Ride-through and Stability of Critical Facility Microgrids Connected to Weak Power Systems

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***Abstract*—Microgrids with distributed energy resources (DERs) are expected to ride-through a utility disturbance while transitioning to an island from grid-connected operation. However, when the utility system becomes weak with low inertia and system strength, strict adherence to certain ride-through settings can result in instability and interruptions to critical processes within the microgrid. In this work, an electromagnetic transient (EMT) model of a critical facility microgrid (CFM) with IEEE 1547-2018 ride-through and protection settings is prepared and connected to a weak utility to study the impact of such settings on microgrid stability. Specifically, events such as loss of inertia, transmission fault, and changes to system strength are simulated at the upstream utility to study the impacts to ride-through performance of the microgrid. The results suggest that significant vulnerabilities can occur to the resilience and stability of a CFM when IEEE 1547-2018 ride-through settings are enforced at its point of common coupling (PCC) with a weak utility.**

***Index Terms*—grid-following (GFL) inverters, IEEE 1547-2018, microgrid stability, phase-locked loop (PLL) desynchronization, ride-through, seamless islanding, unplanned intentional islanding, weak grids.**

I. Introduction

Microgrids are being increasingly deployed as part of resilience strategies in critical facilities. Such critical facilities include datacenters that train large language models (LLMs), defense infrastructure that serve mission-critical operation, and manufacturing plants with sensitive loads where service interruption can be highly undesirable. Additionally, microgrids are also common in rural communities where utility-owned distributed generation serves a local load during outages and provides much needed improvements to resiliency [1]. However, during a grid emergency, as a microgrid transitions from grid-connected operation to form an island supported by local generation, the transition is expected to be seamless. In other words, as the microgrid PCC is disconnected from the utility, the following must occur: (1) The microgrid generation remains stable. (2) No interruptions occur to critical processes within the microgrid. Such a seamless transition often requires timely disconnection from the utility to prevent instability in local generation and interruption to critical processes within the microgrid.

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On the other hand, regional interconnection standards such as IEEE 1547-2018 [2] enforce strict requirements on the performance distributed generation connected to medium voltage (MV) interconnections. Specifically, such standards require distributed generation to ride-through grid voltage or frequency abnormalities for a certain duration before either forming an intentionally islanded microgrid or ceasing energization. Such ride-through performance from distributed generation is considered essential to maintaining and restoring grid stability in scenarios with high contribution from distributed generation [3]. However, when the utility system is weak with low system strength [4], meeting IEEE 1547-2018 ride-through requirements can be challenging for CFMs.

Weak grid conditions are often characterized by low system strength and short circuit ratio (SCR) with very sensitive voltages and currents. Such grids are common in electrically remote areas and areas with reduced inertia due to replacement of synchronous generators (SGs) with renewable generation. In such systems, the high sensitivity in voltages and currents at the onset of a disturbance can result in instability in distributed generation. Specifically, synchronization stability issues can occur in GFL DERs [5] that rely on a PLL for grid synchronization and small scale rotating generation such as diesel generators and natural gas generators with low inertia that are commonly installed in microgrids. This can consequently impact the microgrid's ability to form a stable and seamless island.

While several works in the literature discuss various aspects of microgrid behavior [6]–[9], the impact of grid codes such as IEEE 1547-2018 on the ability of microgrids to form a seamless island is largely overlooked. Additionally, prior work has also studied synchronization stability issues with inverters tied to weak grids, including aspects such as PLL interactions and control instability during grid faults [10]; microgrid transient stability and fault behavior when dominated by inverters [11]. While such analyses focus on ride-through of individual inverters, there is currently a gap in literature on challenges with ride-through of an entire microgrid with multiple generators.

