Calculating AC Line Voltage Drop for M215 Microinverters with Engage™ Cables

Overview

This technical brief describes methods for calculating the AC line voltage drop (or voltage rise) and presents voltage rise guidelines for dedicated PV branch circuits using M215 microinverters and Engage cable.

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

These calculations are commonly called voltage drop (VDrop) calculations, but PV systems generate electricity and voltage actually rises at the AC terminals of microinverters. Voltage rises because microinverters are a current source rather than a voltage source or a load. This brief refers to these calculations as voltage rise (VRise).

Recommendations

To minimize voltage drop or 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%, which includes less than 1% VRise in the Engage Cable. Use the calculation examples 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 system.
- 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 the branch circuit greatly reduces the voltage measured at the last microinverter in an end-fed 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.
- Wire sizing is important as use of undersized conductors can result in nuisance tripping of the microinverter OCPD. What Contributes to Voltage Rise provides more information.

You can use the calculation methods shown in this brief to calculate VRise values for your project.

Background

The IEEE 1547 standard requires that utility interactive inverters cease to export power if the voltage measured at the Point of Common Coupling (PCC) exceeds +10% or -12% of nominal. The PCC is generally at the main electric service meter. 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 microinverter enters an AC Voltage Out Of Range (ACVOOR) condition and ceases to export power.

All components within system wiring contribute to resistance and must be considered when calculating the total VRise. Typically, you can quantify the resistance of three distinct wire sections and several wire terminations as follows:

- The distance from the microinverters to the PCC. The reference point for a microinverter voltage measurement is at the microinverter AC output. Since microinverters are located at the array, the distance from the microinverters to the PCC can be substantial.
- Undersized conductors that cause the voltage measured at the microinverter to be outside of the IEEE limits.
- VRise within system wiring that can combine with the necessity (of the microinverter) to match AC Grid voltage, causing microinverters to sense an over-voltage condition and cease operation.

All resistances of the system components are in series, and are cumulative. Since the same current is flowing through each resistance, the total VRise is simply the total current times the total resistance. In a PV system, total VRise calculations are:

- For a single-phase system, total resistance is equal to two times the one-way resistance.
- For a three-phase system, each of the three line currents and resistances are calculated, and then combined.

There is also some resistance associated with each OCPD (Over Current Protection Device), typically a circuit breaker.

Engage Cable and Internal Voltage Rise

The Engage Cable is a continuous length of 12 AWG stranded copper, outdoor-rated cable, with integrated Engage connectors for M215 Microinverters.

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

Engage Cable Types

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.

The following tables provide VRise values for the available Engage cable types. Use these values and the examples in Calculating Total Voltage Rise for Single-Phase Installations and Calculating Total Voltage Rise for Three-Phase Installations to calculate VRise values for your project.

Internal VRise for 240 VAC, 4 Wire, 1.0m Portrait Engage Cables and M215s, End-Fed

Microinverters per Branch in Portrait																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
VRise	0.01	0.04	0.08	0.13	0.19	0.27	0.35	0.46	0.57	0.70	0.84	0.99	1.15	1.33	1.52	1.72	1.94
%	0.01	0.02	0.03	0.05	0.08	0.11	0.15	0.19	0.24	0.29	0.35	0.41	0.48	0.55	0.63	0.72	0.81
Current	0.90	1.79	2.69	3.58	4.48	5.38	6.27	7.17	8.06	8.96	9.85	10.75	11.65	12.54	13.44	14.33	15.23

Internal VRise for 240 VAC, 4 Wire, 1.7m Landscape Engage Cable and M215s, End-Fed

Microinverters per Branch in Landscape																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
VRise	0.02	0.06	0.13	0.21	0.31	0.44	0.59	0.75	0.94	1.15	1.38	1.64	1.91	2.20	2.52	2.85	3.21
%	0.01	0.03	0.05	0.09	0.13	0.18	0.24	0.31	0.39	0.48	0.58	0.68	0.80	0.92	1.05	1.19	1.34
Current	0.90	1.79	2.69	3.58	4.48	5.38	6.27	7.17	8.06	8.96	9.85	10.75	11.65	12.54	13.44	14.33	15.23

