Safety and Power Quality Issues in Solar PV Installations

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A: GENERAL SAFETY REQUIREMENTS OF SOLAR PV
Class A: General access, hazardous voltage, hazardous power applications

Modules rated for use in this application class may be used in systems operating at greater than 50 V DC or 240 W, where general contact access is anticipated.
- **Class B: Restricted access, hazardous voltage, hazardous power applications**
  Modules rated for use in this application class are restricted to systems protected from public access by fences, location, etc.

- **Class C: Limited voltage, limited power applications**
  Modules rated for use in this application class are restricted to systems operating at less than 50 V DC and 240 W, where general contact access is anticipated.
IEC 62109-2 PV Inverter Specific Requirements

- PV Ground fault protection
- Power Quality – THD, DC injection, flicker
- Voltage and frequency control
- Anti islanding protection
- Opening and Reclosing time
A.3  DC CABLES – SAFETY REQUIREMENTS

- **IS 17293 : 2020**: Electric cables for PV systems for rated voltage **1500 V dc**.
- Covers **single core cables** for use in PV systems for DC.
- Suitable for outdoor installations **directly exposed to solar radiations**.
- Cables are **weather and UV resistant**.
- Cables are designed to operate at a normal **continuous conductor temperature of 90°C**.
- The permissible period of use at a maximum **conductor temperature of 120°C** is limited to **20,000 h**.
- Safety tests includes **Spark test, Vertical flame propagation test, smoke emission**,.
PV systems are considered non-inductive and the utilisation category of the disconnect must be minimum DC21 (with moderate overloads).

- DC PV1 category is used for switching of single PV string(s) without reverse and over current.
- DC PV2 category is used for switching of several PV strings with reverse and over current.
B: REGULATIONS OF SAFETY AND PQ
The interconnection of the renewable energy system with the distribution system of the licensee shall conform:

- CEA (Measures relating to Safety and Electric Supply) Regulations, 2010

- CEA (Technical Standards for connectivity of the Distributed Generation Resources) Regulations, 2013 (Amended as CEA (Technical Standards for connectivity below 33 kV) Amendment Regulation 2019)
Safety provisions for electrical installations and apparatus of voltage not exceeding **1000 Volts AC & 1500 V DC**:

All earthing systems shall maintain earth fault loop impedance sufficiently low to permit adequate fault current and this shall be achieved by supplementary bonding or Protective Multiple Earthing (PME).
Safety standards to DGRs at injection point:
- Harmonic current injections shall not exceed the limits specified in IEEE 519.
- DC injection shall not be greater than 0.5% of the full rated output.
- Flicker produced shall not exceed limits specified in IEC 61000.
- Automatic Synchronizing shall be available.
OV & UV trip functions if voltage reaches above 110% or below 80% respectively with a clearing time upto 2 secs; (*)

OF & UF trip functions, if frequency reaches 50.5 Hz and below 47.5 Hz with a clearing time upto 0.2 secs; (*)

A function to prevent the DGR from reconnecting with electricity system unless voltage and frequency is within the prescribed limits and are stable for at least 60 secs.

- (*) Appropriate licensee may prescribe a narrower range for the purpose.
A function to prevent the DGR cease to energise the electricity system *within two seconds* of the formation of an unintended Island.

While synchronising DGR, Voltage fluctuation shall not be more than +/-5%
Manually operated isolating switch between the DGR and the electricity system:

- Allow **visible verification** that separation has been accomplished;
- Include **indicators** to clearly show open and closed positions;
- **Accessible** 24 hours a day by licensee's personnel;
- Be capable of being **locked in the open position**;
- May **not be rated for load break** nor may have feature of over-current protection;
- Be located at a height of at least **2.44 m above the ground** level.
A function to prevent the DGR cease to energise the electricity system **within two seconds** of the formation of an unintended Island.

