White Paper

SAFEGRID

Solutions for High Impedance Faults

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Detecting What Others Miss:

The case for continuous monitoring solutions for High Impedance Faults (HIFs)

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1. Executive Summary

High impedance faults (HIFs) remain one of the most difficult and consequential challenges facing modern power system operators. Unlike conventional low-impedance faults, HIFs often do not produce fault currents large enough to reliably trigger traditional protection devices. As a result, energized conductors may remain in abnormal and potentially hazardous states for extended periods, posing risks to public safety, increasing the likelihood of wildfires, degrading grid reliability, and negatively impacting utility financial performance.

While utilities have long been aware of this blind spot, the operating environment has changed significantly. Aging infrastructure, increasing wildfire exposure, expanding vegetation interfaces, distributed energy resources, bi-directional power flows and heightened regulatory scrutiny have all amplified the consequences of undetected or poorly localized faults. In this context, the limitations of relying solely on impedance-based protection and manual patrols have become increasingly clear.

This paper explores the physical nature of high impedance faults, their operational and economic impact, and the reasons they are difficult not only to detect but also to locate. It proposes the use of continuous, non-contact monitoring as a complementary layer of grid intelligence, and describes how Safegrid's Intelligent Grid System® (IGS) can help utilities reduce risk, improve restoration performance, and strengthen overall grid resilience.

2. Understanding High Impedance Faults

High impedance faults are best understood not as a single fault type, but as a class of abnormal operating conditions in which fault current is constrained by the characteristics of the fault current path. Unlike low-impedance faults, where direct metallic contact leads to large, sustained currents, HIFs involve fault paths with significantly higher resistance that restrict current flow.

These conditions arise when energized conductors interact with dry or resistive ground surfaces, asphalt, concrete, vegetation, contaminated insulation, degraded connectors, wildlife, or partially failed components. The resulting fault current often has a low energy, exhibits irregular temporal patterns and can demonstrate deformed waveforms due to arcing and nonlinear conduction.

Crucially, high impedance faults include both earth faults (phase-to-ground faults) and short circuit (phase-to-phase or phase-to-neutral) faults. While phase-to-ground contact on resistive surfaces is common, high impedance phase-to-phase or phase-to-neutral faults also occur, particularly through tree branches contacting multiple phases, contaminated insulators, or failing connectors. High impedance faults to ground or neutral produce significant zero-sequence current due to their unbalanced nature but can closely resemble common load imbalances because of the low total fault current, making them difficult to detect by impedance-based fault location systems.

The grounding method employed can influence how HIFs manifest. In all impedance grounded, Petersen coil grounded, or ground-isolated (delta) grid schemes the zero-sequence voltage (U_0) will rise above normally very small voltage potential and the voltage of the conductors of the non-faulted phases can rise up to 1.7 times the normal voltage, depending on the grounding impedance and the grid capacitance. This elevated voltage stresses the entire network but is noticeable primarily only at weak points. In some cases, a single HIF may not be constrained as an isolated event, but more as a trigger event to cascading failures in other points of the grid where insulation or, for example, surge arresters are compromised. In some cases, a so-called double-earth-fault may be formed, which is a hard-to-locate short-circuit between two phases and two locations via the earth. .

What these scenarios have in common is not simply low fault current - which enables HIFs to avoid detection by traditional protection systems - but ambiguous electrical behavior that falls between normal operation and classical fault conditions. This is exactly where traditional protection systems struggle to perform.

3. Operational and OPEX Impact on the Grid

The consequences of undetected or poorly localised HIFs are substantial.

From a safety perspective, sustained arcing or energized conductors in contact with ground, vegetation, or structures create conditions that can ignite wildfires, expose the public to electrocution hazards, and endanger maintenance crews. Unlike low-impedance faults, where the faults are typically cleared within some tens of milliseconds by automatic de-energising by opening a circuit-breaker or a recloser, HIFs may persist long enough to interact with environmental factors such as dry weather, wind, or vegetation growth, significantly increasing hazard potential.

High impedance faults do not always cause immediate interruptions to service. Instead, they tend to drive longer restoration times once action is taken, because locating the fault becomes the dominant challenge. This distinction is important: SAIFI (System Average Interruption Frequency Index) measures how often customers are interrupted, while SAIDI (System Average Interruption Duration Index) measures how long those interruptions last. Low-impedance faults increase SAIFI due to repeated trial-and-error switching when trying to locate the fault and disproportionately affect SAIDI through extended patrol while line is de-energized, unless the grid operator is willing to take a risk in keeping the line energized under a fault condition. This, in case the grid operator is aware of a fault condition, e.g. due to increased U_0 causing an alert.