Internal VRise for 240 VAC, 4 Wire, 1.0m Portrait Engage Cables and M215s, Center-Fed

Microinverters per Sub-Branch (Two Sub-Branches) in Portrait									
	1	2	3	4	5	6	7	8	9
VRise	0.01	0.04	0.08	0.13	0.19	0.27	0.35	0.46	0.57
%	0.01	0.02	0.03	0.05	0.08	0.11	0.15	0.19	0.24
Current	0.90	1.79	2.69	3.58	4.48	5.38	6.27	7.17	8.06

Internal VRise for 240 VAC, 4 Wire, 1.7m Landscape Engage Cable and M215s, Center-Fed

Microinverters per Sub-Branch (Two Sub-Branches) in Landscape									
	1	2	3	4	5	6	7	8	9
VRise	0.02	0.06	0.13	0.21	0.31	0.44	0.59	0.75	0.94
%	0.01	0.03	0.05	0.09	0.13	0.18	0.24	0.31	0.39
Current	0.90	1.79	2.69	3.58	4.48	5.38	6.27	7.17	8.06

Internal VRise for 208 VAC, 5 Wire, 1.0m Portrait Engage Cable and M215s, End-Fed

Microinverters per Branch in Portrait								
	3	6	9	12	15	18	21	24
VRise	0.08	0.21	0.39	0.65	0.96	1.35	1.79	2.30
%	0.04	0.10	0.19	0.31	0.46	0.65	0.86	1.11
Current	1.79	3.58	5.37	7.16	8.95	10.74	12.53	14.32

Internal VRise for 208 VAC, 5 wire, 1.7m Landscape Engage Cables and M215s, End-Fed

Microinverters per Branch in Landscape								
	3	6	9	12	15	18	21	24
VRise	0.12	0.32	0.63	1.05	1.58	2.41	2.95	3.78
%	0.06	0.16	0.30	0.51	0.76	1.16	1.42	1.82
Current	1.79	3.58	5.37	7.16	8.95	10.74	12.53	14.32

Internal VRise for 208 VAC, 5 wire, 1.0m portrait Engage Cables and M215s, Center-Fed

Microinverters per Sub-Branch (Two Balanced Sub-Branches) in Portrait				
	3	6	9	12
VRise	0.08	0.21	0.39	0.65
%	0.04	0.10	0.19	0.31
Current	1.79	3.58	5.37	7.16

Internal VRise for 208 VAC, 5 wire, 1.7m landscape Engage Cables and M215s, Center-Fed

Microinverters per Sub-Branch (Two Balanced Sub-Branches) in Landscape				
	3	6	9	12
VRise	0.12	0.32	0.63	1.05
%	0.06	0.16	0.30	0.51
Current	1.79	3.58	5.37	7.16

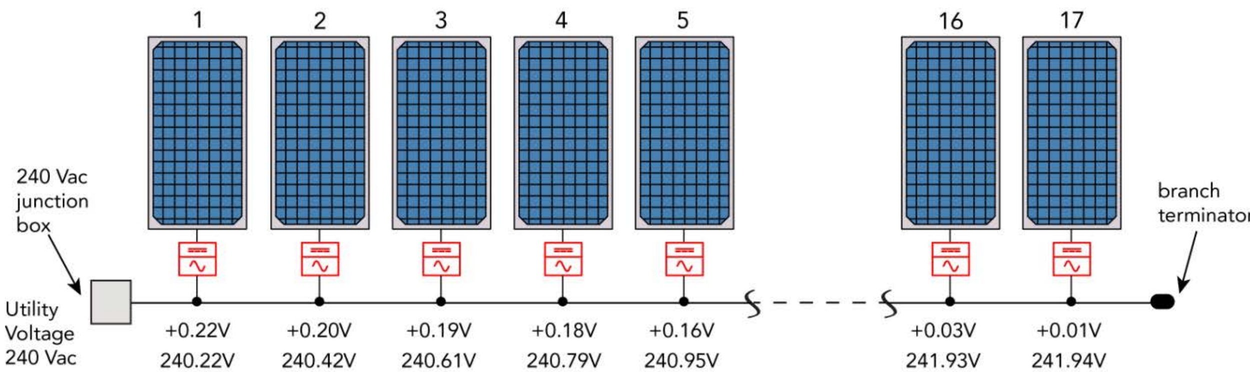
What Contributes to Voltage Rise

Enphase M215 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 each branch circuit must be considered when calculating VRise.

