Screening and Guidelines for Unintentional Islanding Protection in Distributed Energy Resources

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***Abstract*— The increasing penetration of distributed energy resources (DERs) in distribution networks introduces new challenges for maintaining system safety, particularly in the context of unintentional islanding. This paper presents a comprehensive screening framework that supports utilities in determining when advanced anti-islanding protection—such as direct transfer trip (DTT) - is necessary and what cost-effective alternatives can be applied. While DTT provides a reliable means of ensuring full DER de-energization, its high implementation and maintenance costs, along with its point-to-point configuration, limit its practicality for widespread DER deployment. To address this, the paper evaluates lower-cost communication-based schemes and protection combinations such as live-line reclose blocking (LLRB) and undervoltage protection relay combined with DER unintentional islanding detection (UV-UID) methods. The proposed framework identifies where these alternatives can achieve comparable reliability to DTT while reducing costs and dependence on dedicated communication channels.**

***Index Terms*—Unintentional islanding, distributed energy resources, direct transfer trip, distribution networks.**

I. Introduction

By increasing the penetration of distributed energy resources (DERs), modern distribution networks have become more complex in both operation and protection coordination [1]. Traditionally, North American distribution feeders were designed as radial circuits, energized from a single source through a substation breaker. When this breaker opened, the entire circuit de-energized. The interconnection of DERs, however, introduces multiple sources of energization along the feeder, so the loss of the primary source no longer guarantees circuit de-energization. Islanding in distribution systems refers to a condition in which a portion of the distribution circuit remains energized solely by DERs while being disconnected from the rest of the grid. Such unintentional islanding (UI) conditions pose safety and reliability concerns, as DERs may continue supplying local loads without a grid reference [2]. Therefore, all DERs must cease energization rapidly upon loss of utility supply to ensure personnel safety, protect equipment, prevent asynchronous reclosing, and maintain voltage and frequency within acceptable limits. To mitigate these risks, standards such as IEEE Std 1547-2018 and IEC 62116 specify that DERs must cease energizing within two seconds of an UI event [3].

To ensure compliance, utilities and DERs employ various UI protection schemes that can be categorized into passive, active, and communication-based methods [4]. Passive methods monitor local electrical quantities, such as voltage magnitude, frequency, rate of change of frequency (ROCOF), or voltage phase angle—and initiate tripping when deviations exceed predefined thresholds. Active methods, by contrast, introduce small perturbations or positive feedback signals into the DER control loop to deliberately force detectable changes upon grid disconnection. Communication-based methods rely on information exchange between field devices, typically through direct or supervisory channels, to confirm the presence or loss of the utility source. Among them, direct transfer trip (DTT) is widely used because it provides a deterministic, highly reliable means of tripping DER following system separation [1], [4].

A 2023 EPRI survey of 51 (4 from Asia and Europe) utilities highlights wide variation in UI protection practices across North America. While most utilities recognize the low probability of sustained islanding from certified inverter-based DERs, many continue to mandate DTT under certain generation-to-load ratios or short reclosing intervals [5].

In Canada, BC Hydro applies a Two-to-One criterion, considering an island unsustainable when feeder minimum load is at least twice total generation. Hydro One requires DTT for DERs larger than 1 MW or exceeding 50% of feeder minimum load, while smaller units (≤500 kW) may use passive methods such as ROCOF or vector shift. SaskPower mandates DERs above 100 kW to cease energization within two seconds, requiring DTT when analytical proof of compliance is insufficient. ATCO Electric enforces DTT or other teleprotection schemes whenever a close generation-to-load balance exists. EPCOR and ENMAX require both passive and active protection methods, with DTT generally applied for DERs > 500 kW or when DER export exceeds one-third of feeder minimum load [6].

In the United States, Xcel Energy, Central Hudson Gas & Electric, and Eversource Energy adopt study-based approaches to evaluate islanding risk. Each utility conducts interconnection studies to determine whether local UI protection is sufficient.

