Powerwall 2 AC Utility Interconnection Support

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1. Introduction

This document provides technical information about Powerwall, Tesla's home battery solution. The information provided in this document may be used by Authorized Resellers and Tesla Certified Installers or the electric utility itself as part of the interconnection process. This document also codifies a general interconnection process most suitable for grid operators to assess and review interconnection of the Powerwall and may be useful for other behind-the-meter storage systems.

Tesla Powerwall is a state-of-the-art battery system intended for residential and light commercial applications. It enables the storage of energy from the grid or renewable sources, such as solar power, that can then be used at night. Powerwall can also provide backup power in case of a grid outage.

Powerwall 2 AC is an assembly that consists of lithium-ion battery cells, an isolated DC/DC converter, an integrated AC inverter and a liquid thermal management system. The battery cells inside Powerwall are the components closest to being a conventional battery; however, the installer or user is never exposed to these cells since they are electrically and physically isolated from contact by maintenance personnel or homeowners.

For backup applications, the Backup Gateway is used to isolate Powerwall from the grid and facilitate the powering of backed up loads. The Backup Gateway is a separate piece of equipment from the Powerwall, and is not directly connected to the Powerwall via power cables. The Gateway is connected to the Powerwall via communication cables and thus functions together with the Powerwall as a complete system. Within the Backup Gateway enclosure is a microprocessor controlled power contactor, inclusive of line- and load-side voltage sensing and current measurement.

2. Specifications

The specifications below are for reference only. See product datasheets for more detail and country specific variations.

Powerwall Electrical Specifications

Energy*	13.5 kWh
AC Voltage (Nominal) and Maximum Continuous Current	120 V, 208 V, 240 V: 24 A 100 V, 200 V, 220 V, 230 V: 25 A
Frequency (Nominal)	50/60 Hz
Real Power, max continuous	5 kW (charge and discharge)
Real Power, peak (10 s)	7 kW (discharge only)
Apparent Power, max continuous	5.8 kVA (charge and discharge)
Apparent Power, peak (10 s)	7.2 kVA (discharge only)
Power Factor Output Range	+/- 1.0 adjustable
Power Factor (full-rated power)	+/- 0.85
Overvoltage Category	Category III
Max Supply Fault Current	10 kA
Max Output Fault Current	32 A RMS
Round Trip Efficiency (Beginning of Life)[1]	90%

* Values provided for 25°C (77°F), 3.3 kW charge/discharge power.

Powerwall Environmental Specifications

Operating Temperature[2]	-20°C to 50°C (-4°F to 122°F)
Operating Humidity (RH)	Up to 100%, condensing
Storage Conditions (up to 12 months)	-20°C to 30°C (-4°F to 86°F) Up to 95% RH, non-condensing State of Energy (SoE): 25% initial
Maximum Altitude	3000 m (9843 ft)
Noise Level @ 1 m	< 40 dBA at 30°C (86°F)
Enclosure Type	NEMA 3R
Ingress Rating	IP67 (battery and power electronics) IP56 (wiring)
Wet Location Rating	Yes
Pollution Degree Rating	PD3
Seismic Rating	AC156, IEEE 693-2005 (high)

[2] Performance may be de-rated in extreme ambient temperatures.

Powerwall Mechanical Specifications

Height	1150 mm (45.3 in)
Width	755 mm (29.7 in)
Depth	155 mm (6.1 in)
Weight	125 kg (276 lbs)

Backup Gateway Electrical Specifications

Disconnect Current	200 A
Overcurrent Protection Breaker***	100-200 A
Overvoltage Category	Category III
Fault Current Withstand Rating	10 kAIC
AC Meter	Revenue grade
Service Rating	Suitable for Use as Service Equipment

*** Circuit breaker required for installation at service entrance

Backup Gateway Environmental Specifications

Operating Temperature	-20°C to 50°C (-4°F to 122°F)
Operating Humidity (RH)	Up to 100%, condensing
Maximum Altitude	3000 m (9843 ft)
Enclosure Type	NEMA 3R
Ingress Rating	IP44
Pollution Degree Rating	PD3

Backup Gateway Mechanical Specifications

Height	740 mm (29.1 in)
Width	378 mm (14.9 in)
Depth	129 mm (5.1 in)
Weight	16.4 kg (36 lbs)

