Harmonics and Renewable Power Plants – Modeling, Analysis, and Mitigation

A Guide to Performing Harmonics Analysis and Mitigation

Accurate and efficient harmonic analysis with frequency domain software tools.

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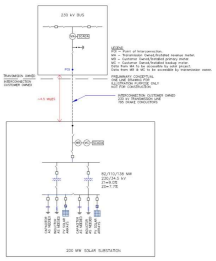
Power System Data Acquisition

Acquiring the pertinent data to perform a harmonic analysis requires electrical information from multiple components of a photovoltaic power plant. Most data will be provided by the manufacturers of the pertinent component, but some electrical characteristics will be affected by the system design. Building a complete system model for harmonic analysis consist of the following information:

- Utility (Short Circuit Equivalent)
- PCC (Point of Common Coupling) Breaker
- Main Power Transformer (MPT) / Substation Transformer
- Collector Cable System
- Generator Step Up (GSU) Transformer
- Inverter Characteristics
- DC Network



Inverters generate harmonics in converting DC to AC power. Accurately evaluating this harmonic contribution, engineers must acquire inverter manufacturer's harmonic spectra.

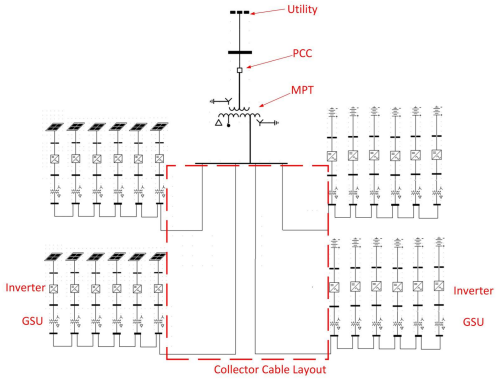
Request project specific data from inverter vendor.

High Vdc Input	Limit (%)	Limit (+) (A)	(A) Phase		
			33%	66%	100%
ITHD	5%	192.50	15.27	17.78	15.98
1	100%	3850.00	1272.65	2543.04	3848.01
3	4%	154.00	3.32	3.75	2.60
5	4%	154.00	9.30	10.86	9.50
7	4%	154.00	6.95	8.43	6.00
9	4%	154.00	0.86	0.82	0.86
11	2%	77.00	0.27	4.29	5.30
13	2%	77.00	2.96	3.74	4.18
15	2%	77.00	1.05	1.03	0.65
17	1.5%	57.75	0.61	0.33	1.03
19	1.5%	57.75	1.33	1.16	1.06
21	1.5%	57.75	0.39	0.81	0.24
23	0.6%	23.10	0.76	0.46	1.48
25	0.6%	23.10	3.70	2.43	3.35
27	0.6%	23.10	1.55	0.55	0.89
29	0.6%	23.10	0.28	0.54	0.32
31	0.6%	23.10	1.21	1.16	0.85
33	0.6%	23.10	0.68	0.57	0.10
35	0.3%	11.55	0.06	0.22	0.13
37	0.3%	11.55	1.11	0.69	0.79
39	0.3%	11.55	0.57	0.95	0.36

Modeling

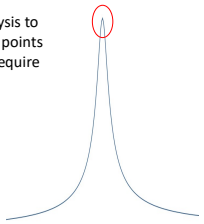
Software tools provide time or frequency domain analysis. Frequency domain software provide efficient modeling methods to develop solar power plant electrical systems. Frequency dependent network models evaluating power system harmonics must consider-

- Skin Effect
- Proximity Effect
- Frequency Dependent Reactance & Capacitance



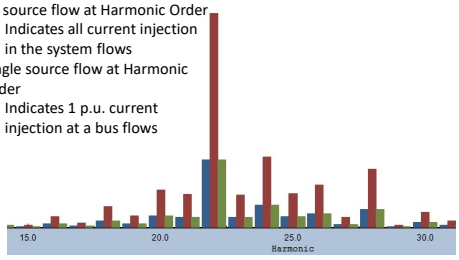
Analysis & Harmonic Contribution

Modeling tools allow a frequency scan analysis to determine resonant points. These resonant points are power system vulnerabilities that may require mitigation.



Investigate contributing factors through simulation options

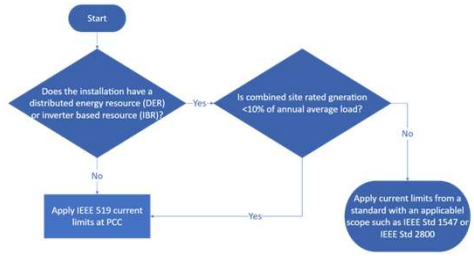
- Fundamental voltage & current
  - Positive, negative, & zero sequence
- Harmonic voltage distortion bar chart at pertinent bus
  - Indicates voltage response to current injection
- All source flow at Harmonic Order
  - Indicates all current injection in the system flows
- Single source flow at Harmonic Order
  - Indicates 1 p.u. current injection at a bus flows



Criteria & Mitigation

Determine applicable criteria that must be achieved, including-

- IEEE Std 519-2022
- IEEE Std 1547
- IEEE Std 2800



Applicable criteria determine reporting requirements from the PCC

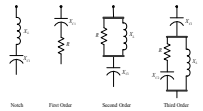
IEEE 519 Report for Breaker:

From Bus Name: To Equipment Name:

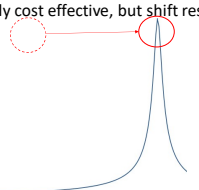
Harmonic Current Distortion In Percent of Plant Loading							
Harmonic Number	2 to 6	7 to 10	11 to 16	17 to 22	23 to 34	35 to 50	ITDD (%)
Odd Harmonics	0.78	0.54	0.7(	1.6(	1.4(	0.11	11.48%
IEEE Limits (h<=50)	2.00	2.0(	1.0(	0.7(	0.3(	0.15	2.50%
Even Harmonics	0.42	0.5(	0.6(	9.9(	3.0(	0.42	
IEEE Limits (50% if h<=6)	1.00	2.0(	1.0(	0.7(	0.3(	0.15	
Plant Load kVA = 74500							
PCC Isc/Iload = 16.0							

Harmonic Voltage Distortion in Percent of PCC Base Voltage		
	Max Individual	VTHD(%)
PCC Bus	13.327	15.566%
IEEE Limits (h<=50)	1.500	2.500%
PCC Base kV = 115.000		

Mitigation Options consist of passive or active filters. Passive filter provide multiple options for mitigation:



Passive filters are generally cost effective, but shift resonant point:



Active harmonic filter compensate for harmonic current with active harmonic injection at key locations.

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