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When the analysis identifies potential risk, additional mitigations such as voltage-supervision reclosing (VSR), also known as live line reclose block (LLRB) or DTT is required. Dominion Energy applies a 33% generation-to-load threshold, while Pepco Holdings mandates DTT when generation reaches 80% of minimum load. The Joint Utilities of New York use a tiered screening process based on Sandia criteria, and National Grid mandates reclosers or DTT when DER penetration exceeds 33%. Pacific Gas & Electric (PG&E) recently introduced capability-based screening, requiring LLRB, DTT, or SCADA-equipped reclosers when aggregate DER exceeds 50% of minimum load or when rotating-machine-based DERs account for more than 40% of total generation [7].

As the literature shows, DTT schemes have been widely adopted for their proven reliability in ensuring complete DER disconnection during UI events. However, DTT implementation involves substantial installation and maintenance costs and is constrained by its point-to-point communication architecture. Recent research by Sandia National Laboratories [2] and the Interstate Renewable Energy Council (IREC) [7] indicates that the probability of sustained unintentional islands involving certified inverter-based DERs is extremely low. Consequently, many utilities are now exploring screening methodologies to determine when DTT is truly necessary and when alternative, lower-cost protection strategies can provide equivalent reliability and safety.

To the authors' knowledge, prior utility screening practices and published methods have not reported an end-to-end framework that (i) differentiates criteria by DER technology (inverter-based vs. rotating-based), (ii) accounts for DER size and mix of resources within the potentially islanded segment, and (iii) links screening outcomes to actionable mitigation guidance using defined thresholds. This paper builds upon the primary authors' previous work presented at the IEEE PES General Meeting 2025 [8], which focused on determining the appropriate generation-to-minimum-load threshold and DER size criteria for screening the likelihood of sustained UI. While that study established a quantitative basis for islanding-risk screening, it did not address mitigation alternatives or the effectiveness of inverter-based UI methods. Building on that work, this paper presents an integrated screening-and-guideline framework to support utility decisions, including cost-effective options such as LLRB and undervoltage protection combined with DER unintentional-islanding detection (UV-UID). The framework uses feeder minimum-load data and DER characteristics and updates reactive-power mismatch bounds by linking allowable imbalance to system frequency-trip settings. Inverter-based resources considered in this paper are limited to grid-following DERs; grid-forming (GFM) inverters are outside the scope of this study.

II. Risks and Screening Treshold for Unintentional Islanding

The UI assessment framework developed in this study is primarily based on the methodology outlined in the Sandia National Laboratories reports [1]-[2], [4] and [9], which distinguishes between low- and high-risk operating conditions. These conditions establish the thresholds at which UI can be reasonably excluded and identify cases that require further evaluation or additional protection schemes. By integrating these guidelines with feeder-level minimum load information and DER penetration data, utilities can more accurately evaluate islanding risk and determine suitable mitigation strategies.

A. DER Capacity

DER capacity alone does not inherently determine the risk of UI; rather, the concern arises from the relationship between the total DER generation and the feeder's minimum load. In the primary authors' previous study [8], a statistical analysis was performed using five years of minimum-load and installed-DER data from a Canadian distribution system to evaluate islanding risk. Based on this analysis, a 4 MW threshold was established as a conservative criterion for rotating-based DERs, which pose higher islanding risks due to their GFM characteristics compared with inverter-based DERs. The results indicated that DERs exceeding 4 MW are more likely to match feeder minimum load under certain operating conditions, thereby sustaining islanded operation and necessitating advanced protection measures such as direct DTT. Conversely, DERs below 4 MW were typically located on feeders where minimum load varies significantly throughout the year—making it difficult to reliably predict load-generation balance. Therefore, a detailed screening process is recommended for these cases to accurately assess the risk of UI.

