Microgrid Design Guide

Revision 1.3

PRODUCT SPECIFICATIONS

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Reference Documents

This section summarizes microgrid-specific and key microgrid-related documents about using Tesla Energy products in microgrids throughout different phases of implementation, and contains links to documents referenced throughout this guide. Visit the Partner Portal for the full library of reference material, including additional documentation specific to Megapack and Powerpack.

Table 1. Reference Documents by Phase

Document	Offering	Contracting	Design	Installation	Commissioning	Operation
Microgrid Primer - *available via Tesla contact*	✓					
Microgrid Design Guide (this document) – *https://partners.tesla.com/home/en-US/content/download/Microgrid_Design_Guide.pdf*			✓			
Tesla Industrial Energy Approved Vendors List – *https://partners.tesla.com/home/en-US/content/download/Tesla_IndustrialEnergy_Approved_Vendor_List.pdf*			✓			
Application Note: Microgrid Fault Current and Protection – *https://partners.tesla.com/home/en-US/content/download/Tesla_Powerpack_ApplicationNote_MicrogridFaultCurrentandProtection.pdf*			✓			
Microgrid example SLDs - *available via Tesla contact*			✓			
Microgrid example network schematic - *available via Tesla contact*			✓			
SCADA Design Manual – *https://partners.tesla.com/home/en-US/content/download/SCADA_Design_Manual.pdf*			✓			
Scope of Works - *available via Tesla contact*		✓				
Islanding Controller Specification – *https://partners.tesla.com/home/en-US/content/download/Islanding_Controller_Specification.pdf*				✓	✓	
Customer Breaker Status Override Request Form – *https://partners.tesla.com/home/en-US/content/download/Customer_Breaker_Status_Override_Request_Form.pdf*		✓				
Using the SEL-700G With Tesla Products – *https://partners.tesla.com/home/en-US/content/download/Using_the_SEL-700G_With_Tesla_Products.pdf*				✓		
Solar Inverter Configuration Specification – *https://partners.tesla.com/home/en-US/content/download/Tesla_Solar_Inverter_Configuration_Specification.pdf*				✓	✓	

Document	Offering	Contracting	Design	Installation	Commissioning	Operation
Generator Controller Configuration Specification – *https://partners.tesla.com/home/en-US/content/download/Tesla_GeneratorController_Specification_Configuration.pdf*				✓	✓	
Configuration Specification: Using I/O Devices with Tesla Products – *https://partners.tesla.com/home/en-US/content/download/Configuration_Specification_Using_IO_Devices_with_Tesla_Products.pdf*				✓	✓	
Megapack Deployment Overview – *https://partners.tesla.com/home/en-us/content/download/megapack_deployment_overview.pdf*					✓	
Microgrid Controller Owner's Manual (Microgrid Operations Manual) – *https://partners.tesla.com/home/en-US/content/download/MicrogridController_Manual_Owners.pdf*						✓
Powerhub User Manual – *https://partners.tesla.com/home/en-US/content/download/Powerhub_User_Manual.pdf*						✓
Microgrid Quick Start Guide – *coming soon*						✓
Tesla Energy Controls and Communications Manual – *https://partners.tesla.com/home/en-US/content/download/Tesla_Energy_Controls_and_Communications_Manual.pdf*			✓			✓

1 Introduction

Countries, islands, and facilities around the world are embarking on the journey to 100% sustainable, reliable energy. Tesla's mission is to enable and accelerate that transition.

Grids or sites producing electricity from diesel generators and other high operating cost sources are well positioned to transition. Tesla has mapped out a clear plan to transition from making basic reductions in diesel or other fossil fuel consumption, to enabling diesel-off operation for short periods of time, to ultimately achieving 100% renewable operation.

Although the sustainable energy transition is a global mission, different locations and grids have diverse near-term and long-term needs. This guide provides the site designer, engineer, or other interested party the information necessary to design optimal microgrid functionality using Tesla and Tesla-approved products. This includes requirements that are necessary to work with Tesla products, recommendations for different microgrids scenarios, and various best practices worth highlighting.

Customers can expect requirements to be enforced by Tesla in the process of supplying and deploying microgrids, while recommendations and guidelines are for consideration and at the discretion of the microgrid designer.

1.1 Microgrid Goals

Despite diverse grid needs, microgrids typically address these common goals:

- **Sustainability:** Increase renewables penetration and maximize the energy demand supplied by clean sources.
    - Integrate some renewables by reducing operating levels of existing generation (20-40%).
    - Achieve high annual renewable penetration (50-90%) by switching off diesel generation and using as backup source only.
    - Achieve 100% annual renewable penetration through a highly diverse mix of renewables and storage assets.
- **Cost**: Minimize levelized cost-of-energy (LCOE).
    - Reduce operating costs by minimizing energy required from generators and maximizing efficiency when running.
    - Design financing structures for renewable and storage capex investments to enable secure long-term energy prices.
- **Reliability:** Improve service for electricity users.
    - System Average Interruption Frequency Index (SAIFI).
    - System Average Interruption Duration Index (SAIDI).
- **Quality**: Maximize quality of service, defined as:
    - Voltage sag or swell.
    - Voltage and frequency stability (flicker, oscillation).
    - Protections including generation trip settings, under-frequency load shedding, fault selectivity and energy injection.
- **Modularity:** Meet load profile and load growth.

Tesla's microgrid product objectives aim to achieve these goals, but will prioritize safety and maintaining power to loads ahead of secondary goals such as cost and power quality.

1.2 Glossary of Key Terms

Terminology, abbreviations, and acronyms in this guide are used as defined below.

Table 2. Glossary of Key Terms

Term	Definition
Active	Connected to the microgrid and able to produce power. For grid-forming assets, *active* means the breaker is closed, connected to the bus and ready to produce power according to the droop curve. For solar, *active* means producing power according to irradiance and the max power command.
Approved Vendor List (AVL)	The list of non-Tesla hardware makes and models that have been tested and validated to integrate with Tesla products and published via the Tesla Energy Approved Vendors List on the Partner Portal.
Asset	The equipment in a microgrid that can produce and/or consume power.
Automatic frequency control (AFC)	The control system (usually consisting of PID - proportional-integral-derivative - elements) that ensures system frequency returns to within the specified band after disturbances.
Automatic generation control (AGC)	A major control function to track load variations while maintaining system frequency, net tie-line interchanges, and optimal generation levels close to scheduled (or specified) values.
Automatic mode	An asset control mode that is responsive to commands sent from the Microgrid Controller. During normal operation, generators will remain in automatic mode.
Automatic Transfer Switch (ATS)	An electrical switch that automatically transfers loads between two sources when it detects a loss or gain of power on one source.
Balance of plant (BOP)	The supporting and auxiliary components of a power system.
BESS	Battery energy storage system, such as Tesla Powerpack or Tesla Megapack. Also referred to in this document as "battery system."
Battery Management System (BMS)	The hardware and software required to manage a battery system, including thermal regulation, protection and optimization.
Battery system	BESS: Tesla Powerpack or Tesla Megapack, as used within this document.
Bill of materials (BOM)	Typically covering all equipment to be supplied and installed as part of a project.
Blackstart	Exciting a de-energized AC bus or power system.
Curtail	Typically referred to as an intentional reduction of power output from an energy source through communication- or droop-based means.
Droop	A control method that increases or decreases power output in response to a decrease or increase in frequency or voltage. Frequency droop relates the real power output of each asset to frequency, allowing assets to autonomously share load based on net real load and each source's droop settings. Voltage droop similarly relates the reactive power output of each source to voltage.
Energy Remaining (Wh)	This is the energy remaining if a battery system is operated at nominal temperature (25°C). This value updates based on faulted battery units.

Term	Definition
Faulted	Reporting a fault, identified by the Microgrid Controller as *faulted*, or not communicating with the Microgrid Controller.
Full Pack Energy (Wh)	This value indicates the available energy of a battery system when fully charged and at nominal temperature (25°C). This value updates based on faulted battery units and includes the retention of energy over time.
Genset / Generator	A grid-forming source that is powered by burning fuel. Generators are integrated assemblies that include a fuel reservoir/tank, engine, alternator, and generator controller. Generators have an incremental cost of generation based on the cost of fuel.
Grid disconnect	Also referred to as the utility breaker or grid breaker. A controllable contactor or circuit breaker that connects the microgrid to the utility grid, and is controlled by an islanding controller.
Grid-following (PQ)	The asset requires an external voltage and frequency source to operate and goes into a faulted state automatically when external voltage is lost. The inverter alters the output current waveform and amplitude to provide the required active and reactive power. Solar and on-grid batteries are grid-following assets.
Grid-forming (VF)	The asset can stand alone and support loads as a voltage and frequency source on the microgrid. Generators and islanded batteries are grid-forming assets. In Tesla microgrid systems, VF real and reactive power outputs are governed by asset droop curves.
Human Machine Interface (HMI)	Analogous to user interface (UI).
Inrush current	Line starting (closing in) of transformers, motors.
Islanding / islanded	Islanded operation refers to the operation of a microgrid when off-grid and operating independently of the utility grid, and for BESS, specifically refers to grid-forming operation. Islanding systems are typically systems which are connected to a utility grid, but have the ability to disconnect and operate independently -- in other words, to meet the definition of a microgrid.
Islanding controller	A controller which monitors the grid and controls the state of the islanding breaker in order to connect the microgrid to a larger grid or isolate it. The islanding controller is an external relay, not part of the Tesla Site Controller.
Manual mode	An asset control mode that ignores commands from the Microgrid Controller but responds to commands sent via the asset's physical HMI. A generator in manual mode cannot be started by the Microgrid Controller.
Microgrid Controller (MGC)	A real-time control system that coordinates microgrid assets to supply power to loads. Tesla's Microgrid Controller is a rules-based, real-time controller within the Tesla Site Controller that manages spinning reserve and least-cost dispatch for the microgrid. The Microgrid Controller works alongside Microgrid Opticaster when Opticaster is present.
Microgrid Opticaster	Tesla's variant of Tesla Opticaster that runs as part of the Microgrid Controller to provide least-cost and other microgrid-specific features.
Microgrid/Minigrid	Tesla uses microgrid is as a catch-all term to avoid confusion between microgrid/minigrid. In other words, it represents both off-grid electrification and grid-tied islanding systems with no size boundary per the below definition: "Electricity distribution systems containing loads and distributed energy resources (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded." - CIGRE WG C6.21

Term	Definition
Missing in Action (MIA)	Loss of contact with a device for unknown reasons, thereby requiring the assumption that this device is not operating.
Modbus TCP	Transmission of information using Modbus and TCP protocols.
Opticaster	Tesla's forecasting and optimization software algorithm that runs on the Tesla Site Controller in certain control modes.
Out of service	Identified by user as out of service, or identified by the Microgrid Controller as being in *manual*. When an asset is out of service, it will not be dispatched by the Microgrid Controller.
Overload	Load exceeds generation capacity, detectable through component overcurrent or sustained microgrid low-voltage measurements.
Parallelling	Connecting two voltage-forming sources in parallel. Stability and load-sharing are of top concerns.
Real-Time Automation Controller (RTAC)	A Schweitzer Engineering Laboratories (SEL) hardware and software platform designed for use in industrial control and automation systems.
Schweitzer Engineering Laboratories (SEL)	A company that manufactures and provides products and services for protection, automation, and control systems.
Solar / solar plant	An asset that produces intermittent power from solar photovoltaic panels connected to an inverter. Solar power output can be limited but otherwise the asset’s power availability is a function of the solar irradiance. Solar typically has no incremental cost of generation.
Source	An asset that can generate power in either grid-following or grid-forming mode. Also known as distributed energy resource (DER).
Spinning reserve	Excess (or buffer) generation beyond instantaneous load to cover load spikes or steps.
Standby	Not producing power but ready to be placed in *active* by the Microgrid Controller. For parelleling generators, *standby* means the breaker is open.
State of charge/ energy (SOC/SOE)	The amount of energy left in a battery system measured as a percentage of energy available when fully charged. Tesla battery systems measure this as *energy remaining divided by the full pack energy*, in units of percent.
Supervisory control and data acquisition (SCADA)	Hardware and software required to control and monitor an industrial system in a safe, reliable and secure manner. This includes the Tesla Site Controller, Microgrid Controller, islanding controller, and associated UIs.
Tesla Site Controller (TSC)	An all-in-one controller deployed with all Tesla Industrial battery energy storage systems containing Tesla battery controls as well as the Microgrid Controller and Opticaster.
Uninterruptible power supply (UPS)	A type of continual power system that can supply emergency power to loads in the event that the main power supply fails, and do so seamlessly such that the loads experience no outage.
User Interface (UI)	The interface through which the user interacts (commands or monitors) with the system. Analogous to HMI.

1.3 Working With Tesla

To ensure successful design, procurement, deployment, and operation of microgrid projects, it is important that customers and Tesla are aligned throughout the process. Microgrid projects follow the same overall process as all Tesla industrial storage projects, but with some microgrid-specific touchpoints to ensure Tesla's products will work as intended within the customer's overall microgrid project.

The chart below provides a conceptual summary of this process, including the documents that are required and form the basis of project alignment at each stage. Any documents or templates provided by Tesla are available on the Tesla Partner Portal (see *Reference Documents on page 3*). If you are unsure of where to find documents or the expectations at each stage, reach out to your Tesla contact for assistance.

Table 3. Tesla Microgrid Implementation Phases

Analysis	Technical Review	Contracting	Design	Construction	Commissioning	Service
Phase Description						
The customer defines project goals and applications to arrive at conceptual design, system sizing, and project scope. In certain limited cases, Tesla can provide sizing optimization support to form clear business case assessments.	The Tesla Sales Engineer will conduct a preliminary review of draft design information with the customer to ensure the proposed project conforms to standard design requirements and all parties are aligned prior to contracting.	The customer and Tesla align and contract for the agreed microgrid scope.	The customer completes detailed design of the project with support of Tesla. The Tesla Project Engineer reviews and approves all the critical documents to ensure successful deployment of the project.	After approval of detailed design documents by the Tesla Project Engineer, the site can be constructed, and the Tesla system can be installed in accordance with Tesla guidelines.	Once all project equipment is installed and pre-commissioning for all individual assets is completed by the customer, Tesla supports commissioning of the BESS and overall microgrid controls if applicable.	Depending on the region and O&M agreement for the project, Tesla or a partner will provide regular preventative maintenance for the Tesla scope, and support system operation with 24/7 monitoring and service response.
Required Deliverables Per Phase						
Template provided by Tesla and completed by customer: *Modeling Checklist* (if Tesla support to be provided)	Template provided by Tesla and completed by customer: *Site Configuration Checklist* Template provided by Tesla and reviewed by customer: *Scope of Works*	Documents provided by Tesla and reviewed by customer: *Sales Agreement* *Software Services Agreement (if applicable)* *Site Configuration Schedule*	Template provided by Tesla and completed by customer: *Design Checklist* Final documents provided by customer: *Single Line Diagram*	Template provided by Tesla and completed by customer: *Battery system construction checklist* *Applicable Acceptance checklists: Battery system, Islanding Controller, Solar PV, Generator*	Tesla issues a commissioning report and identifies any remaining snag items. The customer is introduced to Tesla's operations and service team.	

Analysis	Technical Review	Contracting	Design	Construction	Commissioning	Service
	Preliminary documents provided by customer: *Single Line Diagram* *Networking schematic* *Site layout*	*Scope of Works Schedule*	*Networking diagram* *Civil works layout*			

2 Standard Microgrid Archetypes

Tesla microgrids are defined as including one or more of the following Tesla product components:

- Tesla battery energy storage system (BESS - Powerpack or Megapack) required to operate in grid-forming mode (see *Grid-Forming BESS Overview on page 14*)
- Islanding controller used for on/off-grid transitions (see *Islanding Controller Overview on page 14*)
- Tesla Microgrid Controller used to control approved non-Tesla equipment assets such as solar PV and generators (see *Microgrid Controller Overview on page 15*)

All Tesla microgrids have at least one of these components. The majority have at least two, and many have all three. The following categories are defined according to these product combinations:

Table 4. Microgrid Types and Tesla Scope

Type	Summary	Tesla Scope
Backup BESS	BESS powers loads directly No other assets (generation sources) operating in parallel	BESS + Islanding Controller
Off-Grid Microgrid	BESS + solar + generator(s) No utility grid connection All assets operate in parallel	BESS + Microgrid Controller
Grid-Tied Microgrid	BESS + solar [+ generator(s)] + grid All assets operate in parallel when off-grid; BESS + solar operate together when on-grid Generator(s) may or may not be present	BESS + Islanding Controller + Microgrid Controller

Furthermore, a **standard microgrid** is one which fully meets Tesla's product requirements and design guidelines as laid out in this document, and does not require bespoke customization or product feature development. Designing a standard microgrid ensures all products can operate as intended for highest reliability and lower cost operation, and enables rapid project deployment.

Due to the potential complexity of microgrids, many deviations from these guidelines can be imagined. Electrical systems should, first and foremost, be designed according to high engineering standards and local regulations. Any deviations from Tesla's standard definition need to be reviewed during the technical review process (see *Working With Tesla on page 9*) prior to contracting. Depending on the deviation and associated risks, some deviations may be accepted if associated consequences are acknowledged as customer scope and Tesla will not be liable for any adverse outcomes, while others may block contracting if the risk is not acceptable.

As Tesla products evolve and new features are added, the definition of standard will be expanded to maximize the depth and breadth of microgrid projects that can be deployed with streamlined product configuration and operation. The below table summarizes the current high-level definition of standard linked to each Tesla product's scope, and more details are covered throughout this document:

Table 5. Standard Tesla Microgrid Guidelines

Tesla Scope	Guidelines	
BESS	Battery mode	VF (grid-forming) when off-grid and PQ (grid-following) when on-grid
	Inverter settings	Inverter voltage at 400, 415, or 480, and no customized settings required
	Equipment	BESS meter installed
Islanding Controller	Sizing (normal operation)	[BESS kW/kVA] > [peak site load kW/kVA]
	Equipment	Tesla Islanding Controller Site Meter installed according to on-grid control need
	Topology	Single grid feeder
	POI voltage	POI is at low voltage
Microgrid Controller	Sizing (normal operation)	[BESS kW/kVA] > [peak site load kW/kVA] OR [BESS + each generator kW/kVA] > [peak site load kW/kVA]
	Blackstart	[BESS KW/kVA] > [blackstart load kW/kVA] AND [each generator kW/kVA] > [blackstart load kW/kVA]
	Inrush current	[BESS kVA] > [peak site load kVA] + [inrush kVA]
	Equipment	All devices (solar, generator controllers, etc) fully validated on Tesla AVL Site Meter highly recommended for grid-tied. Solar meter recommended. 3rd party monitoring is standard, but 3rd party control is not
	Control features	All required features are released and described in the *Microgrid Controller Owner's Manual*
	Topology	Site topology follows Tesla's recommended architecture with no deviations that have impact on controls or operations (single bus, all assets in parallel, no ampacity limits).
	Distribution voltage	LV distribution network at 400, 415, or 480 MV/HV distribution network is standard if POI voltage and Inrush current conditions met

Examples of project-specific considerations that could differ from this include:

- Integration with different sources (e.g., wind turbines, hydro) or equipment not listed on the *Tesla Industrial Energy Approved Vendor List* (AVL).
- Site topology requiring specific considerations for control scheme:

- The site cannot be treated as a single bus with all equipment connected in parallel
- The grid requires sectionalized operation
- Transmission constraints are present and need to be accounted for in controls
- Locational voltage control is needed

- The sequence of operations requires other control features not yet developed or significantly deviating from the current control philosophy
- The BESS needs to be run in PQ mode while the site is off-grid
- Tesla controls will compete with another controller for commands (e.g., existing AGC/AFC)
- Detailed guidance required for setting inertia coefficient and/or frequency droop (transient stability study)

Tesla has also supported and delivered advanced projects that need many of these or other changes to standard product scope; in general, this means that project-specific consultation, scoping, and pricing will be needed before the project can be contracted and deployed, to ensure product/project fit. This document will cover some considerations across project types but cannot cover all possibilities. Engage your Tesla contacts if your project differs significantly from Tesla's standard microgrid archetypes.

