Calculating AC Line Voltage Drop for S280 Microinverters with Engage Cables

Overview

This technical brief presents voltage rise guidelines for dedicated PV branch circuits and methods for calculating the AC line voltage drop (or voltage rise) when using the Enphase S280 Microinverter™ and the Enphase Engage Cable™.

The application of proper voltage rise calculations in your site plan will help to prevent nuisance voltage out-of-range trip issues due to high line voltage conditions. Less resistance in conductors also results in less heat at the terminals, less power loss, and improved performance of the PV system.

When designing circuits for electrical loads, these calculations are commonly called voltage drop (VDrop). But PV systems with inverters generate electricity instead of consume electricity, so voltage actually rises at the AC terminals of inverters. Therefore, this brief refers to these calculations as voltage rise (VRise).

Recommendations

To minimize voltage rise issues, Enphase recommends that you apply these guidelines when planning your system:

- The total VRise in the AC wiring should be less than 2% in all wire sections from the point of common coupling (PCC) to the last microinverter on each branch or sub-branch circuit as described in Voltage Rise by Wire Section on page 3. A good practice is to maintain less than 1% VRise in the Engage Cable.
- Center-feed the branch circuit to minimize voltage rise in a fully-populated branch. Since the VRise is nonlinear, reducing the number of microinverters in a branch circuit greatly reduces the voltage measured at the last microinverter in the branch. To center-feed a branch, divide the circuit into two sub-branch circuits protected by a single overcurrent protection device (OCPD). Find out more in Advantages of Center-Feeding the AC Branch Circuits.
- Use the correct wire size in each wire section. Using undersized conductors can result in nuisance tripping of the microinverter anti-islanding function when an AC voltage out-of-range condition occurs. What Contributes to Voltage Rise provides more information.
- Use the calculation methods in Calculating Total Voltage Rise for Single-Phase Installations and Calculating Total Voltage Rise for Three-Phase Installations to determine voltage rise values for your project.

Background

The IEEE 1547 standard requires that grid-tied or utility-interactive inverters cease power production if voltage measured at the inverter terminal exceeds +10% or -12% of nominal. Enphase Microinverters, like all utility-interactive inverters, sense voltage and frequency from the AC grid and cease exporting power when voltage or frequency from the grid is either too high or too low.

If the voltage measured is outside the limit, the Enphase Microinverter enters an AC Voltage Out-Of-Range (ACVOOR) condition and ceases to export power until this condition clears. Besides voltage variations from the AC grid, voltage changes within system wiring can also contribute to VRise and could cause microinverters to sense an over-voltage condition and cease operation.

The Enphase Microinverter reference point for voltage measurement is at the microinverter AC output. Since the microinverter is located at the array, and the point of common coupling (PCC) is generally at the site load center, the distance from the microinverter AC output to the PCC could be substantial.

All components within system wiring contribute to resistance and must be considered when calculating the total VRise. The main factors that determine voltage rise in an Enphase Microinverter system are: 1) distance from the microinverters to the PCC, and 2) conductor size. What Contributes to Voltage Rise provides details.

Typically, you can quantify the voltage rise of three distinct wire sections and several wire terminations, as described in Voltage Rise by Wire Section. There is also some resistance associated with each OCPD (Over Current Protection Device), typically a circuit breaker.

What Contributes to Voltage Rise

Enphase Microinverter systems are installed as dedicated branch circuits with each branch circuit protected by a 20A OCPD. Wire size, circuit current, circuit length, voltage margin, and utility voltage for each branch circuit must be considered when calculating VRise.

- Wire size: Wire sizing is important because improper wire size can result in nuisance tripping of the utility protective functions in the microinverter. Undersized conductors can cause the voltage measured at the microinverter to be outside of the IEEE limits, triggering an ACVOOR condition. This results in loss of energy harvest. Although the National Electric Code recommends that branch circuit conductors be sized for a maximum of 3% VRise (Article 210.19, FPN 4.), this value in practice is generally not low enough for a utility-interactive inverter.

