Xcel Energy

Guideline for Inverter Based Renewable Generation (IBRG)

Power Quality Measurements and Reports

Rev. A: 5-13-21, Brent R. Lease

Background:

This document replaced the prior "Guideline for Wind Farm Power Quality Measurements and Report Rev. B, dated 6-8-16". This document is intended to apply to Inverter based renewable generation (IBRG) facilities including Wind, Solar and Battery Storage generation facilities.

IBRG facilities produce power that is typically supplied to or interconnected with a Utility Distribution system (*typically 12,470 Volt to 34,500 Volt Distribution line*), or a Utility Transmission system *(typically 69,000V to 345,000V transmission line*). Large IBRG sites will generally supply power onto the utility transmission system.

In order to supply power to end users and also to utility owned equipment (*example – transformers in substations*) that does not include high levels of harmonic currents that can adversely affect electrical equipment (*cause higher levels of losses or heating in equipment, or cause resonant conditions with accompanying high over-voltages*), power quality measurements are required upon completion of a IBRG project as a part of the commissioning of the facility.

It is also possible that the utility, at the point of interconnection with the IBRG facility already contains high levels of harmonic voltage distortion where the IBRG connects to the utility (*PCC or Point of Common Coupling).* This is known as "Utility background voltage distortion".

IBRG Interconnect Agreement:

The interconnect agreement between the utility and the IBRG facility will typically include Power Quality requirements that reference meeting IEEE standard 519 *(IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems)* to avoid:

- Excessive Voltage Flicker
- Excessive Sinusoidal Current Distortion
- Excessive Sinusoidal Voltage Distortion

IEEE 519 places obligations on both the Utility (to not have high levels of sinusoidal voltage distortion that can negatively affect the users equipment), and the user (or in our case, IBRG power plant) to not cause high levels of harmonic currents to flow on the utilities system that can affect the utility or users of electricity that the utility serves.

Applying IEEE 519 to an IBRG site:

IEEE 519 is written primarily for the more common and traditional application of a utility supplying power to an end user of electricity. The end user would most commonly be purchasing power from the utility at their voltage utilization level (such as 120V, 240V, or 480V) or less commonly at a Distribution level voltage (such as 12,470V to 34,500V).

As the voltage that the power is supplied at increases, IEEE 519 allowable limits on harmonic voltages and harmonic currrents become increasingly restrictive. As an example, if the utility is supplying power at less than 1000V, the maximum total harmonic distortion of the utility voltage waveform is 8%. When the utility connection is at a voltage higher than 161,000V, the maximum total harmonic voltage distortion drops to 1.5% (see Table 1, IEEE standard 519).

IEEE 519 is a recommendation, not a requirement, and it is recommended that it be used as a tool to aid in resolving or avoiding serious harmonic issues affecting equipment. IEEE 519 is meant to be applied to steady state conditions only, not transient conditions.

Because IEEE 519 was not written for the application of a IBRG power plant supplying power onto a Utility transmission system, there are areas where we recommend deviating from IEEE 519 or allowing higher limits than IEEE 519 recommends. These areas include:

1. IEEE standard 519 (*section 5.1 – Recommended harmonic voltage limits*) requires that voltages measured be "line to neutral" voltages at the point of common coupling. ***We require that instead at the point of common coupling (transmission line interconnect) and at the 34,500V collection voltage level that voltages be measured from "line to line" only.*** Reasons for this include:

- Transmission and Distribution lines are 3 wire systems (*no neutral wire, but typically does contain a ground wire*). Power from the wind farm is supplied to the phase conductors (*3 wire system*), there is no neutral wire from the IBRG at the point of common coupling. Current is normally intended to return on the phase conductors only (with the exception of a fault returning on a ground conductor), and IEEE 519 standard applies to steady state (*not transient or fault*) conditions.
- All loads on a transmission system (items such as transmission lines, transformers at adjoining substations) draw steady state power from line to line (not line to neutral or line to ground).
- Balanced three phase harmonic voltages (and other triplen harmonics – 9^{th}, 15^{th}, 21^{st}, etc.) that exist between line and neutral on a transformer cancel each other out when added together to calculate line to line voltages (i.e. will not appear on line to line voltage readings and do not affect other equipment drawing power from a line to line source).