- Wire size: 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 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.
  Wire sizing is important because improper wire size can result in nuisance tripping of the microinverter's utility protective functions. 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 is generally not low enough for a utility-interactive inverter.
- Circuit current: The circuit current varies depending on which "wire section" is being considered in the installation. A typical installation contains three wire sections as described in Voltage Rise Calculations by Wire Section. With Engage Cable, current increases with each inverter added to the circuit.
- Circuit length: There is often little choice in 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.
- 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.

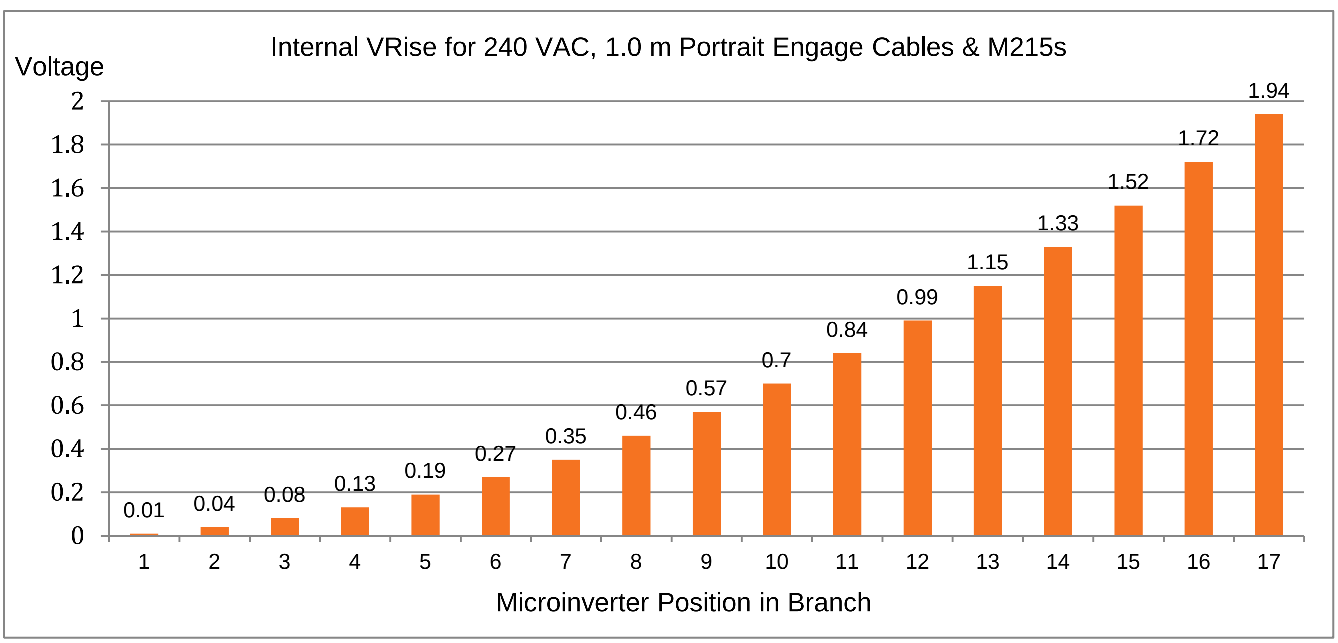
Internal VRise within the Engage Cable

VRise within the microinverter branch circuit can be easily determined. The following diagram represents a 240 VAC system with fully populated branch circuit that is end-fed. It illustrates how voltage measured at an individual microinverter increases by position in the branch circuit. As the number of microinverters in a branch circuit increase, the voltage at each microinverter rises in a nonlinear manner.



The top row of numbers is the incremental voltage rise from one microinverter to the next, and the bottom row is the cumulative line-to-line voltage overall.