2.1 Grid-Forming BESS Overview

During islanded operation, the Tesla BESS operates in VF mode and does not use the real and reactive power modes commonly used when on-grid in PQ mode. The system runs in droop. Nominal frequency and voltage setpoints, together with power-frequency and power-voltage slopes, are used to determine the active and reactive power outputs.

In addition, the following considerations are specific to BESS operation in VF:

- In addition to the droop parameters, system behavior (especially on/off-grid transition behavior) is governed according to predefined islanding modes.
- Blackstart is enabled and can be configured to occur automatically or commanded.
- Low SOE behavior is defined by configuring three special thresholds.
- SOE frequency shift can be configured if desired.
- A DC Balancer must be supplied in systems using the Powerstage-based inverter architecture.
- The Tesla Microgrid Controller can be used to parallel the BESS with other generation sources in the microgrid.

These concepts are explained in more detail in *Battery Energy Storage System on page 28*.

2.2 Islanding Controller Overview

An islanding controller is a device that monitors the grid status and controls the state of the grid disconnect in order to connect the microgrid to a larger grid or isolate it. The grid disconnect is located at the utility grid point-of-interconnection (POI). The islanding controller is an external relay, not part of the Tesla Site Controller.

> **NOTE:** Currently the only device supported by Tesla for use as the islanding controller is the Schweitzer Engineering Laboratories SEL-700G+ relay.

An islanding controller is required for any backup BESS or grid-tied microgrid – in other words, for any islanding system that will transition between on-grid (connected to the utility grid) and off-grid (islanded from the utility grid). It is responsible for detecting grid outages, isolating the microgrid to prevent back-feeding during islanded operation, coordinating with the Tesla Site Controller to make sure the BESS enters VF mode when islanded, and enabling the Microgrid Controller when applicable.

Customers can select *normally on-grid* or *normally off-grid* operation for their grid-tied microgrid:

- Most grid-tied microgrids operate as *normally on-grid*. In this case, the microgrid will follow the utility grid when it is available and within specifications, and island when an outage is detected or it is commanded to do so by the operator.
- A *normally off-grid* system will operate off-grid unless a failure causes a microgrid blackout and the utility grid is available, in which case the system will transition on-grid. The islanding controller will intermittently check if the fault is cleared before transitioning off-grid again.

Customers who do not want to use Tesla's standard islanding controller and associated sequence of operations can choose to sign the *Customer Breaker Status Override Request Form* and take islanding within their own scope to do customer-controlled islanding transitions.

Islanding transitions and associated concepts are explained in more detail in *Islanding on page 33*.

2.3 Microgrid Controller Overview

A microgrid controller is a real-time control system that coordinates microgrid assets to supply power to loads. The Tesla Microgrid Controller is a Tesla software product that can be enabled in the Tesla Site Controller in order to operate the entire microgrid, beyond the Tesla battery system. It runs when the microgrid is off-grid, and like the Tesla Site Controller generally, uses a standardized, rigorously tested codebase deployed across Tesla's fleet so that all sites benefit from bug fixes, improvements and new features.

> **NOTE:** During on-grid operation, the battery system will run according to the configured on-grid control modes in the Tesla Site Controller. See more information in the *Tesla Energy Controls and Communications Manual*.

The Tesla Microgrid Controller is a rules-based, real-time controller within the Tesla Site Controller. It is required if the customer desires Tesla to control and curtail solar, start/stop and manage dispatch of generators, or generally control and coordinate any microgrid assets outside of the Tesla battery system and islanding transitions (which are done using the islanding controller). Key functions of the Microgrid Controller include:

- Controlling all microgrid assets (battery system, solar, generators, controllable loads) when off-grid to balance power and energy while minimizing costs:
  - Curtailing solar on over-generation when the power cannot be absorbed by the loads or battery system.
  - Starting generators when the battery system hits low SOE or additional power is required to meet loads, and stopping generators once they are no longer needed.
- Managing spinning reserve by keeping sufficient upwards and downwards reserves of power available according to the maximum expected load steps and instantaneous renewables generation.
- Maintaining nominal frequency of the microgrid through open-loop frequency control.

Microgrid Opticaster is a version of Tesla's Opticaster forecasting and optimization engine that can be enabled to work with the Microgrid Controller and provide advanced features such as:

- Improved least-cost dispatch by using day-ahead forecasts and efficiency curves to optimize generator dispatch and loading.
- Flexible Quiet Hours that leverage the forecasting insights to ensure the battery system is pre-charged and generators are turned off during the selected time periods.

Examples in which a Microgrid Controller might not be required include:

- Back-up only: If only the battery system will power loads when islanded, and no other generation sources will be operating in parallel.
- SOE frequency shifting: If the customer elects to use battery system SOE frequency shifting only to curtail solar and does not need to control other microgrid assets.
- ATS generators: If the only generator(s) present are isolated from the battery system behind an ATS, and direct control of other microgrid assets is not needed.
- Third-party microgrid controller: Customers can also choose to use a third-party microgrid controller to operate the Tesla battery system in coordination with other microgrid assets. The communications interfaces available are detailed in the *Tesla Energy Controls and Communications Manual*.

In the above cases in which Tesla is not providing the Microgrid Controller scope, Tesla is not in any way responsible for operation of the overall microgrid nor the battery system interactions with any non-Tesla microgrid assets. This will be reflected in the *Scope of Works* for the project.

2.4 User Interfaces

In addition to the Tesla product components defined above, Tesla provides several user interface options in which to monitor system performance. All industrial battery system customers have access to Powerhub Cloud and the Tesla mobile app. Customers who purchase the Tesla Microgrid Controller also receive expanded Powerhub Cloud capabilities that allow them to monitor all assets integrated with the Tesla Site Controller, as well as Powerhub Local, which allows basic real-time monitoring by LAN when needed. The following features are included:

- Powerhub Cloud
  - Real-time source-level power flows
  - Site and fleet-level metrics for monitoring portfolio health
  - Alerts reporting with active and historical alerts including severity and steps-to-resolve
  - Configurable data trending, exploration and download of asset- and equipment-level metrics across battery, solar inverters and generators
  - Remote telemetry data backup
- Powerhub Local
  - Real-time source-level power flows
  - Breaker controls
  - Active site-level alerts

For more information, see the *Powerhub User Manual*.

For customers who wish to develop their own UIs or integrate with other SCADA systems, monitoring interfaces are available as detailed in the *Tesla Energy Controls and Communications Manual*.

3 Electrical Architecture

A standard microgrid has all assets and loads electrically interconnected to one another as though they are connected to a single bus. The exception is a generator connected behind an ATS, which can be implemented in certain circumstances as covered in *Generators on page 49*.

The power flow between assets and load must not be constrained by ampacity limits in the switchgear or distribution network. For example, a transformer connecting a battery system to a bus with solar and load must be large enough to support the peak charging current from solar to battery and the peak discharging current from the battery system to the load. If this is not the case, the microgrid is considered non-standard and this deviation must be flagged to your Tesla engineering contact.

Designers should also consider of out-of-sync breaker closure risks and implement solutions to mitigate this risk. For sites using Tesla's standard islanding controller configuration, this risk for the grid breaker will be managed by the islanding controller. However, this risk can occur in other forms – for example, by breakers tripping between the main microgrid bus and a generation source. Implementing a simple intertie to trip the source when relevant breaker trips is a common solution and should be considered. Any major out-of-sync closure risk should be flagged and called out during the design review process.

3.1 Common Architectures

Below are conceptual diagrams for a set of common standard electrical architectures:

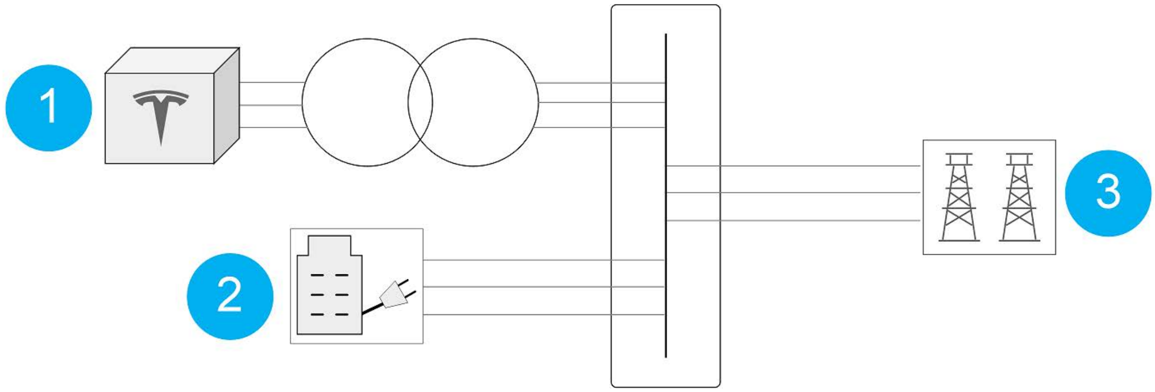
- *Back-Up BESS Only on page 18*
- *Grid-Tied Microgrid With PV on page 18*
- *Grid-Tied Microgrid With Solar and Parallel Generator on page 19*
- *Grid-Tied Microgrid With Solar and ATS Generator on page 20*
- *Off-Grid Microgrid With Solar and Parallel Generator on page 21*

These diagrams show the general connection principle of the microgrid assets. How these assets are connected to the common bus bar (directly or via a transformer) is specific to the project design, as are the required sources. A source is defined as a single battery inverter (one Powerpack inverter block or one Megapack) or an individual generator. The following should be considered:

- All off-grid microgrids should have more than one grid-forming source. Microgrids with only one source represent a risk for operational reliability. This also applies to weak-grid islanding sites which will operate off-grid on a frequent basis – in other words, islanding once a day or more.
- All sites without a reliable utility grid or a 3-phase paralleling generator should ensure a reliable jumpstart source to provide external 24 V DC is available on site.
- Even if a paralleling 3-phase generator is not part of the microgrid design, it is strongly recommended to have a temporary one available for commissioning in all cases. Not having one available will significantly complicate and slow down the commissioning process.

Regardless of the specific microgrid configuration, designers with a grid connection, solar, or generators can refer to *Islanding on page 33*, *Solar on page 44*, or *Generators on page 49* respectively to explore how to design their microgrid with those assets.

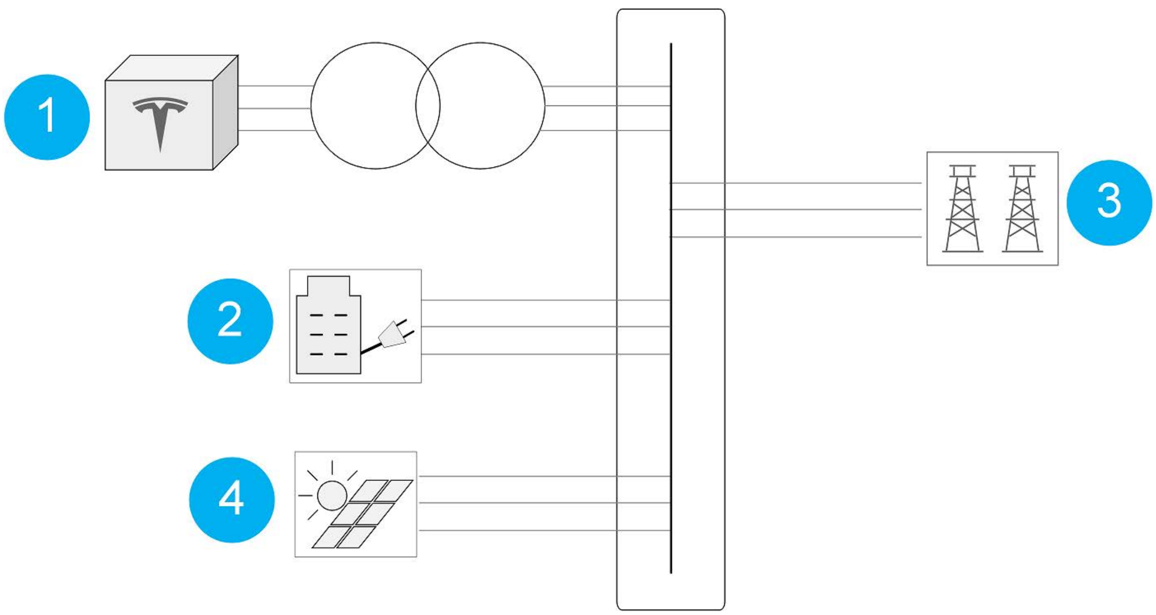
Figure 1. Back-Up BESS Only



Equipment included:

1. Tesla battery system
2. Customer loads
3. Grid connection

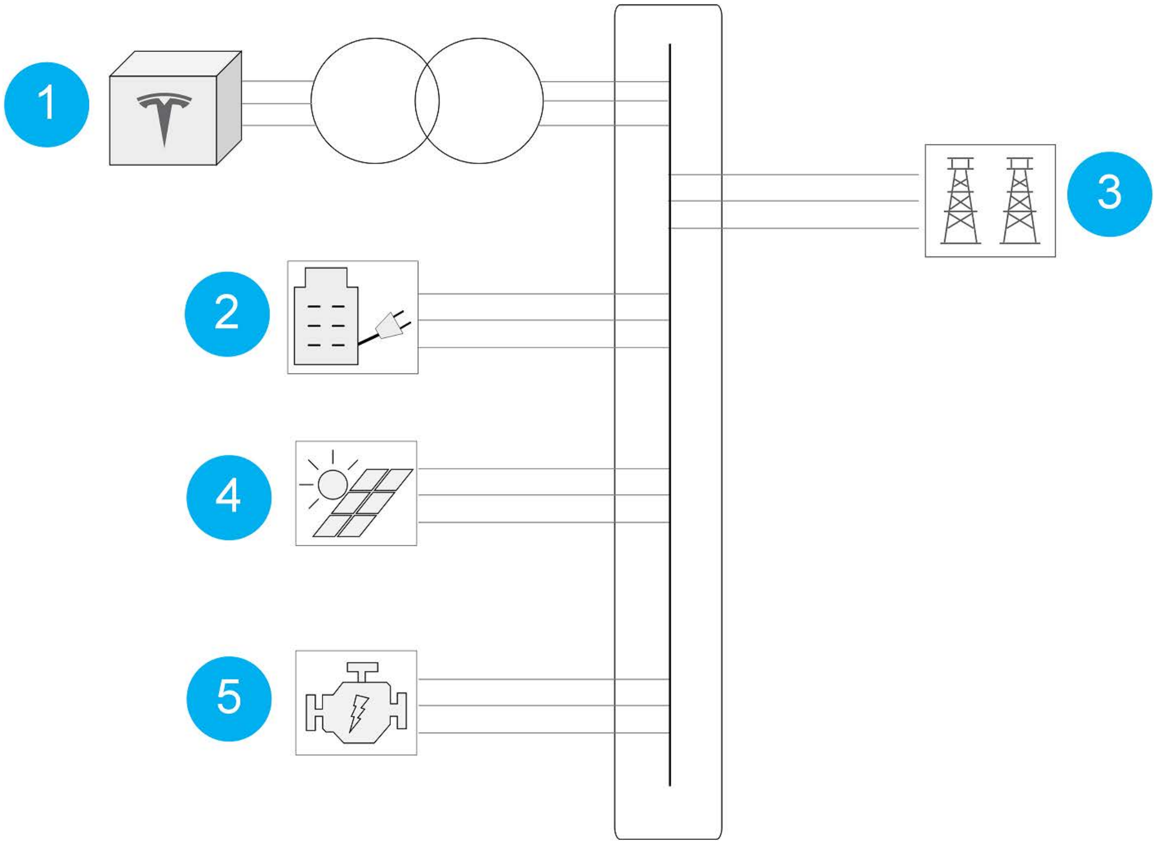
Figure 2. Grid-Tied Microgrid With PV



Equipment included:

1. Tesla battery system
2. Customer loads
3. Grid connection
4. Solar PV plant

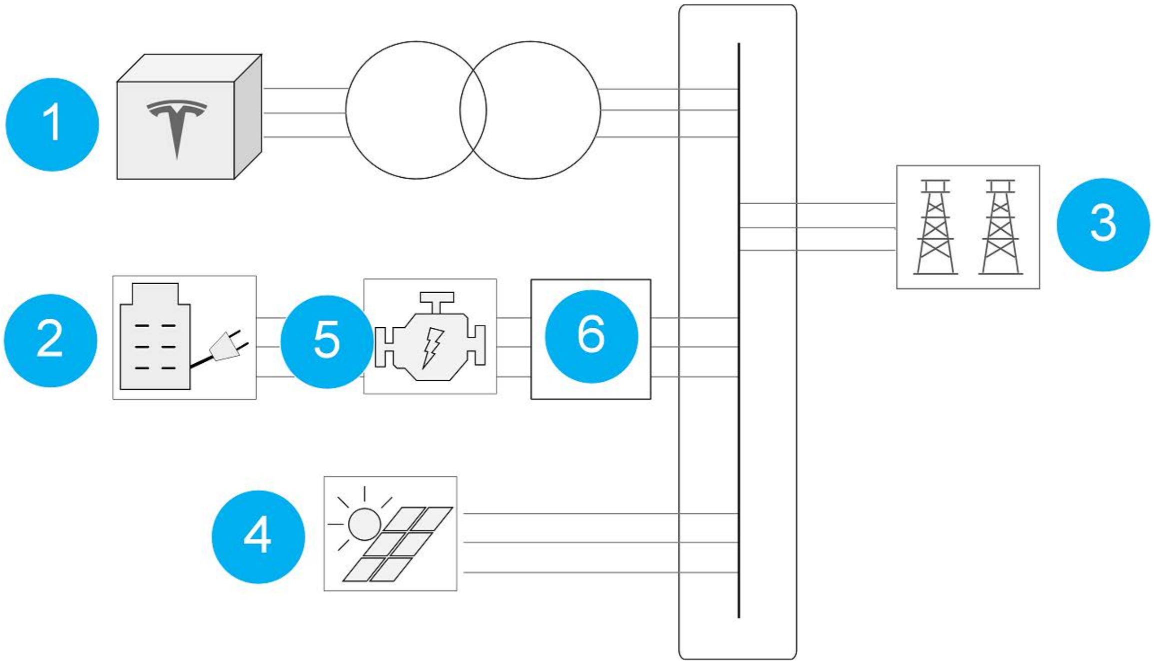
Figure 3. Grid-Tied Microgrid With Solar and Parallel Generator



Equipment included:

1. Tesla battery system
2. Customer loads
3. Grid connection
4. Solar PV plant
5. Generator(s)

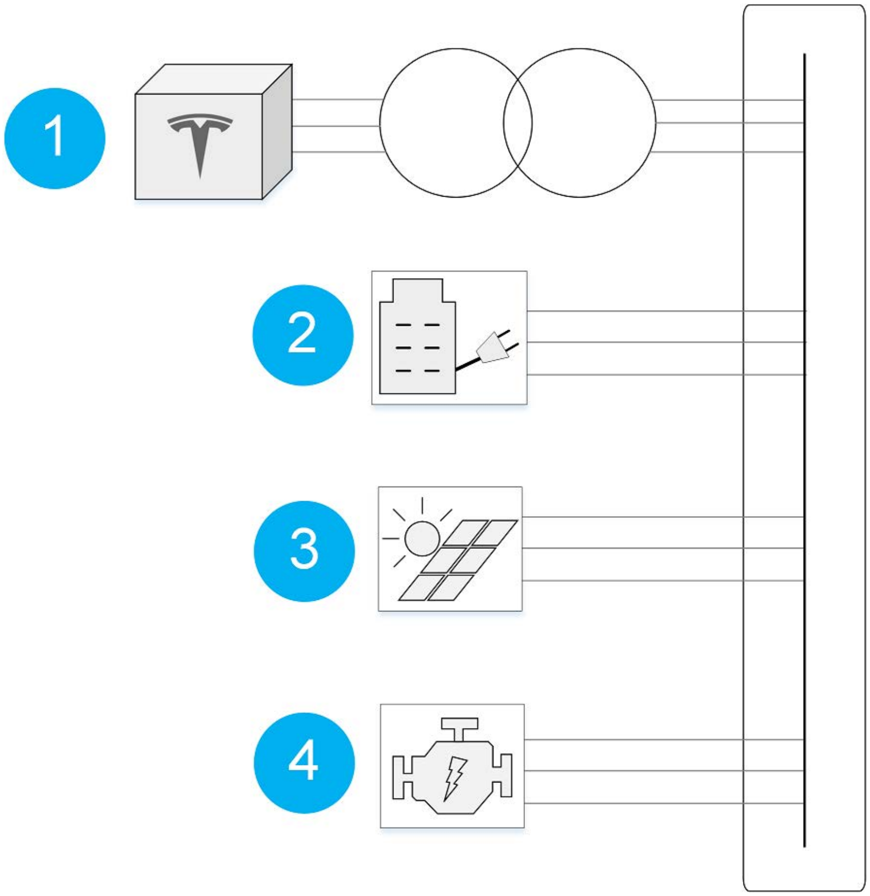
Figure 4. Grid-Tied Microgrid With Solar and ATS Generator



Equipment included:

1. Tesla battery system
2. Customer loads
3. Grid connection
4. Solar PV plant
5. Generator(s)
6. Automatic Transfer Switch

Figure 5. Off-Grid Microgrid With Solar and Parallel Generator



1. Tesla battery system
2. Customer loads
3. Solar PV plant
4. Generator(s)

3.2 Grounding Transformers

Transformer requirements differ between Powerpack and Megapack. As Megapack has a 3-wire inverter compared to Powerpack's 4-wire inverter, Megapack more commonly requires a grounding transformer to ensure a solidly grounded circuit and to support its capability to supply single-phase loads when operating off-grid.