While synchronising DGR, Voltage fluctuation shall not be more than +/-5%
C & D: POWER QUALITY
ISSUES RELATED TO
PQ,
MITIGATION
International Electrotechnical Commission defines Power Quality as

“set of parameters defining the properties of the power supply as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (magnitude, frequency, waveform)”. 
POWER QUALITY PARAMETERS

Supply: Interruptions
Magnitude: Sag, Swell, Transients, Under/Over deviations
Frequency: Under / Over frequency
Waveform: Harmonics
# Voltage Distortion Limits (IEEE 519-2014)

<table>
<thead>
<tr>
<th>Bus Voltage V at PCC</th>
<th>Individual Harmonic (%)</th>
<th>Total Harmonic Distortion THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V \leq 1.0 \text{ kV}$</td>
<td>5.0</td>
<td>8.0</td>
</tr>
<tr>
<td>$1 \text{ kV} &lt; V \leq 69 \text{ kV}$</td>
<td>3.0</td>
<td>5.0</td>
</tr>
<tr>
<td>$69 \text{ kV} &lt; V \leq 161 \text{ kV}$</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>$161 \text{ kV} &lt; V$</td>
<td>1.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>
## CURRENT HARMONICS AT POINT OF COUPLING (IEEE 519-2014)

Max Current Harmonic Distortion in % of $I_L$ (Avg Max Demand Current)

<table>
<thead>
<tr>
<th>$I_{sc}/I_L$</th>
<th>$3 \leq h &lt; 11$</th>
<th>$11 \leq h &lt; 17$</th>
<th>$17 \leq h &lt; 23$</th>
<th>$23 \leq h &lt; 35$</th>
<th>$35 \leq h &lt; 50$</th>
<th>TDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 20</td>
<td>4.0</td>
<td>2.0</td>
<td>1.5</td>
<td>0.6</td>
<td>0.3</td>
<td>5.0</td>
</tr>
<tr>
<td>20 &lt; 50</td>
<td>7.0</td>
<td>3.5</td>
<td>2.5</td>
<td>1.0</td>
<td>0.5</td>
<td>8.0</td>
</tr>
<tr>
<td>50 &lt; 100</td>
<td>10.0</td>
<td>4.5</td>
<td>4.0</td>
<td>1.5</td>
<td>0.7</td>
<td>12.0</td>
</tr>
<tr>
<td>100 &lt; 1000</td>
<td>12.0</td>
<td>5.5</td>
<td>5.0</td>
<td>2.0</td>
<td>1.0</td>
<td>15.0</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td>15.0</td>
<td>7.0</td>
<td>6.0</td>
<td>2.5</td>
<td>1.4</td>
<td>20.0</td>
</tr>
</tbody>
</table>
POWER QUALITY ISSUES AFFECTING UTILITIES/END USERS

PROBLEMS DUE TO HARMONICS

- Increased installation and utility cost
- Overheating of components
- Equipment malfunction
- Nuisance tripping of circuit breakers
- Inaccurate measurements on sensors
- Premature failure of capacitors
HARMONIC EFFECT IN DISTRIBUTION TRANSFORMER

• Harmonics of the order \( h = 1,7,13 \) are purely positive sequence.

• Harmonics of the order \( h = 5,11,17 \) are purely negative sequence.

• Triple N harmonics of the order \( h = 3,9,15 \) are purely zero sequence. Thus are purely co-phasal.

Increased Iron and Copper losses, heating in Delta winding.

Use K-rated transformers to carry Triple N harmonics.
<table>
<thead>
<tr>
<th>K-rating</th>
<th>Linear Load</th>
<th>Non-Linear Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-1</td>
<td>100%</td>
<td>0%</td>
</tr>
<tr>
<td>K-4</td>
<td>100%</td>
<td>50%</td>
</tr>
<tr>
<td>K-13</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>K-20</td>
<td>100%</td>
<td>125%</td>
</tr>
<tr>
<td>K-30</td>
<td>100%</td>
<td>150%</td>
</tr>
</tbody>
</table>
Rapid fluctuations in voltage of power supply
Affects human perception, as in flickering in lights

Pst. Perception of light flicker in the short term (10-minute interval) severity and long term (2 hour)
- $Pst \leq 0.35$ and $Plt \leq 0.25$

Penetration Limits – depends on the feeder stiffness, types of load, and on solar fluctuations

