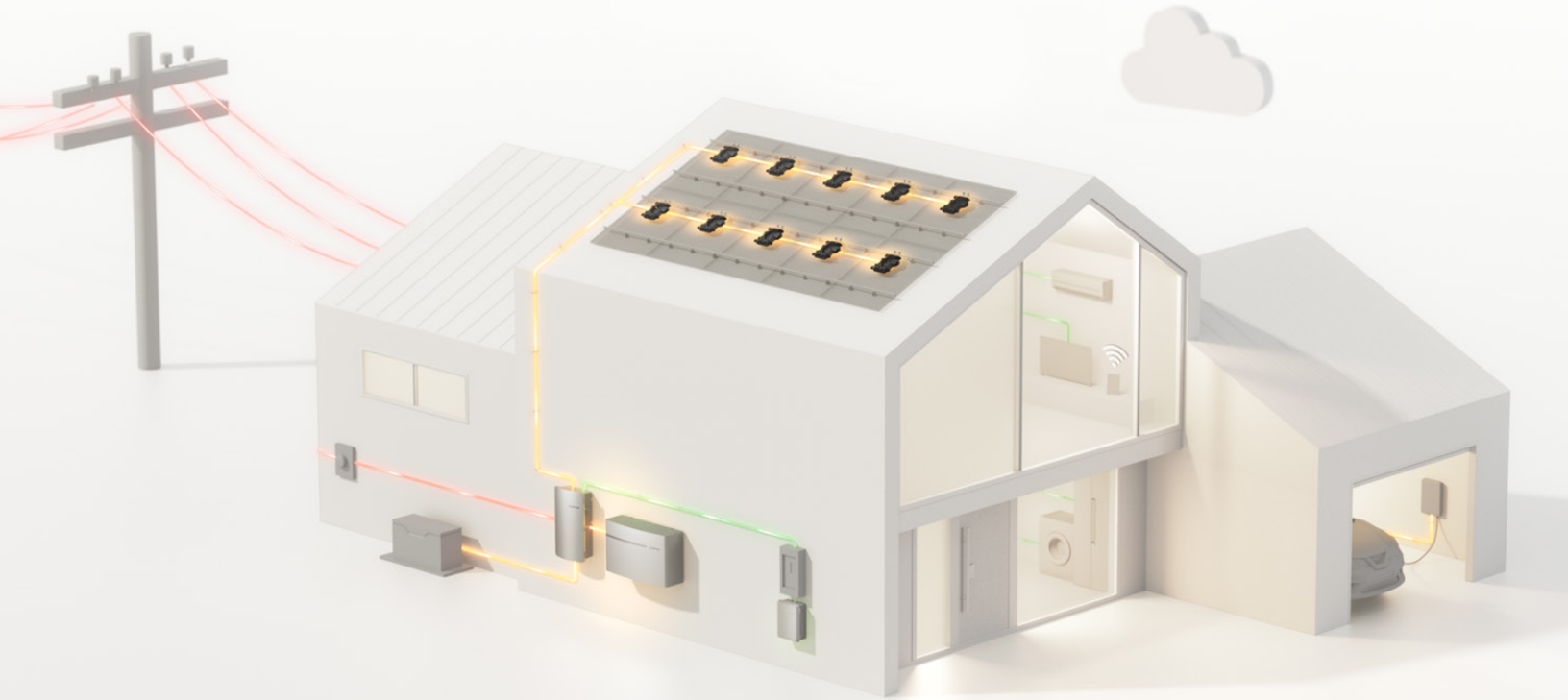
WHITEPAPER

IQ Battery 5P Power Start capability



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February 2024
WHP-00002-4.0

Contents

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Introduction

A backup system with IQ Battery 5P relies on the battery to support loads when the system is running as a microgrid. In the off-grid mode, the IQ Battery 5P can accommodate starting currents of loads via the integrated microinverter's surge capabilities and Power Start technology.

The Power Start capability of the IQ Battery 5P for any compressor-based appliance or load is 48 Amps (A) per battery. The Power Start capability varies based on many parameters, including the other loads on the system when the compressor load needs to be started.

This document describes how Enphase has tested Power Start capability and compares the IQ Battery 5P Power Start capability to that of the leading competitor.

Understanding inrush current requirements and inverter characteristics

Inrush current of an HVAC

Inrush current is the peak instantaneous current drawn by alternating current (AC) motors, transformers, and power converters. These electrical devices may draw their steady state current many times during startup. Compressor-based motor loads, like the condenser in a heating, ventilation, and air conditioning (HVAC) unit, can have an inrush current over five times the steady state current. The following figure shows voltage and current measurements when a compressor or HVAC starts. The high starting current is needed to create the magnetic field and torque required to start the motor.