3.2.1 Powerpack Transformer Design

For details of Powerpack's transformer requirements, refer to the *Powerpack 2 System Site Design Manual*.

3.2.2 Megapack Transformer Design

In order to operate, Megapack requires a solidly grounded circuit to ensure that the line-to-ground nominal voltage does not exceed 300 V AC during steady-state conditions. The circuit is solidly grounded by connecting the Megapack terminals to the wye side of a transformer. The transformer may be:

- A step-up/step-down transformer
- A grounding transformer

- An isolation transformer

Customers can parallel multiple Megapacks on a single secondary (low voltage side) winding. One transformer grouped with several Megapacks is called a "transformer block."

Megapacks do not require galvanic isolation from each other; therefore, a standard single winding primary single winding secondary transformer is sufficient for connecting multiple Megapacks. Megapack also does not require any additional transformer features such as k-factor or shielding requirements.

For operations and maintenance needs, the line side bus bars and cables within the Megapack must be able to be isolated and locked out using a visually verifiable means. This can be generally performed with a no-load disconnecting means at the secondary of the transformer (due to the circuit breaker in the Megapack performing the load break functionality), or via a load break disconnect at the primary winding. Arc flash, personal safety and operational procedures should be considered when selecting the means of disconnection.

The customer's engineer should ensure that the requirements listed in this section are met alongside other technical considerations such as utility compliance, protection, maintenance, certification and load requirements. For transformer configurations not discussed here, contact Tesla for review.

NOTE: For more information on transformer design considerations, refer to the *Application Note: Grounding Conductor Recommendations for Megapack Applications*.

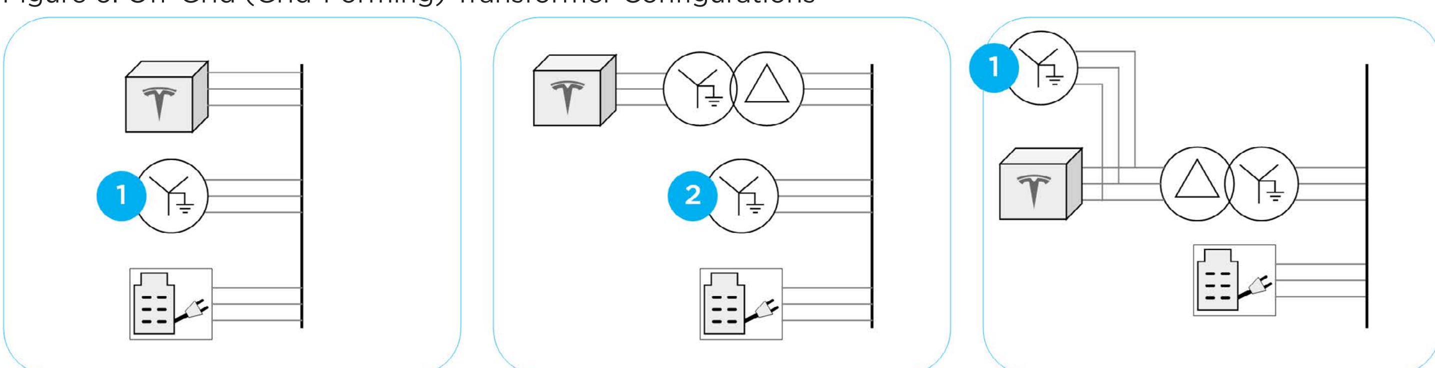
NOTE: For more information about transformer design, refer to the appropriate product *Design and Installation Manual*.

For more information or with specific questions, contact your Tesla representative.

3.2.2.1 Approved Off-Grid (Grid-Forming) Configurations

The side of the transformer connected to Megapack must be a wye-grounded connection. The other side of the transformer must be a delta connection for off-grid (grid-forming) applications.

Figure 6. Off-Grid (Grid-Forming) Transformer Configurations

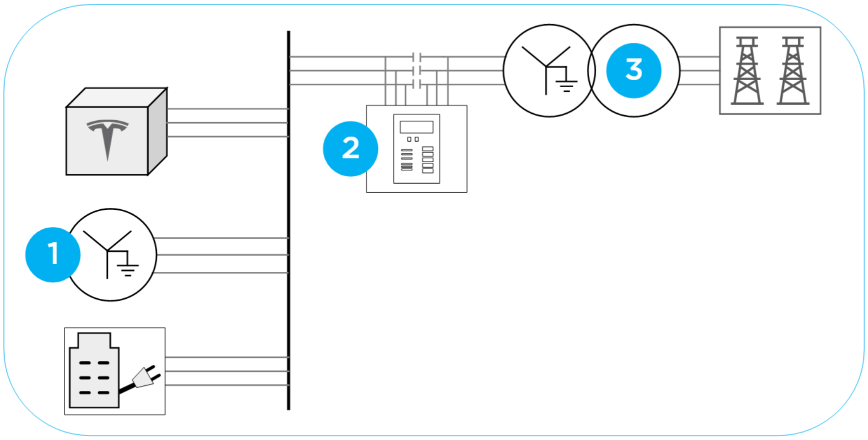


1. Grounding Transformer
2. Optional Grounding Transformer: An example of a potential system ground source and neutral source for line-to-neutral loads if present. This is not required for Megapack's proper operation in this example.

3.2.2.2 Approved Islanding Configurations

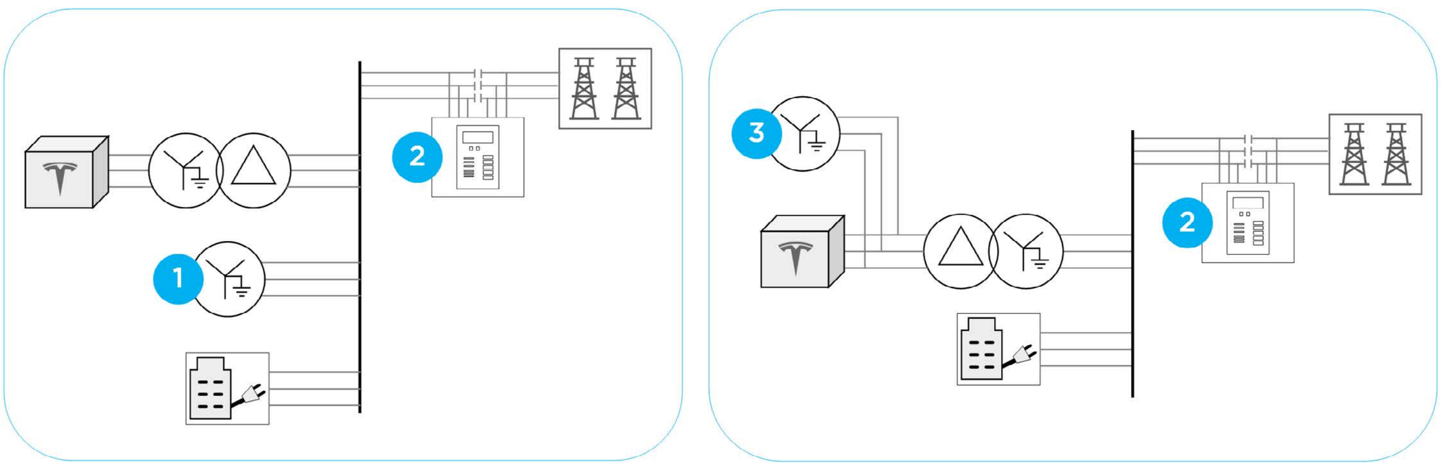
For islanding applications, ensure that a solidly grounded circuit exists during both on-grid and off-grid operation, as shown in the figures below. Depending on the project requirements, the grounding transformer may require disconnection when on-grid.

Figure 7. Islanding with a Utility Transformer and a Grounding Transformer



1. Grounding Transformer
2. Islanding Controller
3. Delta or wye

Figure 8. Islanding with a Step-up/Step-down Transformer



1. Optional Grounding Transformer: An example of a potential system ground source and neutral source for line-to-neutral loads if present. This is not required for Megapack's proper operation in this example.
2. Islanding Controller
3. Grounding Transformer

3.3 Backup Power Sources

Devices critical to sustaining a microgrid must be backed-up with redundant power sources for reliable operation. The Tesla Site Controller is designed to be able to draw from two redundant sources of power. The Meanwell DR-RDN20 is a redundancy module within the Tesla Site Controller that selects the higher DC voltage between these two sources.

This redundancy ensures that the battery system can blackstart the microgrid if the AC bus goes down but the DC bus stays up, that the Microgrid Controller can still run the microgrid using other assets if the battery system is faulted, and that the islanding controller is accurately reporting the status of the grid disconnect regardless of the utility grid and microgrid status.

3.3.1 Backup Power Options

There are three options when designing backup power for the microgrid:

1. **Battery-system-provided power -** Up to 2 A at 24 V power is available as long as the SOC is above 1% and the power supply board is functional. In this state, the energy is provided from the battery modules and is available regardless of the incoming AC power to Megapack. See the respective battery system's *Site Design Manual* for wiring requirements.
2. **Customer-provided DC power -** As an alternative to the 24 V DC from the battery system, customers can provide a 24 V DC UPS that terminates into the 24 V DC redundancy module in the Standard Tesla Site Controller Enclosure.
3. **Customer-provided AC power -** Customers can supply power from a UPS or other backed-up power supply (strongly recommended for microgrids and high-reliability sites). This supply must terminate upstream of the AC transformer in the Standard Tesla Site Controller Enclosure. Do not add components to or modify the Standard Tesla Site Controller Enclosure

4 Networking Architecture

The Tesla Site Controller is the single point of interface for the utility, network operator, or customer SCADA systems to control and monitor the entire energy storage site. It hosts the control algorithm that manages the charge and discharge functions of the battery system units, aggregating real-time information and using the information to optimize the commands sent to each individual battery unit.

The battery system communicates with the Tesla Site Controller over a private TCP network. Customer systems communicate with the Tesla Site Controller via Modbus, DNP3, or REST API interfaces.

By default, Tesla provides two Tesla Site Controllers for each point of interconnection. These controllers may be configured for automatic failover as detailed in the *SCADA Design Manual*. Tesla does not include additional networking equipment that may be required for the system to operate.

The Tesla Site Controller has three network interfaces:

- LAN 2 RJ45/Ethernet port, which connects to the Tesla Network
- LAN 1 RJ45/Ethernet port, which connects to the Customer Network and can be configured for WAN access
- Integrated cellular modem, which by default provides cellular access for Tesla's remote connection

There are two physical variations of the Tesla Site Controller:

- **Standard Tesla Site Controller -** used in sites up to 18 MW. Delivered in an enclosure called the Standard Tesla Site Controller Enclosure, which includes two Standard Tesla Site Controllers.
- **Large Tesla Site Controller -** for sites larger than 18 MW. Delivered as a pair of two controllers.

Figure 9. Standard Tesla Site Controller in the Standard Tesla Site Controller Enclosure

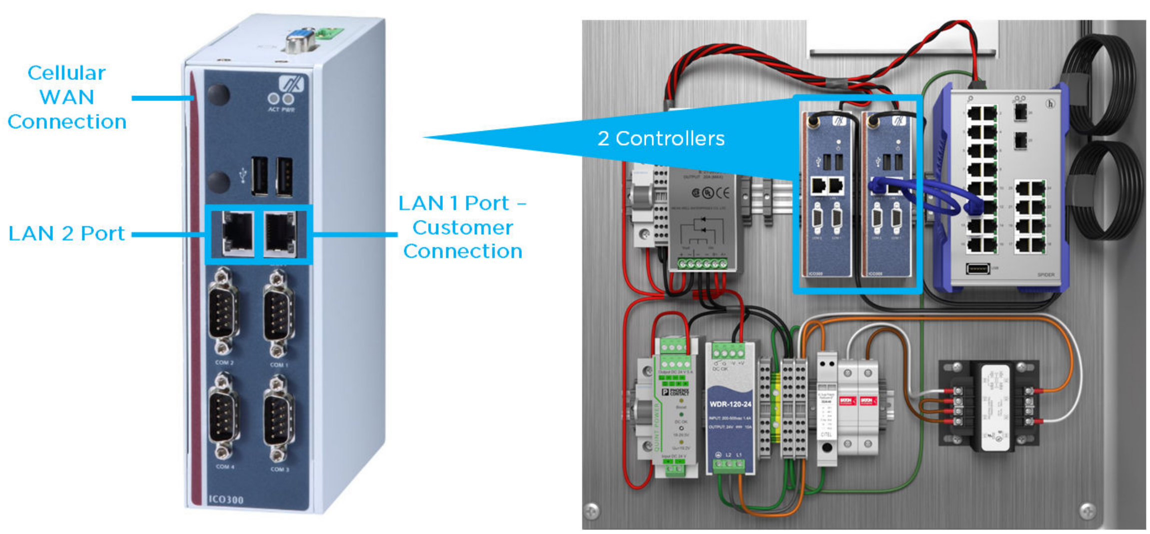
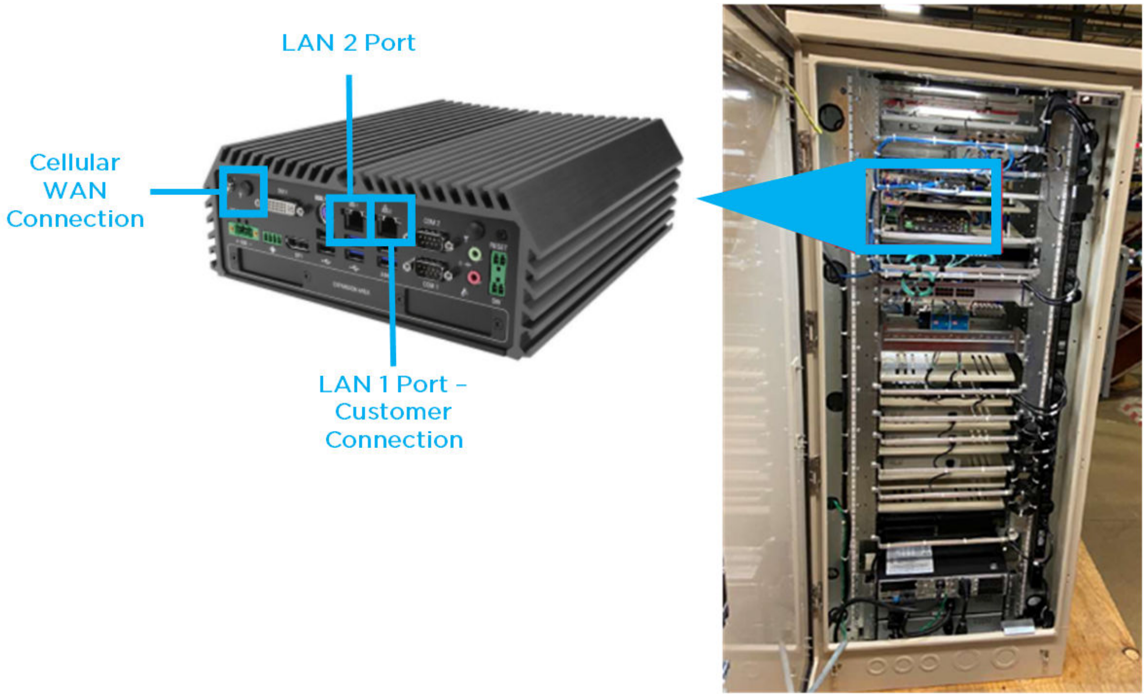


Figure 10. Large Tesla Site Controller mounted inside SCADA Rack Enclosure



To keep the customer network and Tesla's private network isolated, the LAN 1 and LAN 2 networks should use independent physical switches.

The choice of physical Tesla Site Controller computer is dictated by the size of the project. The same firmware and software will run on both physical variants. The Tesla Site Controller also contains higher level control functions, including the Tesla Microgrid Controller and Microgrid Opticaster. It is the single point of interaction for communications with meters and controllers over Modbus TCP. Two Tesla Site Controllers can be installed for redundancy. See the *SCADA Design Manual* for more information.

The TCP/IP network used for communications and control must be a single network allowing for Modbus communications (port 502) between all devices. All switches, ports, SFPs, and fiber transceivers should be 100Mbps.

For more information:

- See the *SCADA Design Manual* for additional, required information when designing an energy storage site larger than 18 MW.

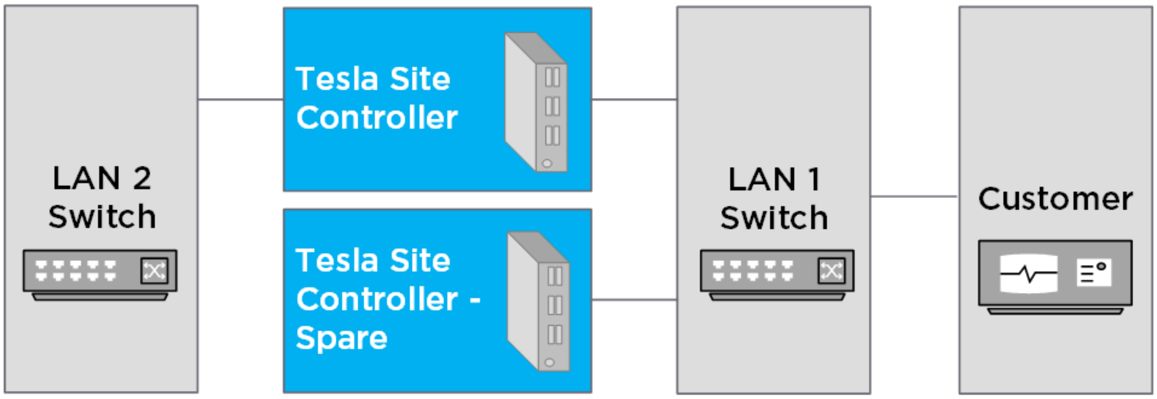
4.1 Computer Networking

The Tesla Site Controller (*Networking Architecture on page 25*) has a single LAN 1 RJ45 port, a single LAN 2 RJ45 port, and an integrated cellular modem.