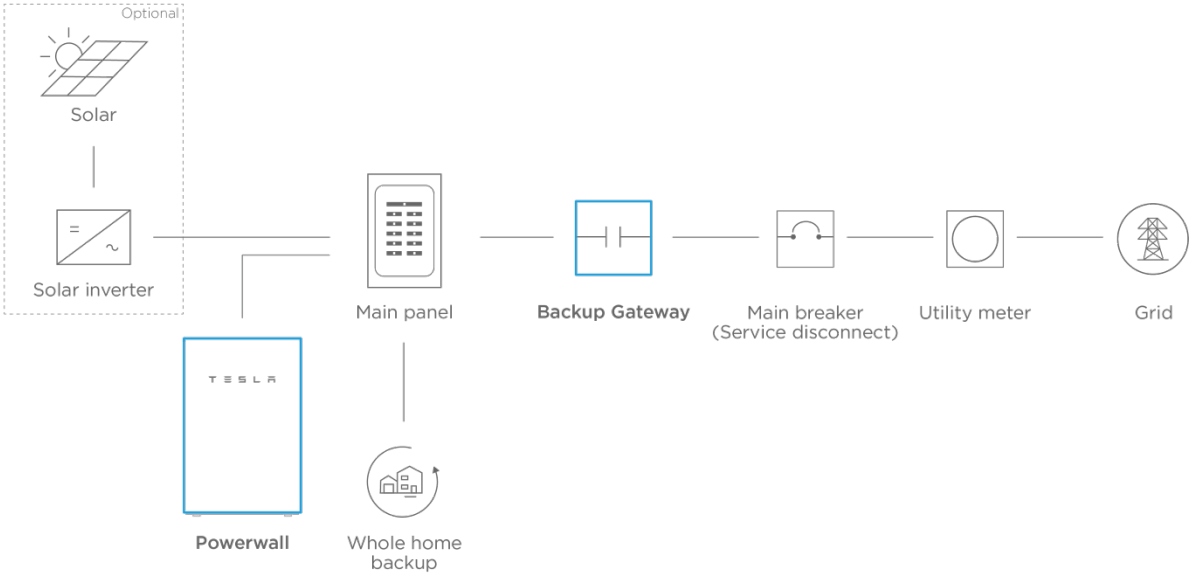
3. Certifications and Standards

The Tesla Powerwall is certified and tested to the standards listed in the following table. If physical certificates are required, please email powerwall@tesla.com with your request.

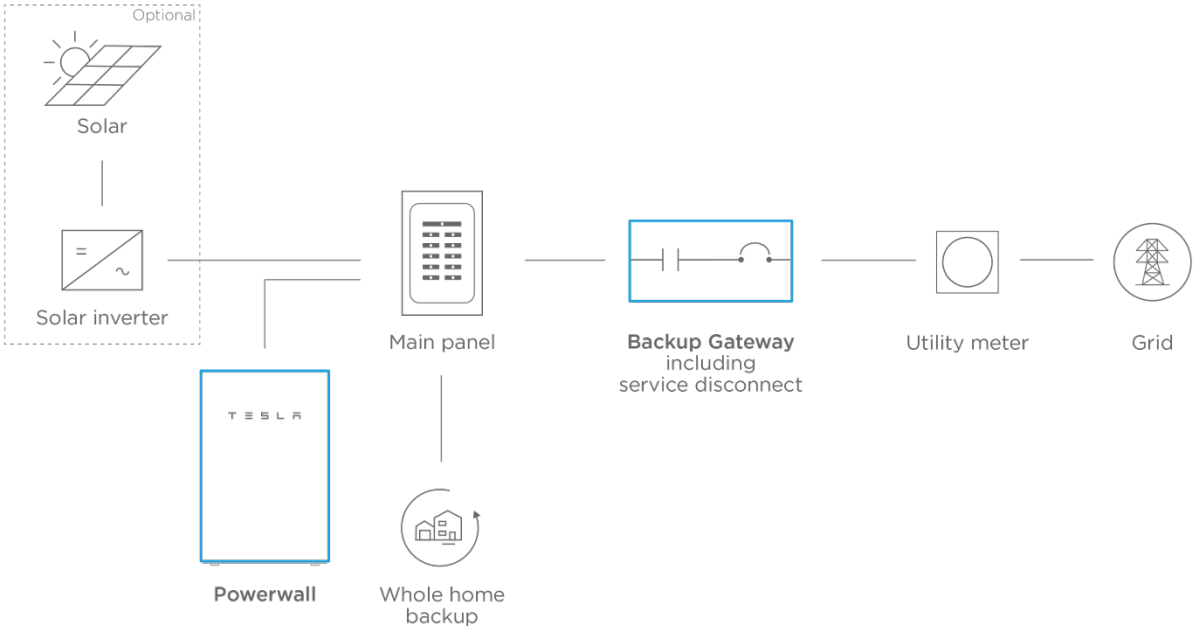
Safety	UL 1642, UL 1741, UL 1973, UL 9540, UN 38.3, IEC 62109-1, IEC 62619, CSA C22.2.107.1
Grid Standards	Worldwide compatibility
Emission	FCC Part 15 Class B, ICES 003
Environmental	RoHS Directive 2011/65/EU, WEEE Directive 2012/19/EU, Battery Directive 2006/66/EC
Seismic	AC156, IEEE 693-2005 (high)