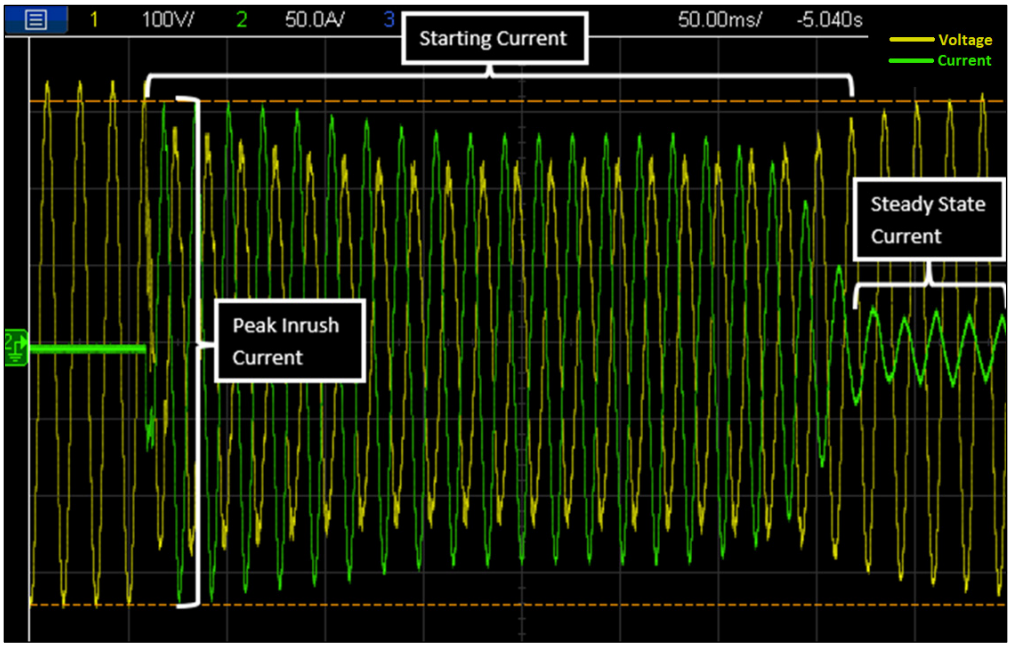

Figure 1: Scope snapshot of voltage (in Volts, yellow) and the current (in Amps, green) while starting an HVAC

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Locked rotor amperes

The inrush current at the nominal voltage of an HVAC load is specified by the LRA on its nameplate. This value can be five times or larger than the nominal current, a.k.a. the continuous current or the running load Amps (RLA) of the load. The ability of a battery to support the inrush current determines its Power Start capability.

Power Start capability

To successfully start a load in an off-grid mode, a battery does not need to supply an inrush current equal to the Power Start capability, that is, the nameplate LRA of the HVAC. The battery must supply a high enough current at a sufficiently high voltage to generate the torque required to start the compressor and accelerate the motor shaft until it reaches a steady state. When the voltage applied to the HVAC is lower than the nominal voltage, the starting current required by the HVAC is also reduced. When this starting current decreases, it reduces the starting torque. However, if the voltage is too low, there will be insufficient torque, and the HVAC will fail to start. Limiting the current does increase the time required to accelerate the motor shaft of the HVAC compressor. Still, the HVAC compressor typically starts within half a second if the starting torque can be generated.

Inverter droop

The voltage and current delivered by the battery inverter follow characteristics known as inverter droop. Inverter droop is the relationship between voltage and current supplied by an inverter. It specifies how low the voltage of an inverter will droop to supply a specified current to a load.

Voltage limits and waveforms during droop

While supporting the startup of an HVAC load, the voltage supplied by a battery (with integrated inverters) must be above 0.65 p.u. (per unit) or 65% of the nominal voltage for the other appliances in the home to function properly. A high-quality power supply with sinusoidal voltage and current waveforms is recommended. Lower-quality power supplies with distorted waveforms applied to an HVAC motor can cause overheating and, when applied over several cycles, can cause severe damage to the motor. Therefore, the battery inverter must start an HVAC load with limited distortion of the voltage and current waveforms, that is, with high power quality.

Current supplied by IQ Battery 5P

The following list provides the current supplied by an IQ Battery 5P:

- 48 A Power Start capability
- 32 A for 3 seconds
- 25 A for 10 seconds
- 16 A continuously at a steady state

Each IQ Battery 5P can supply sufficient current to start appliances with a nameplate LRA higher than 32 A per battery for half a second or less. Though the HVAC load takes longer to start than at nominal voltages, the batteries will be able to start the load successfully. The batteries do this by reducing the voltage in the system, that is, a momentary sub-second brownout in the system voltage. The voltage brownout occurs quickly, corrects itself, and returns to nominal voltage once the HVAC load reaches a steady state.

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It is critical to know the Power Start capability of the battery to tell whether an HVAC can or cannot be started by the IQ Battery 5P. The Power Start capability is additive per battery. Based on the LRA on the HVAC's nameplate and the battery's Power Start capability, you can calculate the minimum number of batteries needed to be installed. If other loads are running when the HVAC load starts up, the number of batteries required to support the load will need to be high enough to support the LRA of the HVAC and the current being drawn by the other loads.

Modular vs. monolithic

The system must have enough batteries to start an HVAC successfully. HVAC loads are often defined in tonnage, where 1 ton of HVAC has a cooling capacity of 12,000 BTU/hour. The higher the cooling capacity of an HVAC, the higher the LRA of that HVAC. The following table shows the general LRA range for the different tonnage of HVAC units.

Table 1: Typical LRA range for different tonnage of HVAC units

HVAC tonnage	Typical LRA range of top HVAC manufacturers in Amps
1	25–40
1.5	37–63
2	35–65
2.5	45–85
3	70–85
3.5	75–120
4	83–130
5	110–153

The LRA of the HVAC loads varies between the different tonnage steps in about 10 A–15 A range, that is, a 1-ton HVAC usually has an LRA in the 25 A–40 A range. As we increase the HVAC tonnage to two tons, the typical LRA for this size HVAC varies between 35 A–65 A. Modular battery sizes enable backup system designers to meet the LRA needs of a particular tonnage of HVAC load while optimizing system cost.

Price and benefit of modularity

If a manufacturer has a modular battery offering as Enphase does, then customers will have the flexibility to buy just the amount of storage necessary to supply power-hungry loads and reduce the upfront investment required for the system. Conversely, if a manufacturer only has one extensive battery offering for specific HVAC sizes, more than the Power Start capability of one battery might be required. In that case, significant investment would be needed to buy another large battery.