In this work, a 2.5 MVA microgrid with hybrid generation is simulated in EMT domain. The microgrid consists of photovoltaic (PV) generation, battery energy storage system (BESS), and diesel generators . The ability of such a microgrid to ride-through disturbances arising in the utility and transition

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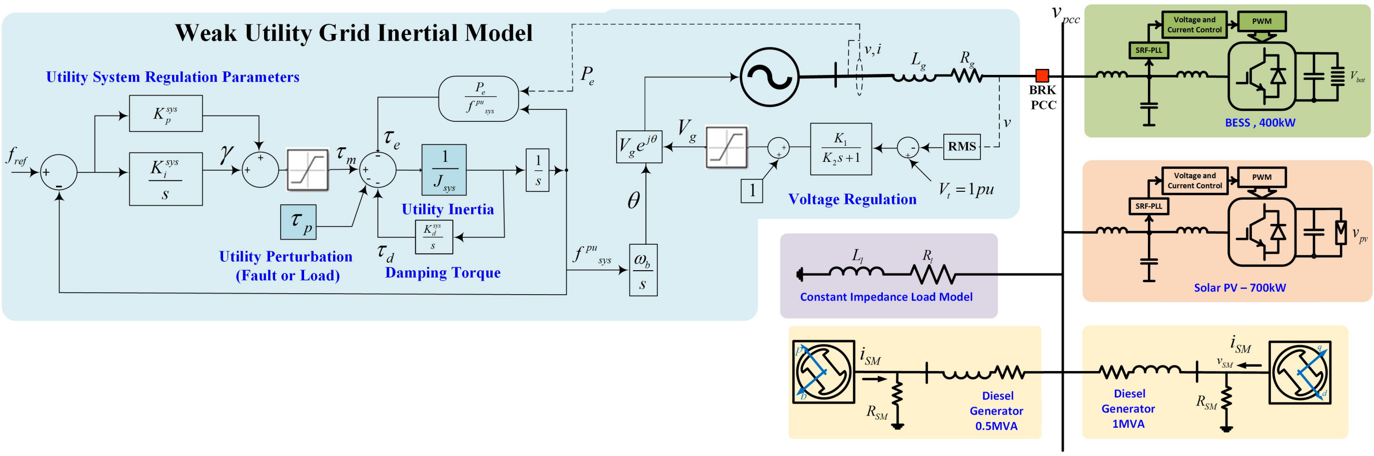

Fig. 1: Hybrid microgrid with diesel generators, PV, and BESS connected at 25 kV PCC to a weak utility.

to a seamless and stable island is comprehensively analyzed. Following are the contributions from this work:

- Prepares a EMT model of a hybrid microgrid along with weak utility. Alongside, protection and ride-through settings from IEEE 1547-2018 are modeled to study their effect on microgrid resilience.
- With EMT simulations, analyzes the impact of IEEE 1547-2018 ride-through settings on seamless unplanned islanding in CFMs.
- Simulates utility disturbances such as sudden loss of inertia, severe faults in the transmission system, and changes in system strength of the upstream utility to study their impacts on microgrid ride-through and stability.

The remainder of this paper is organized as follows. Section II discusses the IEEE 1547 voltage and frequency ridethrough requirements with respect to microgrids. Section III describes the microgrid system model along with the weak utility. Section IV utilizes the EMT model of the CFM with weak utility and discusses the challenges of grid code compliance, along with the impacts on microgrid stability for the disturbance scenarios above. Section V concludes the paper.

II. IEEE 1547-2018 Requirements for Microgrids

TABLE I: IEEE 1547 Ride-Through Settings at the PCC

Frequency			Voltage		
Func.	Thresh [Hz]	Time [s]	Func.	Thresh [pu]	Time [s]
OF2	62.0	0.16	OV2	1.20	0.16
OF1	61.2	300	OV1	1.10	2.00
UF1	58.5	300	UV1	0.70	5.00
UF2	56.5	0.16	UV2	0.45	0.32

IEEE 1547-2018 [2] specifies performance requirements for distributed generation under normal and abnormal power system conditions. During abnormal power system conditions, the standard provides requirements under three categories for ride-through. Such requirements are intended to maintain grid support during disturbances, with the applicable category selected by the interconnecting utility. Table I summarizes the voltage and frequency ride-through settings enforced at the microgrid PCC for a Category III resource. The settings define under and over voltage and frequency bands with associated clearing times, during which resources must remain connected before disconnection.