4. Common System Configurations

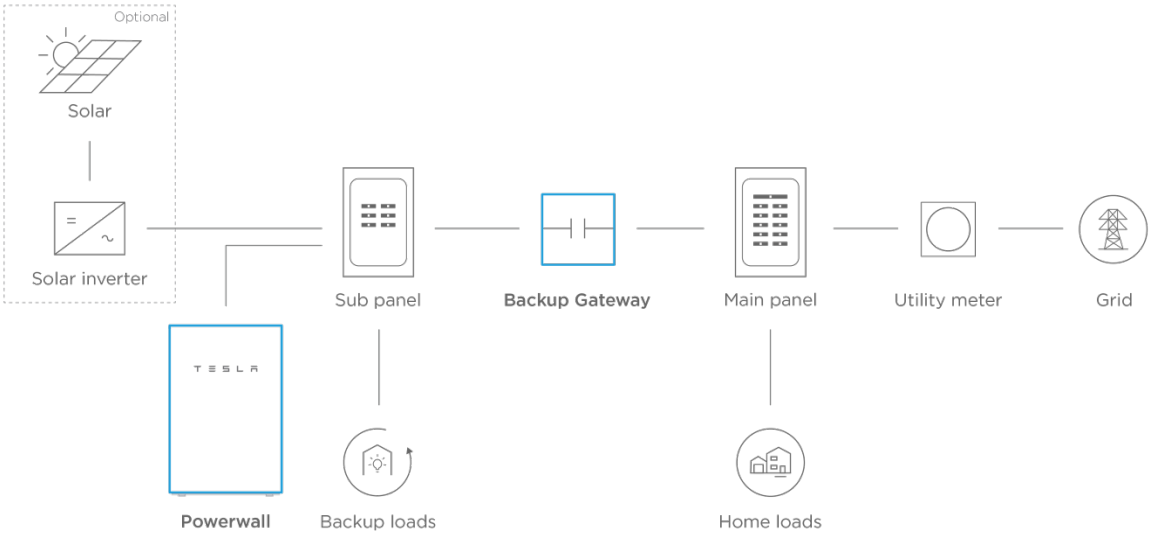
Whole Home Backup – Downstream of Customer Main Breaker



Whole Home Backup – Upstream of Customer Main Breaker



Partial Home Backup (Backup of Selected Loads)



5. Modes of Operation

Three standard modes of operation will be made available for the Powerwall: Backup, Solar Self-Consumption, and Load Shifting (in development).

Backup Mode

Backup Mode allows for partial or whole home transition to off-grid during a grid outage.

The Powerwall's interaction with the grid is primarily handled by the Backup Gateway. As shown in the previous section, the Backup Gateway is installed between the main panel and utility meter for whole home backup, and between the main panel and an essential loads subpanel for partial home backup. The Backup Gateway contains a synchronizer within its controller and uses the synchronizer when transitioning on and off grid. The Backup Gateway manages the disconnection with the grid through an internal power contactor that is automatically controlled. The contactor opens and disconnects the backed-up loads from the grid when a grid outage is detected.

When transitioning the home loads between off-grid and on-grid, the following steps occur:

Disconnect from Grid	1. Backup Gateway detects grid outage. 2. Backup Gateway sends signal to Powerwall to prepare for off-grid operation. 3. Backup Gateway opens contactor within approximately 30 ms of outage detection, physically isolating the backed-up loads from the utility grid. 4. Powerwall begins off-grid operation (changing from grid following to grid forming) within approximately 25 ms of isolation from grid.
Reconnect to Grid	1. Backup Gateway detects grid within normal operating conditions for the required amount of time. 2. Backup Gateway sends signal to Powerwall to prepare for on-grid operation. 3. Backup Gateway synchronizes with the grid and closes contactor, reconnecting to the grid and transitioning on-grid within approximately 25 ms.

If the Powerwall is configured for Backup Mode, it will charge and discharge as follows:

Site Configuration	Charge	Discharge
Standalone	The Powerwall will charge from the grid. The default charge power is 1.67 kW per Powerwall.	Only during a grid outage, when the backed-up loads are isolated from the utility grid via the Backup Gateway.
Solar Onsite	During normal operation, the Powerwall will charge from any onsite solar production. The Powerwall may charge from the grid during abnormal conditions, such as following a grid outage or when the Powerwall's state of energy is critically low.	

Solar Self-Consumption Mode

If the home has solar on site, the customer may choose to operate their Powerwall in Solar Self-Consumption Mode (also known as Self-Powered Mode). In this mode, the Powerwall will charge from solar during normal operation and discharge to serve loads behind the customer's meter. Solar Self-Consumption Mode has a user-configurable Backup Reserve. The Powerwall will reserve this energy in the event a grid outage occurs and will not use this energy for Solar Self-Consumption.