B. Active Power Mismatch:

The active power mismatch (ΔP) is the difference between the islanded load's demand (P_{load}) and the aggregate DER generation (P_{DER}):

$$\Delta P = P_{load} - P_{DER} \qquad (1)$$

When ΔP is small—indicating close generation-to-load balance—the islanded section may remain energized within normal voltage and frequency limits, creating a non-detection zone (NDZ) where islanding detection becomes difficult. Conversely, a large mismatch causes voltage or frequency to deviate rapidly beyond IEEE Std 1547-2018 trip thresholds [3], leading to prompt DER disconnection and system de-energization.

The non-detection zone can be analytically expressed as, [10]:

$$\left(\frac{V_{min}}{V_{nom}}\right)^2 \leq \frac{P_{DER}}{P_{Load}} \leq \left(\frac{V_{max}}{V_{nom}}\right)^2 \qquad (2)$$

Using IEEE Std 1547-2018 voltage trip thresholds [3]—Category I for rotating-based DERs and Category II for inverter-based DERs—the corresponding power balance ranges are approximately

$$\text{Category I:} \quad 0.45 \leq \frac{P_{DER}}{P_{Load}} \leq 1.12 \qquad (3)$$

$$\text{Category II:} \quad 0.19 \leq \frac{P_{DER}}{P_{Load}} \leq 1.12 \qquad (4)$$

For rotating-based DERs, many utilities adopt conservative generation-to-load thresholds, typically between 33% and 50%, to determine when communication-assisted protection such as DTT is required. According to IEEE Std 1547.2-2023 [11], if the aggregate DER capacity is less than one-third of the local load, the DERs are generally unable to sustain acceptable voltage and frequency during islanding. Accordingly, a 33%

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threshold was applied for rotating-based DERs in the proposed screening framework.

For inverter-based DERs, investigations conducted under Sandia National Laboratories [9] demonstrated that higher penetration levels can be tolerated due to current-limited operation and integrated UI detection methods. Accordingly, a 66% threshold is established as a practical screening limit for inverter-based DERs. Below this level, sustained islanding is unlikely since inverters cannot maintain stable voltage and frequency conditions within IEEE Std 1547-2018 limits [3].

C. Reactive Power Mismatch:

The reactive power mismatch (ΔQ) is the difference between the reactive demand of the islanded load (Q_{load}) and the reactive output of the DERs (Q_{DER}) and local capacitor banks (Q_{CB}).

$$\Delta Q = Q_{load} - Q_{DER} - Q_{CB} \quad (5)$$

When this mismatch is small, voltage and frequency can remain within acceptable limits, increasing the risk of an undetected island. Conversely, a large mismatch drives system variables outside the IEEE Std 1547-2018 thresholds [3], causing inverter disconnection and preventing sustained islanding.

Following the approach in [7], [10], the reactive power non-detection zone can be expressed as:

$$R_Q = \frac{Q_{DER} + Q_{Cap} + Q_{load}}{P_{load}} \quad (6)$$

$$Q_f\left(1 - \left(\frac{f_{nom}}{f_{min}}\right)^2\right) \leq R_Q \leq Q_f\left(1 - \left(\frac{f_{nom}}{f_{max}}\right)^2\right) \quad (7)$$

Using IEEE Std 1547-2018 Category I–III default frequency trip limits ($f_{max} = 62\ Hz, f_{\min} = 56.5\ Hz$) for a 60 Hz nominal system with a quality factor of 1 [3]; Hence, the corresponding mismatch boundaries can be defined as:

$$-0.1277 \leq R_Q \leq 0.0635 \quad (8)$$

For simplicity and contingency, these limits are rounded to approximately.

$$-13\% \leq R_Q \leq 7\% \quad (9)$$

If non-default frequency trip settings are applied, the bounds should be recalculated accordingly.