  There is a tradeoff made between increased wire size and increased cost. You can often increase wire size by one AWG trade size with minimal cost impact. At some point, increasing the wire size necessitates increases in the conduit and/or terminal size and this also increases costs. However, these increases in wiring and conduit costs can be offset by the increase in energy production over the lifetime of the system.

- Circuit current: Circuit current varies depending on which “wire section” is being considered in the installation. Voltage Calculations by Wire Section describes a typical installation containing three wire sections where current is considered. With Engage Cable, current increases with each inverter added to the circuit.

- Circuit length: There is often little control over circuit length, but center-feeding the dedicated branch circuit significantly reduces voltage rise within the branch, as described in Advantages of Center-Feeding the AC Branch Circuits.

- Voltage margin: If service voltage is chronically high, the utility will sometimes perform a tap change on the distribution transformer. This can provide a percent or two of additional voltage margin. Also, if your system interconnection voltage is not 240 V single-phase or 208Y/120 V three-phase and you need to use transformers, the transformers may provide voltage taps to adjust the voltage by some percentage within your AC PV electrical system.

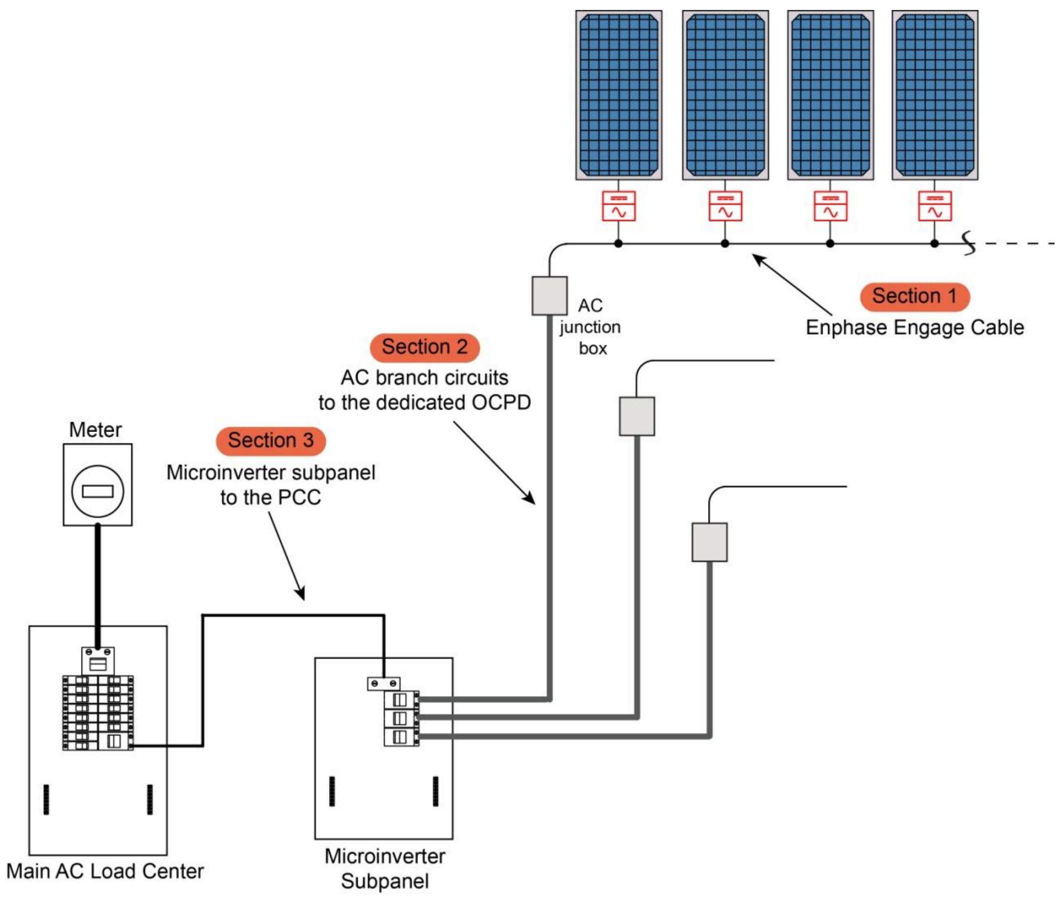
- Utility voltage: The utility strives to maintain voltage at the PCC within +/- 5% of nominal. The protective functions of the microinverters are set to +10%/-12% by default. The high voltage end of the tolerance is of most concern because the inverters are a SOURCE and not a LOAD. If the utility is consistently 5% high, that leaves less than 5% for all wiring and interconnection losses and inverter measurement accuracy. If you are concerned about the utility’s voltage, you may request that your utility place a data logger at the PCC and make a record of the voltages available to you at the site.

