Instability Risk of Distributed Energy Resources (DERs) in Weak Distribution Networks: Impact of Anti-Islanding Schemes

Chien Tschang, Yazhou “Leo” Jiang
Electric Distribution Planning Department
New York State Electric and Gas (NYSEG)
Binghamton, NY 13904
{CTschang, ljiang}@nyseg.com

Wei Ren, Tom Key
Electric Power Research Institute (EPRI)
Knoxville, TN 37932
{wren, tkey}@epri.com

***Abstract* — This paper investigates the instability risks of Distributed Energy Resources (DERs)—such as solar photovoltaics and battery storage—when integrated into weak distribution networks. Field experience indicates that instances of load and DER incompatibility are increasing with higher penetration levels. This case focuses on the impact of anti-islanding schemes, particularly in rural upstate New York, where high DER penetration and weak grid conditions have led to power quality issues. The paper describes and analyzes a real-world DER instability event; it identifies various anti-islanding detection methods and proposes a hybrid approach combining passive and active schemes. Electromagnetic transient (EMT) simulations validate the effectiveness of this hybrid method in mitigating stability risks without jeopardizing detection of unintended islanding.**

***Keywords*— Anti-islanding, Distributed Energy Resource, Solar energy, Stability risk, Solar interconnection, Weak grid.**

I. Introduction

Increasing deployment of distributed energy resources (DERs) raises the potential risk and concern for unintentional islanding. To mitigate this risk, IEEE Standard 1547 requires DERs to detect an island condition and cease energizing within two seconds [1]. Although the standard defines a type test using a single inverter and an RLC circuit to certify islanding-detection performance, this test setup does not fully capture the diversity of real-world grid operational conditions. In particular, the effectiveness of certain islanding-detection methods (IDMs) is known to degrade in systems with multiple inverters and/or rotating machines [2].

When the DER capacity on a feeder approaches or exceeds the minimum load, utilities commonly implement feeder-level preventive measures such as a direct transfer trip (DTT) scheme. These practices have its origins with engine-driven synchronous generators but have since been extended to inverter-based solar photovoltaics (PV) and energy storage systems. However, due to the high cost and complexity of DTT installations, applying DTT to every DER system, especially small-scale installations, is often uneconomical. The challenge is further compounded in weak distribution networks characterized by limited fault levels, long feeders, high resistance-to-reactance (R/X) ratios, and low short-circuit ratios (SCR). Under such conditions, stability issues can arise, affecting voltage and frequency stability, dynamic response to disturbances, and protection coordination performance.

To assist utilities in weak grid integration of inverter-based resources (IBRs), the North American Electric Reliability Corporation (NERC) has developed some guidelines on “Integrating Inverter Based Resources into Low Short Circuit Strength Systems” [3]. The following risk mitigation strategies are recommended including: 1) install synchronous condenser, 2) adjust plant control time constant and gains, 3) modify converter control parameter and/or structure, 4) reduce plant capacity or power output, 5) reinforce transmission/distribution grids, and 6) install FACT devices. These recommendations have been instrumental in mitigating and solving oscillation issues due to the weak grid integration of IBRs. The anti-islanding schemes for DERs however have not been well documented and discovered. This DER stability event and study contributes to the reliability guideline by adding hybrid passive and active island detection schemes as one of the potential mitigation solutions for oscillation in weak grid integration of DERs.

For grid-connected DERs, standards require onboard island-detection capability. IEEE Standard 1547-2018, for instance, mandates that DERs “detect the island, cease to energize the Area Electric Power System, and trip within 2 seconds of the formation of an island” [1]. To comply, commercial inverters implement various onboard IDMs, whose performance is evaluated according to IEEE Standard 1547 and UL 1741 [4]. Certification is granted when the inverter’s run-on time (RoT)—the interval between island formation and inverter trip—is less than two seconds under balanced load and output conditions with grid-support functions (GSFs) enabled. However, unlike synchronous machine-based DERs, inverter control mechanisms and responses remain somewhat opaque. The performance of different IDMs can vary significantly, and some could lead to unexpected power quality issues including oscillation in weak distribution networks when perturbance is injected for island detection. This lack of transparency highlights the growing need to better understand IDM operating principles and effectiveness particularly under integration of various DERs in weak distribution networks.

