NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

PRC-024-2 Gaps Whitepaper

NERC Inverter-Based Resource Performance Task Force (IRPTF)

Purpose

The NERC Inverter-Based Resource Performance Task Force (IRPTF)[1] scope document[2] includes a deliverable on "recommendations on inverter-based resource performance and any modifications to NERC Reliability Standards related to the control and dynamic performance of these resources during abnormal grid conditions." The whitepaper presented here details the findings of the IRPTF as a result of investigations related to this deliverable. Specifically, the whitepaper details potential gaps and needed clarifications in PRC-024-2: *Generator Frequency and Voltage Protective Relay Settings*. There is some overlap between the findings of this whitepaper and the Integration of Variable Generation Task Force (IVGTF) Summary and Recommendations of 12 Tasks[3] which was published in 2015.

Background

Multiple grid disturbances in the Western Interconnection have highlighted the potential risk of fault-induced solar photovoltaic (PV) tripping. While these disturbances have been prominent in the West, the underlying issues are systemic in the solar PV fleet across interconnections.

- On August 16, 2016, the Blue Cut Fire disturbance resulted in approximately 1200 MW of solar photovoltaic (PV) resources tripping offline or momentarily ceasing output in Southern California. NERC and WECC created an ad hoc task force to investigate causes of the solar PV tripping, develop a disturbance report[4], initiate remedial actions, and provide recommendations for future work.
- On October 9, 2017, the Canyon 2 Fire disturbance in Southern California resulted in approximately 900 MW of solar PV tripping or momentarily ceasing output. This disturbance involved voltage-related tripping, and highlighted an unintended interpretation of PRC-024-2. NERC and WECC developed a disturbance report[5], which included key findings and recommendations for mitigating action.

Both disturbance reports have led to NERC Alerts to gather necessary data to understand the extent of the conditions identified as well as to recommend mitigating actions to these potential reliability risks to

[1] NERC Inverter-Based Resource Performance Task Force (IRPTF) webpage. Available: https://www.nerc.com/comm/PC/Pages/Inverter-Based-Resource-Performance-Task-Force.aspx.
[2] IRPTF Scope Document. Available: https://www.nerc.com/comm/PC/InverterBased%20Resource%20Performance%20Task%20Force%20IRPT/IRPTF_Scope_20170619.pdf.
[3] IVGTF Report. Available: https://www.nerc.com/comm/PC/Integration%20of%20Variable%20Generation%20Task%20Force%20I1/IVGTF%20Summary%20and%20Recommendation%20Report_Final.pdf
[4] Blue Cut Fire Disturbance Report. Available: http://www.nerc.com/pa/rrm/ea/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_Interruption_Final.pdf.
[5] Canyon 2 Fire Disturbance Report. Available: https://www.nerc.com/pa/rrm/ea/Pages/October-9-2017-Canyon-2-Fire-Disturbance-Report.aspx.

the Bulk Electric System (BES). Following completion of the Blue Cut Fire disturbance analysis, NERC formed the NERC IRPTF to continue focusing on inverter-based resource performance during steady-state

PRC-024-2 Issues

FERC approved the NERC Reliability Standard PRC-024-2: *Generator Frequency and Voltage Protective Relay Settings* in May 2015 and the standard went into effect on July 1, 2016. The original version of the standard, PRC-024-1, was approved by FERC in 2014. The purpose of PRC-024-2 is to "ensure Generator Owners set their generator protective relays such that generating units remain connected during defined frequency and voltage excursions."6[6] The primary purpose of the revision was not to ensure the protection of generation resources, but rather to aid BES stability without jeopardizing the generation resources. Hence, the standard includes requirements that generator protective relays be set such that they do not trip the applicable generating unit(s) when operating within specified frequency and voltage "no trip zones".

Event analysis for both the Blue Cut Fire and Canyon 2 Fire disturbances revealed that misinterpretation of the requirements of PRC-024-2 led to the intentional and unnecessary tripping of solar PV resources during these events. In addition to identifying the need to provide clarity around the requirements in PRC-024-2, the IRPTF also found errors within the standard. Based on these findings, the IRPTF has concluded that the following issues in PRC-024- 2 should be addressed:

- The region outside the "No-Trip" zone of the PRC-024-2 ride-through curves should be clearly marked as a "May-Trip" zone so it is not incorrectly interpreted as a "Must-Trip" zone. The preferred behavior is for the generators to ride-through disturbances to the greatest extent possible.
- There is inconsistency between the Curve Data Point tables and the Off Nominal Frequency Capability Curves as the table identifies "instantaneous" trip points while the time axis of the curve starts at 100 ms.
- There is confusion in point #5 of the Curve Details section of the Voltage Ride-Through Curve Clarifications regarding crest and RMS voltage relationship.
- There is confusion regarding the inclusion of the four second cumulative timer functionality, as well as when the timer starts, stops, and resets.
- There is confusion regarding footnote 1 and the applicability of inverter control systems to the standard.