D. Mixed-source DER Configuration

As discussed in the Sandia reports [2] and [9], the likelihood of sustaining an unintentional island increases significantly when rotating-based DERs account for a large portion of the total DER capacity. Rotating-based units, due to their GFM and inertial characteristics, can maintain voltage and frequency stability after grid disconnection, especially when operating alongside grid-following inverter-based DERs. Experimental results and simulations presented in the Sandia report [9] demonstrated that when rotating-based DERs exceed approximately 40% of the total DER capacity within a potential island, the probability of sustained energization rises sharply. This threshold, therefore, serves as a practical upper limit—beyond which detailed system studies or communication-based protection (e.g., DTT) are recommended to ensure secure disconnection.

E. Mixed Inverter Islanding-Detection Methods

Most North American utilities require that inverters connected to distribution systems be certified to standards such as UL 1741 [12], which is aligned with IEEE Std 1547 [3] and includes specific tests to evaluate the performance of each unit's UI detection method. Certified inverters undergo rigorous abnormal-condition and loss-of-utility testing to verify compliance with islanding detection and ride-through requirements. However, these standardized tests cannot represent all real-world conditions, particularly when diverse inverter technologies and detection strategies coexist on the same feeder.

According to the Sandia National Laboratories report [9], mixing inverters employing different detection principles can reduce the overall islanding detection effectiveness, as their active perturbations or passive monitoring responses may counteract each other. Sandia classified islanding detection methods into eight groups, with Group 1 (e.g., Sandia Frequency Shift) and Group 2A (e.g., Sandia Frequency Shift with Saturation Limit) demonstrating the most effective and consistent performance across test scenarios. Based on laboratory evaluations and field verification, Sandia concluded that when at least 66% of inverter-based DERs employ these effective methods, the probability of sustained islanding remains low. If 100% of the inverters fall within Groups 1 or 2A, the risk becomes negligible. Consequently, in this study's proposed screening framework, these penetration thresholds are adopted to distinguish low- and high-risk inverter configurations and determine whether additional mitigation such as DTT or LLRB protection is required.

III. The Adopted Screeing Methodology

Building upon current North America utility practices and UI standards, a structured screening methodology was developed. It uses minimum-load data and installed DER information from a representative Canadian distribution utility, as shown in Fig. 1. The approach also incorporates guidance from Sandia National Laboratories, EPRI [13], and the AESO [6]. The resulting framework, illustrated in Fig. 1, outlines a systematic process for screening DERs based on their technology type—rotating-based or inverter-based. The method was developed considering only grid-following inverter-based and certified resources, as GFM inverters are beyond the scope of this study.

It is assumed that detailed information about each DER's active UI detection method is typically unavailable during the initial screening phase. This information is requested prior to detailed studies; however, if not provided, it is conservatively assumed that Group 1 and 2A UI detection methods are not implemented. In such cases, all steps of the flowchart are applied, and LLRB or DTT protection will be required as the final mitigation measure when necessary. If verified documentation confirms that effective active UI detection is in place, certain protection steps may be bypassed accordingly.

In this screening process, a reclosing interval of approximately five seconds is considered. This extended reclosing delay helps reduce the likelihood of out-of-phase reclosing and provides a practical, cost-effective alternative to widespread DTT implementation and in some cases LLRB.