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This need was underscored by a recent power-quality issue at a solar farm commissioned in NYSEG's service territory in upstate New York. Field measurements revealed oscillations and waveform distortions linked to inverter interactions with the distribution network. NYSEG collaborated with the solar developer, inverter manufacturer and research institutes to troubleshoot the issue. The manufacturer proposed a hybrid anti-islanding scheme that combines passive and active island detection methods to mitigate oscillations and improve grid integration performance in weak networks. An extensive electromagnetic transient (EMT) study was conducted to assess inverter stability under the hybrid scheme and to determine the grid-strength requirements for stable DER operation. Based on these findings, recommendations and actionable items were developed for NYSEG, the broader power community, and for consideration in future IEEE standard updates.

The rest of this paper is structured as follows: Section II describes the DER instability event and reviews common anti-islanding schemes used in commercial solar inverters; Section III presents the proposed hybrid anti-islanding approach, combining active and passive methods, and outlines solutions for islanding detection during outages; Section IV details the EMT study results validating the proposed scheme and discusses grid-strength requirements for DER inverter stability in weak distribution networks. Additionally, Section IV also discusses recommendations for utilities and standards bodies, including potential updates to IEEE standards for integrating DERs with anti-islanding schemes in weak grids. Section IV concludes the study.

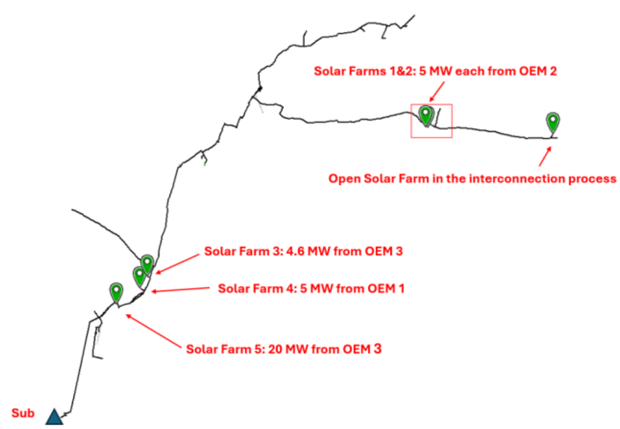

Fig. 1. One-Line Diagram of the feeder circuit with multiple solar farms: Black line indicates three-phase 34.5kV mainline.

II. DER Stability Event and Anti-Islanding Schemes

A. Utility DER Stability Event

The DER instability site is a rural feeder circuit located in upstate New York. The 34.5 kV feeder circuit as shown in Fig. 1 is serving a peak load of ~18 MVA. Currently, there are 5 major solar farms connected to this substation with a total of solar capacity of 39.6 MVA and these solar farms are summarized as:

- Solar Farms 1 and 2: 5MW solar farm each with inverters from OEM 2 (marked within the rectangle)
- Solar Farm 3: 4.6MW solar farm with inverters from OEM 3
- Solar Farm 4: 5MW solar farm with inverters from OEM 1
- Solar Farm 5: 20MW solar farm with inverters from OEM 3

A sixth solar farm is in the interconnection process. The Thevenin equivalent impedance at the substation is 0.27 + j4.488 ohms. When solar generation was high and load was low during the Spring, NYSEG customers were experiencing flicker issues; high resolution sensors were installed at the solar farm site and different tests were performed to locate the instability source. It was determined that Solar Farms 1 and 2 were the source of oscillations by curtailing the output and observing whether the flicker issues were still present. A sample export current and voltage waveforms from one of the plants is shown in Fig. 2.