If the Powerwall is configured for Solar Self-Consumption Mode, during normal operation it will charge and discharge as follows:

Load Relative to PV Generation	Charge[1]	Discharge
Load > PV	Will not charge.	Will discharge to serve onsite load.
Load < PV	Will charge from excess PV.	Will not discharge.

Energy from the Powerwall is not exported to the grid. The export of energy is limited to only PV generation; however, the mode tries to maintain this export of energy as close to zero as possible. The Backup Gateway monitors the power exchange with the utility through the Tesla-provided whole home meter. If export is detected, the Backup Gateway quickly commands the Powerwall to reduce discharge power or increase charge power.

As Solar Self-Consumption is a load-following mode of operation, a short duration inadvertent export from the Powerwall may occur when loads turn off. The magnitude of export is generally limited to the size of the largest load and the duration is bound by interconnection tariffs.

Non-Export Mode

In some jurisdictions, customers may choose to make both their Powerwall and PV inverter non-export in order to go through a simpler interconnection process or due to a regulatory requirement. Non-Export Mode limits the export of energy to the grid to zero for both the Powerwall and PV inverter, even if the Powerwall is fully charged and there is excess PV energy. In this subset of Solar Self-Consumption, short duration inadvertent export may still occur. The interconnection process and operating criteria of non-export systems are discussed in the section on Fast Track Review for Non-Export Storage Systems.

[1] The Powerwall may charge from the grid during abnormal conditions, such as following a grid outage or when the Powerwall's state of energy is critically low.

Load Shifting Mode

In Load Shifting Mode (in development), the Powerwall charges during off-peak times when utility rates are low, and discharges to serve onsite loads during on-peak times when utility rates are high. The on-peak and off-peak times are influenced by the utility Time-Of-Use (TOU) rates. As with Solar Self-Consumption Mode, Load Shifting Mode has a user configurable Backup Reserve. The Powerwall will reserve this energy in the event a grid outage occurs and will not use it for load shifting.

6. Frequently Asked Questions

Provided below are questions commonly asked during the utility interconnection process.

Device Specific Questions

What is the power and energy rating of the Powerwall?

- 5 kW Real Power continuous max.
- 5.8 kVA Apparent Power continuous max.
- 13.5 kWh usable energy.

See the Powerwall datasheet for more specifications.

Is the Powerwall UL 1741 certified?

Yes, the Powerwall is UL 1741 certified.

Can the Powerwall provide advanced inverter features?

The inverter within the Powerwall is able to provide advanced inverter features. For California and Hawaii, these functions are certified to UL 1741 SA.

Will the Powerwall comply with voltage and frequency ride through requirements, if applicable?

Yes, if the local jurisdiction has voltage and frequency ride through requirements, the Powerwall will comply.

Does the Powerwall ever export to the grid?

