Field Guide's 0–9 yard score (Section 3.1) is a visit-level triage tool. This appendix supports fleet-level prioritization and budget justification by separating 1 reliability performance from 2 strategic importance:

- Reliability Index (RI) (0–10): Yard reliability performance using local System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI), and Momentary Average Interruption Frequency Index (MAIFI), wildlife cause codes, and event history.
- Strategic Importance Index (SII) (0–10): Strategic importance (critical loads like hospitals/data centers/military, key system nodes, conservation priorities where applicable).

A simple prioritization score can be used, for example, Opportunity = SII + (SII – RI) (or a local variant). Use this overlay to decide where to fund targeted/complete mitigation and schedule planned follow-up work packages.

Appendix C

Standards Crosswalk

IEEE 1656-2010

Scope: IEEE 1656 provides recommended test methods to evaluate the electrical, mechanical, and durability performance of wildlife protective devices used on overhead distribution systems (up to 38 kV), especially devices installed in contact with, or adjacent to, energized parts/conductors.

Service conditions: IEEE 1656 describes usual environmental service conditions and provides examples of unusual conditions (e.g., corrosive exposure or heavy contamination) that may warrant additional testing or different device selection.

Core test areas covered the following:

- **Electrical performance** (device should not degrade insulation performance)
    - **Wet withstand** evaluates electrical withstand under wet conditions. Pass/Fail is based on no puncture across multiple samples under the specified procedure.
    - **Wet flashover (comparative)** compares fixture baseline vs. fixture and device. A common acceptance benchmark is maintaining flashover performance close to baseline (IEEE includes a ≥90% criterion).
    - **Lightning impulse withstand** evaluates using IEEE impulse procedures. Intended to verify the device does not introduce new dielectric weaknesses under impulse conditions.
- **Durability and environmental exposure** (device should not become brittle, crack, or degrade in normal service)
    - **Cold temperature** includes cold soak (–25°C) with repeated installation or reinstallation cycles. Failure includes cracking, splitting, or inability to reinstall.
    - **UV aging** includes a defined UV exposure duration and requires documentation of condition change. IEEE notes UV aging is primarily observational (no single universal pass/fail).
    - **Salt fog aging (for unusual service)** includes extended exposure and criteria tied to whether the device can remain in service following exposure/testing.
- **Mechanical retention and survivability** (device should stay installed under wind and handling)

- **Retention testing** includes wind retention targets and allows other retention approaches (e.g., displacement, weight, water) as appropriate to device type.

- **Fire or arc behavior** IEEE 1656 also includes flammability and power-arc related test concepts for polymer devices where post-fault behavior is a concern.

How this ties to the following guides:

- **Field Guide**: Field acceptance is performed via installation checks and photo verification. IEEE 1656 is not a field checklist; it is a product testing reference.

- **Technical Guide**: Use IEEE 1656 in procurement submittals (requested test evidence) and as background for why durable, well-retained, non-dielectric-degrading mitigation is required.

IEEE 1264-2022

Scope: IEEE 1264 documents methods and designs to mitigate interruptions, equipment damage, and personnel safety issues from animal intrusions into electric power supply substations (i.e., substation-focused, not overhead line device testing).

Service conditions: IEEE 1264 explicitly emphasizes that mitigation selection depends on local operating history factors like geography, seasonality, operating history, design and constructability, and local animal behavior.

Core decision criteria: IEEE 1264 provides "application determination" criteria and states that mitigation need is influenced by factors such as outage frequency/duration, outage cost, safety hazards, equipment type, customers served, location, and quality of service requirements.

Core mitigation method categories: IEEE 1264 organizes mitigation methods into categories of physical barriers, increased isolation or insulation, deterrent methods, plus other methods. IEEE 1264 also adds guidance on materials properties and performance testing (and includes practical annexes like sealing guidance and animal dimension references).

Performance monitoring: IEEE 1264 includes guidance for mitigation and includes performance monitoring as part of that program logic (i.e., not "install and forget").

How this ties to the Technical Guide: Use IEEE 1264 in Appendix C of the Technical Guide to justify (1) the criteria-first approach (targeted retrofits based on history/risk), (2) the organization of mitigations by method type (barriers vs insulation vs deterrents), and (3) the emphasis on monitoring/inspection so mitigations do not silently fail over time.

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