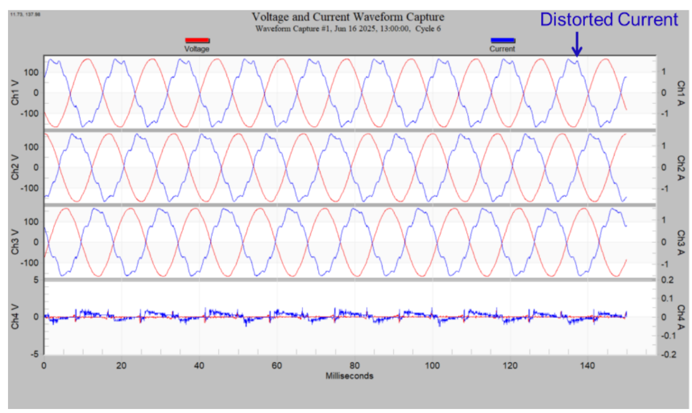

Fig. 2. Monitored voltage and current waveforms from one solar farm.

Voltage oscillations and distortion at the customer caused light flickers leading to power quality concerns. NYSEG worked with the solar developer and inverter OEM to trouble shoot this event and identify that the active anti-islanding scheme with dynamic reactive power injection caused the oscillation issue.

B. DER Anti-Islanding Schemes

The islanding-detection methods can be categorized into two groups: 1) passive anti-islanding methodologies and 2) active anti-islanding methodologies [4].

Passive islanding detection methods monitor specific power parameters, such as over/underfrequency, over/undervoltage, rate of change of frequency (RoCoF), vector shift (phase), harmonic level, or negative-sequence voltage, to identify changes that indicate loss of the main grid and formation of an island. In passive anti-islanding schemes, there is no action to drive a measured quantity to a trip limit as there are no perturbations or alterations of output current for the purpose of islanding detection.

Active islanding detection methods instead perturb the grid by injecting signals, such as current, either continuous or time-varying at one or more harmonic frequencies, for the purpose

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of island detection. Since active signals are intentionally injected to perturb the grid, it exposes the grid to oscillation risks. This risk is further exacerbated when the DER is integrated into weak power grids with high impedance.

Some commonly used passive and active islanding detection methodologies are summarized in Table I and the pros and cons of these two categorized methodologies are summarized in Table II. It is worth noting that if the grid is strong and generation penetration is low, passive detection may suffice. In weak grids or with high penetration of DERs, active island-detection scheme is generally preferred.

Table I Common islanding detection methodologies in commercial solar inverters.

	Anti-Islanding Scheme	Description
Passive Scheme	Passive Voltage and Frequency Monitoring	Continuously monitors the grid for deviations in voltage and frequency. If values fall outside predefined thresholds, the inverter disconnects. This is simple and widely used but may not detect balanced islanding conditions.
	RoCoF	Measures the rate at which frequency changes. A rapid shift typically indicates a loss of grid connection.
	Vector Shift Detection	Detects sudden changes in the phase angle (ride through <20 degrees) of the voltage waveform. A significant shift suggests a disconnection from the grid. Often used in combination with ROCOF for redundancy.
Active Scheme	Enhanced RoCoF	A more sensitive and configurable version of standard RoCoF. It allows for dynamic threshold settings and faster detection, especially in systems with high inertia or weak grid conditions. Enhanced ROCOF often features reactive power injection (Q-control). Often used in utility-scale PV plants for improved reliability.
	Slip Mode/Sandia Frequency Shift (SMS)	The inverter intentionally shifts its output frequency slightly. If the grid is present, the shift is absorbed. In an islanded condition, the frequency drifts, triggering disconnection.
	Active Frequency Drift (AFD)	The inverter introduces a small distortion in its output frequency. If the grid is absent, the distortion accumulates, leading to a detectable deviation and disconnection.
	Impedance Measurement	The inverter injects a small signal and measures the impedance of the grid. A significant change in impedance indicates a loss of grid connection. This method is accurate but more complex and less commonly used.

Table II Comparison of passive and active islanding detection methodologies.