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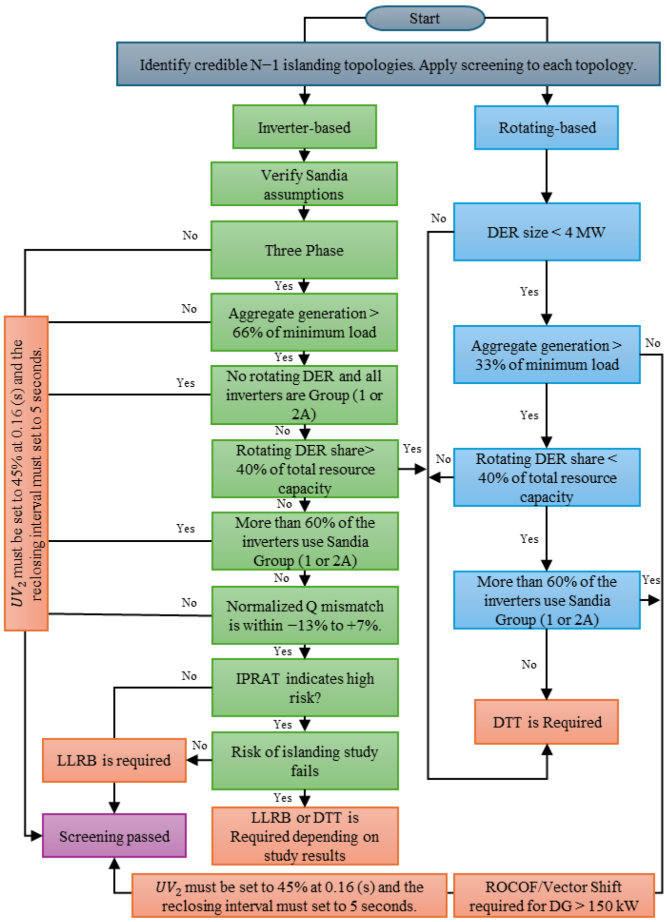

Figure 1. Proposed Screening method for UI

A. Inverter-Based DERs

Step 1: Start:

Confirm DER classification as inverter-based (grid-following).

Step 2: Sandia Assumptions Verification:

At this stage, the screening process verifies compliance with the foundational Sandia assumptions:

- The DER is an inverter-based resource.
- The DER is certified under UL 1741 SB [12], confirming the implementation of an active UI detection method.
- The DER meets the voltage and frequency trip requirements specified in IEEE Std 1547-2018 [3].

Step 3: Unit Type Determination:

At this stage, the type of DER unit is identified as either single-phase or three-phase. Single-phase installations generally present a lower risk of sustaining UI and typically require no further evaluation. For three-phase units, the screening continues through the subsequent assessment steps.

Step 4: Active Power Mismatch:

For feeders without rotating-based DERs, the screening process evaluates whether the aggregate generation nameplate rating exceeds 66% of the feeder's minimum load. If this condition is met, the assessment proceeds to the next step; otherwise, no further analysis is required.

The undervoltage protection element (UV_2) must be configured to trip at 45% of nominal voltage within 0.16 seconds, consistent with IEEE Std 1547-2018 Category II requirements [3]. This fast-acting setting ensures prompt DER disconnection during severe undervoltage conditions, minimizing the likelihood of sustaining an unintentional island. If this configuration is not properly implemented or verified, additional review or mitigation measures are required.

Step 5: Verification of Active Islanding Detection (100% Criterion):

This stage assesses whether any rotating-based DERs are present within the potential island and confirms the type of islanding-detection method used by the inverters. If all rotating machines are either absent or protected via DTT, and every inverter on the feeder employs Sandia-certified active UI detection techniques—classified as Group 1 or Group 2A—the risk of sustained islanding is minimal, and no additional evaluation is required. Otherwise, the process advances to detailed review.

Step 6: Mixed-Source DER Configuration:

When a potential island includes both inverter-based and rotating-machine-based DERs, the relative contribution of rotating machines must be evaluated. If the combined capacity of the rotating-based DERs exceeds 40% of the total DER capacity within the island, a detailed engineering study or implementation of direct transfer trip (DTT) protection is required. Otherwise, the screening process goes to the next step.

Step 7: Verification of Active Islanding Detection (60% Criterion):

This step evaluates the proportion of inverter-based DERs equipped with active UI detection. If more than 60% of the inverters on the feeder utilize Sandia-certified active detection methods—classified as Group 1 or Group 2A—the likelihood of sustaining an island is substantially reduced. If this condition is not met, the process proceeds to further assessment.