The Standard Tesla Site Controller Enclosure may have one or two controllers (Standard Tesla Site Controllers), hence one or two LAN 1 RJ45 ports and one or two LAN 2 RJ45 ports. Each controller has an integrated cellular modem. Large-scale sites typically ship with two controllers (Large Tesla Site Controllers).

For Standard Tesla Site Controller Enclosures including two Standard Tesla Site Controllers or for sites including dual Large Tesla Site Controllers, LAN 1 of each computer may be connected in parallel, as indicated in the diagram below:

Figure 11. Dual Computer Networking



CAUTION: Contact Tesla before attempting to connect LAN 2 of both controllers in parallel.

NOTE: If you are connecting through a firewall, see the *Firewall Rules* table in the *SCADA Design Manual* for important connection information.

5 Battery Energy Storage System

In any microgrid system, whether permanently off-grid or temporarily disconnected from the utility system, the Tesla battery system (BESS) will run in VF mode. The system will operate in droop, and normal active and reactive power modes as described in the *Tesla Energy Controls and Communications Manual* will not apply. The only other modes that can be stacked with VF operation are *Heat Mode*, *Peak Power Mode*, and *Load Control* (for more information, see respective sections in the *Tesla Energy Controls and Communications Manual*).

NOTE: Customers can choose to run their Tesla battery system in PQ mode in a microgrid. However, it will then not be possible for the customer use Tesla's Microgrid Controller or islanding controller. For all intents and purposes, the system will be indistinguishable to Tesla from any other on-grid project, and the design considerations in this document as they relate to Tesla products will not apply

NOTE: Cold climate conditions can impact the available charge/discharge power (if soaked cell ambient temperature falls below 10°C / 50°F), which in the worst case can cause an outage if insufficient total power is available for the microgrid. Heat mode should be implemented as necessary per the guidelines in the *Tesla Energy Controls and Communications Manual*, and associated energy consumption should be considered when sizing the microgrid assets.

5.1 Droop Operation

In grid-forming mode (VF), the battery system will operate as a voltage source, and the active and reactive power outputs will be determined by power-frequency and power-voltage droop curves respectively.

Generally, the operating voltage and frequency of the microgrid are 480 V and 60 Hz, or 400 V and 50 Hz. However, when the battery is coupled with other generation sources, microgrid power balance charge/discharge profiles can be controlled by adjusting the power-frequency droop parameters. The reactive power is controlled by adjusting the reactive power-voltage droop parameters. The adjustable parameters are listed below, followed by frequency droop graphs demonstrating the frequency droop control concept.

Table 6. Islanding Inputs

Parameter	Description	Units	Default	Range
Island Nominal Frequency Setpoint	Nominal frequency setpoint	mHz	60000 or 50000	[45000-65000]
Island Frequency Slope	Frequency vs. real power slope	%P/Hz	100	[20-500]
Island Nominal Voltage Setpoint	Nominal voltage setpoint	0.1V	4800	[2000-5300]
Island Voltage Slope	Voltage vs. reactive power slope	%Q/%ΔV	10	[5-20]

The %P (Active Power) value is calculated using the Nameplate Charge Power, and the %Q (Reactive Power) value is calculated using Nameplate Apparent Power.

Consider the full battery as a single power source interfacing with the Tesla Site Controller. For multiple Megapack islanded installations, the Tesla Site Controller distributes droop profiles to individual Megapacks based on their available energy to ensure they balanced. If the Megapacks become unbalanced, the Tesla Site Controller unevenly splits the parameters to individual Megapacks to balance the system over time.

5.2 Blackstart

The battery system will initiate a black start sequence if it detects a dead bus when you command the system to transition from standby to active. During black start, the AC voltage is ramped from 0 V to nominal voltage over the course of a few seconds. In order to prevent the system from tripping on low voltage during the ramp, low voltage faults are suppressed for six seconds following the transition to active. Total voltage ramp time will vary depending on the impedance of the system being energized, but is typically between three and five seconds. The voltage ramp reduces the inrush currents caused by the magnetization of inductive loads and also allows inverters to synchronize with each other.

For off-grid only systems that do not use an islanding contactor/circuit breaker, toggle between Island Modes 2 and 3 (see *Island Modes on page 35*) to turn the system on and off. In Island Mode = 2, the system is in a Standby state with no AC output, but the DC is still online. In Island Mode = 3, the system is active and supporting the loads.

5.2.1 Grid Form Retry Behavior

When the battery hits a grid-forming trip limit, either during regular operation or during blackstart, it will stop grid forming. This will result in a dead AC bus unless other generators in parallel are able to support the bus voltage. The Tesla Site Controller determines that the microgrid AC bus is dead when the microgrid voltage is less than 15% of the battery's nominal voltage for a default of 10 seconds.

In response to a dead bus, the Tesla Site Controller can be configured to either automatically retry or wait for a user-initiated retry. When a retry is initiated, the battery inverter will follow the standard blackstart sequence. The inverter will continue to retry up to three (3) times (Retry Count) per sixty (60) seconds (Retry Time). If three (3) retries have been unsuccessful within sixty (60) seconds, the Tesla Site Controller will wait for the start of the next minute to retry again. If the inverter exceeds the configured number of Maximum Retry Limit (15 by default) in twenty-four (24) hours (Maximum Retry Time), it will enter the Wait for User state, awaiting a manual intervention as described below.

The retry behavior determined by the following parameters can be set by Tesla during commissioning only:

- Retry Count
- Retry Time
- Maximum Retry Limit
- Maximum Retry Time

5.3 Low SOE Behavior

In VF mode, the battery system will also operate using specific SOE thresholds designed for projects where alternative reliable power sources may not be available. These are referred to as "Wait for" SOE levels and are intended to maximise continuity of system supply using tiered thresholds.

Wait for Solar SOE ≥ Wait For User SOE ≥ Wait for Jumpstart SOE ≥ End of Discharge (0% SOE)

There is a default value for each level, but they can be configured differently at commissioning if necessary.

Table 7. Low SOE: Default Values

SOE Level	Default Value	Purpose	Behaviour
Wait for Solar	10%	Automatically recharge from solar when it is next available.	DC bus will stay up, but the inverter will stop grid-forming. Blackstart will be attempted once per hour during daylight hours.

SOE Level	Default Value	Purpose	Behaviour
Wait For User	5%	Wait until an operator can manually intervene to either provide an external AC source or initiate a blackstart.	DC bus will stay up, but the inverter will stop grid-forming without any automatic retry behaviour.
Wait for Jumpstart	3%	Wait until an operator can manually intervene to either provide an external AC source or initiate a blackstart using 12 V.	DC bus will be dropped. No automatic retry. System stays in this mode until End of Discharge.

5.4 State of Energy Frequency Shifting

For grid-forming (VF) systems, the system can be configured to shift the Island Nominal Frequency Setpoint as a function of the system's State of Energy. This is used to trigger frequency-dependent control functionalities of other components in the microgrid, such as Frequency Dependent Power reduction of solar PV inverters. By default, the system is configured to ramp by +3Hz from 98% State of Energy to 99%. The settings for State of Energy Frequency Shift can be modified by Tesla during commissioning only.

If the Tesla Microgrid Controller is used, this frequency shift capability will be incorporated as part of the overall controls strategy for the microgrid. If the Tesla Microgrid Controller is not used, customers can choose to use this as a standalone control feature for their own purposes, such as curtailing solar inverters. However, the full scope of this control method (determining and coordinating settings to achieve the desired behaviour) is not in Tesla scope. It is not recommended to use this approach (frequency shifting only) unless the solar inverter power is less than the battery system power. A more detailed assessment of the considerations is covered in *Solar on page 44*.

5.5 DC Balancer

Tesla battery systems with the Powerstage and Powerpack Inverter architecture require a DC Balancer included within each inverter to ensure the DC bus remains balanced when operating in VF, since certain loads or faults can imbalance the DC bus when the system is a voltage source rather than a current source. The DC Balancer takes the slot of a normal Powerstage but only interacts with the DC bus, and therefore does not impact the AC interface of the inverter.

This part requires no specific action from the designer other than to note that the total potential inverter capacity is reduced because the DC Balancer uses a Powerstage slot, and to ensure your Tesla contact is informed that the system needs to operate in VF and is therefore supplied with the DC Balancer included.

5.6 Phase Rotation

During commissioning, the battery system inverter will learn the phase rotation applied to the inverter terminals. If no voltage is applied during commissioning this will be clockwise rotation. If a new phase rotation is presented to the inverter during on-grid operation, it will re-learn this phase rotation temporarily until reset. If the phase rotation needs to be changed, contact Tesla to reset the previous phase rotation learned by the inverter.

5.7 Tesla Microgrid Controller

Coordinating the battery system with other sources in the microgrid requires a microgrid controller, whether supplied by Tesla or a third party. Customers using a third-party microgrid controller will need to determine the appropriate settings for *Droop Operation on page 28*, *Blackstart on page 29*, *Low SOE Behavior on page 29*, and *State of Energy Frequency Shifting on page 30*. Customers using the Tesla Microgrid Controller will have the settings provided by Tesla as part of the microgrid control scheme and be able to access the features described below.

5.7.1 Standard Settings

Standard microgrids using the Tesla Microgrid Controller will start with the following settings:

- Droop Slope = 200%
- Wait for Solar (disabled)
- Wait for User = 3%
- Wait for Jumpstart = 1%
- Frequency Shift Table
    - 94% = +0Hz
    - 95% = +1.4Hz
    - 96% = +3Hz

5.7.2 Features

5.7.2.1 Off-Grid SOE Range

The Microgrid Controller will operate the battery between 10% and 94% SOE to ensure sufficient space is allowed for the intended behaviors at low and high SOE, which will in turn ensure stable and reliable operation for the overall microgrid.

At low SOE, the Microgrid Controller will dispatch diesel generators if they are available. See *Generator Control Modes on page 50* for details. The 10% threshold is set to ensure sufficient time is available for user intervention if no generators turn on due to issues such as loss of communications or a generator fault, and to reserve space for the battery system to contribute to the spinning reserve scheme by serving load transients if needed.

At high SOE, the Microgrid Controller will ramp down the battery charge power over a 1% range and curtail solar. For details, see *Curtailment at High SOE on page 45*. The 94% threshold is set to ensure the battery system does not experience an unanticipated drop in available charge power that results in overpower in the microgrid, and to reserve space for the battery system to contribute to the spinning reserve scheme by absorbing load transients if needed.

5.7.2.2 Spinning Reserve Management

The Microgrid Controller manages the microgrid “swing bus,” which includes all active battery and generator assets operating in grid-forming mode (see the *Microgrid Controller Owner’s Manual* for more information about the swing bus). The battery system contributes its full available discharge power to the swing bus maximum power. The battery system contributes its full available charge power to the swing bus minimum power.

When loads are high the Microgrid Controller will turn on additional sources (generators) to ensure that the swing bus does not trip on overload. The “spinning reserve required” setting should be set to maintain a safe margin between loads and the maximum swing bus power. A general recommendation is to set this at the maximum load step that could occur in the time it takes to turn on a generator.

When load is low (or solar is high) and no more generators can be turned off due to the spinning reserve requirement, the Microgrid Controller will curtail intermittent assets (meaning solar) to ensure the swing bus does not trip on underpower (battery charging overload, generator reverse power).

5.7.2.3 Automatic Frequency Control (AFC)

The Microgrid Controller will adjust the no load frequency (the nominal frequency) of the battery system to regulate frequency and control load sharing with other assets. While it is operating, any manual no-load frequency commands will be overwritten by the Microgrid Controller.

5.7.2.4 Microgrid Opticaster

Microgrid Opticaster uses load and solar forecasts to optimize for least-cost dispatch of the microgrid by minimizing generator fuel consumption and taking the battery's roundtrip efficiency into account. Depending the efficiency curve of the generator related to the battery efficiency, it may make sense to charge the battery from the generator in some cases. Microgrid Opticaster will autonomously determine and implement this dispatch within the Microgrid Controller.

6 Islanding

Tesla battery systems can operate as direct backup or within a grid-tied microgrid to support loads during a grid outage. Using an islanding controller, the system can transition to islanded operation upon a grid loss or via a direct command.

During a utility grid interruption such as a fault event, or due a direct command from the operator, the islanding system will follow the standard sequence of operations (SOO) to transition to an islanded, off-grid system. The detection and response times will vary depending on the type of fault, location of the fault, pre-fault operating state of the battery system, and other factors. Depending on these factors, the speed of the transition will differ:

- In some cases, a rapid transition causes no interruption to local loads, with the change-over to islanded mode typically occurring within 1 second.
- In other cases, an interrupted transition causes an interruption to local loads. Change-over can take several seconds, with the microgrid voltage not maintained during this period.

NOTE: While the Tesla islanding system is designed to optimize the change-over speed as much as possible, it is important to note that interrupted transitions will occur at times. Tesla's islanding architecture is designed to provide reliable backup functionality but is not an Uninterruptible Power Supply (UPS) and cannot achieve guaranteed seamless transitions with standard breaker and line-interactive topology. To cater for critical loads that cannot accept interrupted transitions, customers are advised to install a UPS or Variable Frequency Drives (VFDs) designed to handle short power interruptions. Small short-duration UPS installed on critical equipment combined with site-level Tesla battery system backup is a common way to a achieve a low-cost, high-reliability energy resiliency solution.

6.1 Islanding Controller

An islanding controller is required for customers who have a utility grid connection and intend to switch between grid-connected and islanded configurations. There are two islanding options customers can choose from depending on their use case.

6.1.1 Tesla-Approved Controller (SEL-700G Relay)

For systems integrating with an approved islanding controller (the SEL-700G Relay), Tesla requires that this controller have direct control over the system islanding contactor or circuit breaker (called "grid disconnect"). The islanding controller will manage the state and transitions of the islanded system, automatically isolating the battery system and loads from the grid during grid outages and transition to grid-forming, and providing seamless reclose operations when the grid returns to then transition back to grid-following. See the *Islanding Controller Specification* for additional details.

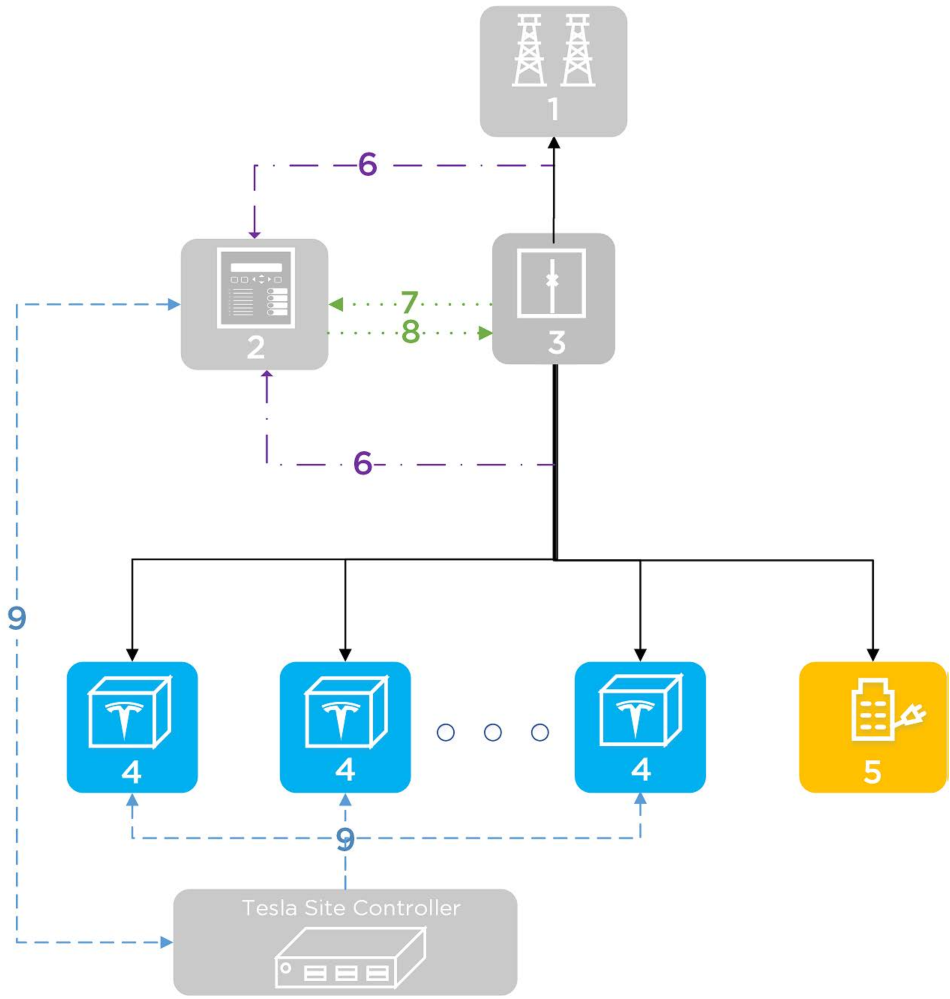
6.1.2 Customer-Managed Third-Party Controller

Customers may also choose to directly dictate the grid-following or grid-forming behavior of the battery system. In this option, Tesla does not require an islanding controller to be integrated with the Tesla system. The customer is responsible for maintaining the system in the appropriate state relative to the status of the grid connection and handling conditions such as loss of communications. The customer is required to sign the *Customer Breaker Override Form,* and control should be done by commanding the system's Island Mode.

6.2 Islanding Architecture

The figure below shows the islanding architecture for the battery system:

Figure 12. Islanding Architecture



1. Utility, or point of common coupling (PCC)
2. Islanding controller
3. Grid disconnect (contactor/circuit breaker) – can be OPEN or CLOSED
4. Battery system. Can be in one of three modes:
    - Grid-following (PQ)
    - Grid-forming (VF)
    - Standby
5. Loads
6. Voltage and frequency sensing lines
7. Status
8. Control (to OPEN or CLOSE)
9. Network communication

6.3 Island Modes

This table summarizes the island modes that can be configured in the battery system and which dictate system behavior in relation to islanding transitions.

Table 8. Islanding Control Modes

Island Control Value	Island Control Mode	Description
Primary Control Modes		
1	Auto Active	Automatic transitions based on grid availability. If the grid is available, grid connection is preferred and the system will operate in grid-following mode.Upon grid loss, the system opens the islanding breaker and the battery system runs in grid-forming mode to support loads.
2	Island Ready	Automatic transitions based on grid availability. If the grid is available, grid connection is preferred and the system will operate in grid-following mode. Upon grid loss, the battery system is in standby and does not support loads.
3	Intentional Island	The system opens the islanding breaker/contactor regardless of grid state and the battery system operates in in grid-forming mode to support loads. If no islanding controller is present, the battery system will operate in grid-forming mode.
Alternative Control Modes		
4	PQ Island	Only used for sites configured as Off Grid. When the system detects an external voltage, the system operates in grid-following or “PQ” mode, responding to real and reactive power commands. If the system does not detect an external voltage, the system goes into standby and does not support loads.
5 This is the default mode of operation.	Island Off	The system operates as a grid-following or “PQ” source but if the grid is lost the system shuts down (including the DC bus and controls voltage) to preserve energy.

6.4 Islanding Sequence of Operations

This section describes the standard sequence of operations for islanding systems when configured with Tesla’s approved islanding controller.