Category	Pros	Cons
Passive Anti-Islanding Scheme	○ Easy to implement ○ No impact on power quality and stability ○ Low cost with lower hardware/firmware complexity	○ Low detection effectiveness with large non-detection zone (NDZ) ○ Slower detection ○ Setting thresholds can be challenging (lower thresholds may cause nuisance tripping and conflict with ride-through requirements including RoCoF and phase-jump while higher thresholds can reduce the detection effectiveness and lead to larger NDZ) ○ Implemented together with other methodologies to prevent detection failures of unintentional islanding
Active Anti-Islanding Scheme	○ Higher detection effectiveness with smaller non detection zone ○ Faster detection ○ More reliable under varying/grid-weak conditions ○ Typically only one active islanding detection methodology is available in each inverter to prevent control instability	○ May disturb system power quality, especially when its magnitude and /or feedback gain is set high for fast detection. ○ Higher implementation complexity (requires injection of perturbations, monitoring of response, algorithm logic) which can increase cost, firmware/hardware demands. ○ The perturbation amplitude/frequency/harmonics must be chosen carefully to avoid adverse interaction with loads or other inverters

III. Stability Risk Mitigation Strategy with Hybrid Islanding Detection Methodologies

A. *Proposed Hybrid Anti-Islanding Schemes*

For Solar Farms 2 and 3, the primary islanding detection method used in the deployed solar inverters is Enhanced RoCoF with optimized reaction time by dynamical reactive power injection. The enhanced RoCoF detects an island by comparing the measured rate of change of frequency against a predefined threshold, e.g., 0.5 Hz/s. The inverters are also equipped with passive voltage and frequency monitoring to ensure robust and standards-compliant grid disconnection behavior. The inverter supports the flexibility of switching to the standard RoCoF anti-islanding scheme by changing the configuration.

In the inverter manufacturer's manual, it states that "In weak grids, injecting large amounts of dynamic reactive power—especially when using 20 or more inverters—can lead to undesirable flicker effects." The solar developer installed string inverters each rated at 125 kW. Since Solar Farms 2 & 3 have 80 string inverters in total, the site risks oscillation issues despite a moderate strong grid condition at the 34.5 kV distribution system.

To mitigate flicker while maintaining effective islanding detection, the solar inverter manufacturer recommended the following hybrid anti-islanding detection configuration for the solar farm:

- At the low voltage output of each transformer, keep 25% + 1 inverters in Enhanced RoCoF and deactivate it on the remaining inverters.

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For example, if transformer A has 40 inverters interconnected with a total of 5 MW capacity, 11 inverters (40 * 0.25 + 1 = 11) will be configured with Enhanced RoCoF while the remaining 29 inverters with the standard RoCoF.

B. Islanding Detection Procedure of the Hybrid Configuration

The hybrid anti-islanding configuration for a solar farm can still effectively detect and disconnect when an island is formed. The following procedure describes the sequence of islanding detection:

Step 1) When the islanding condition occurs, the generation and load may be initially balanced with the frequency and voltage remaining in normal range.

Step 2) Inverters with the Enhanced RoCoF activated (25% + 1) are injecting reactive power perturbation to try to destabilize the island. The resulting positive feedback response causes large signal instability and pushes the system frequency away from the nominal value.

Step 3) All inverters of the PV plants detect the frequency drifting and disconnect from the grid, as required, when the rate of change of frequency exceeds the tripping threshold.

IV. Validation of the Hybrid Anti-Islanding Schemes

The project team investigated the oscillation issue in an EMT environment with the blackbox inverter model provided by the OEM. Different configurations of the anti-islanding scheme, e.g., with only passive islanding detection methodology and with active islanding detection configuration, were studied to understand the grid strength requirement and potential instability risk. The short circuit MVA at the high voltage side of the step-up transformers for Solar Farms 2 and 3 is calculated to be ~74 MVA and the corresponding short circuit ratio (SCR) at the Point of Interconnection is estimated to be ~7.4.

A. Stability Issues with Passive Anti-Islanding Scheme

In this scenario, the Enhanced RoCoF island detection methodology is turned off and the inverter is in the passive island-detection mode. The continuously decreasing grid strength as quantified by the SCR is simulated and the corresponding inverter voltage and power outputs are monitored. The simulation results are documented in Fig. 3.