For example, one Enphase IQ Battery 5P costs significantly less than the leading competitor's large, monolithic battery. If it is determined that one IQ Battery 5P is enough to start the HVAC load, then one can invest less upfront than the cost of the battery from this leading competitor. Another example is where one battery of a leading competitor is insufficient to start an HVAC load with 125 LRA as it has a Power Start capability of 115 LRA. If the customer has a 125 LRA HVAC, they must invest and buy another large, monolithic battery just to supply an additional 10 LRA. With Enphase, customers can buy IQ Battery 5P units just enough to meet the LRA requirements without investing in vast amounts of unwanted extra capacity.

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The following sections compare the 5 kWh IQ Battery 5P's response with that of the leading competitor's large, monolithic battery while starting HVAC loads.

IQ Battery 5P vs. leading competitor: Starting HVAC loads

Two HVAC units were used to test and compare the Enphase IQ Battery 5P response with that of the leading competitor. The first HVAC had a tonnage of 3 tons with a nameplate LRA of 75 A.

Figure 2: Nameplate of the 3-ton HVAC with LRA of 75 A

The second HVAC had a tonnage of 5 tons with a nameplate LRA of 144.2 A.

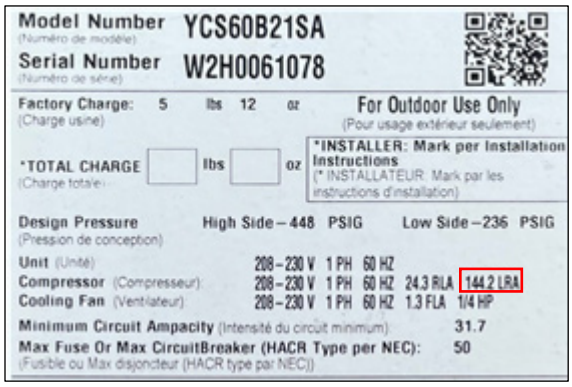

Figure 3: Nameplate of the 5-ton HVAC with LRA of 144.2 A

Both HVAC units were tested with the IQ Battery 5P, then tested using the leading competitor's large, monolithic battery. No other loads were connected to the system during the tests. No solar system was connected to ensure that only the batteries supplied the LRA of these HVAC units. The following table shows the test cases:

Table 2: Tests done to compare the response of Enphase IQ Battery 5P with the leading competitor

Test case #	System type	Load on system	PV status	Other loads
1	Enphase	3-ton HVAC, 75 LRA	OFF	OFF
2	Leading competitor	3-ton HVAC, 75 LRA	OFF	OFF
3	Enphase	5-ton HVAC, 144.2 LRA	OFF	OFF
4	Leading competitor	5-ton HVAC, 144.2 LRA	OFF	OFF

The systems were then taken to the backup mode in all the test cases, and the HVAC units were started.

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Test results for 3-ton HVAC

Test case 1: The first set of tests was conducted with the 3-ton HVAC, which has an LRA of 75 A. An attempt was made to start it with a single IQ Battery 5P, which resulted in a microgrid collapse. A single IQ Battery 5P cannot start a 3-ton AC with an LRA of 75 A.

The next attempt was to start the 3-ton HVAC with two IQ Battery 5P units. The two batteries successfully started the HVAC.

Test case 2: A single battery of the leading competitor was used in the test case to start the 3-ton HVAC unit. As anticipated, a single battery of the leading competitor could successfully start the HVAC. A single battery of the competitor has more capacity than two IQ Battery 5P units.

Responses of IQ Battery 5P and the leading competitor while starting the 3-ton HVAC are compared.

Two IQ Battery 5P units vs. one battery of the leading competitor

Table 3: Comparing the responses of two Enphase IQ Battery 5P units with one battery from the leading competitor

HVAC tonnage	LRA value in Amps of HVAC	Enphase response			Leading competitor response		
		Minimum voltage in Volts	Maximum current in Amps	Time to start in ms	Minimum voltage in Volts	Maximum current in Amps	Time to start in ms
3	75	170.5	70.74	330	178.3	70.79	300

Table 3 shows that the responses of two Enphase IQ Battery 5P units are comparable to that of one battery of the leading competitor, even though a single battery of the leading competitor is bigger and more expensive than two Enphase IQ Battery 5P units. One Enphase IQ Battery 5P costs significantly less than a single battery of the leading competitor. In fact, even two IQ Battery 5P units are lower in cost than a single battery of the leading competitor, yet they can start the same HVAC load as a single battery of the leading competitor.

A scope-measured snapshot of the current and voltage while starting a 3-ton, 75 LRA HVAC with two IQ Battery 5P units is shown in the following figure.

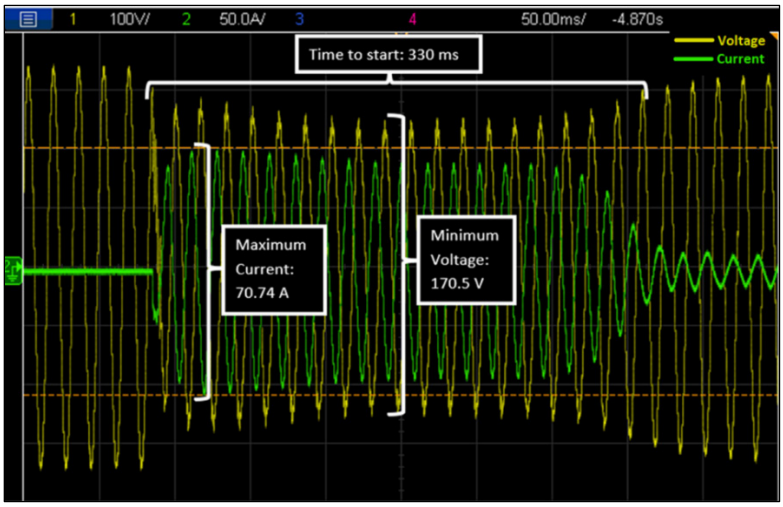

Figure 4: Scope snapshot of the current and voltage while starting a 3-ton, 75 LRA HVAC with two IQ Battery 5P units

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The following figure shows a zoomed-in snapshot of the voltage and current.

