Discussion on Utility Source / Distribution Grid Power Quality Concerns for Solar Inverter Applications

Overview:

During past involvement in problematic Solar installations, little was found published on solutions for Power Quality issues. As Solar installations expand into new markets and electrical environments, there is a need for discussions on Power Quality and Power Conditioning options for successful deployment. Documentation and Specification of minimum Power Quality requirements should be defined and formalized to establish a base Utility Source/Point of Common Coupling (PCC) criteria for Solar installations. Discussions will include a few key elements on PCC Power Quality considerations.

Solar installations are becoming more common-place and are often installed in environments where harmonic distortion from large non-linear load structures, such as variable speed drives (VSDs), and supply voltage regulation issues are present. These supply power conditions can compromise the solar system operation, its continuity of service and shorten the equipment life cycle. High levels of voltage distortion, voltage imbalance, poor voltage regulation, and transient/surge considerations are being experienced in installations within Oil & Gas, Agricultural, Industrial, Commercial and many other environments.

Reliance on the assumption that the Utility/ Distribution Grid tie will always follow ANSI and IEEE Standards for Power Quality is not a viable engineering strategy. Likewise, the assumption that the Solar Equipment manufacturer can withstand these same system conditions is not a given. Review of the equipment specification must be made against known grid tie conditions for a successful installation and to ensure optimal performance. Power conditioning equipment can and should be deployed when the conditions warrant.

In Agricultural applications, challenges are typically related to the proliferation of VSDs used for both horizontal or deep water, electrical submersible pumps and agricultural processing equipment.

Oil & Gas Production and Mid-stream operations are a growing segment for the Solar market. This expansion is due to an enhanced focus on green energy in the petroleum industry. Government subsidy programs coupled with the expansion of solar generation leasing programs is driving this growth. Again, VSD proliferation, particularly within artificial lift equipment, has created significant challenges.

Solar expansion into the heavy industrial manufacturing sector is also growing with its ability to provide peak demand shaving to reduce utility charges and lower the site's overall carbon footprint. Heavy industrial is synonymous with high harmonics and other power quality challenges.

And Commercial market deployments face significant challenges due to continued growth of non-linear loads for various applications in these markets.

Major Power Quality concerns include:

1. High Levels of Utility/Distribution Grid Tie Voltage Distortion:
    - Levels substantially above the IEEE Std 519 limit of 8% VTHD are fairly common.
    - The presence of a high source voltage distortion can trigger nuisance tripping, equipment malfunction or even damage of the equipment itself.

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- Many equipment manufacturers now place warranty qualifications on source voltage distortion limits or reference Engineering Standards within the specifications.

2. Source Voltage Imbalance:
   - ANSI C84.1-2020 suggests the electric utility system not exceed 3% voltage imbalance.
   - Unfortunately, no standards presently mandate this imbalance limit.
   - Can be caused by several issues, including load imbalance.
   - Can lead to significant issues with loads or power supply equipment from mundane operational issues to equipment failure.
3. Over-Excitation/Under Voltage and Voltage Coordination:
   - Voltage level fluctuations are a challenge since they can change due to other users loading, voltage regulation equipment operation by the utility and other factors.
   - ANSI C84.1-2020 has established 2 range qualifications that most Utilities will design around.
   - These operating ranges may be outside the solar inverter's ability to operate properly, leading to operating challenges or even damage to the equipment itself.
4. Transient and Surge Considerations:
   - As with any power electronic equipment, transient and surge protection is important to prevent misoperation or equipment failure.
   - Solar inverter installations should consider transient/surge protection to ensure clamping voltage is coordinated with the inverter withstand levels.
   - Reliance only on utility or grid operators providing the required protection is not prudent.

Source Voltage Distortion Considerations:

IEEE Std 519-2022 is the current standard for harmonic control guidance from the IEEE Society. First launched in 1992 as a Recommended Practice, revised in 2014 and converted to a Standard in 2022.

The standard establishes shared responsibility between Generators and Users:

> *The limits in this recommended practice represent a shared responsibility for harmonic control between system owners or operators and users. Users produce harmonic currents that flow through the owner's or operator's system, which lead to voltage harmonics in the voltages supplied to other users. The amount of harmonic voltage distortion supplied to other users is a function of the aggregate effects of the harmonic current producing loads of all users and the impedance characteristics of the supply system.*

The principle goal is to control voltage distortion by limiting load current harmonics. The relevant Voltage Distortion Limits are covered in Table 1, Section 5.1 – Recommended voltage harmonic limits, Page 6.