The results show that with the passive island detection configuration, the solar inverter from OEM 2 remains stable until SCR = ~1.1. The project team further investigated that when the solar farm output is limited to 80%, the solar farm remains stable at the grid strength of SCR = ~1.1. This test study leads to the following conclusion:

1) the solar inverter with only passive island detection configuration remains stable at weak grid conditions for SCR as low as ~1.1;

2) it confirms the recommendation from NERC that solar output reduction helps maintain DER stability;

B. Stability Issues with Active Anti-Islanding Scheme

In this study, the enhanced RoCoF island detection methodology is turned on for all string inverters at the two-5 MW solar sites. The SCR of the grid is first configured to be 2, representing a weak grid condition. The EMT study results as summarized in Fig. 4 show that the instantaneous voltage and current at the inverter terminal have low-frequency oscillatory issues at weak distribution networks.

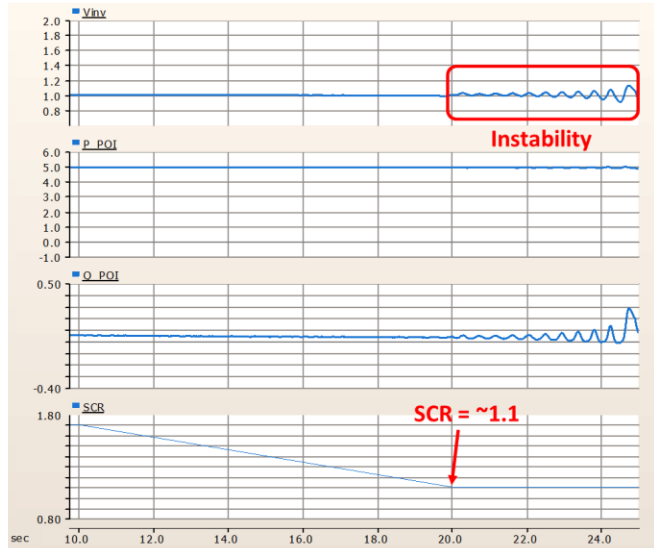

Fig. 3. DER stability study with passive island detection: voltage, P, and Q at the DER point of interconnection when the SCR is reduced.

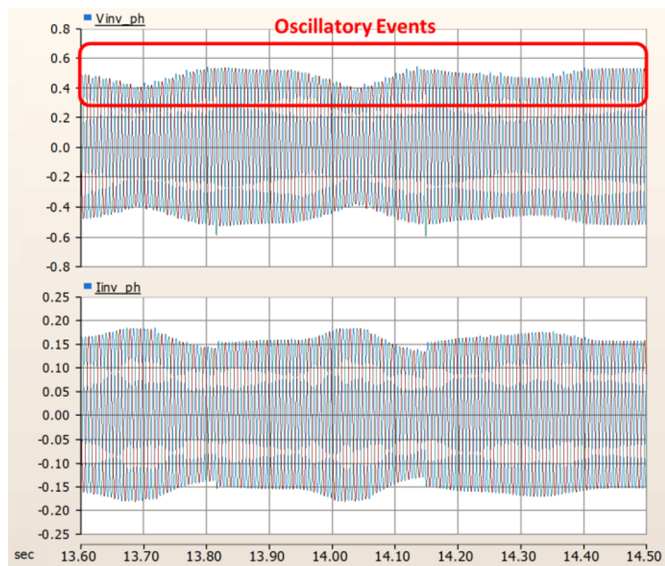

Fig. 4. DER stability study with active island detection: instantaneous three-phase voltage and current waveforms.

A further study at SCR = 3 in Fig. 5 shows that the oscillation occurs at 4.5 Hz and the voltage fluctuates as high as 4.1%. The low frequency voltage oscillation shows that the active island detection method can expose the DER into potential stability risks under weak grid conditions. A summary study of different island detection approaches under different grid strengths is documented in Table III. Some observations are as follows:

- For SCR =2, the solar inverter with active RoCoF from OEM 2 will have 4.0 Hz low frequency oscillation with

7.3% voltage fluctuation; when the hybrid configuration is turned on with 25% + 1 inverters equipped with active RoCoF schemes while the remaining inverters use the passive island detection schemes, the DER oscillates at 4.6 Hz with a reduced voltage fluctuation of 2%. The hybrid anti-islanding scheme can effectively reduce the voltage fluctuation.

