APPLICATION GUIDELINE
REVISION A

Time Domain System Impacts

For DER Interconnections

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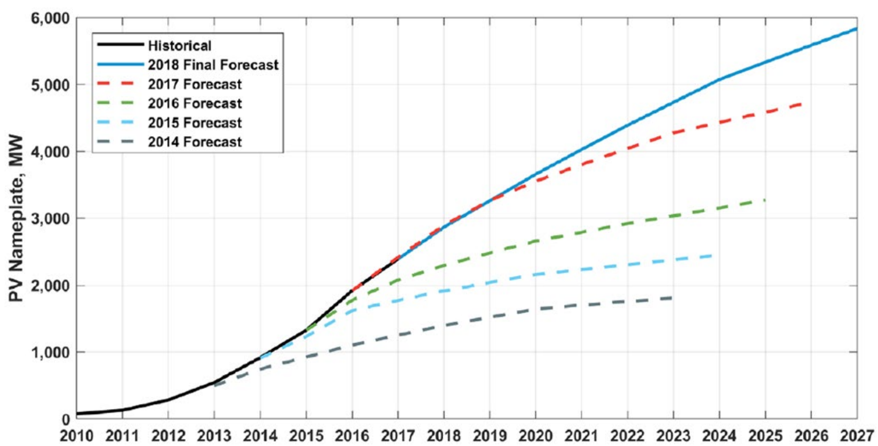
Application Guideline on Time Domain System Impacts for DER Interconnections

PURPOSE

This guideline investigates the new IEEE 1547-2018 standard and other industry requirements for Time Domain System Impact Studies (TD SIS). It also identifies the benefits of these studies to ensure system reliability and to reduce interconnection costs.

BACKGROUND

The rapid increase and high penetration of Distributed Energy Resource (DER) interconnections fundamentally changed traditional distribution systems. New challenges and adverse impacts of these interconnections have resulted in extensive changes and the development of the recent IEEE 1547-2018 standard. Many new requirements are just now being implemented in the industry with much uncertainty due to lack of testing and certification listings.



Source: ISONE forecasting Solar PV in New England

Traditionally, distribution impact studies were performed using steady state software for conducting short circuit and load flow analyses, which were used to determine total project interconnection upgrade costs. However, due to new standards and an increasing penetration of DER, TD SIS are becoming a requirement to analyze impacts on transient overvoltage (TrOV), temporary overvoltage (TOV), islanding, transient stability, and other time domain concerns. While steady state analysis can predict some time domain impacts through simplified screens, it cannot accurately simulate the true effect as it is based on RMS fundamental frequency sources on an impedance model. Time domain software, such as PSCAD, utilize electromagnetic properties in the system model, and consider control algorithms of equipment in sub-cycle time intervals. This provides a more accurate and in-depth representation of system influences from the DER project.

Unlike urban distribution systems in the US, rural distribution systems are occasionally fed from subtransmission sources, have very long, lightly loaded distribution feeders, have vast land availability for more DER interconnections, and weak infrastructure to accommodate large generation injections. While the existing distribution infrastructure was adequate to serve customer load, these factors contribute to the likelihood of feeder and substation adverse impacts when interconnecting large amounts of DER. Adverse impacts such as thermal overloads, voltage rise, voltage flicker, islanding, TrOV, and TOV are more prevalent in the Area Electric Power System (EPS) in rural distribution systems. Furthermore, this typically adds more complexity to the scope of TD SIS.

APPLICATIONS FOR TIME DOMAIN STUDIES

Many adverse impacts can occur in the transient region of the time spectrum at the Area EPS due to the addition of DER. This application guideline addresses multiple common transient impacts that can lead to significant damage and lost reliability if not properly addressed.

Risk of Unintentional Islanding (ROI)

ROI is of great concern to public safety and power quality to distribution customers. IEEE 1547-2018 Clause 8.1.1 states, "*For an unintentional island in which the DER energizes a portion of the Area EPS through the PCC, the DER shall detect the island, cease to energize the Area EPS, and trip within 2 s of the formation of an island.*"

ROI Screening

The steady state analysis portion of the Standard System Impact Study (SSIS) may use screens to determine if Direct Transfer Trip (DTT) is required for ROI in lieu of a TD SIS. This allows expedited cost estimates to be provided and for the interconnection queue to continue in a timely manner. The developer can then elect further study utilizing the TD SIS to determine if DTT and other system upgrades are necessary in the design phase of the interconnection.