Voltage Rise by Wire Section

A typical installation as shown in the illustration has three wire sections where you must consider voltage rise:

Section	Description
1.	Enphase Engage Cable. Internal voltage rise within the Engage Cables from the microinverter to the array-mounted AC junction box. You can find VRise values for S280s in Internal VRise Values of Engage Cables with S280 Microinverters on page 5.
2.	AC branch circuits to the dedicated OCPD. Voltage rise from the array-mounted AC junction box, along the AC branch circuits, to the load center containing the dedicated microinverter OCPDs (circuit breakers). The tables in Conductor Lengths for Wire Sections on page 4 list maximum distances that maintain a 1% voltage drop for this wire section.
3.	Microinverter subpanel to the PCC. Voltage rise from the load center to the PCC. The tables in Conductor Lengths for Wire Sections on page 4 list maximum distances that maintain a 1% voltage drop for this wire section.

Calculate each component individually and verify that the total voltage rise is less than 2%. Calculating Total Voltage Rise lists formulas to determine voltage rise. Additional losses exist at the terminals, connectors, and in circuit breakers; however, if you design for a 2% total voltage rise, these other factors may be ignored.



Conductor Lengths for Wire Sections

This section lists the maximum conductor lengths from the AC junction box back to the main service panel for maintaining a 1% voltage rise.

External Branch (Home Run) Wiring Maximum Distance to Maintain 1% V_{Rise} for 240 VAC Single-Phase

Microinverters per Branch for 240 VAC Single-Phase														
AWG	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Maximum One-Way Wire Length (in Feet) to Maintain 1% VRISE													
#12	539	269	180	135	108	90	77	67	60	54	49	45	41	38
#10	860	430	287	215	172	143	123	108	96	86	78	72	66	61
#8	1371	686	457	343	274	229	196	171	152	137	125	114	105	98
#6	2172	1086	724	543	434	392	310	272	241	217	197	181	167	155
#4	3463	1732	1154	866	693	577	495	433	385	346	315	289	266	247

External Branch (Home Run) Wiring Maximum Distance to Maintain 1% V_{Rise} for 208 VAC Three-Phase

Microinverters per Branch for 208 VAC Three-Phase							
AWG	3	6	9	12	15	18	21
	Maximum One-Way Wire Length (in Feet) to Maintain 1% VRISE						
#12	270	135	90	67	54	45	39
#10	431	215	144	108	86	72	62
#8	687	343	229	172	137	114	98
#6	1088	544	363	272	218	181	155
#4	1734	867	578	434	347	289	248

Use these tables to determine maximum conductor lengths for the wire sections in your installation.

Engage Cable and Internal Voltage Rise

The Engage Cable is a continuous length of 12 AWG stranded copper, outdoor-rated cable, with integrated connectors for S280 Microinverters.

The following table lists the Engage Cable types available for your project.

Voltage type and conductor count	Connector spacing	PV module orientation
240 VAC, 4 conductor	1.025 m (40”)	Portrait
240 VAC, 4 conductor	1.7 m (67”)	Landscape
208 VAC, three-phase, 5 conductor	1.025 m (40”)	Portrait
208 VAC, three-phase, 5 conductor	1.7 m (67”)	Landscape

Regardless of the application, Enphase recommends that the total percentage of voltage rise in the AC wiring be less than 2%, with (an inclusive) less than 1% voltage rise in the Engage Cable. Although Engage Cable is optimized for minimal VRise, it is still important to calculate total VRise for the entire system from the array to the PCC.