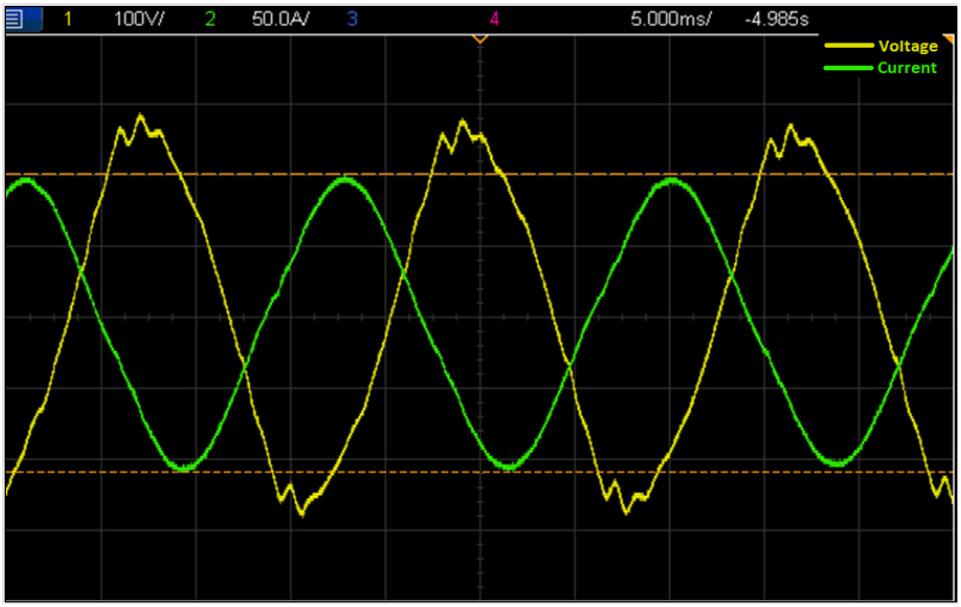

Figure 5: Zoomed-in view of the voltage and current while starting a 3-ton, 75 LRA HVAC with two IQ Battery 5P units

The voltage and current are almost sinusoidal.

The following figure shows a scope-measured snapshot of the current and voltage while starting a 3-ton, 75 LRA HVAC with the leading competitor's large, monolithic battery.

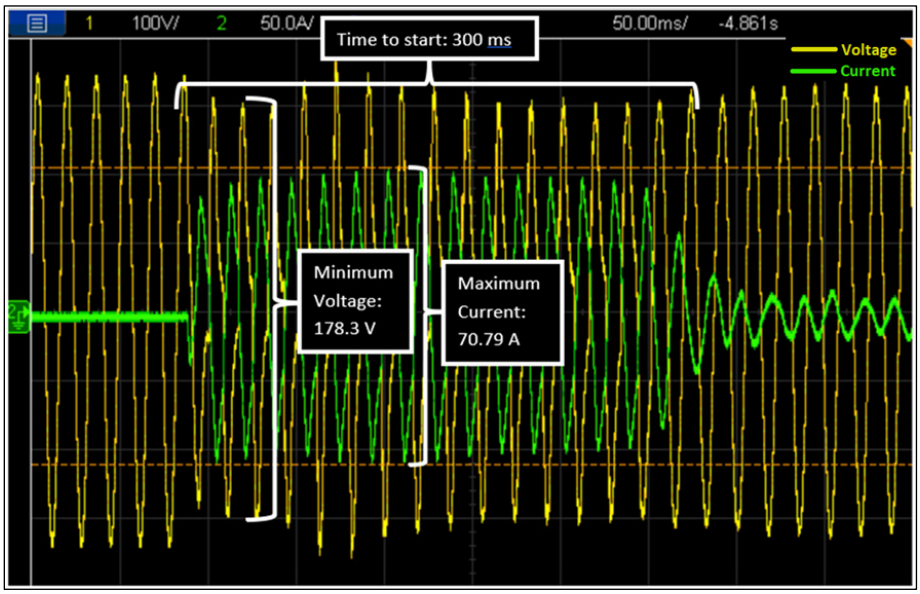

Figure 6: Scope snapshot of the voltage and current while starting a 3-ton, 75 LRA HVAC with a single large, monolithic battery of the leading competitor

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The following figure shows a zoomed-in snapshot of the voltage and current.