Step 8: Reactive Power Mismatch:

Assess whether the reactive power mismatch among generation, load, and capacitor banks lies within the range of –0.13 to 0.07. For inverter-based DERs, system frequency is more sensitive to reactive power balance than voltage is to active power balance, which may allow UI to persist. If a reactive match is possible, proceed to the next step for detailed study. If a reactive match is not possible, the probability of sustaining an unintentional island is very low, and no additional mitigation is required.

Step 9: Islanding Risk Evaluation with IPRAT:

Apply the islanding prevention risk assessment tool (IPRAT) [12] to estimate the probability of island formation. If the assessed risk is high, proceed with detailed analysis; otherwise, no further study is required.

Even when the calculated risk is low, a LLRB scheme should still be implemented as a backup mitigation measure, including at the substation level due to uncertainty in the IPRAT analysis. This requirement exists because, at this stage of the screening process, less than 60% of the inverters employ Group 1 or 2A UI protection methods. As current Sandia recommendations do not fully address this condition, the risk of

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out-of-phase reclosing remains. The LLRB prevents automatic reclosing of feeder breakers while DERs continue to energize an islanded section of the feeder.

Step 10: Risk of Islanding Assessment:

If the risk of islanding (ROI) evaluation using electromagnetic transient (EMT) simulations indicates a failure, either a LLRB scheme or DTT protection must be implemented. If the ROI assessment passes, the screening is considered complete, and no further study is required.

It is essential to assess both the severity of the failure and the confidence level of the model used in the ROI study. For example, if results suggest that an island could persist for approximately five seconds twice per year, implementing an LLRB with an extended reclosing interval may be sufficient. Conversely, if the study predicts that islanding could continue for up to one minute, DTT protection may be warranted. Engineering judgment should be applied to balance reliability, system safety, and the relative costs of LLRB versus DTT solutions.

B. Rotating-Based DERs

Step 1: Start:

Begin the process by verifying whether the DER is a synchronous or induction-based unit.

Step 2: DER Capacity Evaluation:

For DER units rated below 4 MW, proceed to the next screening steps. For units rated above 4 MW, DTT protection is required.

Step3: Active Power Mismatch:

If the aggregate generation nameplate rating exceeds 33% of the minimum feeder load, additional screening is required; otherwise, the screening process is complete.

Also, for DERs rated above 150 kW, rate-of-change-of-frequency (ROCOF) or vector-shift protection should be considered as part of the overall scheme.

Step 4: Mixed-Source DER Configuration::

The ratio of aggregate rotating-machine DER capacity to total DER capacity should remain below 40%. If this threshold is exceeded, a detailed analysis or a communication-based protection scheme, such as direct transfer trip (DTT), is required.

Step 5: Verification of Active Islanding Detection (60% Criterion):

Verify whether more than 60% of inverter-based DERs on the feeder employ Sandia-certified active UI detection techniques—specifically Group 1 (Sandia Frequency Shift) or Group 2A (Sandia Frequency Shift with saturation limits). If this condition is satisfied, the screening passes and no additional review is needed. Otherwise, a detailed study or implementation of direct transfer trip (DTT) protection is required.

VI. Conclusion

This paper provided background on islanding prevention practices and presented a comprehensive screening and guideline framework for assessing UI risk in distribution systems with DERs. The proposed methodology integrates key findings from IEEE Std 1547-2018 and Sandia National Laboratories' research with practical data from utility operations to establish threshold-based decision criteria. Active and reactive power mismatch relationships, DER capacity ratios, and technology-based distinctions were systematically analyzed to identify when detailed studies or advanced protection schemes—such as DTT or LLRB—are warranted.

Future Work: This framework is developed for grid-following DERs consistent with IEEE Std 1547-2018. Future work will extend the workflow to explicitly identify GFM resources and treat them as voltage-forming sources (similar in function to synchronous generation in establishing island voltage and frequency), while recognizing their converter- and control-limited dynamics. Accordingly, screening triggers and escalation logic will be updated for GFL/GFM mixes and coordinated DER schemes, with greater reliance on time-series and EMT-based verification for representative feeder conditions.

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