6.4.1 Automatic Transition from On-Grid to Off-Grid

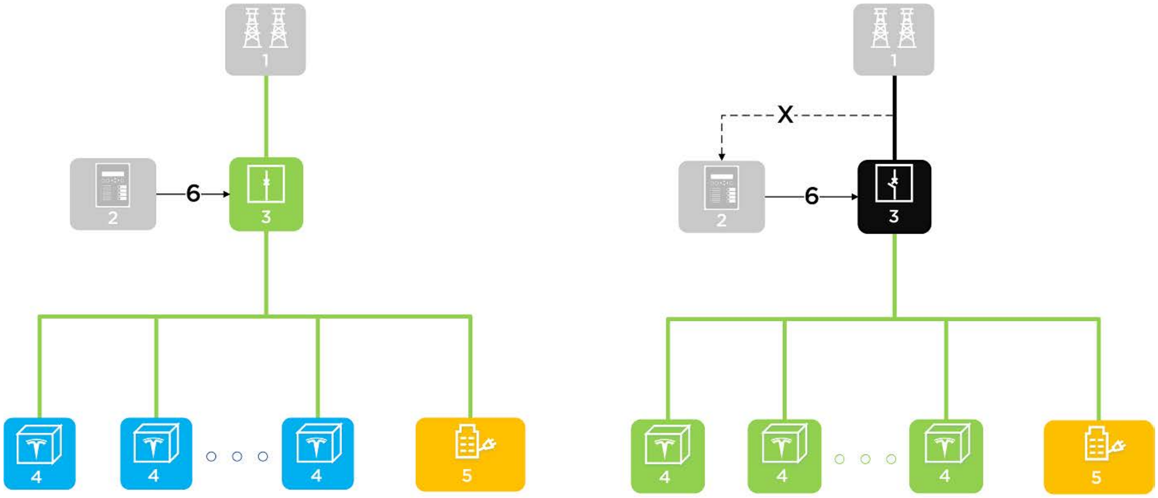
In all cases, the islanding controller isolates the local system upon a large grid disturbance or complete blackout. For Island Modes 1 and 2, the islanding controller automatically opens the islanding contactor/circuit breaker if a grid disturbance is detected and keeps the breaker open for the duration of the grid disturbance/loss. The state of the system after the transition depends on whether the system is set to Island Mode 1 or 2.

- If Island Mode = 1 (Auto Active), the system immediately starts up in grid-forming mode once the islanding contactor/circuit breaker opens. To get a near seamless transition for supporting loads, the system must be active prior to the grid disturbance. To ensure the system is active, it is recommended to use the Always Active. The degree to which loads experience a seamless transition when the system is active also depends on the nature of the grid disturbance (including fault type, impedance, clearing time) and latency in the local communications network.
- If Island Mode = 2 (Island Ready), the system remains in standby state.

6.4.1.1 Island Mode Set to 1 (Auto Active)

1. If a grid disturbance is detected by either the inverter or the SEL-700G, the inverter switches to hybrid mode, which is a temporary operating mode of the inverter where it activates grid-forming while performing active anti-islanding.
2. Whether this disturbance was a false alarm determines what happens next:
    a. If non-intentional islanding is not confirmed because the grid disturbance was a glitch/transient and a strong grid connection is still present, the grid disturbance detector deasserts and the inverter switches back to grid following.
    b. If non-intentional islanding is confirmed because the disturbance was due to a high-impedance fault (loss of potential), the activation into hybrid mode attempts to recover the voltage waveform, after which the Tesla Site Controller commands the SEL-700G to open the grid disconnect.
    c. If non-intentional islanding is confirmed because the disturbance was due to a low-impedance fault (bolted fault, a short circuit between phases, or a fault with a new low impedance load), the SEL-700G will command the grid disconnect to open. Voltage waveform should immediately recover once the grid disconnect physically opens.
3. Confirmation from the SEL-700G to the Tesla Site Controller that the grid disconnect is open will prompt the inverter to go into full VF mode. If confirmation does not come within 2 seconds of entering hybrid mode, the inverter is commanded to off/standby.
4. Should the inverter at any point operate outside of its safe operating limits, the inverter will go to standby for a few seconds before re-initiating VF mode via blackstart (see *Blackstart on page 29*).

Figure 13. Island Mode = 1 (Auto Active). Automatic transition from on-grid to off-grid.



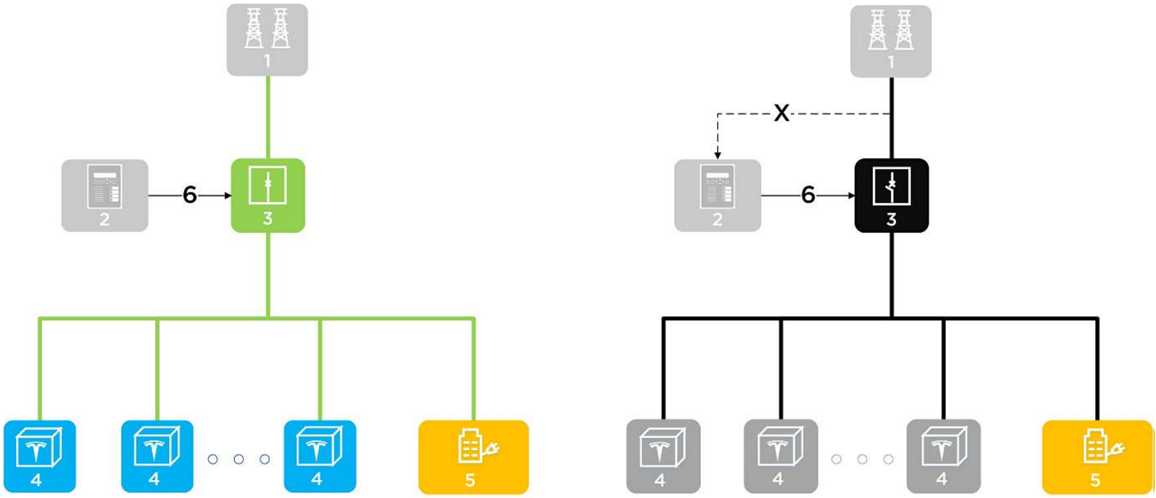
Before grid loss, inverters in grid-following mode	After grid loss, breaker open and inverters active in grid-forming mode
	X. Loss of grid detected
1. Utility	**1.** Utility
2. Islanding controller	**2.** Islanding controller
3. Islanding circuit breaker CLOSED	**3.** Islanding circuit breaker OPEN
4. Inverters in grid-following (PQ) mode	**4.** Inverters in grid-forming (VF) mode
5. Loads	**5.** Loads
6. CLOSE command issued	**6.** OPEN command issued

6.4.1.2 Island Mode Set to 2 (Island Ready)

If a grid disturbance is detected by either the inverter or the SEL-700G, the grid disconnect will open and the inverter will be commanded to standby to comply with anti-islanding rules.

Standby refers to a system state in which the DC bus of the battery system is energized to provide logic/thermal power, but the battery system is not responding to real or reactive power commands or producing AC voltage as a grid-forming source.

Figure 14. Island Mode = 2 (Island Ready). Automatic transition from on-grid to off-grid.



Before grid loss, inverters in grid-following mode	After grid loss, breaker open and inverters in standby (not operating)
	X. Loss of grid detected
1. Utility	**1.** Utility
2. Islanding controller	**2.** Islanding controller
3. Islanding circuit breaker CLOSED	**3.** Islanding circuit breaker OPEN
4. Inverters in grid-following (PQ) mode	**4.** Inverters in standby
5. Loads	**5.** Loads
6. CLOSE command issued	**6.** OPEN command issued

6.4.2 Automatic Transition from Off-Grid to On-Grid

For Island Modes 1 and 2, the islanding controller detects when the grid has returned, performs a synchronization check, synchronizes the system to the grid if required, and automatically closes the islanding contactor/breaker when synchronized.

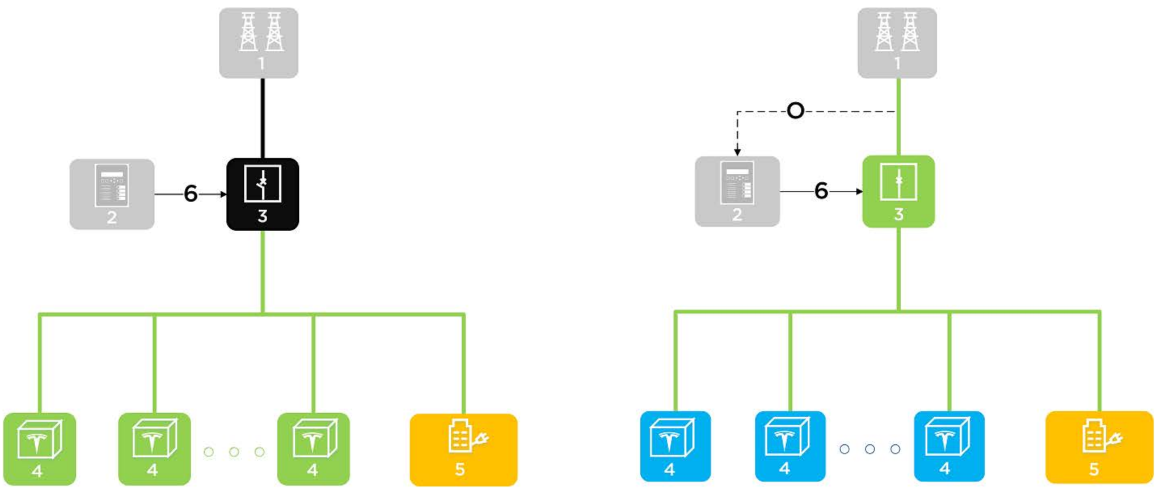
- If Island Mode = 1 (Auto Active): Once the islanded system resynchronizes with the grid and transitions back on-grid, after which the system operates based on the current Real or Reactive power command. Grid reconnection timers may apply.
- If Island Mode = 2 (Island Ready): The islanding controller closes the islanding contactor/breaker once the grid is within the acceptable voltage and frequency limits. This transition differs from Island Mode 1, as it does not rely on resynchronization; the battery system is expected to be offline. If the battery is the only voltage source on the grid, the loads are dropped during this transition. After reconnection, the system operates based on the current Battery Real Power Target Battery Reactive Power Target commands. Grid reconnection timers may apply.

6.4.2.1 Island Mode Set to 1 (Auto Active)

1. When the grid returns, the Tesla system waits until the SEL-700G permits resynchronization. Synchronization is permitted when the grid is within acceptable voltage and frequency limits for at least 5 minutes. The acceptable limits and timer can be configured to different values if desired, as part of SEL-700G logic.

2. The battery system then syncs back to the grid by actively regulating both voltage magnitude and angle to match microgrid values with the reported grid values. The SEL-700G will do a sync check before closing the grid disconnect.
3. Confirmation from the SEL-700G to the Tesla Site Controller that the grid disconnect is closed will prompt the inverter to go PQ mode and resume on-grid operations.
4. Should the inverter at any point fault and drop the microgrid loads, or the operator commands the microgrid to manually go down, if the grid is available the grid disconnect will automatically close on Drop Load Reconnect (break-before-make). After the grid disconnect closes, the battery will resume operations after the grid qualification timer internal to the inverter.
5. If a parallel generator controlled by the Tesla Microgrid Controller is present in the microgrid:
    a. It can only be started if the microgrid is in the islanded state (off-grid).
    b. When transitioning back on-grid, it will first be stopped prior to synchronization. If the generator cannot be turned off due to load or spinning reserve requirements, the system will not transition on-grid.

Figure 15. Island Mode = 1 (Auto Active). Automatic transition from islanded to on-grid.



Off-grid, with inverters active in grid-forming mode	Grid returns, system re-synchronizes then closes the breaker, system operates per real and reactive modes (shown active)
	O. Available grid detected
1. Utility	**1.** Utility
2. Islanding controller	**2.** Islanding controller
3. Islanding circuit breaker OPEN	**3.** Islanding circuit breaker CLOSED
4. Inverters in grid-forming (VF) mode	**4.** Inverters in grid-following (PQ) mode
5. Loads	**5.** Loads
6. OPEN command issued	**6.** CLOSE command issued

6.4.2.2 Island Mode Set to 2 (Island Ready)

If the system was already in Island Ready for the transition from on-grid to off-grid, the system should be in standby. Because the microgrid bus has no voltage, when the grid returns the SEL-700G will permit the grid disconnect to close on a dead bus. After the reconnection countdown timer within the inverter expires (depending on grid reconnect grid code), the battery system resumes its previous grid following operation.

If the system was in Auto Active for the transition off-grid and is then set to Island Ready by the operator, the battery will go to standby and will follow the process described above.

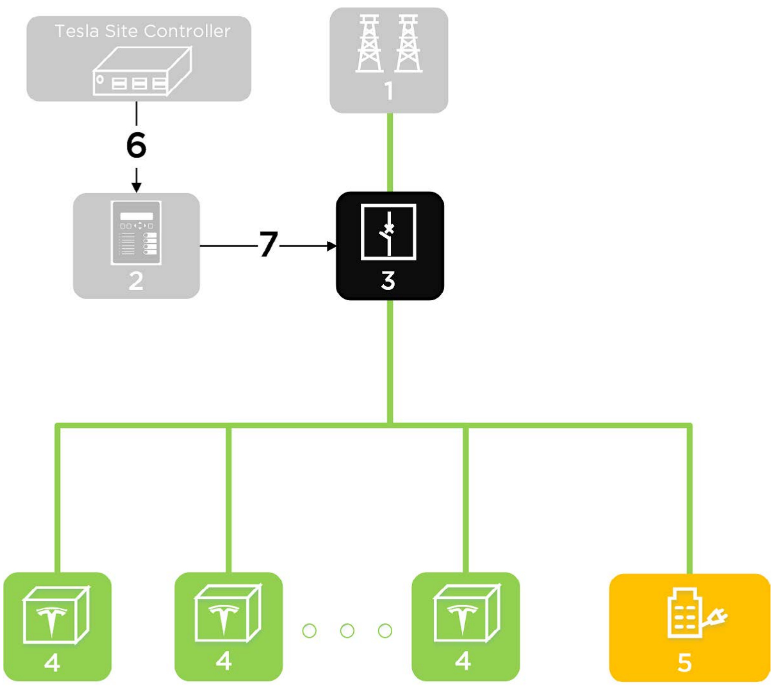
6.4.3 Intentional Transition from On-Grid to Off-Grid

With Island Mode = 3 (Intentional Island), you can island the system while the grid is available. Once you write Island Mode = 3 to the Tesla Site Controller, the islanding controller immediately opens the islanding contactor/breaker, transitions to grid-forming mode, and creates an active microgrid.

When the system is operating on-grid and the Island Mode is changed to 3 (Intentional Island) by the operator:

1. The inverter switches to VF mode.
2. The Tesla Site Controller then commands the SEL-700G to open the grid disconnect.
3. Confirmation from the SEL-700G to the Tesla Site Controller that the grid disconnect is open will prompt the inverter to go into full VF mode. If confirmation does not come within 2 seconds of entering hybrid mode, the inverter is commanded to off/standby.

Figure 16. Island Mode 3 (Intentional Island)



1. Utility
2. Islanding controller
3. Islanding circuit breaker OPEN
4. Inverters in grid-forming mode
5. Loads
6. Island Mode = 3 (Intentional Island)
7. OPEN command issued

Setting the Island Mode to 3 while off-grid **inhibits the automatic transfer back to the grid** and allows the system to continue operating in a microgrid when the grid is present. To initiate reconnection to the grid, change the Island Mode to 1 or 2, which follows the off-grid to on-grid transition sequence described above.

> ⚠ **CAUTION:** When using backup generators that are not approved to parallel with the grid, you are responsible for managing the Island Mode of the battery to avoid closing the islanding contactor/breaker when the backup generator is in operation.

6.4.4 Intentional Transition from Off-Grid to On-Grid

6.4.4.1 Island Mode Set to 1 (Auto Active)

1. As long as the islanding controller's Grid OK signal remains asserted, the Tesla system will sync back to the grid by actively regulating both voltage magnitude and angle to match microgrid values with the reported grid values. The SEL-700G will do a sync check before closing the grid disconnect.
2. Confirmation from the SEL-700G to the Tesla Site Controller that the grid disconnect is closed will prompt the inverter to go PQ mode and resume on-grid operations.

6.4.4.2 Island Mode Set to 2 (Island Ready)

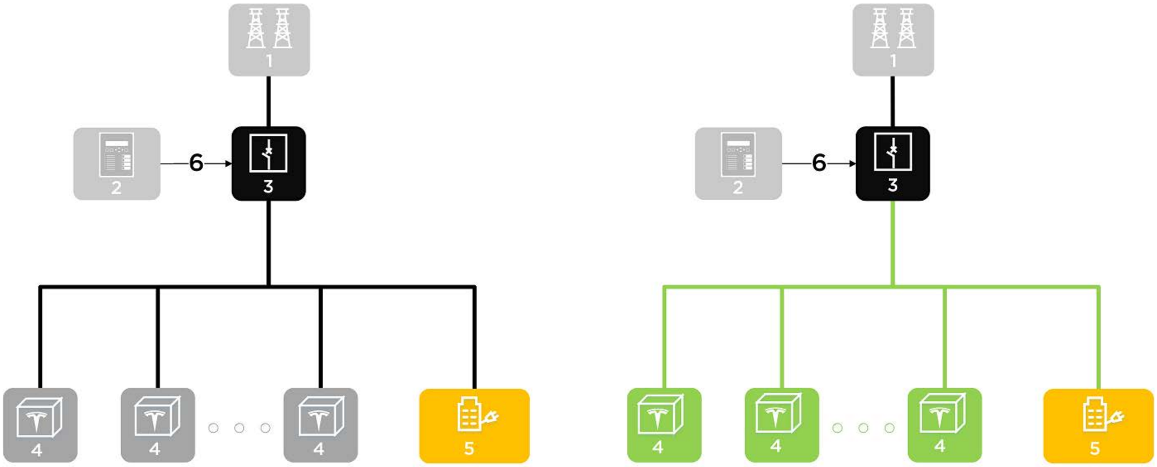
The battery will go to Standby and follow the process as described in *Island Mode Set to 2 (Island Ready) on page 39*.

6.4.5 Using Island Modes 1 and 2 While Islanded

While off-grid (with the breaker open and no grid present or a grid out of specification), you can toggle between Island Modes 1 and 2 to turn the battery on and off. For example, if the system is configured with Island Mode = 2 and the system has already transitioned from on-grid to off-grid, setting Island Mode = 1 will cause the inverters to actively charge/discharge to support the microgrid loads as a grid-forming source. If the grid returns during this period, the system will re-synchronize per the above procedure. Configuring the system to Island Mode = 2 will cause the inverters to transition to Standby, dropping the loads.

An example appears below:

Figure 17. Using Island Modes 1 and 2 While Islanded



Island Mode = 2 (Island Ready)	Island Mode = 1 (Auto Active)
1. Utility	**1.** Utility
2. Islanding controller	**2.** Islanding controller
3. Islanding circuit breaker OPEN	**3.** Islanding circuit breaker OPEN
4. Inverters in standby	**4.** Inverters in grid-forming (VF) mode
5. Loads	**5.** Loads
6. OPEN command issued	**6.** OPEN command issued

6.4.6 Island Off

In order to reduce standby losses in the event of a grid outage, the Island Mode can be set to 5 (Island Off) to allow the system to fully shut down. In Island Off, after one hour has passed without AC voltage at the terminals of the inverter, the system will no longer internally support controls voltage and will drop the DC bus.

This mode can also be used to ensure the system shuts down fully when the AC voltage at its terminals is removed. The inverter AC contactors will be open in this state.

If this occurs in an off-grid microgrid, an external source of AC voltage (or Jumpstart) is needed to power the internal controls voltage. To resume system operation, change the Island Mode to 1 (Auto Active) or 3 (Intentional Island). To place the system in a Standby state, change the Island Mode to 2 (Island Ready).

NOTE: The Always Active add-on, if used, must be disabled before the system can be placed in Island Off and bring voltage down on the DC bus.

6.5 Load Shed Integration

An islanding system can be set up to shed loads using three approaches.

6.5.1 Direct Breaker Control

For loads to be shed that are behind a breaker, customers can parallel the TRIP circuit of the load shed breaker with the grid disconnect's TRIP circuit. This will allow the load shed breaker to follow the same operation/status of the grid disconnect.

If the customer wants to use a wait timer, additional programming and wiring into SEL-700G is required. Refer to *Using the SEL-700G With Tesla Products* for additional details.

6.5.2 Direct Load Control

Customers can also directly shed the load by wiring the low voltage control circuit of the device to be shed to the output card of the SEL-700G. This will disrupt the device's power circuit and shed loads when the grid breaker is opened.