III. Microgrid and Weak Utility Model

An EMT model is developed to study the impacts of the ride-through requirements on a CFM connected a weak utility. The 2.5 MVA microgrid with hybrid generation is connected to at 25 kV weak upstream utility as shown in Fig. 1. The microgrid generation is represented utilizing generic EMT models. Following is a summary of key parameters that represent the behavior of such generation for the subject study:

- **PV and BESS:** A 700 kW PV and 400 kW BESS operate as GFL inverters with a legacy synchronous reference frame (SRF) PLL to inject synchronized current to the microgrid and utility system. Their internal control structures utilize generic power and current control loops with dq-frame current limits set to 1.5 pu.
- **Diesel Generators (DGs):** Two DGs rated for 1.0 and 0.5 MVA, respectively, modeled with inertia $H = 3.0$ s and generic governor and automatic voltage regulator (AVR) dynamics. At the initiation of islanding, the 1 MVA DG operates as an isochronous source to form an island.
- **Weak utility system model:** A synchronous generator with voltage regulation and initial interia $H = 4.3$ s on a 20 MVA base is modeled to represent the upstream weak utility. The utility inertia is varied to simulate a utility disturbance by perturbing the torque τ_p as shown in Fig. 1. This represents a cumulative change in inertial capacity of the utility; for example, a scenario where 30% inertial generation is replaced by noninertial generation such as PV or BESS. Such changes in total inertial generation capacity (TIGC) at the utility result in changes to voltage and frequency at the microgrid which creates

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TABLE II: Ride-through and Stability of the Microgrid during a Loss of Inertia Event at the Utility

TIGC loss	Microgrid Stability after event	Ride-through Performance with respect to IEEE 1547	Ability to Form a Seamless Island	Blackout in the Islanded Microgrid	IEEE 1547 Compliance	Black-start
25%	DGs and DERs stable	Meets B–III Requirements	Not required	None	Full	N/A
30%	DERs and DGs stable	Meets B–III Requirements	Stable island formed	None	Full	No
35%	DERs and DGs unstable and trips	Unable to ride-through	Unable to form an island	Full blackout	No Compliance	Yes
35%	DERs unstable; DGs stable	Partial ride-through in DGs for 0.12 s	Stable island formed	None	Limited	No

stability challenges for the microgrid. Also, to further represent a weak interconnection, a Thevenin impedance with $R = 3\ \Omega$ and $L = 0.34$ H is added at the microgrid interconnection to represent a utility system with low strength or SCR around 2.2. The upstream inertial model is discussed in detail in [12].

The microgrid load is highly inductive and is represented as a constant impedance. The settings from Table I are utilized to control the PCC breaker in Fig. 1 at the onset of a utility disturbance. Further, all DERs and DGs in the microgrid include individual device-level protection for thermal violations.

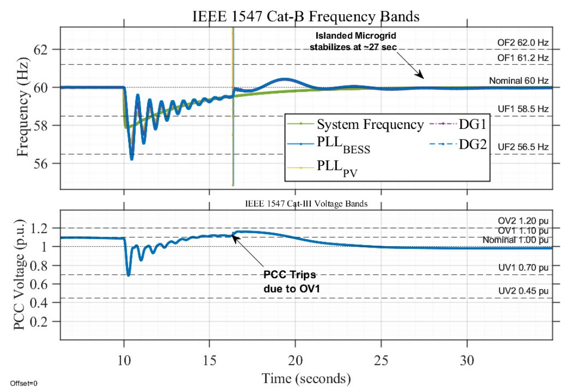
IV. Case Studies: Ride-through of CFMs in Weak Power Systems

For the subject CFM, three types of disturbance are evaluated: (i) step reductions in TIGC; (ii) temporary three-phase faults with 0.16 s clearing; and (iii) reduced system strength via increased Thevenin impedance at fixed TIGC. All disturbances are applied on the utility side and propagate into the microgrid only through PCC voltage and frequency dynamics. Two main performance criteria are evaluated during three types of power system abnormalities with different levels of severity: (i) Does the CFM satisfy the IEEE 1547-2018 Category B-III ride-through requirements for voltage and frequency and (ii) After the onset of the abnormality, does the CFM transition seamlessly to a stable island without interruption to its critical processes or a sustaining blackout? In each scenario discussed next, the analysis of voltage and frequency response at the PCC is provided for clarity.

