

# STRATEGIC HV CABLE MANAGEMENT IN PETROCHEMICAL & REFINING PLANTS

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Paper No. PCIC energy EUR26\_18

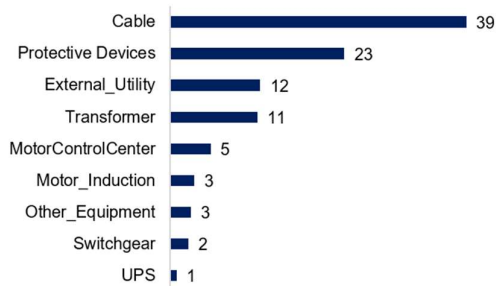
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**Abstract** - Ensuring the reliability of HV cable systems is vital in industrial settings where electrical continuity affects operations. This paper introduces a structured, multi-criteria framework to assess cable condition, performance, and recovery potential. It combines qualitative and quantitative indicators across five dimensions: data collection, cable health, diagnostics, recovery system status, and consequence analysis. Each is scored via a traffic-light system (Green/Amber/Red) to visualize risks and guide maintenance priorities. Recovery feasibility is also evaluated, including re-energization, temporary generation, fault access, and spare availability. A refinery case study demonstrates the framework's effectiveness in identifying vulnerabilities and supporting strategic decisions.

## I. INTRODUCTION

The North Atlantic Port-Jérôme refining complex in France covers a surface area of about 700 hectares, requiring extensive use of high-voltage cabling to distribute power from the utility interconnections until production units, tank farms, and loading facilities. In total, the site operates 315 large distribution feeders representing approximately 85 kilometers of installed high-voltage cable (3.2/5.5/15 & 90 kV). Figure 1 highlights that cable failures have been the leading electrical contributor to production losses at the facility over the last 20 years, making it a clear and compelling case for targeted reliability improvement actions at minimum cost.

Figure 1: 2005-2025 Pareto Analysis of Loss Contributors (%)



## II. FAILURE MODES AND INCIDENT ANALYSIS

A comprehensive root cause analysis was conducted for each cable-related incident. The findings indicate that the failures are primarily driven by stressors given in Table 1. Similar patterns of root causes are widely documented in high-voltage underground cable failure studies [2], [3].

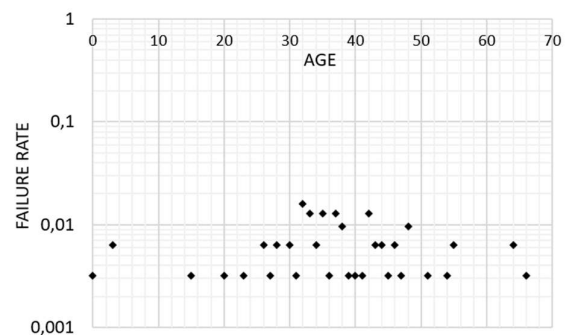
TABLE 1  
ROOT CAUSE OF FAILURES

Main factor	Root cause
Manufacturing defects	- Water treeing for 1970's XLPE
Poor workmanship for joints and terminations	- Insulation nicks and knife marks - Non-uniform tape thickness - Gaps created between the tape - Insufficient cutback length
External stressors	- Excavation works incidents - Steam leaks close to the cable - Overweight above the routing - Tree roots intrusion - Ground subsidence

### Contribution of ageing factor on failures

Counter-intuitively, Figure 2 shows no measurable correlation between cable age and failure rate, despite the fact that the cable population has a median age exceeding 50 years. This indicates that aging plays only a limited role in overall cable reliability. Recent IEEE reviews confirm that ageing mechanisms alone rarely explain field failures when compared to external stressors and workmanship issues [1]. At site, fault occurrences remained erratic over the past 20 years, and the analysis does not support a large-scale replacement strategy based solely on cable age.

Figure 2: Failure Rate as a Function of Age



### Redundancy and contribution of loading factor on failures

In refining, critical units are usually supplied by double-ended feeders, and their electrical loads operate with remarkable stability, showing minimal power fluctuation. Because of these specificities, cables loading should remain <80% with low thermal cycling in normal operation. From our experience, many failures occurred under N-1 conditions, where one feeder was de-energized for any reason and where the remaining in-service cable

had to carry the full load. Similar behaviors are reported in resilience-oriented distribution network studies, where contingency loading exposes hidden weaknesses in distribution feeders [5], [6]. In these situations, the additional load exposes underlying weaknesses and sometimes leads to catastrophic failures, causing a total blackout of the downstream units.

### III. ASSESSEMENT METHODOLOGY

The 315 feeders were assessed following the criteria from APPENDIX A. Each item is scored via a traffic-light system (Green/Amber/Red). The assessment led to identifying 15 critical cables for which a specific equipment strategy is required. For the 300 remaining ones, the fit for purpose strategy is “run to failure” with no further mitigation.