TABLE I
VOLTAGE DISTORTION LIMITS IN IEEE STD 519-2022

Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV $< V \leq$ 69 kV	3.0	5.0
69 kV $< V \leq$ 161 kV	1.5	2.5
161 kV $< V$	1.0	1.5

To achieve these voltage distortion targets, the maximum current harmonic injection allowed at a predetermined location within the circuit, a Point of Common Coupling (PCC), is defined within the Standard Section 3, Page 4:

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Point of Common Coupling (PCC): Point on a public power supply system, electrically nearest to a particular load, at which other loads are, or could be, connected. The PCC is a point located upstream of the considered installation.

In most applications, this is the point where the metering is located but due to equipment requirements or circuit configurations, this is not always the case.

As a current source of power, a Solar installation is technically not a load. But like a load, current source inverters are vulnerable to power quality issues on the source distribution grid into which they are feeding energy.

- Source voltage feeds internal power supplies that control every aspect of its operation.
- High source/grid voltage distortion can increase the level of DC control voltage ripple with the possibility of damaging the DC power supply assembly.
- Can trigger nuisance trips by introducing sensor or monitoring errors and compromising logic circuits.
- Flat topping of the source voltage waveform, typical of high harmonic distortion, can shave the peak voltages required by the 24V DC supply to provide a stable output voltage.
- If voltage distortion is extreme and the waveform features high levels of dv/dt, the increased dielectric stress associated with this condition can exceed the IGBT withstand of the assembly causing component malfunctions or failure.

If a solar inverter manufacturer specifies that its equipment meets IEEE Std 519 limits, then as a low voltage device (less than or equal to 1000V), it should be capable of withstanding a source background voltage distortion of 8%. But an inverter manufacturer may specify a lower VTHD withstand limit in order to protect their equipment, components, and operational integrity.

Source Voltage Imbalance Considerations:

ANSI C84.1-2020, 'Electric Power Systems and Equipment – Voltage Ratings (60 Hz)', suggests a voltage imbalance limit of 3% but this is not a definitive requirement for voltage source providers. Voltage imbalance can be created within the grid/utility system due to unbalanced current loads from other users within the grid, blown capacitor fuse conditions within the distribution system, and transposed transmission circuits as well as others. This imbalance condition can have a significant disruptive effect or even damage internal components.

The more balanced the voltage the more effective and efficient the load equipment operation can be. To this goal, inverter manufacturers may specify a voltage imbalance limit lower than 3%. Sensitive electronic components and some inverter configurations may be susceptible to voltage imbalance as low as 1%, so care must be taken when reviewing the limitations of the equipment.

The NEMA definition for Voltage Imbalance is:

% Voltage Imbalance = (Maximum deviation from average voltage / Average Value) X 100

Example:

With Ph-Ph voltages of:
468V – 475V – 492V
Voltage average is:
468 + 475 + 492 = 1435V/3 = 478.3V
Max deviation from average is:
492V – 478.3V = 13.7V
Voltage imbalance is:
13.7V/478.3V X 100 = 2.86% V

Although below the 3% recommended limit, the wide voltage range (468V low to 492V high) could result in significant current imbalance at the Solar (PV) inverter with fluctuating power factor. Minimizing the source/grid voltage imbalance can improve the current balance of the Solar (PV) inverter.

Voltage Level Considerations:

ANSI C84.1 defines two voltage tolerances for power systems with the suggestion that these conditions be limited in extent, frequency, and duration.

Range A: The normally expected voltage tolerance at any given voltage class.

Range B: Voltage tolerances above and below Range A limits that result from practical design and operating conditions on supply, user systems or both.

So not only is it necessary to anticipate these ranges for the Source/Grid voltages, but they must also be coordinated with the specification and installation guidelines for the solar inverter operation. Over-excitation (over-voltage) and under-voltage conditions can trigger operational challenges in the form of nuisance trips and other conditions impacting the integrity of the inverter DC power supply and operational control circuits.

If access to the upstream transformer voltage correction taps is available, their adjustment may be necessary to ensure proper coordination with the inverter voltage range specifications. If not, a means of adjusting the nominal voltage within these ranges may be necessary.

It is important to remember that the inverter may have a dual voltage rating within its specification (480V and 600V), or a maximum voltage rating, but will be programmed at start-up with the nominal voltage required for the application. This will define the withstands for components and protective relay coordination.