"Must-Trip" versus "May-Trip" Interpretation

PRC-024-2 specifies a "No-Trip" area for voltage and frequency excursions, as measured at the point of interconnection to the BES. According to the Blue Cut Fire Disturbance Analysis Report solar development owners and inverter manufacturers have misinterpreted the area outside of the "No-Trip" curve as a

[6] NERC Reliability Standard PRC-024-2 – Generator Frequency and Voltage Protective Relay Settings. Available: https://www.nerc.com/_layouts/15/PrintStandard.aspx?standardnumber=PRC-024-2&title=Generator%20Frequency%20and%20Voltage%20Protective%20Relay%20Settings&jurisdiction=United States.

"Must-Trip" requirement. This is possibly due to the use of the term "instantaneous trip" in the tables following the voltage and frequency ride-through curves.

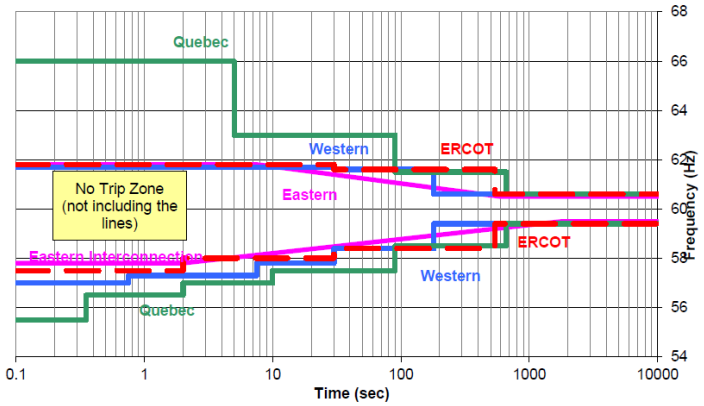

Figure 1: PRC-024-2 Frequency Ride-Through Curve

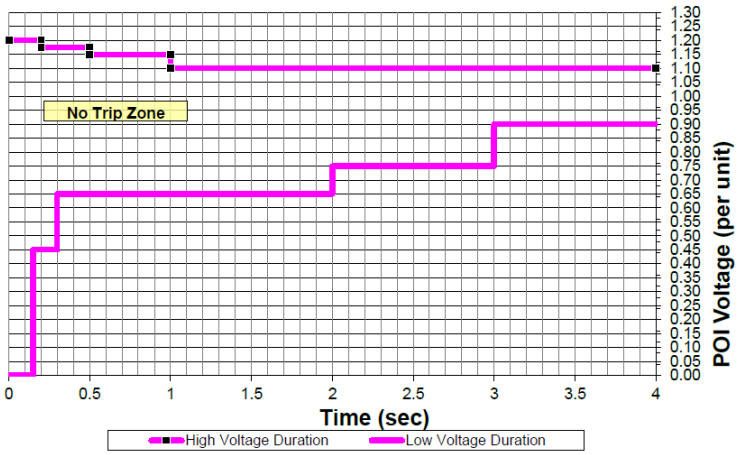

Figure 2: PRC-024-2 Voltage Ride-Through Curve

PRC-024-2 footnote 1 clarifies that Generator Owners are not required to have frequency or voltage protective relays. However, most inverter control systems have built-in protective controls for which the Generator Owners must provide settings. The Canyon 2 Fire Disturbance Report[7] found that all of the owners and manufacturers of the affected inverters had used the PRC-024-2 voltage ride-through curve to set the voltage protective settings. Several of the data request responses indicated that the "May- Trip" zone was being interpreted as a "Must-Trip" zone. Hence, despite the recognition in the Blue Cut Fire Disturbance Analysis Report of this misinterpretation, the industry was still setting the voltage protective settings according to the standard ride-through curve rather than on actual equipment voltage limitations, approximately 14 months after the Blue Cut Fire Event. Further, these set points were incorrectly applied at the inverter terminals, which are subject to wider voltage excursions than at the

[7] Canyon 2 Fire Disturbance Report. Available: https://www.nerc.com/pa/rrm/ea/Pages/October-9-2017-Canyon-2-Fire-Disturbance-Report.aspx.

point of interconnection during transmission system disturbances due to voltage drop or rise across the collection system during the disturbance.

However, the intent of the PRC-024-2 voltage ride-through requirement is to define the minimum and maximum voltage conditions where generating resources may trip from protective relaying for voltage excursions. The region outside the "No-Trip" zone should be interpreted as a "May-Trip" zone and not a "Must-Trip" zone. Inverter settings should be determined based on equipment limitations and should be set to ride-through to the greatest extent possible. This helps support bulk power system (BPS) reliability during and following grid events such as faults.

Similarly, frequency trip settings for generation resources should be set as wide as possible while still ensuring equipment protection and personnel safety to support BPS reliability. This aligns with the intent of PRC- 024-2. One possible solution could be to change the requirement such that relay settings be set based on equipment limitations but no narrower than the "No-Trip" zones.