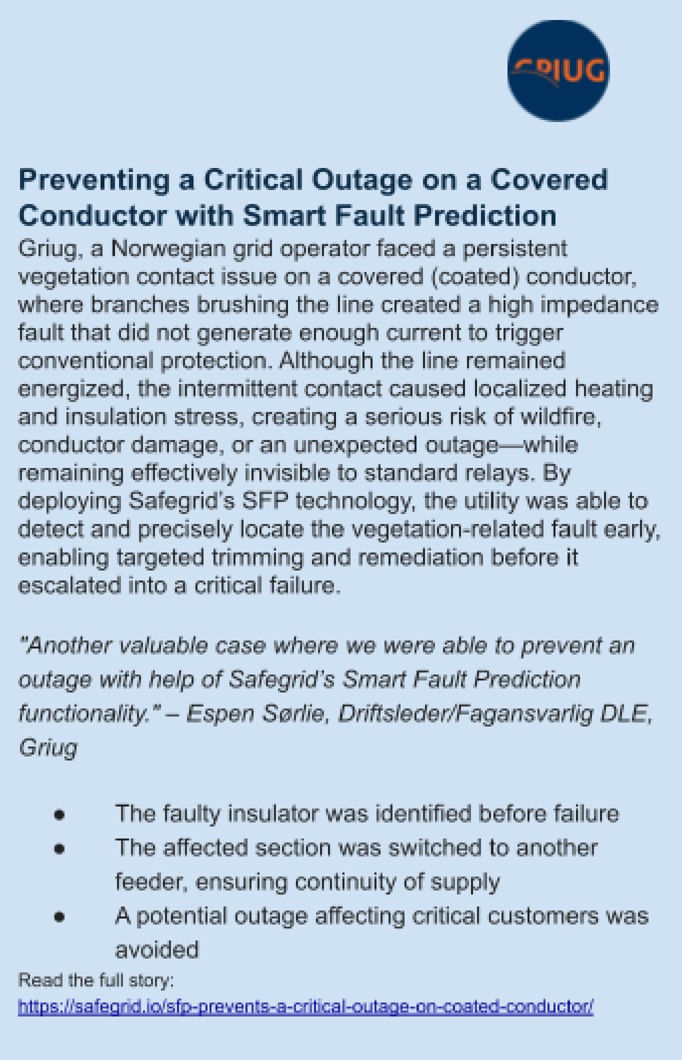
In some cases, however, especially with arc suppression coil grounded grids, intermittent HIF behavior can also lead to repeat recloser operations or miscoordination of protection circuitry, thus increasing SAIFI. More commonly, however, the reliability penalty manifests as prolonged outages that are difficult to predict, explain, or defend in post-event analysis.

The economic consequences extend well beyond direct operational costs. Utilities incur additional expenses related to vehicle and foot patrols, overtime labor, and emergency response. Indirect costs include legal liability, insurance exposure, fire damage, and regulatory penalties. Less visible—but equally important—are the long-term impacts on public trust, regulatory relationships, and perceived risk, which can influence insurance premiums and cost of capital. This in turn increases financing costs, which creates a negatively-reinforcing impact on the grid operator's long-term asset replacement strategy and increased OPEX due to the labour costs of patrolling.

4. Why Detection and Location Remain Difficult

While HIFs are hard to detect, in practice the greater challenge is determining where they are and how urgently to respond.

Most protection, fault location, and fault passage indication methods are fundamentally impedance-based. They determine the presence and distance to fault by analyzing voltage and current measurements. When fault current is low, or highly distorted, impedance estimates become more prone to error. Zero-sequence voltage (U_0) and current (I_0), when they are present, can provide some indication, but they often don't yield precise location under high-impedance conditions.



Preventing a Critical Outage on a Covered Conductor with Smart Fault Prediction

Griug, a Norwegian grid operator faced a persistent vegetation contact issue on a covered (coated) conductor, where branches brushing the line created a high impedance fault that did not generate enough current to trigger conventional protection. Although the line remained energized, the intermittent contact caused localized heating and insulation stress, creating a serious risk of wildfire, conductor damage, or an unexpected outage—while remaining effectively invisible to standard relays. By deploying Safegrid's SFP technology, the utility was able to detect and precisely locate the vegetation-related fault early, enabling targeted trimming and remediation before it escalated into a critical failure.