It must be noted that due to the constraints of steady state analyses, the SSIS is a conservative screen and may flag the need for DTT where a TD SIS may prove it unnecessary. An example of these screens and study processes are further detailed in Attachment A of this application guide.

ROI Mitigation

Mitigation against unintentional islanding includes implementing a DTT scheme, addition anti-islanding protection, or reclose blocking. However, a time domain study may prove DTT unnecessary.

Transient and Temporary Overvoltages

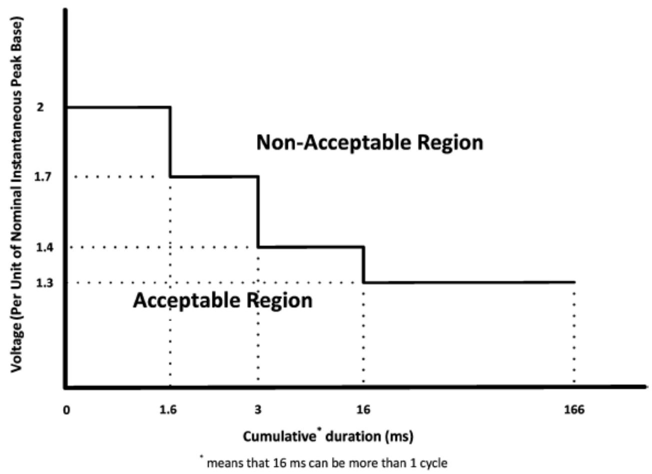
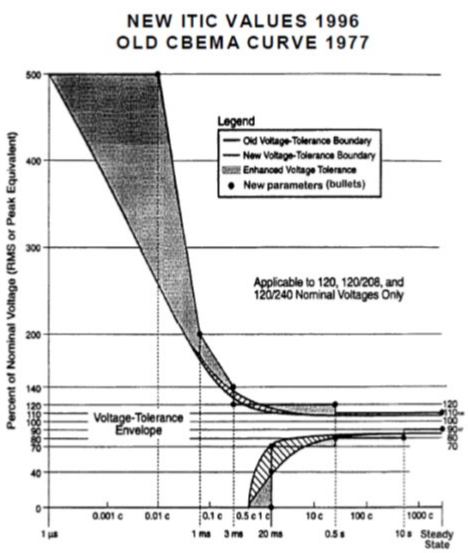


Figure 3 —Transient overvoltage limits

TrOV and TOV requirements are a significant change in the IEEE 1547-2018 edition. Section 7.4.2, Limitation of Cumulative Instantaneous Overvoltage, states, "*The DER shall not cause the instantaneous voltage on any portion of the Area EPS to exceed the magnitudes and cumulative durations shown in Figure 3. The cumulative duration shall only include the sum of durations for which the instantaneous voltage exceeds the respective threshold over a one-minute time window.*" As seen in Figure 3, the cumulative voltage requirements are measured from 1.6 ms to 166 ms. Overvoltages can originate from many Area EPS occurrences not studied in the SSIS, as analysis of this phenomenon is not possible using steady state software and impedance system models.



The basis for the TrOV and TOV requirements originated from the Computer and Business Electronic Manufactures Association (CBEMA) and later revised to the Information Technology Industrial Council (ITIC) standards. The ITIC curve shows the voltage power quality limits in reference with time. This was originally intended to be a design margin for electronic equipment, but later became a standard for voltage quality measurements at the Area EPS. Damage to customer electronic equipment power supplies for appliances, computers, heating systems, and HVAC systems can occur from overvoltages that exceed the ITIC curve limits for extended durations. The previous IEEE 1547-2003 standard did not address the overvoltage threshold of acceptable voltages for interconnecting DER.

Load Rejection Overvoltage (LROV)

LROV is defined by IEEE C62.92.6-2017 as a "*Temporary or transient overvoltage resulting from abrupt disconnection of all or a portion of the load of a generation source.*" LROV takes place when a breaker, recloser, or switch on the Area EPS opens in a no fault condition. This instantaneously creates an islanded condition with a new state of system impedance, loss of the fundamental frequency voltages source, and potentially excessive generation to load ratios. In this scenario, the inverter controls may create unacceptable LROV as they react to the sudden change in load rejection before the anti-islanding protection trips the inverter(s) offline in two seconds. The severity of LROV is based on the amount of generation compared to load in the smallest bounded section and the proprietary control algorithm of the inverters. The focus on inverter controls is key to the outcome of TD SIS.