- When the grid strength increases from 2 to 8, the voltage oscillation issues for both active RoCoF and hybrid RoCoF island detection schemes decrease. Particularly, for the site under investigation with SCR = ~7.4, the DER potentially oscillates at 6.8 Hz with a 1.1% voltage fluctuation when all inverters turn on active RoCoF island schemes. This oscillation goes away with the hybrid RoCoF schemes for the solar farm with 25% + 1 inverter turning on active RoCoF schemes as proposed by the solar inverter OEM.

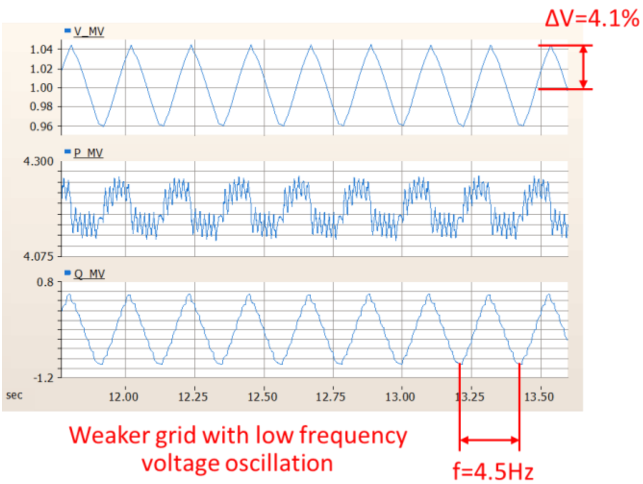

Fig. 5. DER low-frequency oscillation at SCR =3: the upper figure shows the RMS voltage value at the high voltage side of the step-up transformer for the DER, and the middle and lower figures are the oscillatory P and Q values.

Table III Oscillation issues with different island detection configurations at different grid strengths.

SCR	ΔV(%)		f(Hz)	
	All Active RoCoF	25% +1 Active RoCoF	All Active RoCoF	25% +1 Active RoCoF
8	0%	0%	N/A	N/A
7	1.10%	0%	6.8	N/A
6	1.70%	0%	6.0	N/A
5	2.00%	0%	5.7	N/A
4	2.70%	0%	5.0	N/A
3	4.00%	0.80%	4.5	6.25
2	7.30%	2.00%	4.0	4.6

C. *Discussion of this DER Stability Event*

NYSEG worked with stakeholders (solar developer, solar inverter OEM and research organizations) to understand the emerging oscillation issues for weak grid integration of DERs, particularly in the rural settings where most DERs are developed. While the weak grid issues have been studied and investigated in the power industry, the impact of island detection methodologies has not been widely studied and there have not been a universal oscillation mitigation strategy applicable to all solar inverters when the root cause is the active anti-islanding scheme. This DER stability event signifies the importance of the power community to work together to understand and support weak grid integration of DERs.

Despite that IEEE Standard 1547 provides guidance on the performance and inverter test procedure [1, 5], it does not specify the island detection methodologies and more importantly, the test procedure applies to a single inverter and the negative impact of parallel solar inverters from a single solar farm on grid stability have not been captured. This practice could expose power grids to unexpected oscillation with voltage flickering issues. Another gap of the IEEE Standard is the lack of clear guidance on the acceptable level of reactive power injection from the solar inverters with active island detection schemes. These should be considered for future IEEE standard updates.

D. Conclusion

This paper documents a recent DER instability event caused by two solar plants on a weak rural feeder in upstate New York. The project team found that the active anti-island scheme used in these plants led to the low-frequency voltage oscillations. A hybrid anti-islanding scheme with a combination of passive and active island detection methodologies provided an effective means to mitigate the oscillations. An EMT study has validated the effectiveness of the proposed hybrid anti-islanding schemes in mitigation of stability issues in weak grid integration of DERs. The event and study contributes to the dialogue of evolving standards and reliability guidelines needed for increased proliferation of DERs into power grids.

About the Authors

Chien Tschang is a Principal Engineer in the Electric Distribution Planning Department of NYSEG. Dr. Yazhou "Leo" Jiang serves a part-time Principal Engineer at NYSEG and also Associate Professor and Director of the Center for Electric Power System Research at Clarkson University. Tom Key and Wei Ren are technical executives with EPRI.

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