### IV. MITIGATIONS FOR CRITICAL CABLES

The mitigation plan for critical cables aims to address both the probability and the consequence of failures. However, the range of preventive maintenance actions capable of significantly reducing failure probability is inherently limited for high-voltage cable systems. As a result, the site’s strategy is predominantly focused on consequence reduction ensuring that, when a failure occurs, its operational impact, outage duration, and recovery time remain as low as possible

#### A – Repairs and contingency plans

Refinery power systems are often engineered to ride through single contingencies, yet N-1 operations inevitably amplify exposure to downtime: when one feeder is out, any additional fault risks propagating into multi-day outages. In this context, minimizing Time-To-Repair (TTR) is not just desirable—it is the dominant reliability objective. Beyond classical safety and compliance constraints (ATEX, permits, gas testing,...), what ultimately determines production impact is how quickly a fault can be located, accessed, repaired, and safely re-energized within the refinery’s typical two-day window. Achieving this requires pre-positioned enablers—accurate routing knowledge, pre-awarded contracts for fault-location and certified jointers, strategic spares, and disciplined documentation—to remove delays at each step. Table 2 maps the repair sequence to the key optimization drivers that systematically contain TTR and prevent N-1 from drifting into prolonged outages.

In certain situations, restoring service through a temporary generator can be deployed more rapidly than undertaking a full cable repair. However, such an approach requires significant advance preparation: ensuring proper generator sizing, assessing short-circuit contribution, securing adequate physical footprint and access, and verifying the availability of suitable cable routes and connection points. These considerations become markedly more complex when a high-voltage temporary installation is required, where constraints linked to safety clearances, switching arrangements, equipment availability, and interconnection capabilities add a further layer of operational difficulty. It is hence a case-by-case evaluation.

TABLE 2  
Cable repair optimization

Repair Step	Key Optimization Drivers	Supporting Measures / Mitigations
1 – Diagnostic	Fast fault confirmation & isolation	Maintain updated cable route and joint location records
2 – Fault finding	Accurate pinpointing, minimal excavation	Fault-location procedure (TDR, sheath test); 24/7 contract with fault-location agency
3 – Excavation	Rapid and safe access to the cable	Updated routing layouts; excavation procedures adapted to refinery constraints
4 – Jointing	Immediate availability of skilled jointers & correct kits	Contract with certified HV jointers; onsite stock of joints, terminations, cable segments
5 – Energization	Efficient testing and approval process	Agreed repair commissioning plan and re-energization protocol

#### B – Preventive inspection plans

The purpose of the inspection plan is to perform systematic and periodic walkdowns along the entire cable routing to identify abnormal external conditions that may develop into cable failures. These walkdowns include detailed visual checks of above-ground sections—such as sheath cuts, sharp-edge contact, excessive bending, foreign objects, cable or support vibration, and proximity to hot pipes or steam traps—and verification of underground routes to ensure that no unauthorized excavation, soil movement, or heavy loading is present. In addition to these visual inspections, predictive maintenance such as thermal monitoring through routine thermography of accessible joints and terminations (including via IR windows) and acoustic switchgear PD campaigns provides early detection of overheating or emerging defects that cannot be observed visually. By combining visual inspection and condition-monitoring, the inspection plan forms a proactive barrier that captures mechanical, thermal, and environmental precursors before they evolve into insulation degradation or joint/termination failure, thereby reducing unexpected outages and preserving the Time-To-Repair (TTR) performance during N-1 conditions.

#### C – Proactive cable replacement

Proactive cable replacement becomes necessary when a feeder exhibits a persistent and structurally embedded vulnerability that cannot be mitigated through inspection, or corrective repairs. The set of 15kV cables from figure 3 & table 3 (D071/D072/D141/D142) are a representative example: despite decades of operation under a run-to-failure strategy, these feeders have accumulated multiple failures since the early 1990s, originating from diverse mechanisms including water-treeing, mechanical damage, degraded joints and terminations, and defects associated with installation practices or external aggressions. Historical RCFA and forensic laboratory

analyses have repeatedly highlighted the susceptibility of these cables to water-treeing due to their vintage XLPE design, while more recent measurements have revealed water ingress and degradation patterns that remain difficult to quantify with standard diagnostic methods. This combination of known vulnerability, recurrence of faults, and uncertainty in condition assessment effectively designates those cables as ‘bad actors’ within the grid. For such feeders, the probability of future failures remains structurally high, and the operational exposure during N-1 conditions becomes unacceptable. In these situations, planned replacement provides the most robust and cost-effective long-term mitigation strategy, eliminating the underlying failure mechanisms and restoring full reliability margin to the electrical distribution system

FIGURE 3  
Bow tie water treeing identified a “bad actor” cable

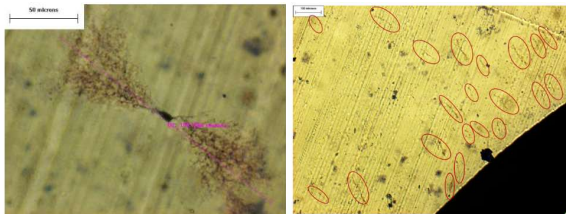


TABLE 3  
Failure history on “bad actor cables”