LROV Screening

LROV screens may include the following:

1. Evaluating if the generation to load ratio on the smallest bounded section of the Area EPS is less than 2:1.
2. Evaluating if the Project inverter has a HECO Rule 14 Appendix I certification letter submitted with the application and if the generation to load ratio on the smallest bounded section is less than 10.[1]

LROV Mitigation

If the inverter controls cannot mitigate TrOV and TOV, surge suppression and/or DTT may be a solution. These potential solutions must be verified with a TD SIS. However, it is possible that the only solution for severe LROV is an express feeder from the interconnecting project to the substation.

Ground Fault Overvoltage (GFOV)

GFOV occurs when the voltage rises on unfaulted phases during a single line to ground fault. GFOV must comply with the cumulative overvoltages requirements mentioned previously. Additionally, IEEE 1547-2018 Clause 7.4.1.a states, "*The DER shall not cause the fundamental frequency line-to-ground voltage on any portion of the Area EPS that is designed to operate effectively grounded, as defined by IEEE Std C62.92.1, to exceed 138% of its nominal line-to-ground fundamental frequency voltage for a duration exceeding one fundamental frequency period.*"

GFOV Screening

The SSIS can evaluate and propose effective grounding parameters required to mitigate GFOV. However, if other TrOV concerns on the distribution system exist, the TD SIS can further validate the ground source components of the project to meet IEEE 1547 requirements.

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[1] To add further challenge with complying with IEEE 1547-2018, the current draft of IEEE 1547.1 "*IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems*" has not addressed testing criteria for LROV. Currently, at the time of this application guide, no UL certification exists for IEEE 1547-2018 overvoltage requirements. To address this industry challenge we look to the State of Hawaii with some of the highest penetration of solar PV DER in the US.

Hawaiian Electric Company (HECO) Rule 14 is the governing tariff for DER interconnection in the State of Hawaii. From their experience with high penetration DER, HECO Rule 14, Appendix I has provided certification requirements for inverter manufacturers to comply with IEEE 1547-2018 cumulative overvoltage requirements. HECO Rule 14 guidance on this states: "*The Certificates of Compliance must indicate certification to UL 1741 SA using the applicable SRD, and list the appropriate firmware version, country code, or applicable configuration that was tested and certified by UL or the NRTL.*" In addition to this, a test procedure in Appendix I, Attachment A is defined to evaluate LROV impacts. The test procedure does have its limits as it considers generation to load ratios of up to 10:1. High DER Penetration that exceeds the 10:1 ration would not be applicable to HECO Rule 14 Appendix I certification. A TD SIS may not be necessary if the inverter manufacture can provide a Certificate of Compliance with HECO Rule 14 Appendix I. However, commissioning testing and inverter firmware validation may be required before Approval to Operate (APO) is granted by the local utility.

Open Phase

Open Phase is a condition that exists when a fuse blows or a conductor opens while the DER is injecting three-phase power into the Area EPS. This condition leads to islanding concerns mentioned in previous descriptions and potential ferroresonance phenomenon that leads to extremely high TrOV. IEEE 1547-2018 Clause 6.2.2 states, "*The DER shall detect and cease to energize and trip all phases to which the DER is connected for any open phase condition occurring directly at the reference point of applicability per [IEEE 1547-2018 Section]4.2 and the applicable voltages per [IEEE 1547-2018 Section] 4.3. The DER shall cease to energize and trip within 2.0 s of the open phase condition.*"

Open Phase Screening

A protection review of the project path between the substation and interconnecting project can identify fuses and single-phase reclosing for replacement with gang-operated three-phase reclosers. Further analysis of inverter controls and additional relay protection to mitigate Open Phase related upgrades can be validated by a TD SIS and verified by testing in the commissioning of the project.

Open Phase Mitigation

The simplest form of open phase mitigation includes upgrading single-phase protection devices with gang-operated equivalents and ensuring three-phase lockout on all devices. It must be noted that this may reduce the reliability of the Area EPS.

A TD SIS with accurate inverter control models can verify whether all these upgrades are warranted.