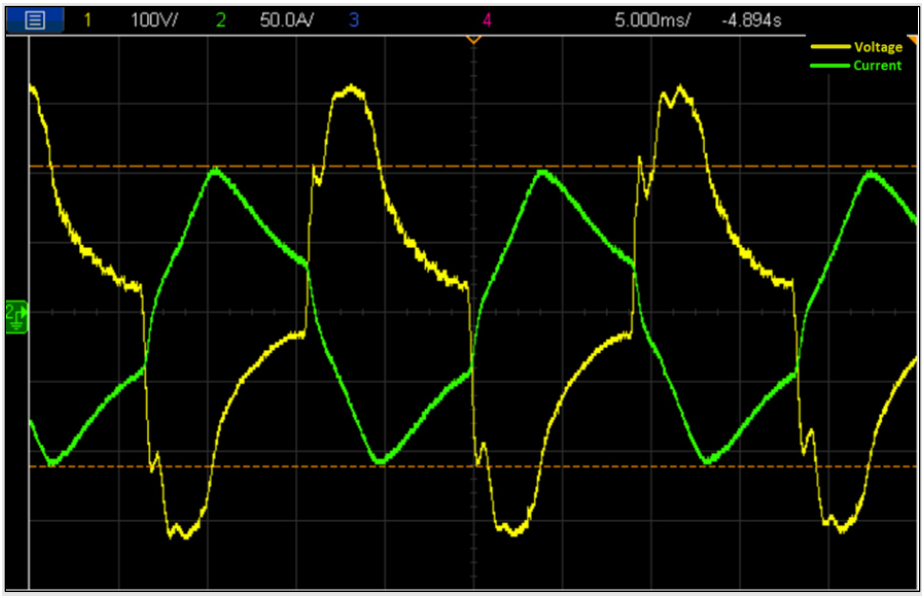

Figure 7: Zoomed-in view of the voltage and current while starting a 3-ton, 75 LRA HVAC with the leading competitor's large, monolithic battery

The voltage and current response of the battery of the leading competitor was severely distorted, which could lead to motor overheating.

Comparing Figure 5 and Figure 7, the voltage and current in the case of IQ Battery 5P were near or almost sinusoidal, while the battery response waveforms of the leading competitor were highly distorted and nowhere near sinusoidal. Distorted waveforms signal a lower power quality and have many harmonics, which can cause heating in the motor coils and, if applied several times across the HVAC, may damage and cause a failure of the HVAC motor.

The Enphase IQ Battery 5P solution proved superior to the leading competitor by starting the 3-ton HVAC at a significantly lower cost, with higher power quality and a comparable startup time.

Test results for 5-ton HVAC

Test case 3: The second set of tests was conducted with a 5-ton HVAC with an LRA of 144.2 A. The first attempt was to start it with two IQ Battery 5P units. The microgrid collapsed since two IQ Battery 5P units could not support the startup of the HVAC load. The test was rerun with three IQ Battery 5P units. The three batteries successfully started the 5-ton HVAC.

Test case 4: As one battery of the leading competitor is almost equal to three IQ Battery 5P units in capacity, an attempt was made to start this HVAC with one battery of the leading competitor. It failed to start the HVAC successfully, and the microgrid collapsed. Then, an attempt was made with two batteries of the competitor, and it successfully started the HVAC. The two competitor batteries have almost six times the energy capacity of a single IQ Battery 5P.

Responses of IQ Battery 5P and the leading competitor while starting the 5-ton HVAC are compared.

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Three IQ Battery 5P units vs. two batteries of the leading competitor

Table 4: Comparing the responses of three Enphase IQ Battery 5P units with two batteries from the leading competitor

AC tonnage	LRA value in Amps of HVAC	Enphase response			Leading competitor response		
		Minimum voltage in Volts	Maximum current in Amps	Time to start in ms	Minimum voltage in Volts	Maximum current in Amps	Time to start in ms
5	144.2	161.7	108	350	183.82	128.93	300

Table 4 shows that the responses of the system with three Enphase IQ Battery 5P units are not the same in terms of voltage and current to a system with two batteries of the leading competitor.
Three IQ Battery 5P units still responded within the acceptable parameters for starting the 5-ton HVAC load. The response is at a lower cost as three IQ Battery 5P units are about half the cost of two batteries from the leading competitor.
A scope-measured snapshot of the current and voltage while starting a 5-ton, 144.2 LRA HVAC with three IQ Battery 5P units is shown in the following figure.

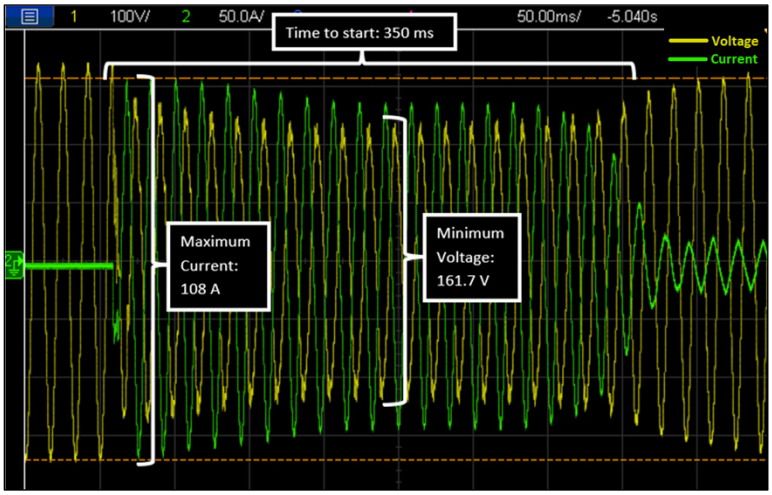

Figure 8: Scope snapshot of the voltage and current while starting a 5-ton, 144.2 LRA HVAC with three IQ Battery 5P units

The following figure shows a zoomed-in snapshot of the voltage and current.