2. IEEE Standard 519 (Table 1 – Harmonic Voltage Distortion Limits). ***Where it can be demonstrated that harmonic voltage distortion limits under steady state conditions have no adverse effects on the wind farm or the utility transmission equipment, it is recommended that the harmonic voltage distortion limits not be strictly adhered to.*** Reasons for this include:

- Harmonic measurements at prior Xcel inverter-based wind generation sites indicated that under the steady state condition of the wind farm being lightly loaded (*power production from the wind farm was low*) that the voltage distortion exceeded IEEE 519 recommended limits. The actual amount of harmonic currents that flowed, however, was very low, and well within the ratings of the main power transformer, and the other equipment connected to it.
- At prior Xcel inverter-based wind generation sites as the amount of power being produced by the wind farm increased, the total harmonic voltage distortion at the point of common coupling decreased, and ultimately fell within the IEEE 519 recommended limits.
- End users of electricity typically connect to the utility at the distribution level or utilization level of voltage. Transformers used to step down to these voltages have the effect of filtering out / reducing the level of harmonic voltages transmitted from the transmission system.

3. IEEE Standard 519 (Table 2, Table 3 – Harmonic Current Distortion Limits). ***Where it can be demonstrated that harmonic current distortion limits under steady state conditions have no adverse effects on the IBRG equipment or the utility transmission equipment, it is recommended that the harmonic current distortion limits not be strictly adhered to.*** Reasons for this include:

- Harmonic measurements at prior Xcel inverter-based wind generation sites indicated that under the steady state condition of the wind farm being lightly loaded (*power production from the wind farm was low*) that the current distortion exceeded IEEE 519 recommended limits. The actual amount of harmonic currents that flowed, however, was very low, and well within the ratings of the main power transformer, and the other equipment connected to it.
- At prior inverter-based wind generation sites as the amount of power being produced by the wind farm increased, the harmonic current distortion at the point of common coupling decreased, and ultimately fell within the IEEE 519 recommended limits as the power production increased.
- IEEE standard C57.12.00 under usual service conditions allows for .05 per unit harmonic factor of the current (*THD current = 5% of the transformer nameplate amp rating before you must consider derating the transformer*). This means that when the transformer is fully loaded, it is capable of having up to 5% total harmonic currents flowing before any de-rate of the transformer is required.
- At prior wind generation sites, the current rating of the main power transformers (sinusoidal, harmonic, or combination of the two) never exceeds the ratings of the main power transformer.

Power Quality Measurements when commissioning an Inverter Based Renewable Generation (IBRG) site:

References:

1. IEEE standard 519-2014 (IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems).
2. IEEE standard C57.12.00-2010 (IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers).
3. IEEE standard C57.110-2008 (IEEE Recommended practice for Establishing Liquid-Filled and Dry-Type Power and Distribution Transformer Capability When Supplying Non-sinusoidal Load Currents).
4. Xcel Energy - Guideline for Inverter Based Renewable Generation (IBRG) Power Quality Measurements and Report - Rev. A

Voltage and Current Measurement Locations:

1. PCC - Point of Common Coupling bus.
    a. Measurements to be made nearest to PCC that voltage transformers (VT or CCVT's) and current transformers are available for connecting to. Measurements are required at only one of the locations identified below (*location nearest the PCC*).
        i. At the PCC
        ii. At the switching substation (remote from collection substation / location of main power transformers).
        iii. At the IBRG collection substation, location of main power transformers.
2. IBRG medium voltage collection bus. If collection system bus voltage varies from 34,500V, replace 34,500V with the correct voltage.
    a. Voltage measurements at each 34,500V Bus (tie between buses open).
    b. Current measurements at 34,500V connection to each main power transformer.

Voltage Measurements:

1. PCC - Point of Common coupling bus.
    a. Line to Line Voltage (*line to ground voltages are not measured / recorded*).
        i. Phase A to Phase B
        ii. Phase B to Phase C
        iii. Phase C to Phase A
    b. Voltage Recording
        i. 1^{st} (fundamental – 60 Hz) to 50^{th} harmonic of fundamental (3000 Hz)
        ii. Odd and Even Harmonics
        iii. Voltage Amplitude
        iv. Voltage Phase displacement from fundamental
    c. Voltage Waveform Snapshot
        i. All main power transformers disconnected (*background / utility voltage*)

ii. IBRG facility at low level of power production, all main power transformers in service.
iii. IBRG facility near full power production, all main power transformers in service.