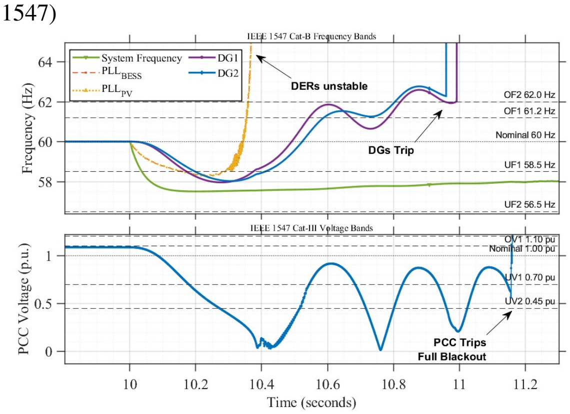
A. Scenario I: Loss of Upstream Inertial Generation

For this scenario, a baseline TIGC of 500 MVA with an effective inertia constant of 4.5 s is assumed for each case at the start of the simulation. The CFM loading in each case is approximately 1.3 MW load. At a time $t = 10$ s, TIGC of the utility is reduced in step by three levels: 25%, 30%, and 35%. The results are summarized in Table II, with voltage and frequency response at the PCC shown in Fig. 2.

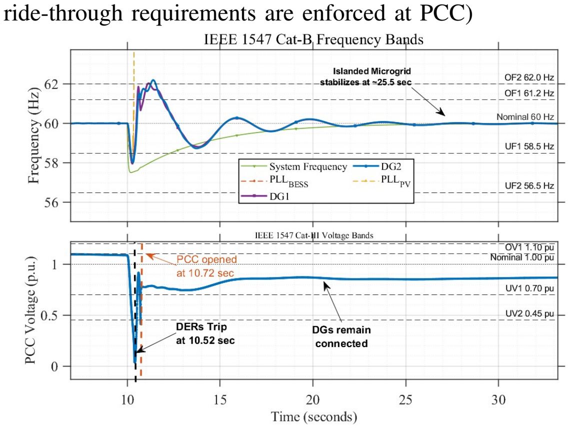
In the first three cases, IEEE 1547-2018 category B III settings are applied at the microgrid PCC for ride-through. Once the microgrid rides through the disturbance, the PCC breaker is opened to initiate an island. In case with 25% TIGC loss, DGs and DERs remain stable at the onset of disturbance. Subsequently, the microgrid rides through, meeting the IEEE 1547 ride-through requirements. In this case, as the utility voltage and frequency restored to nominal levels.



(a) 30% TIGC loss (Stable islanding after meeting IEEE 1547)



(b) 35% TIGC loss (Microgrid instability as IEEE 1547 ride-through requirements are enforced at PCC)



(c) 35% TIGC loss (Stable islanding after relaxing the IEEE 1547 requirements at the PCC)

Fig. 2: Microgrid response during TIGC loss scenarios in a weak upstream grid (load 1.3 MW).

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TABLE III: Ride-through and Stability of the Microgrid during a Fault at the Utility

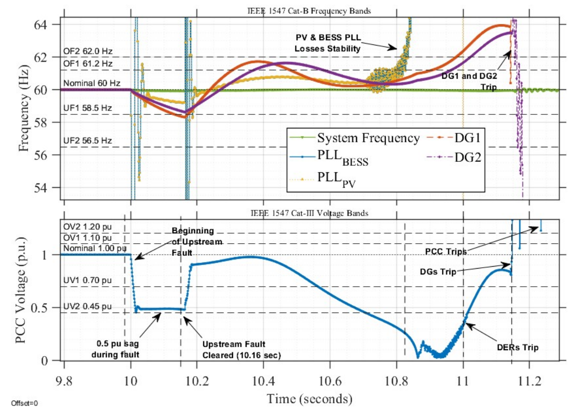
V_{PCC} during fault [pu]	Microgrid Stability after event	Ride-through Performance with respect to IEEE 1547	Ability to Form a Seamless Island	Blackout at the Islanded Microgrid	Requires Black-start
0.50	DER and DG unstable and trips	Unable to ride-through	Unable to form an island	Full blackout	Yes
0.50	DERs unstable; DGs stable	Partial ride-through with DGs for few cycles	Stable island formed	None	No