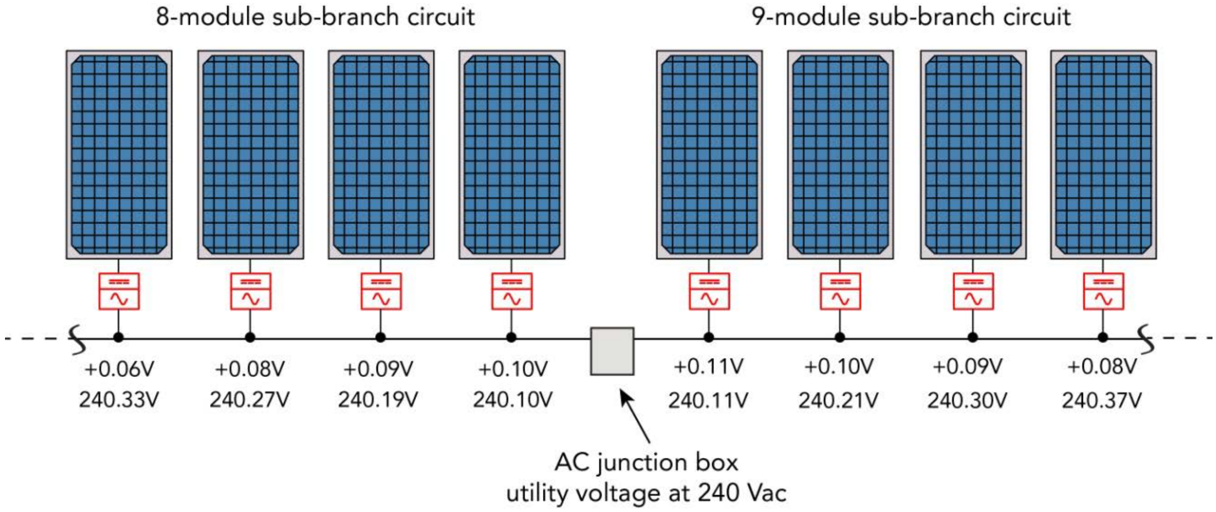
The following graph illustrates how the number of microinverters connected to a portrait-oriented Engage Cable causes a nonlinear voltage rise when operating at 240VAC.



Advantages of Center-Feeding the AC Branch Circuits

The Engage Cable is both more efficient and less impacted by the effects of VRise than past Enphase cabling systems. This is particularly true of the Engage Cable with connectors spaced one meter apart for portrait applications. However, it is still important to calculate voltage rise for the entire system from the array to the PCC.

Since voltage rise is nonlinear, reducing the number of microinverters in the branch circuit greatly reduces the voltage measured at the last microinverter in the branch. One way to minimize this voltage rise is to center-feed the branch, that is, divide the circuit into two sub-branch circuits protected by a single OCPD. The following diagram illustrates the center-fed method.



When a branch circuit feeds multiple roofs or sub-arrays, it is common to divide the sub-arrays into sub-branch circuits. It is acceptable to have different numbers of microinverters on each roof or sub-branch circuit. This is because the conductors from each Engage Cable on that branch circuit are paralleled within a junction box where all red conductors come together, all black conductors come together, etc.