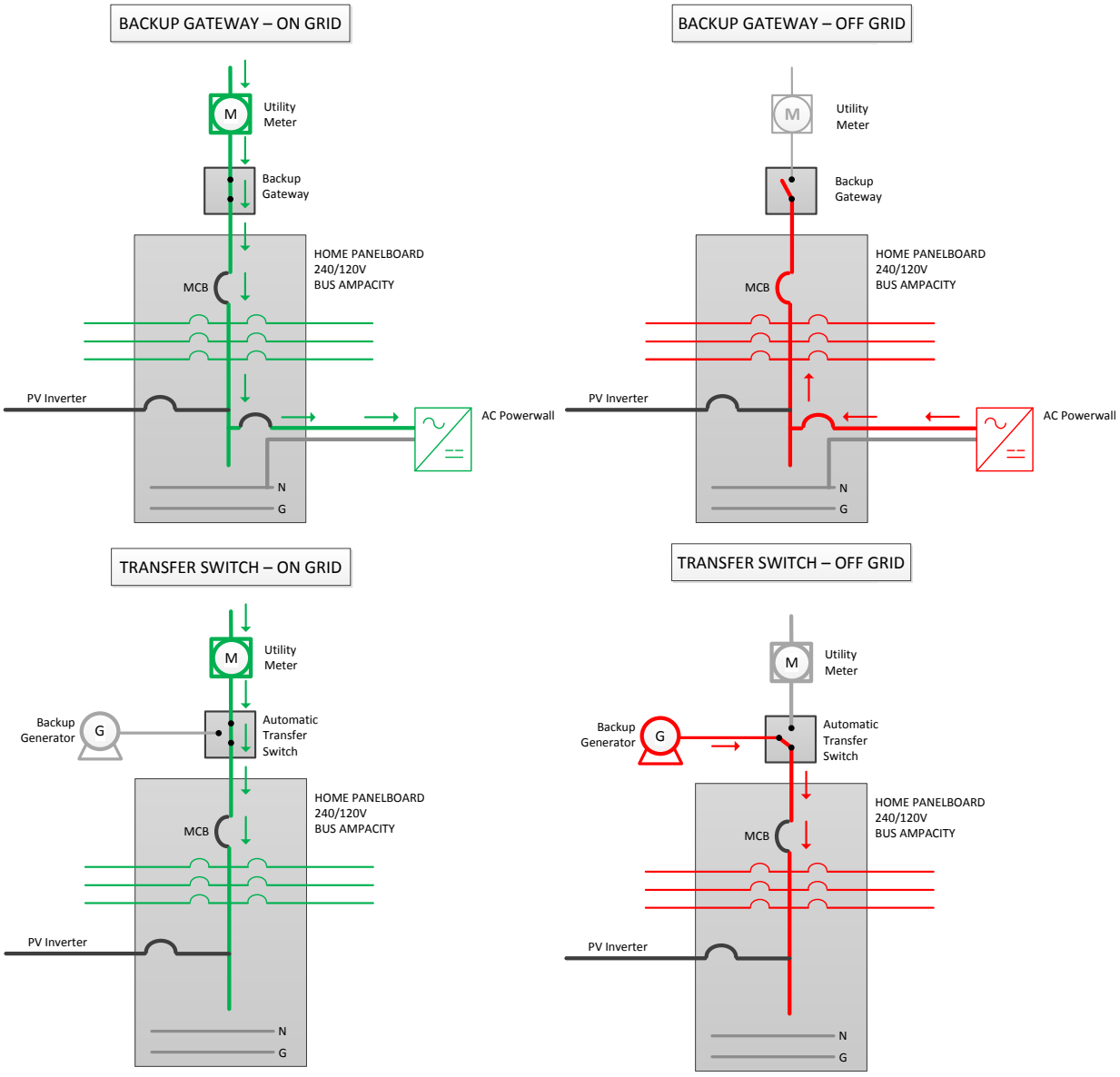
In Backup and Solar Self-Consumption modes, the system is controlled such that energy from the Powerwall is not exported to the grid. The Backup Gateway monitors the whole-home meter and controls the Powerwall such that its discharge is only consumed by onsite load. The Powerwall reduces its discharging or increases its charging to control around the net load at the point of common coupling and ensure the Powerwall does not export. As Solar Self-Consumption is a load-following mode of operation, a short duration inadvertent export from the Powerwall may occur due to a sudden load drop or increase in PV output. The magnitude of export is generally limited to the size of the largest load.

Does the Powerwall operate in parallel with the grid?

If the Powerwall is operating in Backup Mode, it does not operate in parallel with the grid. The Powerwall may charge from the grid, but discharges only when disconnected and isolated from the grid. If the Powerwall is operating in Solar Self-Consumption Mode or Load Shifting Mode, it does operate in parallel, but only as a current source. A short duration inadvertent export event may occur when loads are turned off. Details on these modes can be found in the Modes of Operation section.

Does the Powerwall use a traditional 3-pole automatic transfer switch?

The Powerwall does not use a traditional 3-pole automatic transfer switch. This type of switch would isolate the Powerwall both electrically and mechanically, preventing the Powerwall from charging. In lieu of a 3-pole automatic transfer switch, the Powerwall uses the Backup Gateway. The Backup Gateway is designed to detect any abnormal conditions before the Powerwall. When the Backup Gateway detects an outage, it sends a signal to the Powerwall to prepare for off-grid operation. The Powerwall cannot go into a grid forming mode until the Backup Gateway contactors are open. The figures below highlight the difference between a 3-pole transfer switch and the Backup Gateway.



Do the Powerwall and Backup Gateway use an open or closed transition when backing up load?

The Powerwall and Backup Gateway do not necessarily use an open or closed transition. When an outage is detected by the Backup Gateway, it sends a signal to the Powerwall to prepare for off-grid operation. At the same time, the Backup Gateway also opens its AC contactors, limiting any parallel operation to the approximately 30 ms response time of the contactors. The Powerwall's response resembles a load's response in the sense that the switching on and off of a load has the same impact to the grid as switching the Powerwall on and off. The Powerwall is a current limited source, and does not present the same inertial response as experienced with traditional generators.

How does the Powerwall synchronize with the grid?

The Backup Gateway contains a synchronizer within its controller and uses the synchronizer when transitioning on and off grid. The synchronizer is used to check frequency, voltage, and phase difference before the contactor within the Backup Gateway is opened or closed.

Will the Powerwall be metered separately?

The Powerwall does not have a dedicated meter, but its charge and discharge power and energy are logged by the Backup Gateway.

What happens if Powerwall loses communication with the Backup Gateway?

If the Powerwall and Backup Gateway lose communication with each other, the Powerwall will enter a safe mode. The Powerwall will open the AC contactor within 20 seconds and remain open until communication with the Backup Gateway is resumed. Additionally, the Powerwall's compliance to UL 1741 is not dependent on an Internet connection. The Powerwall will detect when the grid's voltage and frequency are abnormal or when an island occurs.