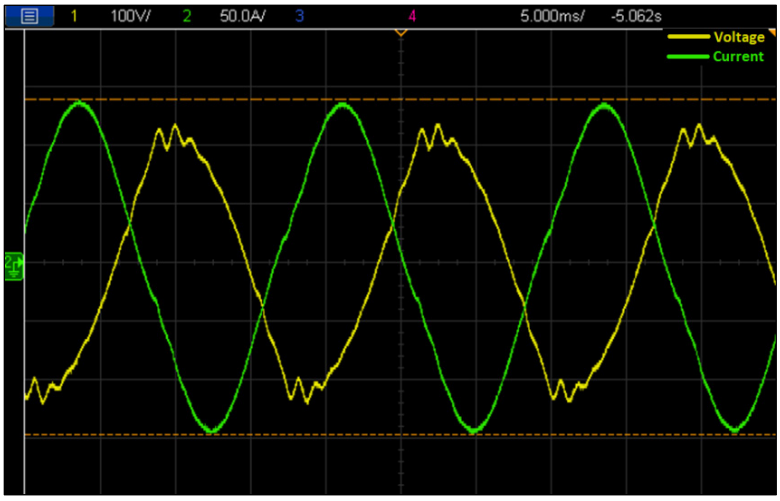

Figure 9: Zoomed-in view of the voltage and current starting a 5-ton, 144.2 LRA HVAC with three IQ Battery 5P units

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The voltage and current have some distortion, but the current is nearly sinusoidal.

A scope-measured snapshot of the current and voltage while starting a 5-ton, 144.2 LRA HVAC with two of the leading competitor's large, monolithic batteries is shown in the following figure.

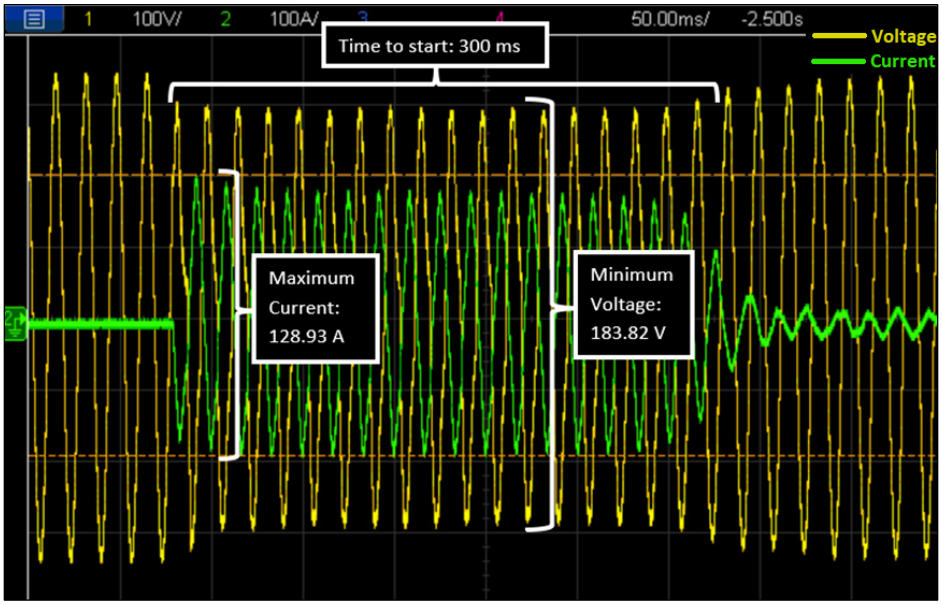

Figure 10: Scope snapshot of the voltage and current while starting a 5-ton, 144.2 LRA HVAC with two batteries of the leading competitor

The following figure shows a zoomed-in snapshot of the voltage and current.

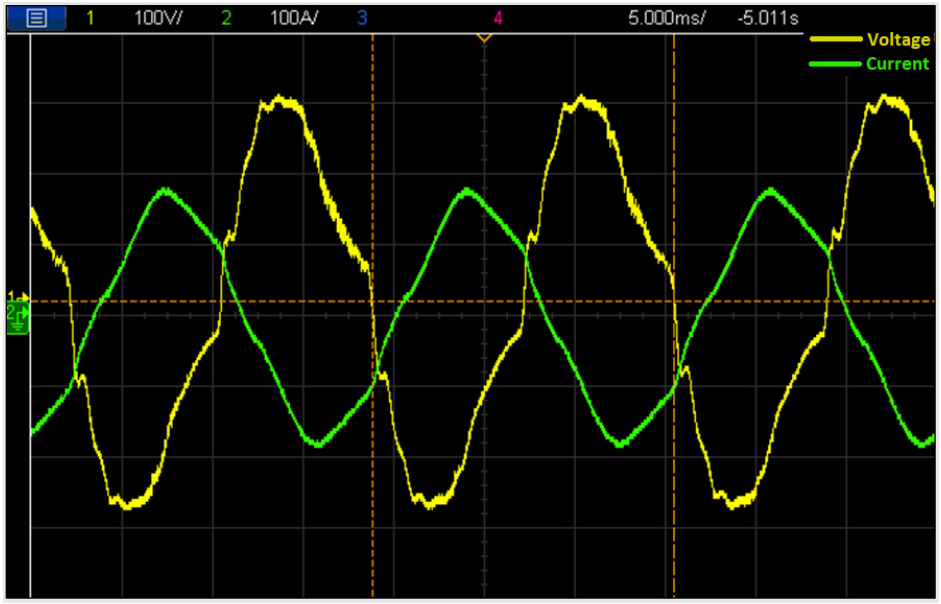

Figure 11: Zoomed-in view of the voltage and current while starting a 5-ton, 144.2 LRA HVAC with two of the leading competitor's large monolithic batteries

Figure 11 shows that the voltage and current response of the battery of the leading competitor was not close to sinusoidal.