PV Impact
Flicker from PV comes from power changes on the inverter
Solar irradiation changes power as the sun rises and falls
Additional flicker may occur during cloud cover events; i.e., clouds moving across the PV cells
- Flicker is minimized by conditioning equipment
- Most PV flicker comes from changes in power levels – i.e., changes in irradiation levels
• Typical Harmonic mitigation is to add harmonic filters – passive or active
• Practically, the limit is the point when harmonic distortion gets high enough from PV penetration that mitigation is required.
• Without mitigation, penetration limits of 50% peak load have been reported
• With mitigation, such as harmonic filters, penetration limits beyond 100% are possible
E: GRID ANCILLARY SERVICES, CASE STUDY
E1. GRID ANCILLARY SERVICES

CERC Indian Electricity Grid Code Regulations, 2010 define Ancillary Services as below:

Ancillary Services “means in relation to power system (or grid) operation, the services necessary to support the power system (or grid) operation in maintaining power quality, reliability and security of the grid, eg. active power support for load following, reactive power support, black start etc..”
Features:

*Market-based mechanisms, deployment and payment of Ancillary Services for maintaining the grid frequency close to 50 Hz.*

*Active power support for load following, reactive power support, black start*

*Nodal agency: National Load Dispatch Center (thro’ SLDC)*
E3. Types of Ancillary services

**Primary Reserve Ancillary Service (PRAS)**: Ancillary Service which immediately comes into service through governor action of the generator or through any other resource in the event of sudden change in frequency;

**Secondary Reserve Ancillary Service (SRAS)**: Ancillary Service comprising SRAS-Up and SRAS-Down, which is activated and deployed through secondary control signal

**Tertiary Reserve Ancillary Service (TRAS)**: Ancillary Service comprising TRAS-Up and TRAS-Down and consists of spinning reserve or non-spinning reserve, which responds to dispatch instructions from the Nodal Agency
### E4. Rotating Machines vs BESS for ancillary service

<table>
<thead>
<tr>
<th>Rotating Machine</th>
<th>BESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Partial bidirectional operation</td>
<td>- Bidirectional operation</td>
</tr>
<tr>
<td>- Not efficient providers due to physical constraints</td>
<td>- 1% or lower static inaccuracy</td>
</tr>
<tr>
<td>- Reaction times of 30 seconds and more.</td>
<td>- 85% or higher round-trip efficiencies</td>
</tr>
<tr>
<td>- They have to generate a large amount of electricity in order to provide a small amount to ancillary services</td>
<td>- Faster reaction time</td>
</tr>
<tr>
<td></td>
<td>- Reduction of conventional ‘must-run’ capacity</td>
</tr>
<tr>
<td></td>
<td>- Inverters capable of providing reactive power</td>
</tr>
</tbody>
</table>
## E5. Functional & Non-Functional Requirements

<table>
<thead>
<tr>
<th>Functional Requirements</th>
<th>Export and Import of active power as per Grid code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-functional requirements</td>
<td>Permissivity of BESS</td>
</tr>
<tr>
<td></td>
<td>Redundancy in active power / energy capacity</td>
</tr>
<tr>
<td></td>
<td>Requirements of Min/Max power of BESS</td>
</tr>
<tr>
<td></td>
<td>Requirement of Minimum ratio between Active power and Energy capacity</td>
</tr>
<tr>
<td></td>
<td>Reactive Power provision</td>
</tr>
</tbody>
</table>
Reaction Speed Vs Accuracy – Fossil Plant vs BESS
(Source: Younicos AG / Aggreko)
1. BESS must continuously export active power due to under-frequency

2. BESS exactly follows active power requirement

3. Available energy constantly drops due to the battery system being discharged while exporting active power

4a. Available energy is zero
4b. BESS cannot follow the active power requirement

5a. End of under frequency, BESS has to import active power
5b. Available energy increases again
BESS STAND ALONE

BESS SITE WITHOUT OTHER GENERATORS OR LOAD

BESS CONTROL SYSTEM
BESS IN A HYBRID POWER PLANT (HPP)

ON SITE CO-LOCATION WITH OTHER CONVENTIONAL OR RE GENERATORS

LOCAL HPP CONTROL
Problem Statement: Low Power Factor after installation of Solar PV plant
Food Processing Industry
Load includes Blower Motors
Existing system having pf correction equipments
Recommended Solution: Passive Harmonic filter
Thank You

Q & A

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