"Another valuable case where we were able to prevent an outage with help of Safegrid's Smart Fault Prediction functionality." – Espen Sørlie, Driftsleder/Fagansvarlig DLE, Griug

- The faulty insulator was identified before failure
- The affected section was switched to another feeder, ensuring continuity of supply
- A potential outage affecting critical customers was avoided

Read the full story:
https://safegrid.io/sfp-prevents-a-critical-outage-on-coated-conductor/

High-impedance faults (HIFs) challenge detection with traditional impedance-based methods because they produce very low fault currents—often under 100 A or even 10 A due to high-resistance contacts like trees or pavement—falling below conventional pickup thresholds. Active arc-suppression devices may reduce high-impedance phase-to-ground faults even down to 0.5 A. Their nonlinear arcing, random waveforms, and masking by load fluctuations or transients (e.g., switching events) make high-impedance faults hard to distinguish from normal operations, forcing utilities into a trade-off: heightened sensitivity risks nuisance alarms and fatigue, while conservative settings delay critical responses to precursor events.

5. The Role of Continuous Monitoring

Continuous monitoring systems offer a complementary perspective on the HIF problem. Rather than relying solely on impedance estimation, they observe waveform phenomena associated with abnormal high-frequency energy events caused by, often very small, intermittent conductivity of the conductor-to-surface touch point.

By deploying distributed, non-contact sensors along feeders and routes, these systems can correlate anomalies across space and time. This capability is especially valuable for faults that are marginal or in early stages of degradation, where traditional indicators fluctuate or disappear altogether.

The principal value of continuous monitoring is not necessarily faster tripping, but earlier fault awareness and improved localization - and where possible - prediction. By narrowing the probable fault area, these systems can dramatically reduce patrol scope and restoration time, most importantly when protection devices do not respond.

6. Current Approaches to HIF Detection and Localization

Utilities today employ a range of technologies to improve fault detection and location, each with distinct strengths and limitations.

Impedance-based protection and fault location systems are the legacy mode of fault location in the modern grid. They can perform well for low-impedance faults and benefit from decades of operational experience, although even in such cases fault location can be a challenge in highly complex branching topologies, longer distance to the fault location, or when the impedance of the ground path is not known, as is typically the case with phase-to-ground faults and often phase-to-neutral faults. Under high-impedance conditions, low or irregular fault current and unknown fault point impedance and return path impedance undermines both detection reliability and location accuracy.

Fault passage indicators (FPIs) are deployed in the purpose of reducing patrol scope for conventional faults and supporting sectionalizing strategies. While they can identify the presence of a high-current low-impedance fault, they can only provide a direction and not a location of the fault. Their effectiveness for HIFs is even further limited by the fact that they employ overcurrent thresholds that are fixed at installation. Once set, their mode of operation typically can’t be changed remotely. Consequently, low-fault-current HIFs often don’t trigger alerts.

7. Safegrid IGS: Touchless HIF Detection and Localization

Safegrid’s Intelligent Grid System (IGS) system is designed specifically to address the detection and localization gap associated with HIFs. It employs a network of non-contact, IoT-enabled sensors that monitor magnetic field phenomena including travelling waves and a >1MHz sampling rate, allowing it to detect the waveform disturbances characteristic of HIFs without requiring physical connection to energized conductors.

Because the system is touchless, it can be deployed without outages or protection reconfiguration, pending local regulations and standards. Its distributed architecture enables correlation across multiple sensing points, improving confidence and localization accuracy even when individual fault signatures are subtle.

IGS evaluates patterns observed by multiple sensor nodes over time rather than relying on a single indicator. In many cases, this allows it to detect sustained arcing or ground leakage current and, under certain conditions, early transient events when a conductor first contacts vegetation or another resistive medium.