As an example, a solar inverter installation in upstate NY was experiencing nuisance trips and the Utility had also claimed that they were seeing a high level of current harmonic at the PCC. Measured voltage at the input to the inverter was 495V, which was within the Range A limits of the nominal 480V supply.

However, it was determined that this higher voltage was possibly affecting the inverter operation. In this case, there was access to the transformer voltage correction taps since it was owned by the Solar System operator. By adjusting the taps upward by 2½%, voltage dropped to 482V and the inverter operation became stable. This also reduced the generated current harmonics to levels acceptable by the Utility.

Transient and Surge Considerations:

Over-voltage transients and surges can have a destructive effect on any connected equipment, including the Solar (PV) inverter. dV/dt withstand of this equipment is often lower than the transient and surge power potentials that can be present on the Utility voltage source.

Arrestors on the high line typically have a relatively high clamping voltage to power ratio providing little protection for this equipment. So low voltage Surge Protection Devices (SPDs) or Transient Voltage Surge Suppression (TVSS) should be considered to protect the Solar (PV) circuit.

Solar Inverter installation instructions should be consulted for guidance on the appropriate clamping voltage and associated power rating for this protection. If this cannot be determined from literature, consult the factory for additional information and guidance.

Temporary over-voltages (TOV) can occur during ground fault conditions and their control is defined in IEEE Std C62.92.6, 'Application of Neutral Grounding in Electrical Utility Systems, Part VI – Systems Supplied by Current-Regulated Sources'. If the load of the Solar System consists of Ph-N loads that are more than 33% of the Solar inverter rating, no treatment is necessary. But if it is < 33%, a supplemental ground source is required. This typically requires the addition of a zigzag or Y-delta transformer with a neutral grounding resistor.

Supplemental ground sources will introduce a low impedance path for circulating common-mode currents (ie. neutral currents). If not effectively blocked, these currents can overload the supplemental grounding equipment. For more information on this topic see Mirus Application Note, MIRUS-AN004-A.

Five Questions to Ask when Installing a Solar System:

1. Does the manufacturer have any stated limits on Grid/Tie Voltage Distortion levels?
    - Is this expressed as a specific Vthd % withstand or by some published Power Quality Standard?
    - What is the existing Voltage Total Harmonic Distortion (Vthd) level at the PCC for this installation?
2. Does the manufacturer have any stated limits on Grid/Tie Voltage Imbalance withstand levels?
    - What level of voltage imbalance can be expected or measured at the intended PCC?
3. Does the manufacturer have a stated Voltage tolerance range for operation based on nominal voltage programmed settings?
    - What is the actual nominal voltage measured at the PCC and range factors to be expected per the source?
4. Does the manufacturer recommend the installation of surge protection or transient suppression within their instruction manual or literature?
    - If so, what is the recommended clamping voltage level or qualifying specification?
5. Is there a need for a Grounding Transformer to prevent TOV?
    - Does the installation require compliance with IEEE Std C62.92.6 or similar standard?
    - What considerations are being taken to address the potential for neutral circulating current?

Mirus Power Conditioning Recommendations:

Although originally designed to control the harmonic currents generated by 3-ph Adjustable Speed Drives and other non-linear loads, the Lineator AUHF Wide Spectrum Harmonic Filter has also been proven effective as a power conditioning device to protect sensitive loads or other connected equipment. When applied in series at the input of Solar Power inverters, the Lineator AUHF can:

- Protect the inverter equipment by reducing Utility Source/Grid voltage distortion downstream by 50% to 70%, especially in the characteristic harmonic frequencies of the 5^{th} (300Hz), 7^{th} (420 Hz), 11^{th} (660 Hz) and 13^{th} (780 Hz).
- Improve voltage imbalance downstream, often to 1% or less, when system levels are as high as 3%.
- Provide some transient and surge protection which can be supplemented with the Coordinated Surge Protective (CSP) option for further voltage clamping.
- Consolidate these Power Conditioning functions into a single assembly to simplify the installation and coordination and allow for design and labor savings while providing protection and conditioning critical to the long-term effectiveness and survival of the solar installation.

When supplemental grounding is required to meet IEEE C62.92.6, Mirus offers a zigzag transformer, grounding resistor and neutral blocking reactor combination that lowers TOV while preventing high levels of neutral circulating current. Again, consolidating these grounding devices into a single assembly simplifies installation and coordination.

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