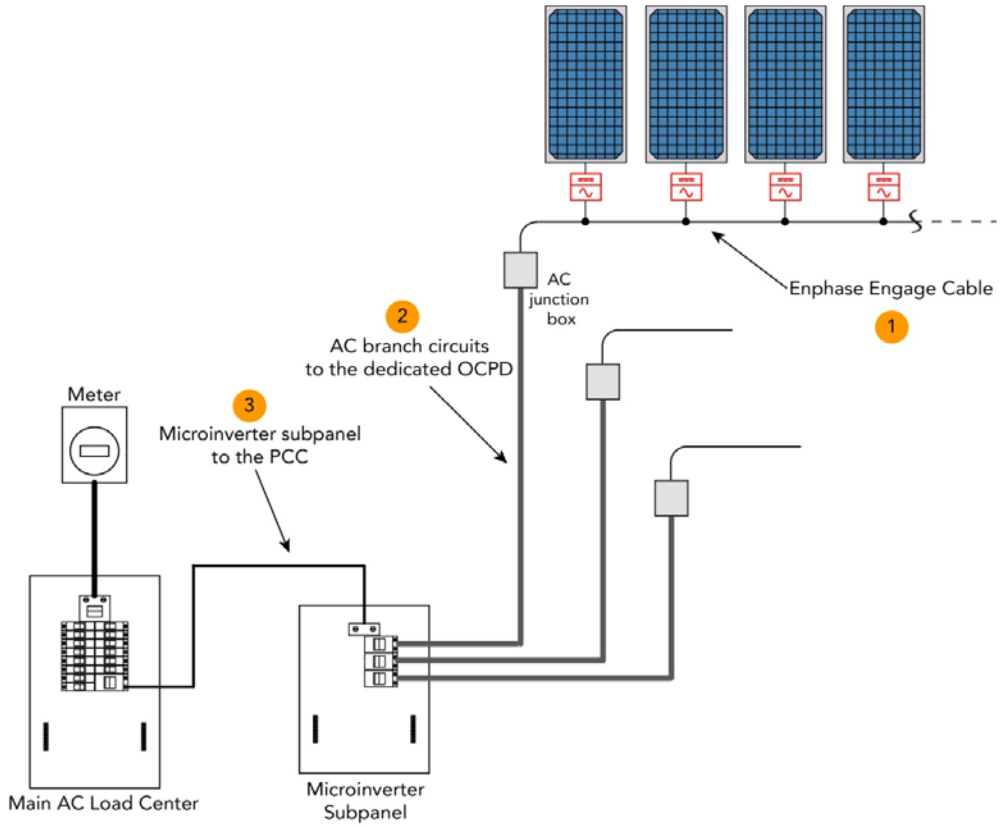
A fully populated center-fed branch circuit has 17 M215 Microinverters, with nine on one sub-branch circuit and eight on the other sub-branch circuit. All microinverters meet in the same junction box. With center-feeding, you will measure a 0.57-volt increase at the last microinverter in the branch circuit rather than a 1.94-volt increase in an end-fed branch circuit.

Voltage Rise Calculations by Wire Section

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

1. Enphase Engage Cable. Internal voltage rise within the Engage Cables from the microinverter to the array-mounted AC junction box.
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).
3. Microinverter subpanel to the PCC. Voltage rise from the load center to the PCC.

Calculate each component individually and verify that the total voltage rise is less than 2%. Additional losses will 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.


AC
junction
box
Enphase Engage Cable
1
2
AC branch circuits
to the dedicated OCPD
Meter
3
Microinverter subpanel
to the PCC
Main AC Load Center
Microinverter
Subpanel

Calculating Total VRise for Single-Phase 240 VAC Installations

Sample Calculation

As part of this analysis, we calculate VRise for a sample scenario of 51 M215 Microinverters in portrait orientation with three branch circuits, each with 17 M215 microinverters. Each branch circuit is center-fed and separated into two sub-branch circuits, one with eight microinverters, and the other with nine microinverters.

Internal VRise for 240 VAC Engage Cable

Refer to Engage Cable and Voltage Rise Values to find the Engage cable VRise appropriate for your project.

Internal VRise within 240 VAC, 4 wire, 1.0m portrait Engage Cables for M215s, center-fed:

Microinverters per Sub-Branch (Two Sub-Branches) in Portrait									
	1	2	3	4	5	6	7	8	9
VRise	0.01	0.04	0.08	0.13	0.19	0.27	0.35	0.46	0.57
%	0.01	0.02	0.03	0.05	0.08	0.11	0.15	0.19	0.24
Current	0.90	1.79	2.69	3.58	4.48	5.38	6.27	7.17	8.06

For a sub-branch circuit of nine M215s, the voltage rise on the 240 VAC Engage Cable is **0.24%.**

Voltage Rise from the Array-Located Junction Box to the Microinverter Subpanel

To calculate the voltage rise in this portion of the circuit, multiply the combined current of the microinverters in the branch by the total resistance of the wire run.

Vrise = (amps/inverter × number of inverters) × (resistance in Ω/ft) × (2way wire length)

The following example is for a fully populated branch circuit of 17 M215 Microinverters.