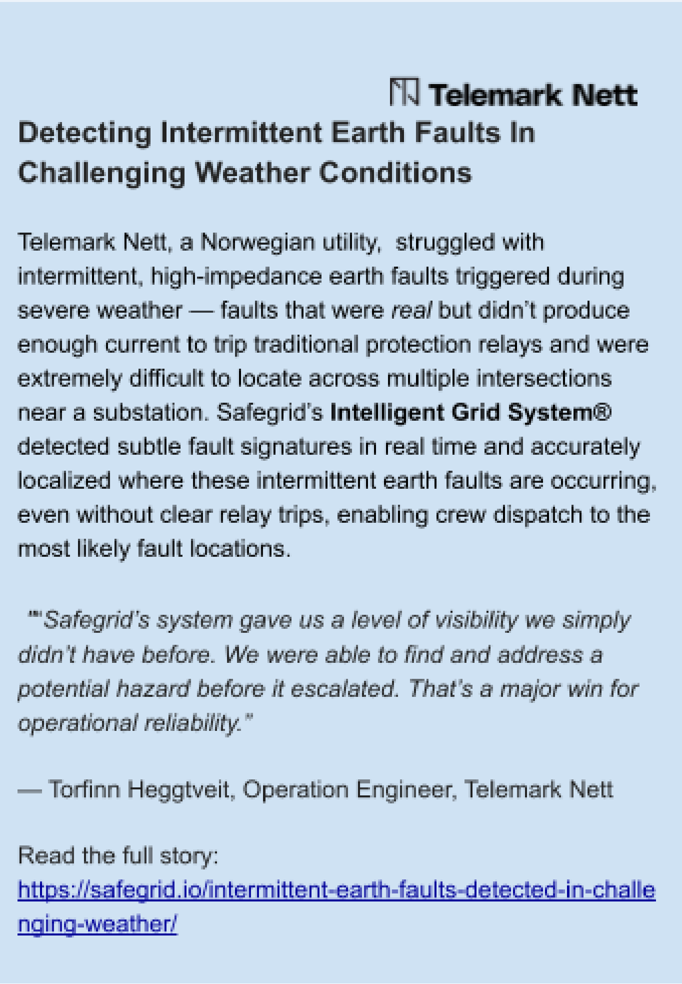
Importantly, IGS is designed to coexist with existing infrastructure. It integrates with DMS and ADMS environments and complements impedance-based protection, fault passage indicators, and other monitoring systems without introducing nuisance trips or coordination risk. In practice, the Safegrid IGS represents the most reliable method for detecting HIFs and promoting a resilient grid architecture.

8. Value Realization

Deployment strategies for continuous monitoring vary by network topology and risk profile. Common starting points include distribution feeders that represent the highest cost risk of downtime, wildfire-prone regions, long rural corridors, substations with aging assets, and renewable interconnects where fault behavior can be complex.

From a value perspective, utilities typically realize benefits through reduced patrol time, faster restoration, improved safety outcomes, and stronger regulatory defensibility. In some cases, avoided costs associated with a single extended outage or patrol campaign can justify investment in a matter of weeks rather than years.

Return on investment is therefore best evaluated not only through traditional reliability metrics such as SAIDI and SAIFI, but also through OPEX expenditures on inspections, patrols, repairs as well as avoided risk exposure and other operational efficiency gains.



Telemark Nett

Detecting Intermittent Earth Faults In Challenging Weather Conditions

Telemark Nett, a Norwegian utility, struggled with intermittent, high-impedance earth faults triggered during severe weather — faults that were *real* but didn't produce enough current to trip traditional protection relays and were extremely difficult to locate across multiple intersections near a substation. Safegrid's **Intelligent Grid System®** detected subtle fault signatures in real time and accurately localized where these intermittent earth faults are occurring, even without clear relay trips, enabling crew dispatch to the most likely fault locations.

""Safegrid's system gave us a level of visibility we simply didn't have before. We were able to find and address a potential hazard before it escalated. That's a major win for operational reliability."

— Torfinn Heggtveit, Operation Engineer, Telemark Nett

Read the full story:
https://safegrid.io/intermittent-earth-faults-detected-in-challenging-weather/

9. Conclusion

HIFs will remain a persistent challenge of power system operation. As grids grow more complex and expectations for safety and reliability continue to rise, relying solely on impedance-based methods and FPIs leaves utilities exposed to risks that are increasingly unacceptable.

Safegrid's continuous, touchless monitoring provides a pragmatic and scalable way to close this visibility gap. By complementing existing protection and automation systems with persistent situational awareness, utilities can detect, localize, and respond to high impedance faults more effectively—improving safety, reliability, and operational performance without compromising protection integrity.

To learn more about how Safegrid IGS can help create a more effective approach to managing HIFs, email info@safegrid.com or visit safegrid.com/demo to reach a sales consultant.

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