With a 30% reduction in utility inertia, the DERs in the microgrid become unstable and trip within a few cycles of the disturbance. The DGs, however, remain synchronized with the utility and successfully ride through the event for the duration required by IEEE 1547-2018. After the ride-through window, the PCC breaker opens and the DGs form a seamless and stable island, avoiding black-start and maintaining uninterrupted operation of critical loads. The system response for this case is shown in Fig. 2(a) When the utility inertial loss is increased to 35%, the microgrid again attempts to comply with IEEE 1547 ride-through requirements. As shown in Fig. 2(b), both the DERs and DGs lose stability a few cycles after the disturbance, leading to their tripping and a full microgrid blackout due to the lack of utility recovery. In the final case, the same 35% TIGC loss is applied, but the PCC protection is relaxed to open the breaker shortly after disturbance onset rather than enforcing the full IEEE 1547 clearing time. As illustrated in Fig. 2(c), the DERs still trip following the disturbance; however, opening the PCC breaker after 0.12 s allows the DGs to form a stable island that sustains critical operations and prevents blackout. These results demonstrate that ride-through success depends strongly on disturbance severity and that strict IEEE 1547 compliance may conflict with resiliency objectives in weak-grid critical-facility microgrids.

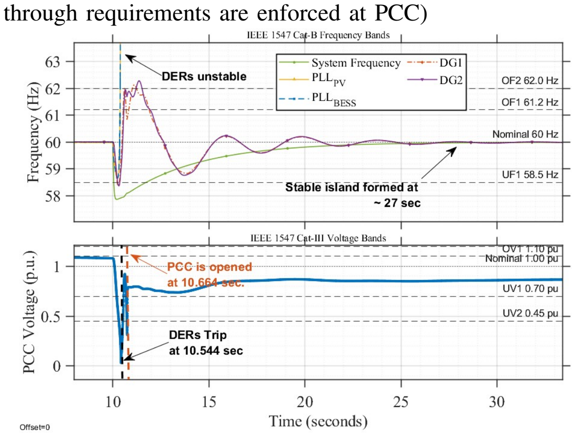
B. Scenario II: Severe Fault in the Transmission System

In this scenario, a temporary three-phase high impedance fault is applied at $t = 10$ s in the upstream utility and cleared after 0.16 s. The worst-case behavior for ride-through at the microgrid PCC occurs with a minimum load of 200 kW and a power export of 2.4 MW. Fault impedance is adjusted to obtain a voltage sag of 0.5 pu at the PCC to study ride-through behavior, as shown in Table III. Below 0.6 pu of voltage at the PCC during the fault, the oscillation induced by the DER PLLs can render the microgrid unstable.

When the voltage sag during the fault is 0.5 pu, DERs PLLs remain active and hit current limits, leading to negative damping and loss of synchronism [13], [14]. If ride-through is attempted at the PCC as per Table I, DER and DG tripping produce a full blackout. If the PCC is opened 0.12 s after the DERs trip due to unstable PLL, a stable island can be formed with all the connected load. This behavior is illustrated in Fig. 3 and reinforces the conclusion from Scenario I: under weak-grid conditions, PLL instability can arise within the ride-through window, so strict enforcement can lead to instability in selected cases.



(a) 0.5 pu sag (Microgrid instability as IEEE 1547 ride-through requirements are enforced at PCC)



(b) 0.5 pu sag (Stable islanding after relaxing the IEEE 1547 requirements at the PCC)

Fig. 3: Microgrid response during three-phase fault scenarios in a weak upstream grid (load 200 kW).