- M215 full load AC current = 0.9 amps (0.8958 amps)
- Wire gauge for individual branch circuit = #10 AWG THWN-2 CU
- #10 AWG THWN-2 CU resistance = 0.00129/ft (from NEC 2008, Chapter 9, Table 8)
- Length of individual branch circuit = 40 feet, with two way wire length= 80 feet

VRise = (0.9 amps × 17) × (0.00129 Ω/ft) × (40 ft × 2)

= 15.3 amps × 0.00129 Ω/ft × 80 ft

= 1.58 volts

= 1.58 volts ÷ 240 volts = 0.66% VRise

The voltage rise from the junction box to the microinverter subpanel is **0.66%**.

Voltage Rise from the Microinverter Subpanel to the PCC

Determine the VRise in this portion of the circuit by multiplying the combined current of all the microinverters in the array by the total resistance of the wire run.

The following example is for three fully populated branch circuits of 17 M215 Microinverters each (51 total units).

Vrise = (amps/inverter × number of inverters) × (resistance in Ω/ft) × (2way wire length)

- Current of 17 M215 = 15.3 amps (15.2286 amps), for current of 3 branch circuits of 17 M215 = 45.9 amps
- Wire gauge for the microinverter subpanel feed = #4 AWG THWN-2 CU

- #4 AWG THWN-2 CU resistance = 0.000321/ft (from NEC Chapter 9, Table 8)
- Length of the microinverter subpanel feed = 80 feet, with two way wire length= 160 feet

VRise = 45.9 amps × 0.000321 Ω/ft × (80 ft × 2)

= 45.9 × 0.000321 Ω/ft × 160 ft = 2.36 volts

= 2.36 volts÷240 volts = 0.99% VRise

The voltage rise from the microinverter subpanel to the main service meter is **0.99%**.

Summary of Calculations for Single-Phase 240 VAC Applications

With the utility operating at the upper limit of their allowable tolerance (+5%) and the microinverters having a measurement accuracy of 2.5%, we are left with a voltage rise budget of 5.4 volts (2.25%) for all wiring to the PCC. The calculated VRise for all three portions of the system must be 5.4 volts or less. For systems with very long branch circuit runs and/or very long runs from the PV load center to the PCC, it is best to make the VRise in the Engage Cable as small as possible. As we have already determined, 5.4 volts is equal to 2.25% of the nominal voltage. After accounting for additional losses within connections, terminals, circuit breakers, and unexpected increases in wire length, we recommend implementation of a total system voltage rise of less than 2%.

Voltage rise from the microinverters to the AC junction box	= 0.24%
Voltage rise from the AC junction box to the microinverter subpanel	= 0.66%
Voltage rise from the microinverter subpanel to the main service panel (PCC)	= 0.99%
Total system voltage rise for all three wiring sections	= 1.89%

Calculating Total VRise for Three-Phase 208 VAC Installations

Sample Calculation

This example considers voltage rise calculations for a system using 72 M215 Microinverters with 208 VAC three-phase service. The system has three fully-populated branch circuits of 24 M215 Microinverters mounted in portrait orientation. For fully loaded branch circuits with 208 VAC, Enphase recommends that you center-feed the circuit to minimize voltage rise. The M215 Microinverter produces power on two legs, and the phases are balanced by the physical internal rotation of the phase cables inside the Engage Cable. A center-fed branch of 24 microinverters has 12 microinverters on one sub-branch circuit and 12 microinverters on the other.

Internal VRise 208 VAC Engage Cable

Refer to Engage Cable and Voltage Rise Values to find the Engage cable VRise appropriate for your project.

Internal VRise within 208 VAC, 5 wire, 1.0m portrait Engage Cables for M215s, center-fed

Microinverters per Sub-Branch (Two Balanced Sub-Branches) in Portrait				
	3	6	9	12
VRise	0.08	0.21	0.39	0.65
%	0.04	0.10	0.19	0.31
Current	1.79	3.58	5.37	7.16

The voltage rise for a branch circuit of 24 M215s center-fed, with two sub-branch circuits of 12 microinverters each in portrait is **0.31%**.