Inconsistency between Ride-Through Curves and Tables

PRC-024-2 Attachments 1 and 2 include graphics showing the off-nominal frequency capability curve and the voltage ride-through curve, respectively, with curve data point tables describing the curves in tabular form. The curves and tables define the frequency and voltage protective relay setting minimum performance requirements. Each table contains a value for which a generation resource is allowed to instantaneously trip, essentially describing at what frequency or voltage a generator is no longer required to stay connected to the system.

The task force that analyzed the Blue Cut Fire event found that, "[a] significant amount of solar PV resources disconnected due to a perceived system frequency below 57 Hz. This perceived frequency was due to the Phase Locked Loop logic indicating a near instantaneous frequency during the transient/distorted waveform period as less than 57 Hz. The solar development owner and inverter manufacturer interpreted outside of the PRC-024-2 no- trip curve area as a must-trip area. The frequency table in PRC-024-2 for the Western Interconnection indicates instantaneous trip for frequency equal to or less than 57 Hz. Therefore, the inverters were set to trip instantaneously upon seeing a frequency of 57 Hz."

However, in generation resource control systems, frequency is calculated over a window of time. Instantaneously derived frequency should not be used for protection. Frequency calculation methods use various types of time windows and filtering methods in order to accurately calculate grid frequency. Typically, these methods use a sliding window with a window width on the order of 100 ms (6 cycles). Thus, a delay would occur even if the protective relay algorithm had no intentional time delay. This measurement interval should be reflected in the standard.

Further, the Off Nominal Frequency Capability Curve of PRC-024-2 is a logarithmic graph that starts at time t=0.1 seconds. Thus, the Curve Data Point table "Instantaneous trip" value is inconsistent with the graphic.

Voltage Ride-Through Curve Clarification Error

Point #5 in the Curve Details section of the "Voltage Ride-Through Curve Clarifications" of PRC-024-2 states, "voltages in the curve assume minimum fundamental frequency phase to ground or phase to phase voltage for the low duration curve and the greater of maximum RMS (Root Mean Square) or crest phase to phase voltage for the high voltage duration curve." Numerically, the crest value is always greater than the RMS value of a periodic waveform, so there is ambiguity and technical concern on how this is applied. Without addressing this, there may be reliability issues, as identified in the Canyon 2 Fire Disturbance Analysis Report.

Any voltage measured and compared with the PRC-024-2 voltage ride- through curve should be a well-filtered, fundamental frequency component of the voltage waveform. This filters out spurious voltage spikes caused by switching actions on the BPS. Voltage protective relays should not operate at the voltage levels specified in the voltage ride-through curve (e.g., 1.2 pu) using instantaneously sampled values, although it is reasonable for a generator resource to trip for instantaneous voltage spikes above equipment limitations if they can be properly detected. The other issue with this clarification is that the overvoltage component of the clarification states "the greater of maximum RMS or crest phase-to-phase voltage". Numerically, the crest value is always greater than the RMS value of a periodic waveform, so there is ambiguity and technical concern on how this is applied.

Further, PRC-024-2 clarifies that the low voltage duration curve is based on either phase-to-ground or phase-to-phase voltage, the high voltage duration curve is only based on phase-to-phase voltage. It is not clear why phase-to-ground voltage should not also be considered for high voltage ride-through. Without addressing these, there may be reliability issues, as identified in the Canyon 2 Fire Disturbance Analysis Report.

Confusion in Cumulative Timer Start and Stop Time

The PRC-024-2 voltage ride-through curve ends at four seconds, and the curve uses a cumulative time duration for the "No-Trip" zone. Protective relays must be set to accommodate the cumulative nature of ride-through curves. Under the current version of PRC-024-2, it is not clear at what points the cumulative values reset or what are the starting and ending criteria. This cumulative aspect is also applied in the Volts/Hertz relay protection that covers both synchronous generation resources and generator step up transformers and needs to have clarification for the action to trip or reset.

Footnote 1 Applicability Confusion

Footnote 1 is intended to clarify that Generator Owners are not required to have frequency or voltage protective relaying, thus the requirements only apply if they do have such relays. The footnote contains a parenthetical with an "including but not limited to" statement that is intended to further clarify and provide examples of the types of relays that are applicable. The list contained within the parenthetical includes "protective functions within control systems that directly trip or provide tripping signals to the generator resource based on frequency or voltage inputs."

As noted in the Blue Cut Fire disturbance report, "PRC-024-2 uses language that is more common for conventional synchronous rotating ac generators with traditional protective relays." Because of the language in the bulk of the standard, there is confusion regarding whether the parenthetical list in the

footnote is intended to make inverter controls applicable to the requirements of the standard, and if so, what operating modes or functions are considered "tripping" the generating resource. Further, if PRC-024-2 applies to inverter controls, do the requirements apply to individual inverters or to the generation resource as a whole? As an example, if 50% of inverters within a generation resource trip for a grid disturbance within the "No-Trip" zone of the ride-through curves, but the generation resource does not trip at a plant level, does that meet the intent of the requirements? These points of confusion should be addressed.