2. Each IBRG medium voltage collection bus.
    a. Line to Line
        i. Phase A to Phase B
        ii. Phase B to Phase C
        iii. Phase C to Phase A
    b. Voltages
        i. 1st (fundamental – 60 Hz) to 50th harmonic of fundamental (3000 Hz)
        ii. Odd and Even Harmonics
        iii. Voltage Amplitude
        iv. Voltage Phase displacement from fundamental

<u>Current Measurements:</u>

1. PCC - Point of Common coupling bus.
    a. Phase and Neutral / Ground Currents
        i. Phase A
        ii. Phase B
        iii. Phase C
        iv. Neutral Current (current returning to transformer neutral via ground connection).
    b. Phase Currents
        i. 1st (fundamental – 60 Hz) to 50th harmonic of fundamental (3000 Hz)
        ii. Odd and Even Harmonics
        iii. Amplitude
        iv. Phase displacement from fundamental
    c. Neutral / Ground Current
        i. Low wind condition, clamp on ammeter, record value
        ii. High wind condition, clamp on ammeter, record value
    d. Current Waveform Snapshots
        v. Phase A, B, C currents
        vi. Wind farm at low level of power production.
        vii. Wind farm near full power production.
2. Each 34,500V Collection bus.
    a. Phase and Neutral / Ground Currents
        i. Phase A
        ii. Phase B
        iii. Phase C

iv. Neutral Current (*current returning to transformer neutral via ground connection*).

b. Phase Currents
    i. 1st (fundamental – 60 Hz) to 50th harmonic of fundamental (3000 Hz)
    ii. Odd and Even Harmonics
    iii. Amplitude
    iv. Phase displacement from fundamental
c. Ground Current
    i. Low wind condition, clamp on ammeter, record value
    ii. High wind condition, clamp on ammeter, record value
d. Current Waveform Snapshots
    i. Phase A, B, C currents
    ii. Wind farm at low level of power production.
    iii. Wind farm near full power production.

Voltage and Current Measurement Duration:

Once the facility is capable of at least 95% of the inverters and their associated power sources (wind generator, solar panel, battery) being in service, measurement / recording of the voltage and currents can begin.

It is anticipated that two weeks of recordings should provide the typical steady state conditions that the IBRG facility will experience (*i.e. conditions from very low level or no output to full or near full output of the site)* If two weeks (14 days) are insufficient to encounter and record output from low to near full, additional days of measurement shall be added as needed.

Power Quality Report:

Upon completion of the power quality measurements, the data shall be analyzed using IEEE 519 standards as a guideline, and a report submitted to Xcel Energy.

The report should include:

1. Executive Summary
2. Interpretation of Data including:
    a. Steady State Fundamental and Harmonic Voltage Content
        i. Background (Utility Voltage Distortion) at the Point of Common Coupling / PCC
        ii. Fundamental and Harmonic Voltages (PCC and collection bus -typically 34,500V)
        iii. Voltage Waveform Snapshots (PCC and collection bus -typically 34,500V)
        iv. Low levels of power production
        v. High level of power production
    b. Steady State Fundamental and Harmonic Current Content
        i. Fundamental and Harmonic Currents (PCC and collection bus -typically 34,500V)

ii. Current Waveform Snapshots (PCC and collection bus -typically 34,500V)
iii. Low levels of power production
iv. High level of power production
v. Neutral current measurements
vi. Harmonic currents flowing through the main power transformer at varying production levels relative to C57.12.00 and the transformer nameplate capacity.

c. Voltage Flicker at the Point of Common Coupling

3. Conclusions and Recommendations
4. Appendix
    a. Site one line diagrams identifying all locations (Voltage Transformers (VT) or CCVT locations, Current Transformer (CT) locations) where measurement data was obtained.
    b. Data files from Power Quality recorder.
    c. Spread sheets containing the calculated short time and very short time harmonic measurements.
    d. Spread sheet containing the statistical evaluation of the short time and very short time harmonic measurements (See IEEE 519 section 4 – Harmonic Measurements).