C. Scenario III: Changes to Utility System Strength

The third scenario investigates the impact of a reduction in strength or SCR of upstream grid. In this case, the inital SCR of the interconnection is 2.2, which is further reduced to 1.83 as shown in Table IV. This is representative of an already weak interconnection becoming more stressed, for example, due to network reconfiguration, additional inverter-based generation, or addition of voltage-sensitive load loss in the bulk system. For both the SCR, a 30% TIGC loss contingency is simulated and the outcomes are summarized in Table IV, while the dynamic system behaviors are shown in Fig. 4. At SCR of 2.2, the 30% TIGC loss does not lead to instability. DGs and DERs ride-through the transient until an OV1 violation occurs, which causes stable islanding. When SCR is reduced to 1.83, ride-through settings in Table 1 cause microgrid instability. In

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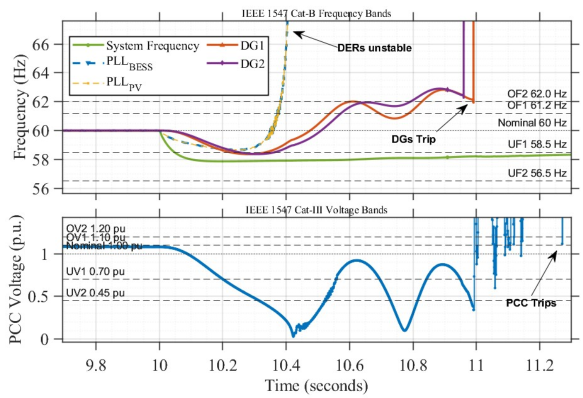
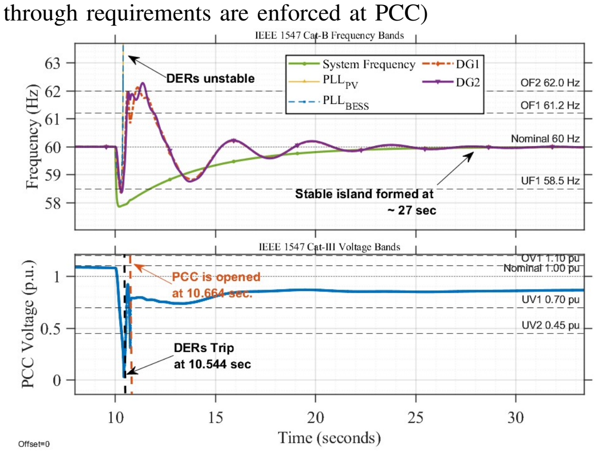
TABLE IV: Ride-through and Stability of the Microgrid during Changes to System Strength at the Utility.

SCR at PCC	Microgrid Stability after the Event	Ride-through Performance with respect to IEEE 1547	Ability to Form a Seamless Island	Blackout at the Islanded Microgrid)	IEEE 1547 Compliance	Requires Black-start
2.2	DGs and DERs stable	Meets B-III Requirements	Stable island formed	None	Full Compliance	No
1.83	DGs and DERs unstable and trips	Unable to ride-through	Unable to form an island	Full blackout	No Compliance	Yes
1.83	DERs unstable; DGs stable	Partial ride-through for few cycles with DGs	Stable island formed	None	Limited Compliance	No



(a) SCR = 1.83 (Microgrid instability as IEEE 1547 ride-through requirements are enforced at PCC)



(b) SCR = 1.83 (Stable islanding after relaxing the IEEE 1547 requirements at the PCC)

Fig. 4: Microgrid response during 30% TIGC loss with changes to upstream system strength.

contrast, when PCC is opened adaptively at 0.12 s after the DERs trip, the DGs can form a seamless island and avoid blackouts.

V. Conclusion

This work highlights that seamless unplanned islanding in a CFMs can be challenging while complying with certain ride-through settings. This is demonstrated using EMT models where compliance with IEEE 1547 ride-through settings are shown to result in instability, blackout, and interruptions to critical processes within a microgrid. Such scenarios include loss of inertial generation capacity in the utility, temporary upstream faults causing voltage sags, and changes to system strength at the utility interconnection. The paper also shows that relaxing the ride-through requirements for few corner-case contingencies help stabilize the microgrid and enable seamless islanding without interruptions to critical loads. The work highlights the importance of EMT analyses for a thorough study of compliance with the IEEE 1547-2018 for microgrids. Future work will address the use of better PLL dynamic controls at the PCC for better ride-through performance.

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