6.5.3 SOE-Based Load Control

By integrating with a load controller, using Tesla's SOE-based load shedding (see the *Microgrid Controller Owner's Manual*) together with the islanding controller, the system can be configured to shed load based on both SOE and grid status. This scenario requires both a Tesla-approved load controller (see *Configuration Specification: Using I/O Devices with Tesla Products*) and integrating it with the SEL-700G. Please discuss with your Tesla engineering contact if you are interested in this option.

7 Solar

Solar is a grid-following source and must be paired with a grid-forming source (such as a utility grid when on-grid, or battery or generator when off-grid). It is also an intermittent source, but since it has zero marginal cost, solar will always be consumed first before using other sources.

When solar power drops, other sources must be immediately available to increase their power output. It must also be controlled to prevent it from overcharging the battery system or back-feeding into generators. There are two main methods of controlling solar when off-grid:

- Frequency shifting:
    - This can be done in limited scenarios just using Tesla battery system as described in *State of Energy Frequency Shifting on page 30*.
    - The Tesla Microgrid Controller incorporates frequency shifting behavior as a fallback control strategy to direct communications.
- Direct communications:
    - The Tesla Site Controller can integrate with third-party solar inverters via Modbus/TCP to monitor key inverter metrics and alerts.
    - For sites using the Tesla Microgrid Controller, the Tesla Site Controller will limit active power through both direct communications and frequency shifting while off-grid.
    - The Tesla Site Controller also has the capability to limit export of a combined battery system and solar system output when operating on-grid.

Tesla recommends using a microgrid controller for more robust operation in all scenarios. In limited scenarios, using frequency shifting only may be preferable if additional communications infrastructure adds too much cost or complexity to the project.

Table 9. Methods of Controlling Solar When Off-Grid

	Frequency Shifting	Direct Communications
Curtailment at high SOE	✓	✓
Curtailment to prevent solar from overpowering battery		✓
Curtailment to prevent solar from backfeeding generator	✓ *(When generator coordinated in droop)*	✓
Curtailment when communications fail	✓	
On-grid curtailment to meet utility export limitations		✓
Increasing and managing spinning reserve based on solar output with Microgrid Controller		✓

	Frequency Shifting	Direct Communications
Solar Inverter details including telemetry and alerts in Powerhub		✓

7.1 Frequency-Watt Only

Frequency-Watt curtailment is the ability to limit power output proportionally as a function of the grid frequency. For microgrid projects, frequency ride-through and frequency-watt curtailment settings on the solar inverter should be adjustable beyond utility grid codes. Frequency-Watt curtailment must be based on the nameplate rating of the solar inverter.

It is the customer's responsibility to determine settings if only frequency curtailment is used.

7.2 Tesla Microgrid Controller (Modbus TCP + Frequency Watt)

7.2.1 Tesla Microgrid Controller Features

7.2.1.1 Spinning Reserve Management

The Microgrid Controller manages the microgrid "swing bus," which includes all active battery and generator assets operating in grid-forming mode. Since solar is an intermittent grid-following resource it must be backed up by grid-forming assets on the swing bus. The Microgrid Controller assumes that at any moment all solar can trip offline; this means that there must always be enough generators and batteries online to meet the full load (without solar).

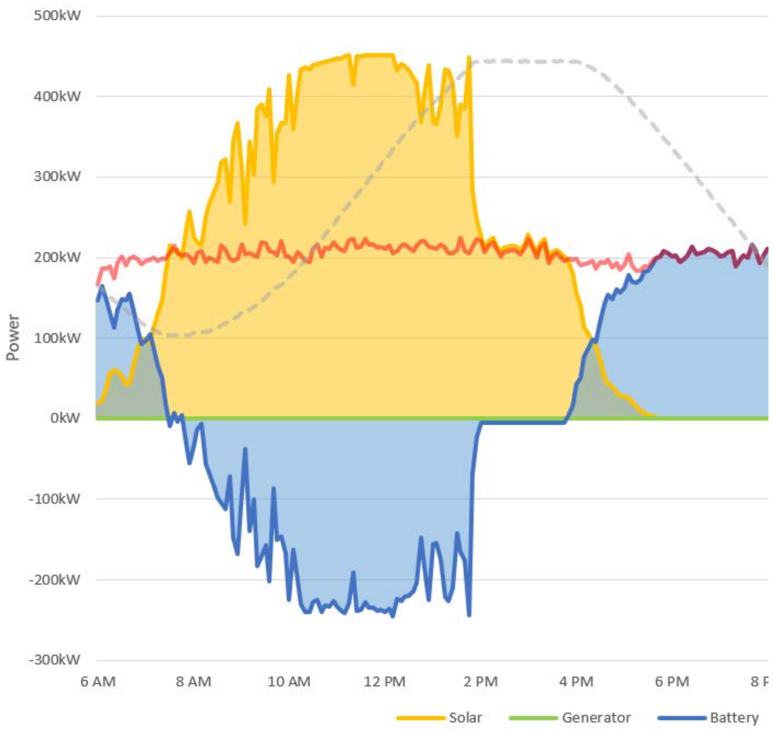
When loads are high, the Microgrid Controller will turn on additional assets (generators) to ensure that the swing bus does not trip on overload. The "spinning reserve required" setting should be set to maintain a safe margin between loads and the maximum swing bus power. A general recommendation is to set this at the maximum load step that could occur in the time it takes to turn on a generator.

When load is low (or solar is high) and no more generators can be turned off due to the spinning reserve requirement, the Microgrid Controller will curtail intermittent assets (such as solar) to ensure the swing bus does not trip on underpower (battery charging overload, generator reverse power).

7.2.1.2 Curtailment at High SOE

When the battery is within 1% of its maximum off-grid SOE as described in *Off-Grid SOE Range on page 31*, solar will start to be curtailed. At steady state, the battery will remain at the maximum off-grid SOE threshold and solar will be curtailed such that all solar is directly consumed by the load.

Figure 18. Solar Curtailment at High SOE



7.2.1.3 Microgrid Opticaster

The Tesla Site Controller records historical 15-minute energy production. This will be used by Opticaster to forecast solar production over the following 24 hours. This forecast will be used in conjunction with load forecasts and other microgrid settings to optimize generator dispatch.

7.2.2 Solar Inverter Integration Requirements

Any solar inverters that will be integrated with the Tesla Site Controller must be listed as approved on the *Tesla Industrial Energy Approved Vendor List* (AVL). If the inverter is listed as Provisional, it has been reviewed by Tesla but is not ready for integration. Refer to the AVL for more details.

The requirements listed in this section have been assessed by Tesla as part of the AVL review process and determined to meet the minimum requirements for integration with the Microgrid Controller. However, since inverter selection and integration are the responsibility of the customer, the microgrid designer should be aware of the requirements and make the inverter selection accordingly. For example, inverters that provide faster responses to curtailment commands and reliable communication will result in more stable microgrid operation.

Where certain settings are required as described in the sections below, these can be found in the standard settings in the *Solar Inverter Configuration Specification* for each type of solar inverter.

7.2.2.1 Modbus Communication Capability

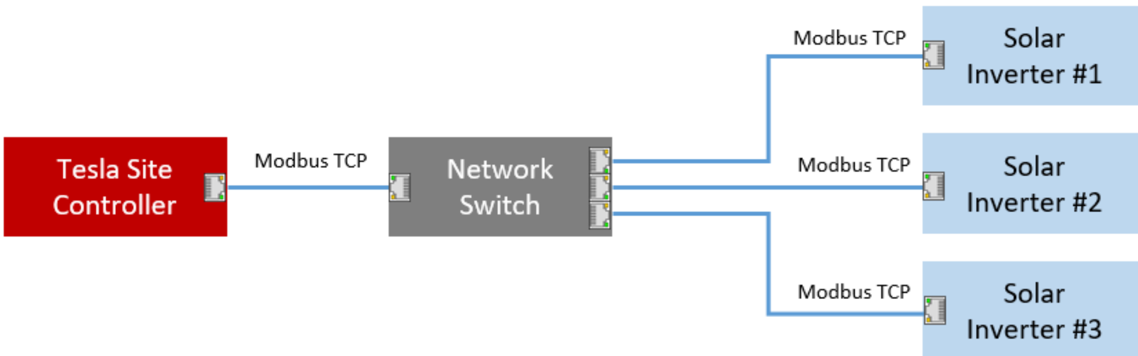
The solar inverter must support Modbus protocol and preferably Modbus TCP. If the inverter only supports Modbus serial RTU communication, a Modbus gateway must be installed to convert Modbus RTU into TCP. The customer is responsible for procuring and installing the Modbus gateway per the devices listed in the *Tesla Industrial Energy Approved Vendor List* (AVL).

The Tesla Site Controller can communicate with the solar inverters through two network topologies as outlined below. Tesla recommends using Direct TCP Communication.

7.2.2.1.1 Direct TCP Communication

Direct TCP, as depicted below, is Tesla's preferred way to communicate. It enables the fastest possible polling rate for monitoring and the fastest possible speed to detect load drops and curtail solar power output.

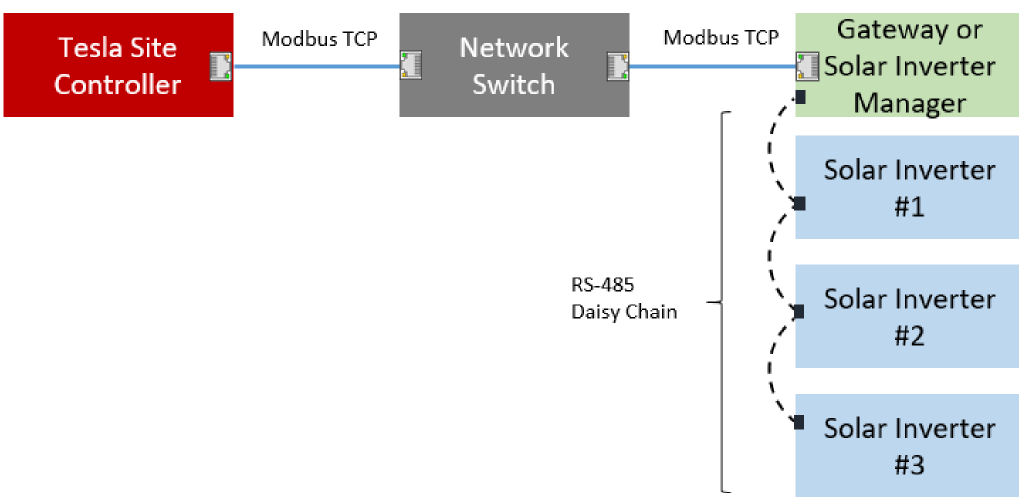
Figure 19. Direct TCP Communication



7.2.2.1.2 RS-485 Communication Behind a TCP/RS-485 Gateway or Solar Inverter Manager

When the Tesla Site Controller is configured with two or more inverters at the same IP address, it will detect that the inverters are connected in a daisy-chain RS-485 connection behind a gateway. Therefore, the Tesla Site Controller will serialize Modbus requests to the inverters one at a time to prevent communication issues that are typically observed in a serial RS-485 connection. Due to the Modbus requests' serialization, it will take longer to receive all the solar inverters' monitoring values. Consequently, issuing curtailment commands will take longer than with Direct TCP Communication. Too many inverters in the daisy-chain could lead to instabilities in the microgrid due to delayed communications.

Figure 20. RS-485 Communication



7.2.2.2 Modbus-Commanded Curtailment

For Microgrid Controller projects or on-grid projects in which the Tesla Site Controller will limit solar export, direct solar control is required. The solar inverter must respond quickly to active power setpoints from Tesla Site Controller to avoid overcharging the battery and inadvertent export.

7.2.2.3 Frequency-Watt Curtailment

Frequency-watt curtailment is the ability to limit power output proportionally as a function of the grid frequency. For microgrid projects, frequency ride-through and frequency-watt curtailment settings on the solar inverter should be adjustable beyond utility grid codes. Frequency-watt curtailment must be based on the nameplate rating of the solar inverter.

The standard settings are:

- Start curtailing at +0.4 Hz from nominal (ie. 60.4 Hz or 50.4 Hz)
- Fully curtail at +1.4 Hz from nominal (ie. 61.4 Hz or 51.4 Hz)

7.2.2.4 Night Mode (Recommended)

In Night Mode, the solar inverter switches to the AC side to draw power for the communication module to keep the communications active when DC power is unavailable. Tesla recommends enabling the Night Mode if the solar inverter supports it.

7.2.3 Transient Overvoltage Protection

While the Tesla Site Controller always attempts to maintain all sources within operating limits, it cannot protect against faults, voltage transients, or equipment malfunction. If the battery inverter suddenly trips offline, improperly configured solar inverters can continue to operate and allow AC voltage to drift up to damaging levels. Depending on the overvoltage magnitude and duration, damage to loads or Tesla battery inverter may result.

For battery systems with the Powerstage-based inverter architectures, an instantaneous line-to-neutral voltage above 474 V (335 Vrms) exceeds the breakdown voltage of the IGBTs inside the Powerstage and could allow passive rectification onto the DC bus that may result in permanent damage to the Powerstages and other components. Given that it takes 100ms for the internal contactor to open and isolate from the AC bus after the Powerstage goes into a standby or faulted state, solar inverters must offer adequate protection against instantaneous overvoltage, such as through effective instantaneous trip settings. Battery inverter damage limits are shown in the table below:

Table 10. Battery Inverter Damage Limits

Instantaneous Voltage (L-N)	Per-Unit Voltage at 277V L-N	Per-Unit Voltage at 230V L-N	Permissible Instantaneous Current from AC Network
< 474 V	< 1.2	< 1.45	> 1.4 p.u.
474 - 553 V	1.2 - 1.4	1.45 - 1.7	1.4 p.u.
≥ 553 V	≥ 1.4	≥ 1.7	0 p.u.

8 Generators

Generators are commonly used as backup load support when operating off-grid, either because the solar and battery system are not sufficiently sized to supply all loads all the time, or as a redundant power source. Depending on system sizing and configuration, this may be because the battery system is at low SOE or has insufficient power to support the loads. Generators can be connected in parallel or behind an ATS. The connection principle of the generator affects its contribution to the microgrid operation.

Tesla recommends paralleling generators where possible as they offer more features and functionality to the microgrid. However, for brownfield sites with an existing generator, it can be simpler to add an ATS rather than upgrading the generator for paralleling. The designer therefore needs to make this trade-off based on project needs:

- For sites in which the generator may run for a meaningful amount of time (any off-grid site or grid-tied sites with weak grids), Tesla highly recommends upgrading to paralleling as this will pay off over the life of the project.
- For on/off-grid sites with an islanding controller in which utility outages are rare and there is an existing isochronous generator, adding an ATS instead may be sufficient.

Table 11. Generator Considerations

Microgrid Functionality	ATS Generator	Paralleling / Microgrid Controller
Charge battery system from generator		✓
Use battery system and generator together to serve larger load		✓
Use generator to provide additional spinning reserve beyond battery system power		✓
Physically isolate solar from generator	✓	
Seamless transition between battery system and generator operation		✓
Optimization of generator dispatch to minimize fuel usage		✓
Optimization to achieve generator Quiet Hours		✓
Generator meter data in Powerhub	✓	✓
Generators details including start/stop commands, target power and alerts in Powerhub.		✓

The Tesla Microgrid Controller is required to control paralleling generators and can control any number of generators with different generator controllers if they are on the *Tesla Industrial Energy Approved Vendor List* (AVL). The Microgrid Controller will not control generators behind an ATS, and all design and operational implications of ATS generators are the customer's responsibility.

NOTE: Tesla does not currently support controlling generators on-grid in parallel with the utility. If your project requires this functionality, please contact Tesla to explore alternatives.

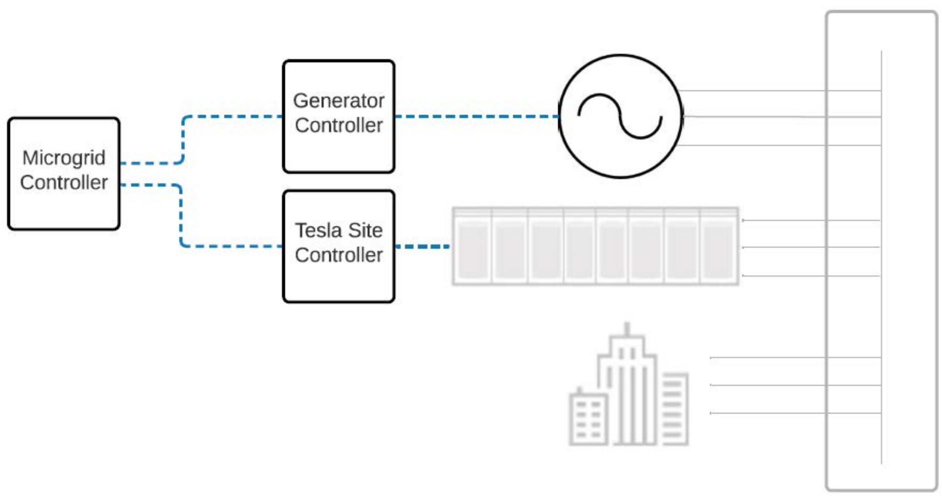
8.1 Parallel Generators

Microgrids which use paralleling generators must use a microgrid controller to coordinate dispatch with the Tesla battery system. Using the Tesla Microgrid Controller will enable the features described in *Tesla Microgrid Controller on page 50*. The Tesla Microgrid Controller requires generator controllers listed on the *Tesla Industrial Energy Approved Vendor List* (AVL) which must be configured to operate in droop and communicate with Modbus per Tesla's specifications highlighted in *Paralleling Generator Integration on page 53*.

8.1.1 Tesla Microgrid Controller

The Tesla Site Controller will send commands to the Generator Controller to start/stop and shift the generator's no-load frequency to achieve the desired load sharing. The features in this section define how the Tesla Microgrid Controller determines when to send start/stop commands and how to determine load sharing.

Figure 21. Tesla Microgrid Controller with Generator Controller



8.1.1.1 Generator Control Modes

There are three generator control modes available:

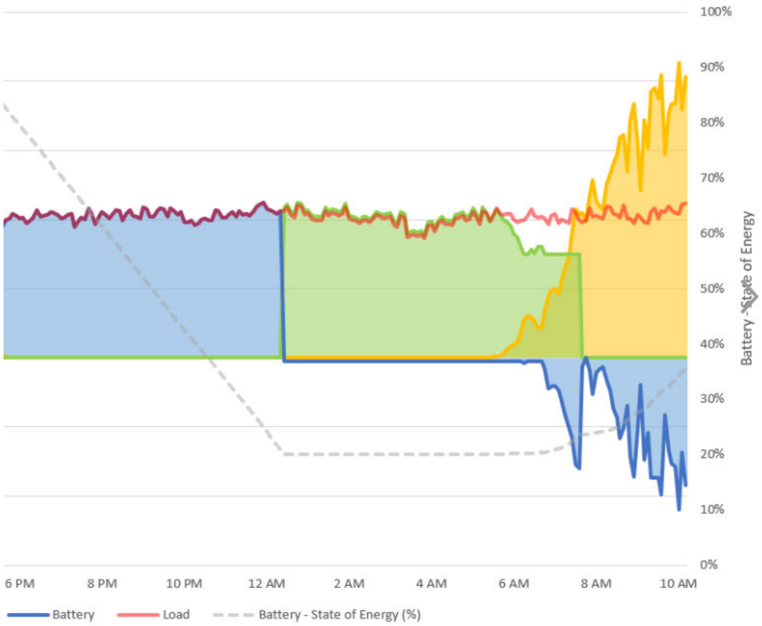
- Load following
- Low SOE charge
- Microgrid Opticaster

One mode must be selected at commissioning time.

8.1.1.1.1 Load Following

When configured for load following, if the battery system hits a low SOE, the Microgrid Controller will match the generator output to the load and maintain a constant battery SOE. The generator will not turn off until another source (such as solar) has started to charge the battery and the "stop generator" SOE threshold has been achieved.