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Comparing Figure 7 and Figure 9, the voltage and current in the case of the Enphase response were near or almost sinusoidal, that is, they had a high power quality. However, the waveforms of the response from the battery of the leading competitor are highly distorted and nowhere near sinusoidal. As stated before, such distorted waveforms have lower power quality and many harmonics, which can cause heating in motor coils. If applied several times across the HVAC, these can damage the HVAC motor and cause failure.

The following table shows the summary of the test. For both HVACs, the Enphase IQ Battery 5P solution is more cost-effective and has a better power quality than the leading competitor's large, monolithic battery.

Table 5: Test results from the comparison

HVAC Tonnage	One IQ Battery 5P	Two IQ Battery 5P	One battery of leading competitor	Three IQ Battery 5P	Two batteries of the leading competitor
3	✗	✓	✓	✓	✓
5	✗	✗	✗	✓	✓

Power Start capability of the IQ Battery 5P

The IQ Battery 5P can provide current at sufficient voltage to start appliances of much higher nameplate LRA than 32 A per battery. It is important to know the LRA of the load each battery can successfully start (Power Start capability per battery). With this information, system designers can calculate the minimum number of batteries required based on the nameplate LRA of the HVAC.

The IQ Battery 5P's Power Start capability is 48 A. It does not mean an IQ Battery 5P unit will supply 48 A at nominal voltage to start an HVAC. One IQ Battery 5P unit will supply enough current at a sufficiently high voltage to start an HVAC with a nameplate LRA of 48 A. The Power Start capability varies depending on many parameters, including the other loads on the system when an HVAC needs to be started. If a customer owns a 135 LRA HVAC, they can calculate that a minimum of three IQ Battery 5P units are needed to successfully start the load since their IQ Battery 5P units can supply 48 A × 3 A = 144 A. Customers can choose the best number of IQ Battery 5P units needed for their site, depending on other loads that may be running in a backup mode while the HVAC is starting up.

Putting Enphase LRA lab test claims to real-life testing

For a real-life test of the IQ Battery 5P unit's Power Start capability claim, a 2,000 sq. ft. house with a 4-ton, 135 LRA HVAC was chosen. As the Power Start capability per battery of an Enphase battery is 48 A, to start a 135 LRA HVAC, a system with three IQ Battery 5P units was installed. The base load on the system during off-grid mode was 200 W, as shown in the following figure.

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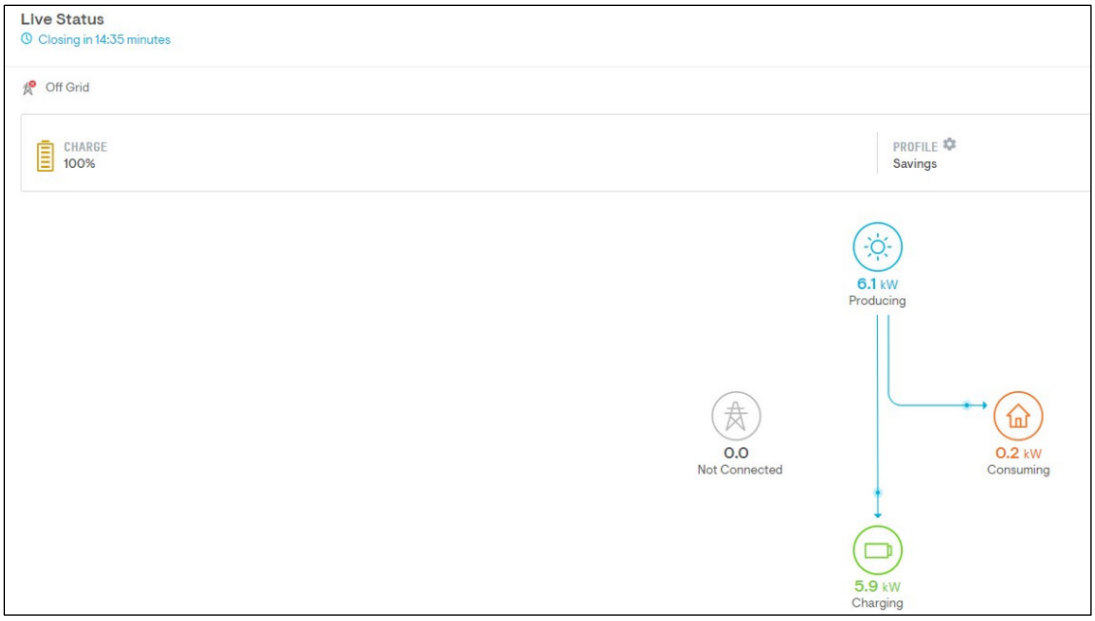

Figure 12: Loads on the system in off-grid mode

The PV on the system was shut off during the test so that only the Power Start capability of the battery was evaluated.

The 4-ton, 135 LRA HVAC was then started with the system in the off-grid mode with no PV and a base load of 200 W. The HVAC started successfully with the three IQ Battery 5P units within 400 ms.