Year	Event
1974	Feeders installation
1991	D071/D072 – Thermal degradation near steam leak
1993	Additional degradation observations on D071/D072
1996	Replacement decision review (D141 / D142 / D071 / D072) => NO GO
2007	D141 – Splice box fault
2010	Early degradation indications on D071/D072
2012	D071/D072 – Thermal degradation near steam leak
2020	D141 – Cable fault (complex, not attributed directly to water-treeing)
2022	D141/D142 – Major failure event (water ingress confirmed on D142)
2025	Diagnostic campaign (sample analysis) confirming end-of-life indicators on D141/D142 => Decision to replace

#### *D – Discussion about cable testing plans*

The site has experimented a wide range of diagnostic methods over the years, including online monitoring, offline VLF measurements, partial-discharge techniques and thermographic inspections, yet none of these approaches has ever yielded a clear or actionable conclusion. This aligns with IEEE guidance, which documents both the strengths and the practical limitations of VLF and PD test methods for ageing insulation systems [4]. In every case, the results fell into an ambiguous ‘gray zone,’ offering insufficient contrast to support a firm assessment of insulation condition or remaining life. This limitation is even more pronounced on vintage 1960s & 70s cable designs, where applying higher test voltages is inherently risky: several past campaigns resulted in the cables failing during the test itself, illustrating how narrow the margin is between diagnostic stress levels and the actual dielectric withstand capability of ageing insulation. As a result, test voltages

must be deliberately limited, which further reduces the diagnostic sensitivity and reinforces the inconclusive nature of the results. Consequently, across all cases where a decision was ultimately required, the only method that has provided a definitive and reliable basis for action has been the laboratory analysis of extracted cable samples. These destructive examinations remain the sole approach capable of characterizing the true extent of degradation—particularly water-presence—and therefore form the most robust input to the decision-making process for ageing high-voltage circuits.

## II. CONCLUSION

This work based on actual site data provides a practical, field-tested framework for managing aging HV cable fleets in complex refining environments. The approach allows operators to clearly identify true risk-driving feeders and focus mitigation efforts where they deliver the greatest reliability benefit. For critical circuits, consequence reduction remains the most effective lever: rapid fault access, streamlined repair logistics, pre-engineered contingencies, and disciplined documentation. Persistent “bad-actor” feeders should be scheduled for planned replacement. Further improvement can be achieved by establishing a refinery-wide HV cable readiness program—aligning jointers, operations, inspection teams, and contractors around standardized response procedures and shared TTR performance targets.

## III. REFERENCES

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## II. VITA

**Julien Mascarell** is graduated from the Grenoble Institute of Technology in 2006 (ENSE3) with a Master degree in electrical engineering and has over 20 years of industrial experience in power systems engineering. He has held specialist and leadership roles in refining, petrochemicals and steelmaking. He is currently Subject Matter Expert for electrical discipline at North Atlantic Refining.

**APPENDIX A**  
Methodology and criteria for cable fleet assessment

Each cable gets a score according to following assessment criteria:

0 - Data collection	Cable tag, type, Size, Voltage, Approximate cable length	<b>Green</b>	<b>Amber</b>	<b>Red</b>
1 – Cable condition Assessment based on comprehensive data	Age	<40y	40 - 50y	> 50y
	Permanent load	<80%	80 - 95%	>95%
	Nr of known splices/repairs	0	1-3 Unknown	>3
	Known degradation ongoing	No issue	Known, stable	Known/increasing
	Known installation issue	No issue	Unknown	Poor
2 – Condition assessment based on cable testing	Online testing already performed	Yes, no issue	No test	Yes, problem
	Offline testing already performed	Yes, no issue	No test	Yes, problem
3 – Recovery system health assessment	Existence/Absence of automatic transfer system (ATS)	Exist	/	Does not exist
	Known issue ATS	No issue	Unknown	Issue
	ATS 100% tested	Tested	Not tested	Tested, issue
	ATS sequence Proven in operation	Proven once	Unknown	Failed
	Known issue on UPS and chargers	No issue	Unknown	Issue
4 - Evaluation of consequence	Known issue on batteries system	No issue	Unknown	Issue
	Consequence of failure (>24h)	Low	Medium	High
	Consequence N-1 of failure (>24h)	Medium	Medium	Very high
5 – Solutions to reduce unavailability	Consequence N-2 of failure (>24h)	Medium	Medium	Very high
	Re-energize cable at reduced load if possible (if cables in //) and define new operating envelop	Possible, no issue	Process limitation	Impossible
	Portable temporary generator installation affordable	Possible, no issue	Process limitation	Impossible
	Fault localization/routing accessibility difficult	Easy	Difficult	Very difficult
	Spare cable, splice and/or termination available on the shelf	On the shelf	<3d	>3d
	Requires special workmanship competencies to repair	No	/	Yes