UFLS Coordination

Under Frequency Load Shed (UFLS) schemes at distribution substations provide support to the transmission system during a stability-impacting event. The UFLS scheme trips off predetermined distribution feeders when low frequency and moderate to normal voltage levels exist. Upon normal system state restoration, a trouble crew is required to manually reset the UFLS and thus return the distribution feeders back to service. If the substation transformer secondary breaker opens, the aggregate amount of interconnected DER could result in a nuisance trip of the UFLS scheme before the DER anti-islanding protection trips them offline. A TD SIS further investigates the possibility of this event and recommends revised protection to mitigate the reliability concern.

Other Requirements

ISO-NE PP 5-6 (Section 6.6) requires PSCAD models for all inverter-based generators (generally over 5 MW). Appendix C calls for a time domain analysis when the interconnecting facility is relatively large compared to the point of the system to which it is connecting, including the interaction with other facilities already connected.

CONCLUSION

IEEE 1547-2018 presents many new challenges in implementing recently developed TrOV and TOV criteria requirements that may require TD SIS' to verify. These requirements are not evaluated in steady state analyses due to their transient nature.

Mitigating adverse transient impacts are also challenging, as traditional protection does not respond quick enough to trip DER offline and the specific nature of these overvoltages may not be applicable to conventional surge suppression. Failure of initial screens without additional analyses may lead to unnecessary grid reinforcements that threaten the economic feasibility of the DER project.

The inverter is often the first line of defense against transient impacts. However, many inverter manufacturers have vast differences in the operation, properties, and controls of their inverters.

The current lack of testing standards and certifications add to the complexity of evaluating the potential impacts to the Area EPS. The screening methods shown in this application guideline and impact study process example present a potential solution.

State tariffs and rulings add additional timeframe constraints when addressing IEEE 1547-2018 interconnection requirements. The failure of screens in the DER application phase may indicate a "complex" interconnection requiring an additional study duration needed to evaluate and resolve all necessary impacts, which may entail further analysis via TD SIS.

Furthermore, the recent National Association of Utility Commissions (NARUC) policy recommends that all state commissions adapt IEEE 1547-2018. As state commissions adapt the new policy, timelines may be extended to account for TD SIS. In addition, the new IEEE 1547.1 will give more direction for testing procedures for further certification testing. In the meantime, TD SIS may be a necessity to ensure sound DER SIS interconnections.

REFERENCES

[1] IEEE Standard 1547-2003 "IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems", 28 July 2003

[2] IEEE Standard 1547-2018 "IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces", 15 February 2018

[3] IEEE Standard 1547.1 "IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems", 1 July 2005

[4] IEEE Standard 142-2007: "IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems" ("Green Book"), June 2007.

[5] IEEE Standard C62.92.6-2017 "IEEE Guide for Application of Neutral Grounding in Electrical Utility Systems, Part VI—Systems Supplied by Current-Regulated Sources", 23 September 2017

[6] ISO-NE, Inverter Source Requirement Document of ISO New England, 6 February 2018

[7] ISO-NE Planning Procedure No. 5-6 – Interconnection Planning Procedure for Generation and Elective Transmission Upgrades, 6 February 2020

[8] ISO-NE, Operating Procedure No. 14 – Technical Requirements for Generators, Demand Response Resources, Asset Related Demands and Alternative Technology Regulation Resources, 10 February 2020

[9] HECO Rule 14, Appendix I "Transient Overvoltage Qualify Instructions", 12 March 2018

[10] NARUC, 2020 Winter Policy Summit, 12 February 2020.

BIOGRAPHIES

Brian Conroy, P.E. is the Manager of Distribution Planning at RLC Engineering. He has BS in Electrical Engineering at the University of Maine and a MBA at Thomas College. He has 33 years of experience in the electric utility industry, holding positions in Meter Engineering and Distribution Engineering, managing the Maine Energy Control Center, and directing the Electric System Engineering organization before focusing on Smart Grids. Mr. Conroy is a senior member of IEEE and former chair of both the Maine Section and the Central New England Council.

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Asa Sproul, P.E. is a Senior Power System Engineer at RLC Engineering. He has a BS in Electrical Engineering as well as an MS in Electrical Engineering with a thesis on Ocean Wave Energy Conversion, both at the University of Maine. He has 5 years of experience in the electrical industry and is currently a registered P.E. in all 6 New England States. Since beginning at RLC, he has managed/conducted over 150 DER Impact Studies across New England. Mr. Sproul is an active member of IEEE PES.