The Powerwall and Backup Gateway do not rely on an internet connection to communicate. While communication with the Backup Gateway is possible through an internet connection, this path is strictly for monitoring and troubleshooting, and is not related to safety.

Will the Powerwall ever be installed standalone without a behind-the-meter PV system?

Yes, it can be installed without solar and operate in Backup Mode and Load Shifting Mode.

Does the Powerwall contribute fault current?

Yes, for a short duration and similar to PV inverters. Short circuit testing for the Powerwall shows a maximum fault current of less than 32 A RMS for a maximum duration of 4 cycles (67 ms).

Mode Specific Questions

What is the intended use of the Powerwall?

Three of the intended use cases for Powerwall are:

1. Backup
2. Solar Self-Consumption
3. Load Shifting

Can the customer configure the operation of the battery?

Yes. The customer can configure settings through a user app. Configurable settings include mode of operation and backup reserve.

During a grid outage, what prevents the Powerwall from backfeeding the utility grid?

The Backup Gateway is designed to detect the abnormal condition before the Powerwall, enabling a smooth transition. The Powerwall cannot go into a grid forming mode until the Backup Gateway contactors are open. Therefore, it is not physically possible to export when the grid is down. If for some reason the Backup Gateway did not open its contactors, the Powerwall would detect the abnormal conditions and trip offline per UL 1741 and IEEE 1547 requirements, just as a PV inverter would do.

During a grid outage, what happens to excess PV generation when the Powerwall is fully charged?

When off-grid and when excess PV generation cannot be stored by the Powerwall, the PV generation will be curtailed or the PV inverter will trip offline.

How are the Powerwall, PV generation, and home load managed?

The Backup Gateway determines how to charge and discharge the Powerwall based on the intended use case or mode of operation. Excess PV generation not consumed by onsite load is stored in the Powerwall, curtailed, or exported. See the Modes of Operation section for more information.

If a solar paired Powerwall system is in Solar Self-Consumption and the Powerwall's state of energy drops below the backup reserve, what is the charging operation?

Charging from the grid would only follow an abnormal condition, such as a grid outage, and would stop when the Powerwall meets its backup reserve. The Powerwall will attempt to charge from the solar. However, when solar is not present, the Powerwall may charge from the grid.

Will adding a Powerwall to a PV system still meet the requirements for NEM eligibility?

NEM eligibility is determined by jurisdiction; however, the Powerwall can be configured such that it is charged by onsite PV generation during normal operation and, aside from any inadvertent export events, the Powerwall's discharge of energy is consumed onsite. In this configuration, the charging and discharging of energy all occurs behind the meter.

7. Interconnection Guide

When used for Backup, Solar Self-Consumption, or Load Shifting, the Powerwall can increase reliability and resiliency, enable customers to consume renewable generation onsite, and reduce the impact a customer's load profile has on the electric grid. **This reduced impact of distributed storage systems on the grid allows for a more simplified interconnection process than is typical of a standalone solar PV system.**