VRise from the Array-Located Junction Box to the Microinverter Subpanel

Determine the VRise in this portion of the circuit by multiplying the branch circuit output power in watts by the total resistance of the wire run divided by the voltage.

$$\text{VRise} = \frac{\text{(Watts/inverter)} \times \text{(number of inverters per branch circuit)} \times (\Omega/\text{ft}) \times \text{(1 way wire length)}}{\text{208 volts}}$$

The following example is for a fully populated branch circuit of 25 M215 Microinverters.

- M215 output in watts = 215 watts
- Number of microinverters per branch circuit= 24
- Wire gauge for individual branch circuit = #10 AWG THWN-2 CU
- #10 AWG THWN-2 CU resistance = 0.00129 Ω/ft (from NEC Chapter 9, Table 8)
- Length of individual branch circuit = 40 feet

$$\text{VRise} = \frac{\text{215 watts} \times 24 \times 0.00129\ \Omega/\text{ft} \times \text{40 ft}}{\text{208 volts}}$$

= 5160 watts × 0.0516 Ω ÷ 208 volts

=1.28 volts

VRise = 1.28 volts ÷ 208 volts = 0.62%

The voltage rise from the junction box to the microinverter subpanel is **0.62%**.

VRise from the Microinverter Subpanel to the Main Service Meter (PCC)

Determine the VRise in this portion of the circuit by multiplying the total microinverter subpanel output power in watts by the total resistance of the wire run divided by the voltage. The phases are balanced by the physical internal rotation of the phases inside the Engage Cable.

$$\text{VRise} = \frac{\text{(Watts/inverter)} \times \text{(number of inverters per microinverter subpanel)} \times (\Omega/\text{ft}) \times \text{(1 way wire length)}}{\text{208 volts}}$$

The following calculations are for three fully populated branch circuits of 24 M215 Microinverters, with two sub-branch circuits of 12 microinverters each, in portrait, for a total of 72 microinverters.

- M215 output in watts = 215 watts
- Number of Microinverters per microinverter subpanel = 72
- Wire gauge for the microinverter subpanel feed = #2 AWG THWN-2 CU
- #2 AWG THWN-2 CU resistance = 0.000201 Ω/ft (from NEC Chapter 9, Table 8)
- Length of microinverter subpanel feed = 80 feet

$$\text{VRise} = \frac{\text{215 watts} \times 72 \times 0.000201\ \Omega/\text{ft} \times \text{80 ft}}{\text{208 volts}}$$

= 15480 watts × 0.01608 Ω ÷ 208 volts

= 1.20 volts

VRise = 1.20 volts ÷ 208 volts = 0.58%

The voltage rise from the microinverter subpanel to the main service meter is **0.58%**.

Summary of Calculations for Three-Phase 208 VAC Applications

With the utility operating at the upper limit of their allowable tolerance (+5%) and the microinverters having a measurement accuracy of 2.5%, the result is a voltage rise budget of 4.88 volts (2.25%) for all wiring to the PCC. The calculated VRise for all three portions of the system must be 4.88 volts or less. For systems with long branch circuit runs and/or long runs from the inverter subpanel to the main service panel or PCC, it is best to make the VRise in the Engage Cable as small as possible. However, after accounting for additional losses within connections, terminals, circuit breakers, and unexpected increases in wire length, Enphase recommends calculating a total system voltage rise of less than 2%.

Voltage rise from the microinverters to the AC junction box	= 0.31%
Voltage rise from the AC junction box to the microinverter subpanel	= 0.62%
Voltage rise from the microinverter subpanel to the main service meter (PCC)	= 0.58%
Total system voltage rise for all three wiring sections	= 1.51%

In this example, we were able keep the VRise to less than 2% by center-feeding the circuit to create two sub-branch circuits at the array.

Conclusion

Center feeding is a great way to decrease costs, improve production, and increase system reliability. Center-feeding each branch circuit in an Enphase Microinverter system is essential, both for optimal microinverter operation and to minimize wire costs for the installer. Follow the guidelines and calculations in this document to help to minimize voltage rise or voltage drop issues with your installation.