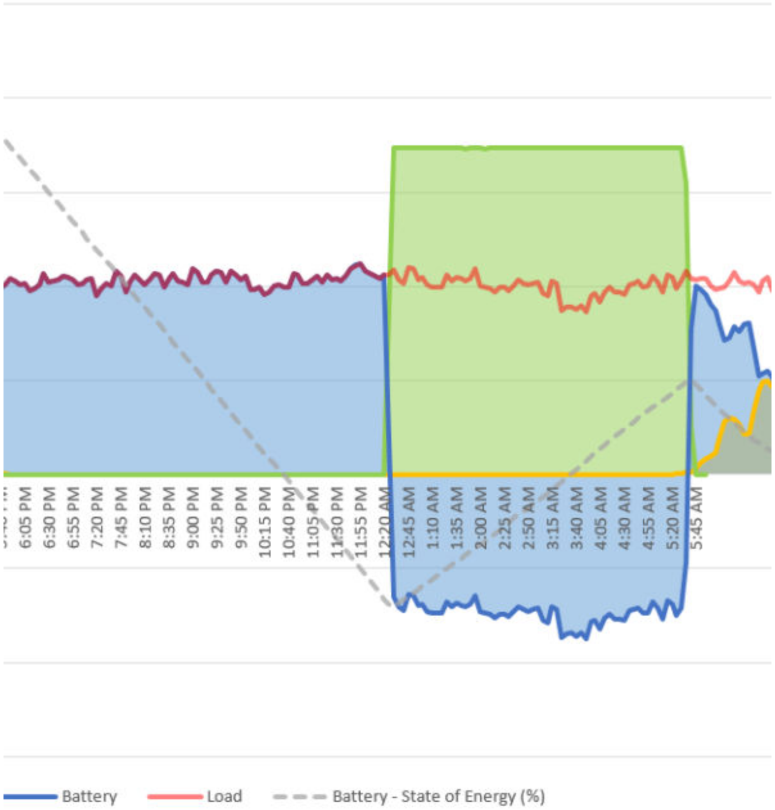
Figure 22. Load Following Generator Control Mode



8.1.1.1.2 Low SOE Charge

When configured for low SOE charge, if the battery system hits a low SOE, the Microgrid Controller will attempt to charge the battery at its maximum charge power by dispatching one or multiple generator(s). The generators will turn off once the "stop generator" SOE threshold has been achieved.

Figure 23. Low SOE Charge Generator Control Mode



8.1.1.1.3 Microgrid Opticaster

When Microgrid Opticaster is enabled with the Microgrid Controller, the following additional features are available:

- Opticaster replaces the rule-based generator control modes with a cost-optimized dispatch that seeks to minimize generator fuel usage.
  - Opticaster uses an efficiency curve for each generator to understand the fuel usage at different power levels, and uses forecasting of renewable generation and loads to provide a 24 hour dispatch forecast that will run generators at their most optimal power levels. This forecast re-runs every 15 minutes and is passed over to the real-time Microgrid Controller.
- If for any reason the Microgrid Controller cannot meet the loads with the assets Opticaster forecasted for a given 15 minute period (e.g., loads are higher than Opticaster forecasted), it will default to load following mode. Keeping loads powered is considered a higher priority than minimizing fuel consumption.

8.1.1.2 Generator Min/Max Run Rate

The Microgrid Controller will always send power commands with the configured minimum and maximum generator run rate settings. Since the Microgrid Controller will send commands up to and including these limits, short transient events could cause the generator to briefly violate these limits. The battery system will absorb as much of the transient events as possible with its steeper droop curve, but all assets will respond according to their relative droop curves and inertia. If this is an expected issue for the generator, set the limits sufficiently narrow to account for the expected transients.

Keeping the generator above the minimum run rate is considered higher priority than load following; if the load drops below the generator minimum run rate but the generator cannot be turned off, excess power will be charged into the battery system.

The only intended violation of these run rates would occur if there is no alternative to keep loads powered. For example, if the load is higher than the maximum run rate and no additional power sources can be called by the Microgrid Controller, it will let the generator meet this load.

8.1.1.3 Spinning Reserve Management

The Microgrid Controller manages the microgrid “swing bus” which includes all active battery and generator assets operating in grid-forming mode. The generator contributes its full nameplate power to the swing bus maximum power. The generator’s contribution to the swing bus minimum power is 0 kW, although the generator should not regularly operate at 0 kW.

When loads are high, the Microgrid Controller will turn on additional assets (generators) to ensure that the swing bus does not trip on overload. The “spinning reserve required” setting should be set to maintain a safe margin between loads and the maximum swing bus power. A general recommendation is to set this at the maximum load step that could occur in the time it takes to turn on a generator.

When load is low (or solar is high) and no more generators can be turned off due to the spinning reserve requirement, the Microgrid Controller will curtail intermittent assets (such as solar) to ensure the swing bus does not trip on underpower (battery charging overload, generator reverse power).

8.1.1.4 Automatic Frequency Control (AFC)

The Microgrid Controller will adjust the no load frequency (the nominal frequency) of the generator controller to regulate frequency and control load sharing with other assets. While it is operating, any manual no load frequency commands will be overwritten by the Microgrid Controller.

8.1.1.5 Blackstart

If the Microgrid Controller detects a dead AC bus (no generation online) and a generator is available, it will automatically attempt to turn on the smallest diesel generator to initiate blackstart. Off-grid or weak grid sites should have at least one generator that is capable of blackstarting the grid in case of issues with other sources.

8.1.1.6 Quiet Hours (Opticaster)

If enabled, Opticaster will ensure that enough solar production and battery energy is available to serve the loads while keeping all generators off between the start and end of quiet hours. This time period is configurable by hour and minute. To achieve a battery state of energy sufficient for the full length of quiet hours, Opticaster may start a generator or extend the operation of a running generator to charge the battery before the start of quiet hours.

8.1.2 Paralleling Generator Integration

To enable the Tesla Microgrid Controller features through no-load frequency shifting, all paralleling generators are configured in droop. The Tesla Site Controller communicates with the generator controller via Modbus and monitors their power output directly. It will operate the generator controller as a “black box” and will not interfere with the generator controller's internal workings. The generator controller is expected to manage everything else related to the starter motor, fuel valve, breaker control, sync check, and faults. Tesla provides required settings for Tesla-approved generator controllers in the *Generator Controller Configuration Specification*.

The generator controller is required to communicate with and coordinate the following:

- Automatic Voltage Regulator (AVR)
- Generator Breaker Control and Sensing

- Engine Control Unit (ECU)
    - Governor
    - Fuel Valve
    - Starter Motor

The generator controller should meet the requirements defined below to operate with Tesla Site Controller. A list of Tesla-approved generator controller that meet all the requirements mentioned below can be found on the *Tesla Industrial Energy Approved Vendor List* (AVL). For generator controllers that are not on the approved list, options provided in *Generator Controller Retrofit Options on page 55* can be explored. The generator should support the operational needs of the generator controller to meet the requirements below.

8.1.2.1 Generator Controller Requirements

- Capability to load share and parallel with other generation sources:
    - Support Frequency and Volt-Var droop operation. The generator controller must be capable of sending analog bias signals required for droop.
    - The engine control unit (ECU) and automatic voltage regulator (AVR) must be compatible with the generator controller and properly configured to allow the generator controller to adjust generator speed and voltage. This document does not include information on the configuration of the ECU and AVR settings.
    - The generator's transient response should meet performance class G3 as per ISO 8528-1:2018.
    - Standard generator droop settings
        - Frequency Droop:
            - 50 Hz sites:
                - 51.4 Hz is the default no load frequency to start commissioning
                - 5.5% droop (%Hz/%P)
            - 60 Hz sites:
                - 61.4 Hz is the default no load frequency to start commissioning
                - 6.6% droop (%Hz/%P)
        - Voltage:
            - 10% droop (%Q/%V)

- Synchronizing breaker control and monitoring:
    - When started in any mode, the generator controller should detect bus voltage and automatically close onto a dead bus or synchronize to a live bus. The synchronizing breaker circuit should be powered from the line side to support dead bus closure.
    - The generator controller should automatically open the breaker to protect generator hardware from hazardous conditions, including overload, reverse power, or fuel exhaustion.
    - The generator controller should be able to monitor breaker position status.

- Modbus TCP communication capability:
    - The generator controller should accept start/stop commands and no-load frequency and voltage setpoints via Modbus TCP. Alerts and operating parameters should be available via Modbus TCP.

- Tesla Site Controller should communicate with each generator controller directly over Modbus TCP instead of a daisy chain network topology. If the generator controller does not support Modbus TCP, a Modbus gateway should be installed to convert serial to TCP communication. Information on the Modbus gateway approved for use by Tesla can be found on the *Tesla Industrial Energy Approved Vendor List*.

- Generator Controller Power
  - The generator controller must be able to draw power from the starter batteries or other UPS source in case the microgrid AC voltage is not available.

> **NOTE:** While the Tesla Site Controller always attempts to operate all assets within their limits, it cannot protect against faults, voltage transients, or equipment malfunction.

8.1.2.2 Generator Controller Recommendations

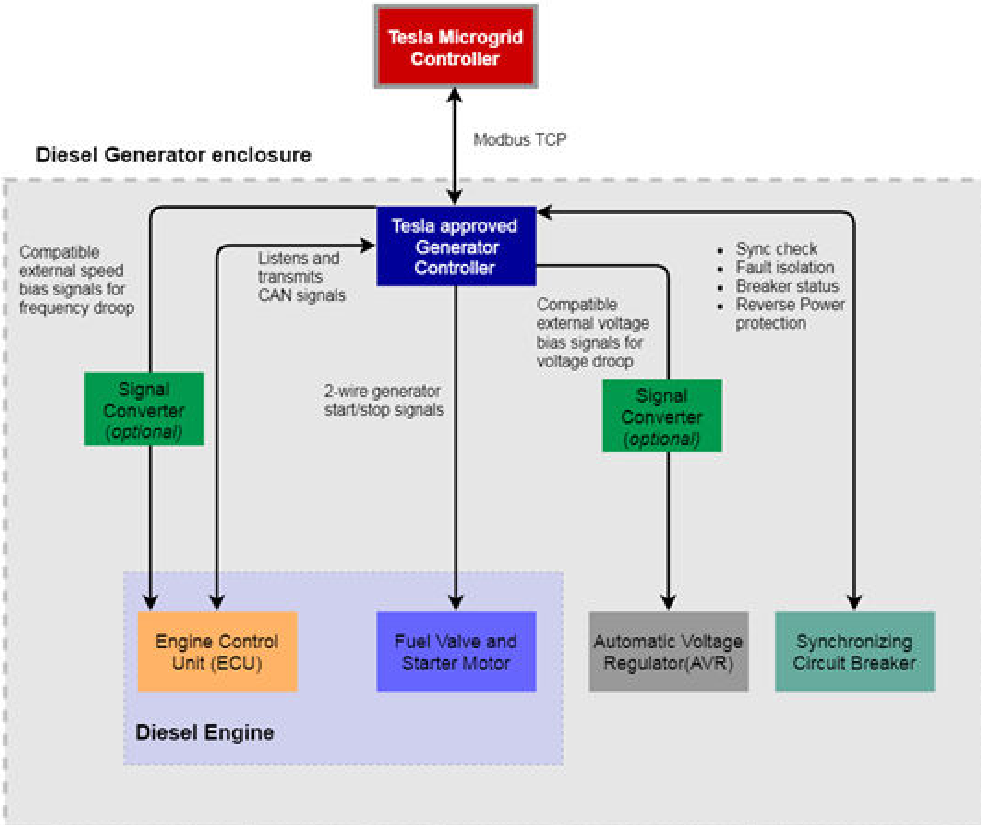
The battery circuit should include a disconnect switch and battery tender powered from a reliable source to maintain and avoid draining or damaging the battery during extended idle periods.

8.1.2.3 Generator Controller Retrofit Options

If the existing generator is not on the *Tesla Industrial Energy Approved Vendor List* (AVL), the generator controller setup must be retrofitted using one of the three options specified below to meet Tesla's microgrid requirements. Tesla recommends replacing the generator controller over stacking whenever possible to allow the generator controller to have direct and complete control on all generator components and operations. Replacing generator controllers also reduces complexity during installation and removes potential undesirable interactions due to two different generator controllers accessing the same components inside the generator.

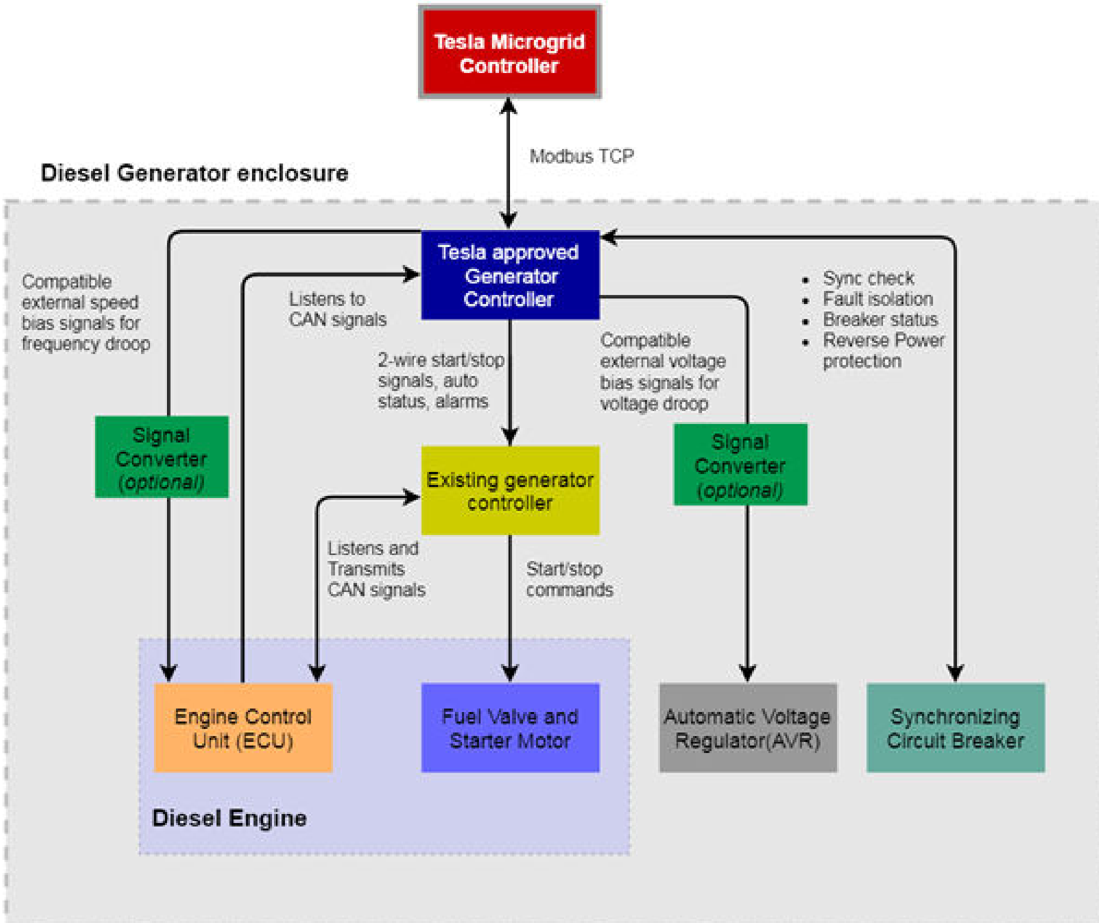
1. **Replace generator controller *(Tesla-preferred)*:** In this option, the existing generator controller is removed, and a Tesla-approved generator controller is installed. The new generator controller can also be upgraded to a different model by the existing controller manufacturer if the model meets Tesla's requirements. If the generator controller is upgraded or replaced, the new setup should meet all the requirements specified in *Generator Controller Requirements on page 54*.

Figure 24. Generator Controller Retrofit Option 1: Replace



2. **Stack a Tesla-approved generator controller:** Stacking should only be considered if replacing the existing generator controller is not a viable solution. When stacking, the existing generator controller stays connected, and a Tesla-approved generator controller is installed to operate in parallel. The Tesla Site Controller will communicate over Modbus TCP only with the stacked Tesla-approved generator controller. In addition to the requirements specified in *Generator Controller Requirements on page 54*, the new setup should also meet the following criteria:
   a. Critical status information from the existing controller like shutdown alarms and auto status must be sent to the stacked Tesla-approved generator controller.
   b. The generator controller must be able to send 2-wire start/stop signals to the existing controller. The existing controller then starts or stops the generator.
   c. The generator controller must be able to send signals directly to adjust frequency and voltage bias signals and control the synchronizing breaker.

Figure 25. Generator Controller Retrofit Option 2: Stack



3. **Develop an interface for existing generator controller:** Tesla can develop an interface to control the existing generator controller provided it meets all the requirements mentioned in *Generator Controller Requirements on page 54*. There is a five-month lead time to review, procure, test, and develop a Modbus interface for the new generator controller on the Tesla Site Controller. A fee will be charged for developing the Modbus interface.

8.2 ATS Generators

When a generator is behind an ATS, it is completely isolated from the Tesla battery system. While a microgrid controller may be needed for controlling the solar and battery system depending on the designer's decision, it will not be used for controlling the generator. It is the customer's responsibility to ensure the ATS operation is coordinated with other microgrid assets and does not resulted in undesirable behavior due to interaction with other control or switching systems.

Tesla will only approve microgrids in which the ATS is in a downstream configuration, as shown in *Common Architectures on page 17*. This allows the battery to manage islanding transitions with the islanding controller and to charge from solar. The generator will only be started when both the battery and grid are down.

An upstream configuration, in which the generator can be closed-in by the ATS at the same time as the battery and solar are operating, will not be approved. This presents risk of out-of-sync closures and reverse power by the PV to the generator.

9 Meters

In addition to reading data directly from sources (such as the battery inverters, solar inverters, or generator controllers), meters can be installed and connected to the Tesla Site Controller. In some cases, this is required, whereas in others this is optional or should be avoided depending on the specific design considerations.

For controls purposes, the Tesla Site Controller can use data from either meters or sources, but not both. For example, if the Tesla Site Controller is configured to communicate with both solar meters and solar inverters:

- The Tesla Site Controller will perform controls based on the aggregate of the solar meters only.
- If any or all solar meters go MIA, the Tesla Site Controller will not fall back on solar inverter readings.

When both meters and sources are connected to the Tesla Site Controller, monitoring data will be available for both in Powerhub.

This table provides a high-level guide for when meters should be installed. Deeper insight into these guidelines per meter is provided in the sections below:

Table 12. Meter Usage Guidelines

Location	Short Answer
Site Meter on page 58	Required for sites connected to a utility under certain conditions
Load Meter on page 59	Required for sites connected to a utility under certain conditions in which a site meter can't be installed
Battery Meter on page 59	Required
Solar Meter on page 59	Optional
Generator Meter on page 60	Sites with a Tesla Microgrid Controller: Not Recommended Site without a Tesla Microgrid Controller: Optional

Any meters being used in a project must be provided, installed, and configured by the customer. Tesla will confirm communication with these energy meters but is not responsible for their accuracy.

Refer to the relevant product *Design Manual* for information on supported meters and requirements.

NOTE: The system requires Ethernet to connect meters to the Tesla Site Controller. RS-485 is not supported.

NOTE: Tesla is not responsible for the accuracy of the energy meters provided, installed and configured by the customer. Please consult with the energy meter manufacturer in the event of faulty communications from energy meters.

9.1 Site Meter

A site meter is only relevant for sites that are connected to a utility grid. It is only required to be installed if the project's on-grid use case matches one or more of the following scenarios:

- Using Opticaster to minimize utility demand charges and time of use rates

- Using Voltage Control reactive power mode at the site level
- Using Site Control real power mode
- Site power limits and non-export controls are imposed
- You want utility consumption and load calculation to be displayed in Powerhub

NOTE: Load calculations are not accurately displayed in Powerhub for periods when the site operates on-grid if a site meter is not installed, because the Tesla Site Controller will not have sufficient datapoints to calculate the load.