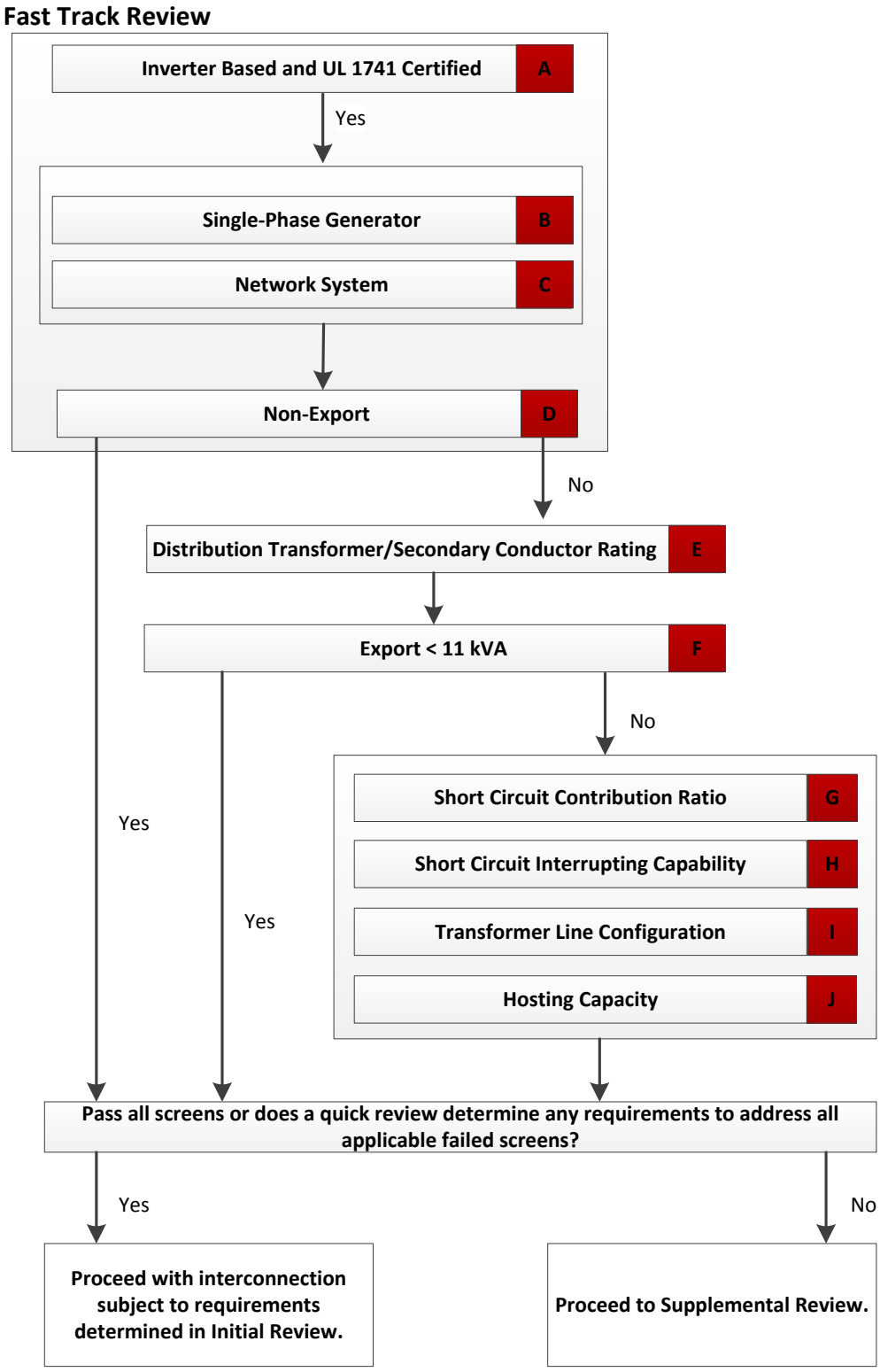
Initial Technical Review Process

A proposed and generalized Initial Technical Review Process that reflects the reduced impact to the grid of storage is described on the following pages. This process is informed by various mature utility interconnection processes focused on distributed solar PV systems (especially Net Energy Metered processes), but tailored to reflect the technical differences of distributed storage systems. The process is applicable to stand-alone energy storage system deployments as well as storage plus solar PV deployments.

As the Powerwall is a resource that can be configured and dynamically controlled, interconnection screens should be based on the system's operating characteristics rather than the nameplate ratings of the Powerwall and PV inverter. Therefore, these storage system operating characteristics can be modified to avoid grid upgrades that might otherwise be triggered if these systems were assessed solely on nameplate capacity. If interconnection screens are failed such that Supplemental Review is required, the storage system operating characteristics should also be considered in lieu of nameplate capacities in the Supplemental Review.

The following diagram overviews the proposed Initial Technical Review Process.

Initial Technical Review Process



Screen A: Is the equipment inverter based and UL 1741 certified?

This is used as the introductory screen to simplify the process that would otherwise be more complicated by rotating machine-based generation. Equipment that fails this screen should follow a different process. UL 1741 certified inverters have had their protective and anti-islanding functions tested. Inverters are also current limited. Their starting voltage drop and fault current contribution are significantly less than rotating machine-based generation.

The Powerwall is inverter based and UL 1741 certified. Tesla will also ensure that any PV inverter used is UL 1741 certified as well.

Screen B: Does the single-phase equipment cause unacceptable imbalance?

This screen ensures that a 120 V connected generator does not cause unacceptable imbalance across the two 120 V phases.

In most applications, the Powerwall and PV inverter used will be connected at 240 V and will not contribute to imbalance on the two 120 V phases.

Screen C: Is the equipment interconnecting to a networked secondary system?

This screen addresses whether or not the system is interconnecting to a networked secondary system, as these systems are designed and operated with network protectors.

If the Powerwall and PV inverter are interconnecting to a networked secondary system, additional review may be required to ensure reliable operation of the networked secondary system.

Screen D: Will power be exported across the point of common coupling (PCC)?

Systems passing this screen bypass the remainder of the initial technical review screens. Their impact on the electric grid is minimal as the grid is still operating within its traditional design parameters. Systems that only inadvertently export energy should be treated as non-export. Thermal overload of distribution transformers or secondary conductors from non-export systems is not expected as any inadvertent export is small in magnitude and short in duration. Inadvertent export is also load following and generally non-coincident with the inadvertent export of other systems.

Depending on the application, the Powerwall and PV inverter may be configured to not export energy across the PCC.