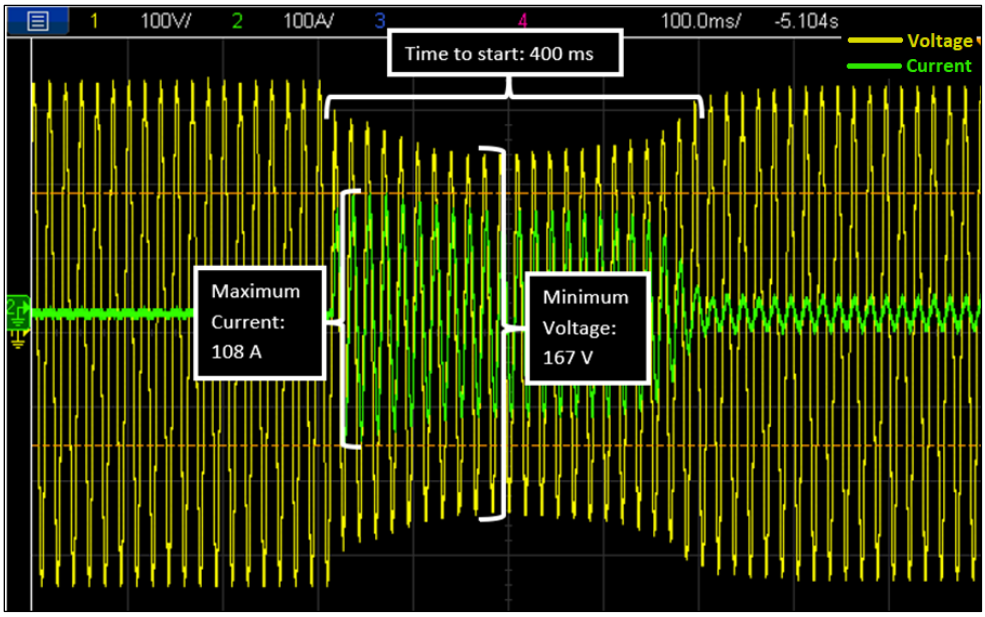

Figure 13: Scope snapshot of the voltage and current while starting a 4-ton, 135 LRA HVAC with three IQ Battery 5P units

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The following figure shows a zoomed-in snapshot of the voltage and current.

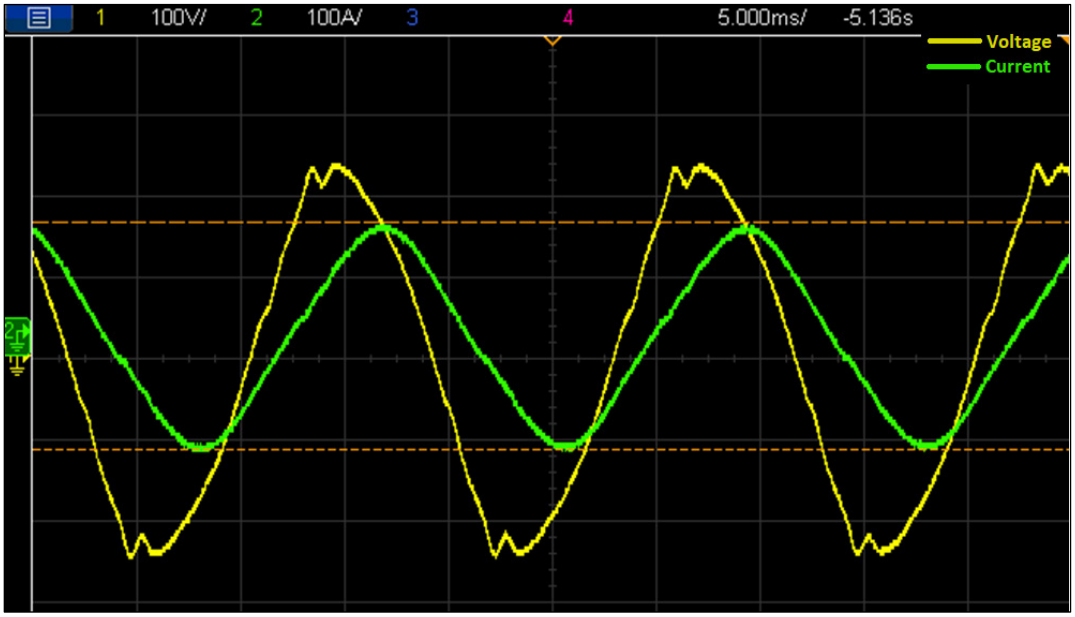

Figure 14: Zoomed-in view of the voltage and current while starting a 4-ton, 135 LRA HVAC with three IQ Battery 5P units

The graph shows that the current was near sinusoidal, while the voltage had minimal distortion near the peaks. The real-life test proves that the three IQ Battery 5P can successfully start a 135 LRA HVAC with very high power quality.

Conclusion

The maximum inrush current at the nominal voltage of a compressor load, such as an HVAC, is specified by the LRA on its nameplate. To successfully start an HVAC load, a battery does not need to supply an inrush current equal to the nameplate LRA of the HVAC compressor. The battery must supply a high enough current at a sufficiently high voltage to generate the torque required to start the compressor and accelerate the motor shaft until it reaches a steady state operation.

Lab tests and real-world tests show that the Enphase IQ Battery 5P response to starting HVAC units has a better power quality than the leading competitor's battery. The recorded current and voltage waveform is near sinusoidal in the case of the Enphase system, but in the case of the leading competitor, harmonics and distortion were present. Such harmonics and distortion can lead to heating in the HVAC motor coils and, when applied over several cycles, can cause damage to the HVAC motor.

The capacity of the IQ Battery 5P solution needed to start an HVAC system is less than the capacity needed by the leading competitor. The battery capacity difference translates to lesser upfront costs for the customer.

The Power Start capability of the Enphase IQ Battery 5P is 48 A, and this Power Start capability is additive per battery. Depending on other base loads to be supported during backup, the customer can select the minimum number of IQ Battery 5P units required for the backup system.

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Revision history

Revision	Date	Description
WHP-00002-4.0	February 2024	Editorial updates.
WHP-00002-3.0	December 2023	Editorial updates.
WHP-00002-2.0	November 2023	Updated load start to Power Start.
WHP-00002-1.0	August 2023	Initial release.

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