Screen E: Is the distribution transformer or secondary conductor rating exceeded?

This screen addresses whether or not the export of energy will overload the distribution transformer or secondary conductor.

There may be situations in which the export of energy triggers a transformer or secondary conductor upgrade. When evaluating possible mitigations, modifying the operating characteristics of the system should also be considered as it may be more economical to curtail or charge from this excess energy.

Screen F: Does the installation export less than 11 kVA across the PCC?

This screen addresses whether or not the system can bypass short circuit, line configuration, and penetration based screens.

This screen should be based on the operating characteristics of the system. Systems passing this screen will have a minimal impact on fault current levels, potential overvoltages from loss of system neutral grounding, and hosting capacity.

Screen G: Is the short circuit contribution ratio within acceptable limits?

This screen addresses whether the installation will impact the transmission and distribution system's protection schemes. When measured at the primary side of a distribution transformer serving the installation, the sum of the short circuit contribution ratios of all installations connected to the distribution transformer should be less than or equal to 10%. If this screen is passed, significant impacts are not expected.

Screen H: Is the short circuit interrupting capability exceeded?

This screen addresses whether the installation will cause any equipment overstress on the transmission and distribution system. In aggregate with other installations, the installation should not cause any protective devices to exceed 87.5% of their interrupting capability. If this screen is passed, equipment overstress is not expected.

Screen I: Is the line configuration acceptable?

This screen addresses whether there is a possibility of overvoltages due to a loss of system neutral grounding.

The Powerwall and PV inverter are typically installed in single phase locations. If connected line-to-neutral, they will not cause overvoltage from loss of system neutral grounding. If connected line-to-line, overvoltages would only be possible if other loads were connected line-to-ground, and would still be unlikely under those conditions. As an additional screen in this scenario, some utilities use 10% of peak load as a penetration threshold. If a system fails these screens, additional analysis should be performed before requiring upgrades.

Screen J: Does the export of power exceed hosting capacity thresholds?

This screen addresses whether the export of power from the installation violates any hosting capacity thresholds. In order to accommodate this screen, a hosting capacity analysis is recommended to determine how much exported energy can be hosted by the electric grid.

Quick Review: Does a quick review determine any requirements to address all applicable failed screens?

This screen addresses whether any simple adjustments can be made to the storage and PV system or grid to pass a previously failed screen. For example, the operating characteristics of the installation could be easily modified to pass Screen E or J. Operating characteristics may also be modified to avoid an upgrade that may otherwise be triggered. Distribution system line equipment settings may also be adjustable to accommodate the system. The intent of this screen is to avoid the Supplemental Review process and system upgrades if small adjustments can be made.

Fast Track Review for Non-Export Storage Systems: Notification Only

In this proposed Initial Technical Review Process, non-export storage systems passing screens A through D qualify for the simplest review process, where a notification-based approach can be used in lieu of an interconnection application. This notification-based approach would appropriately streamline the interconnection process and facilitate deployment of non-export distributed storage systems.

The impact a non-export system has on the grid is de minimis when compared to traditional exporting systems. Operating requirements should be defined to ensure this reduced impact, such as requirements on the amount of energy inadvertently exported. As has been done in Hawaii[2], California[3,4,5], and Colorado[6], it is appropriate to define within interconnection tariffs the requirements of a non-export system. Such definition would allow vendors to certify against such requirements, thus enabling them to utilize a notification-based approach to the deployment of distributed storage systems.

Sample requirements based on California Rule 21[3,4,5] include:

- The Generating Facility must utilize only UL 1741 or UL 1741 SA certified inverters.
- The Generating Facility must monitor that total energy export is maintained to be no more than the Generating Facility's Gross Nameplate Rating multiplied by 0.1 hours per day over a rolling 30-day period (e.g., for a 100 kVA gross nameplate Generating Facility, the maximum energy allowed to be exported for a 30-day period is 300 kWh).
- The Generating Facility must disconnect from the Distribution System, cease to energize the Distribution System, or halt energy production within two seconds after the period of continuous export exceeds 30 seconds.
- Failure of the control or inverter system for more than 30 seconds, resulting from loss of control signal, loss of control power, or a single component failure or related control sensing of the control circuitry, must result in the Generating Facility entering a safe operating mode where inadvertent export events will not occur.

[2] Rule No. 22. Hawaiian Electric Company (HECO), 2017.
[3] Electric Rule No. 21, Pacific Gas & Electric Company (PG&E), 2017.
[4] Rule 21, Southern California Edison (SCE), 2017.
[5] Rule 21, San Diego Gas & Electric Company (SDG&E), 2017.
[6] "Guidance No. 1 for the Interconnection of Electric Storage as Stand-Alone Sources, Parallel Operation for Customers without Generation, and in Parallel with Self-Generation", Xcel Energy, 2017.

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