NOTE: Site meter data should only represent power flow from or to a utility. If the site meter is reading non-utility power, this will impact certain controls like Opticaster (both on- and off-grid).

9.2 Load Meter

Where there is a utility connection, a site meter is usually installed, and load is calculated from that data together with data from other assets. In rare scenarios it may be easier to install a load meter and have the Tesla Site Controller calculate the site power instead.

NOTE: A site can never have both a site meter and a load meter.

9.3 Battery Meter

A battery meter is required to be installed on all Tesla battery system sites. Although for off-grid controls purposes, the Tesla Site Controller will usually not be configured to communicate with this meter, Tesla still requires the meter for warranty purposes. The Microgrid Controller will use data from the battery inverters for controls because of superior behavior in MIA conditions. Using a dedicated battery meter means that if the meter goes MIA, all battery power is lost in net load calculations. The Microgrid Controller will therefore not be able to accurately calculate the load to be supplied by the microgrid, and will distribute incorrect power sharing commands to the microgrid assets.

9.4 Solar Meter

If the Tesla Site Controller is configured to communicate with each solar inverter via Modbus, a solar meter is not required for the Microgrid Controller, but the designer can decide to install one based on the trade-off between data integrity and controls reliability. If no solar meter is installed, the Tesla Site Controller will calculate total solar power by summing the power from each solar inverter, but depending on the number of solar inverters there may be reliability concerns:

- Meters will provide higher data availability of total solar output compared to aggregating a large number of direct solar inverter connections because meters are typically more reliable at communications than solar inverters. If solar inverters are used as the metering source, a single solar inverter going MIA will stop aggregate solar power from reporting in Powerhub, though this will not meaningfully impact controls.
- However, if a dedicated meter is installed and goes MIA, the Microgrid Controller will not be able to account for changes in solar output in spinning reserve calculations. The Microgrid Controller will therefore not be able to accurately calculate the load to be supplied by the microgrid, and will distribute incorrect power sharing commands to the microgrid assets. Frequency shifting will be used as fallback and should be reliable so long as solar production is not larger than battery available charge power.

9.5 Generator Meter

Sites using the Tesla Microgrid Controller will communicate with each individual generator controller. Normally no generator meter is installed, so the Tesla Site Controller will calculate total generator power output from the sum of the generator controllers. If a generator meter is installed and that meter goes MIA, changes in generator power will not be accounted for in net load calculations. The Microgrid Controller will therefore not be able to accurately calculate the load to be supplied by the microgrid, and will distribute incorrect power sharing commands to the microgrid assets.

Sites which are not using the Tesla Site Controller to control generators, but have a generator (such as an ATS site), can install a generator meter in order to show generator power output in Powerhub. The Tesla Site Controller will however not be involved in controlling the generator or ATS – this is for monitoring purposes only.

10 Sizing

10.1 Steady-State Operation

10.1.1 Sizing for Islanding Transitions

The Tesla battery system can support loads during an islanding transition as long as the load is less than the battery system power. Customers with loads larger than the battery system power should explore load shedding solutions described in *Islanding on page 33*, or only install the battery system on a dedicated emergency loads panel.

Generators cannot be used during the islanding transition, as they can only be started once off-grid and need to be stopped before resynchronizing to the grid.

10.1.2 Sizing for Continuous Off-Grid Operation

The maximum power of all sources (grid-forming droop assets such as batteries and generators) must be greater than the microgrid peak load. Reactive loads, distribution system losses, and potential transients (inrush from certain loads like a motor being started during operation) must be considered in this assessment.

Designers should always consider soft-starters or sequenced start-ups for motors using independent SCADA in order to reduce impact on battery system operation and related sizing requirements.

10.2 Blackstart Sizing

For any standard microgrid, the Tesla battery system must be sufficiently sized to be able to blackstart the microgrid, accounting for inrush for transformers and other inductive loads. For off-grid or weak-grid microgrids, a single generator should also be capable of blackstarting the microgrid.

The battery system voltage ramp at blackstart as described in *Blackstart on page 29* means that a transformer rating of about 10:1 relative to the battery system nominal rating can be blackstarted when the transformers are not loaded. This does not apply to transformers being closed in across the line since the battery system will already be operating in steady-state and not executing the soft voltage ramp.

NOTE: Blackstarting with more than one source in parallel is currently not supported by the Tesla Microgrid Controller. Successful blackstart can still be achieves by a manual procedure that includes load management, but this must be flagged and discussed with your Tesla contact.

10.3 Solar Sizing

The solar system size is typically determined as an output of economic modeling that takes load levels and battery system charge power into account. In steady-state off-grid operation, the Tesla Microgrid Controller will curtail solar to prevent over-power.

However, in some cases, such as the scenario described in *Transient Overvoltage Protection on page 48*, a large solar-to-battery power ratio could increase the risk of overvoltage in the microgrid. Designers should be aware of this risk and consider mitigations such as solar trip settings or other voltage protection devices when deploying microgrids with a high solar:battery power ratio.

Islanding sites which may need to suddenly island due to a grid fault are at higher risk of experiencing this scenario, since the Tesla Site Controller will not be actively curtailing solar relative to the battery charge power if the system is operating on-grid. Designers should consider mitigations such as configuring a subset of their solar system to trip based on grid breaker status.

11 Faults and Protections

The Engineer of Record (EOR) is responsible for the electrical distribution system's protection scheme. The behaviour of the Tesla battery system in fault and overload conditions differs from a conventional synchronous generator source and should be considered in the protection scheme for an off-grid or islanded system.

This section provides some protection considerations for the Tesla battery system when deployed in a microgrids. Please note that these recommendations do not substitute for a detailed protection study, which should be conducted on a project-specific basis to determine the optimal protection solution.

11.1 Off-Grid Grid Codes

For projects not in parallel with a utility grid, Tesla configures the battery system with an off-grid grid code which dictates the inverter's voltage and frequency ride-through behavior in grid-forming mode. The table below shows the default grid-forming trip settings relative to the grid code's statically configured nominal voltage (V_{nom}) and frequency (F_{nom}). Refer to *Voltage and Frequency Setpoints* in the *Tesla Energy Controls and Communications Manual* for more information on the real-time no-load voltage and frequency controls of the Tesla battery system available via Modbus and DNP3 interfaces.

For standard microgrids, the default settings described in the table below will be implemented. The nominal voltage and frequency will be configured as 415V/50Hz or 480V/60Hz depending on the project location.

These default grid code settings can be altered to meet individual project needs if required. In addition to the grid code settings, the Tesla battery system has internal limits to self-protect from hardware damage such as overvoltage or overcurrent. Reach out to your Tesla Project Engineer to request alterations to the settings shown below.

Table 13. Default Off-Grid Grid Code Voltage and Frequency Ride-Through Settings

Setting Name	Setting
grid_form_lvrt_v_point_1	$0.85 * V_{nom}$
grid_form_lvrt_v_point_2	$0.5 * V_{nom}$
grid_form_lvrt_v_point_3	$0.2 * V_{nom}$
grid_form_lvrt_t_point_1	10 s
grid_form_lvrt_t_point_2	5 s
grid_form_lvrt_t_point_3	1 s
grid_form_hvrt_v_point_1	$1.1 * V_{nom}$
grid_form_hvrt_v_point_2	$1.2 * V_{nom}$
grid_form_hvrt_v_point_3	$1.3 * V_{nom}$
grid_form_hvrt_vmax_trip	$1.5 * V_{nom}$
grid_form_hvrt_t_point_1	12 s
grid_form_hvrt_t_point_2	0.16 s
grid_form_hvrt_t_point_3	0.016 s
grid_form_under_freq_fault_point_1	F_{nom} - 5 Hz

Setting Name	Setting
grid_form_under_freq_fault_point_2	F_{nom} - 10 Hz
grid_form_under_freq_time_point_1	20 s
grid_form_under_freq_time_point_2	0 s
grid_form_over_freq_fault_point_1	F_{nom} - 5 Hz
grid_form_over_freq_fault_point_2	F_{nom} - 10 Hz
grid_form_over_freq_time_point_1	20 s
grid_form_over_freq_time_point_2	0 s
grid_form_reconnect_time_delay	1 s
grid_form_reconnect_v_min	0.85 * V_{nom}
grid_form_reconnect_v_max	1.1 * V_{nom}
grid_form_reconnect_freq_min	F_{nom} - 5 Hz
grid_form_reconnect_freq_max	F_{nom} - 5 Hz

Figure 26. Default Voltage Ride-Through Settings

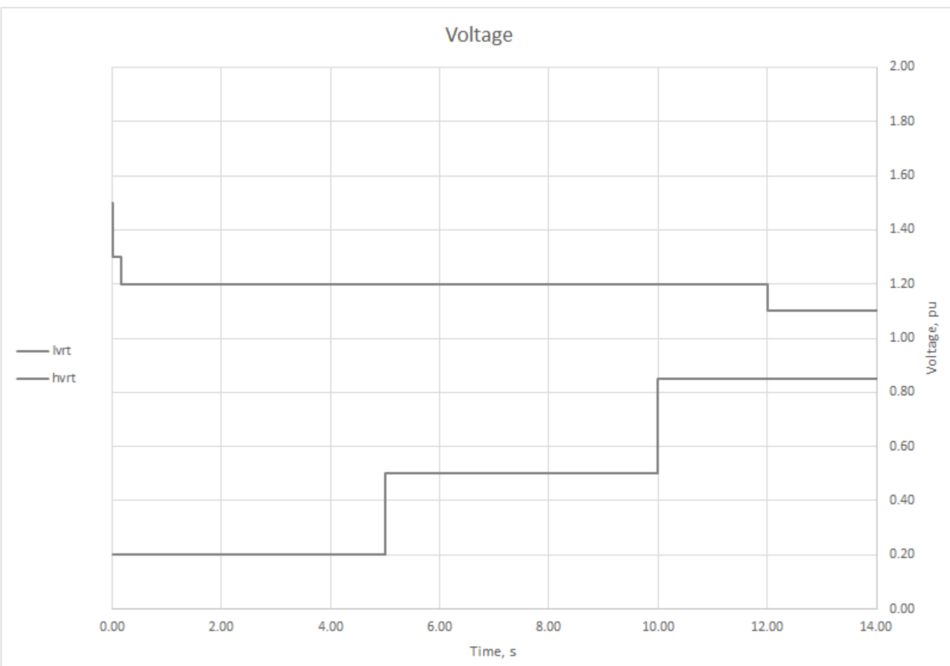
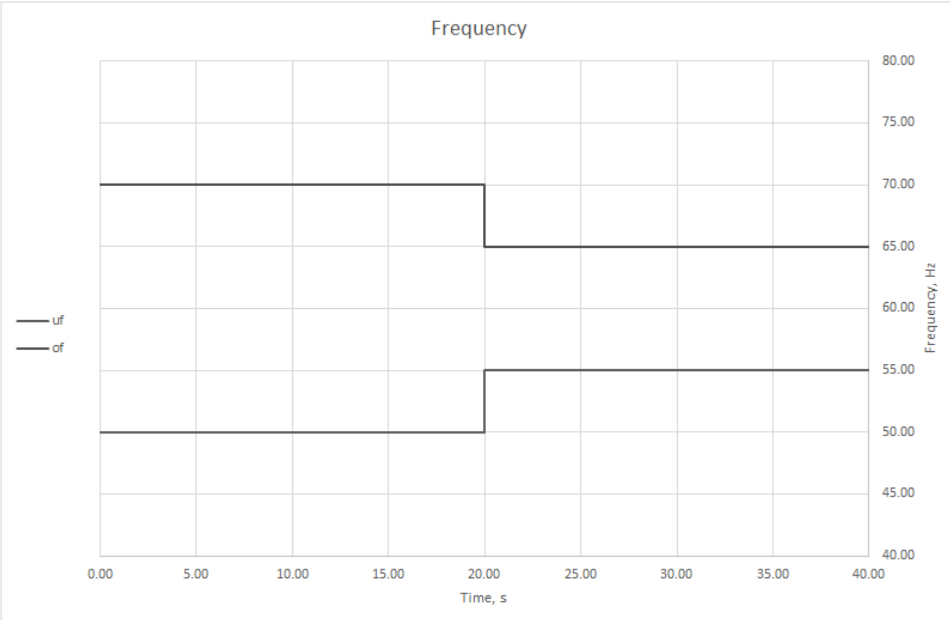


Figure 27. Default Frequency Ride-Through Settings



11.2 Overload Behavior

The battery system has a limited short circuit fault current contribution. The exact fault contribution will vary per product but contrasts with traditional synchronous generators such as turbines or diesel generators, which have expected fault currents that are typically an order of magnitude higher (10 to 20 times the nominal current rating of the generator). Thus, careful considerations should be taken for a system's protection scheme when employing inverters on microgrid applications. Traditional overcurrent protection devices or relay elements may not be capable of detecting the low magnitude fault current produced by the inverter. Therefore, other methods like voltage controlled elements and differential protection may be required to isolate faults.

Under overload conditions, the inverter should continue to grid form but will sag terminal voltage in order to maintain current output within ampacity limit. Inverter overload does not lead directly to an inverter trip but may indirectly result in an undervoltage trip if the voltage sag exceeds undervoltage ride through limits. The short circuit duration can be maintained for up to 10 seconds, as this is a configurable parameter. This can be useful for coordination with overcurrent protection devices.

There are a several situations that result in the Tesla battery system delivering less than nameplate overload capability during overload conditions including:

- 10 minute recovery period following overload event
- faulted or unavailable Powerstage(s)
- faulted or unavailable inverter block

11.3 Battery System Protection Considerations

Unlike a typical synchronous machine, the Tesla battery system is able to self-protect and therefore is not reliant on an external overcurrent protection device to protect against hardware damage. Consequently, over current protection on battery feeder(s) should be configured to protect conductors and may be configured to trip above the inverter's current capability.

Each inverter Powerstage within the Tesla battery system has an integral AC contactor which isolates the semiconductor components of the inverter from the AC bus when not in operation. Megapack also contains an integral circuit breaker which is described in the *Megapack Site Design Manual*. Details on fuses used for additional AC and DC overcurrent protection within Tesla battery systems can be found within the *Design Manual* for each product.

For a given nominal ampacity, the overload capability of an inverter is typically much lower than that of a conventional synchronous generator. This can pose a challenge to overcurrent protection devices which are designed to actuate with fault current at several multiples of generation source's rated current, such as fuses and thermal-magnetic breakers located on main feeders. Smaller breakers in secondary circuits are typically not affected by limited overload current from inverter.

Circuit breakers with improved current detection capabilities such as "LSIG" electronic trip units on a molded case circuit breaker or Siemens Fusesavers may be used to help distinguish current flow during a fault from nominal condition. Protection relays provide additional protection elements beyond overcurrent detection and provide improved selectivity.

11.4 Microgrid Protection Considerations

The most effective microgrid protection scheme is determined by numerous project-specific factors, including but not limited to: the existing protection equipment and settings, power system topology, and type of microgrid application. When developing an operation and protection philosophy, it is important to understand the realistic risks to personnel safety and the preferred selectivity for the power station. A detailed system study must determine the system conditions under various load and fault conditions, to achieve the desired level of fault isolation. When performing the detailed protection study, consider that the Tesla battery systems are certified to UL 1741 and other international grid codes. These certifications require native features that are relevant to system protections, namely 27/59 (over and under voltage) and 81O/U (over and under frequency) which are highly configurable.

The relatively low fault current of the Tesla battery system will impose challenges for systems in which the battery system size and load size are in the same range. In these cases, the protection system has to be thoroughly designed in order to discriminate between load currents and faults. Since the inverter fault current can be maintained for up to 10 seconds, it allows shallow trip curves or short-time duration overcurrent settings on protection equipment set low enough to trip. If a fast and selective solution is required, other methods typically need to be employed. The subsections below provide recommendations for discriminating between expected loading and faulted conditions. These recommendations should not be used in lieu of performing a full protection study for a project.

11.4.1 Voltage-Controlled Time Overcurrent Element

A voltage-controlled time overcurrent element (51C) may be used instead of traditional (50/51) overcurrent elements for detecting faults. In the voltage-controlled time overcurrent relay, a sensitive low pickup time-overcurrent relay is supervised by a voltage relay. The voltage pick-up is user-defined based on the project-specific system operating requirements, and prevents the relay from operating when no voltage anomalies occur. Under specific fault conditions, the voltage reduces, causing the voltage relay to assert and thereby permitting operation of the sensitive time-overcurrent relay. If the expected current and voltage thresholds during periods of heavy loading is known, this aids discrimination between heavy loads versus faults.

11.4.2 Direct Transfer Trip and Differential Line Protection

Other protective methods such as direct transfer trip and differential line protection may be applicable but are outside the scope of this document. Reach out to your Tesla Representative for more information.

11.4.3 Backup 51G Protection

When the microgrid is designed to have a grounding transformer, it is possible to provide a backup protection for earth faults by adding a delayed 51G protection on the grounding connection of the grounding transformer.

11.5 Additional Microgrid Protections

Microgrid systems typically employ multiple generation sources. Other generation systems may also be inverter-based, such as photovoltaic (PV) systems, and often exhibit similar fault characteristics to those offered by the Tesla battery system. When multiple generation systems are connected in parallel and distributed across the microgrid, directional (67) protection may be necessary to distinguish acceptable levels of current flowing between the Tesla system, loads, and other generation.

As an example, directional protection can be used to prevent excessive current flowing in reverse towards other generation sources under fault conditions located at the generation source. Another example is to use directional elements in conjunction with under voltage elements (27) or overcurrent elements (50/51) to detect loss of synchronization in synchronous generation sources that could occur due to generator slip. Directional elements are also useful in detecting hidden phase losses on the line by monitoring zero and negative sequence current and voltage that is usually generated upon phase loss.

12 Other Considerations

12.1 Internet Connectivity

Tesla requires two types of remote connections to sites for warranty and maintenance of Tesla industrial energy storage systems:

1. Data logging, which periodically collects operational data from the system for maintenance and warranty purposes.
2. Remote access, which is required by the Tesla service teams to troubleshoot and diagnose issues, control the system for testing, and deliver firmware updates.

For customers using the Tesla Microgrid Controller, the Tesla Site Controller will be logging data from all the connected assets to provide microgrid-wide troubleshooting and monitoring via Powerhub. Combined with the commonly remote and hard-to-reach nature of many sites, the remote connection to the Tesla Site Controller is a critical consideration for microgrid designers.

An unreliable or insufficient internet connection will prevent Tesla from:

- Providing effective remote support during commissioning and operation
- Providing cloud-based monitoring and control capabilities
- Updating system firmware and software
- Effectively maintaining the system in accordance with warranty obligations

In geographies in which Tesla is not able to provide a cellular connection directly from the Tesla Site Controller, the customer is responsible for designing, procuring and maintaining a suitable internet connection for the Tesla system. Additional details on implementation options can be found in *Tesla Remote Connection* in the *Network Architecture* section of the *SCADA Design Manual*.

The following requirements should be considered for the connection:

1. Minimum 1Mbps upload and download speed.
2. The monthly data upload and download requirements will vary based on microgrid asset sizes. The below formulas can be used to provide indicative figures:
    a. Uploads per month(MB) = 2.88*SystemSize(kW) + 0.32*SystemSize(kWh) +1320
    b. Downloads per month(MB) ≤ 2000 (500 x 4weeks)

Should the connectivity become unmanageable, be not reliable enough for remote support, or cause data loss, Tesla may require that the internet connection is upgraded during commissioning or at a later stage.

12.2 Spare Parts

To enable higher availability and speed of service, your project may require a Service Kit containing a safety stock of spare parts and select service tooling. Your Tesla Account Manager will share options based on your project's location, country, and field service provider. As parts are consumed from the safety stock for approved warranty fulfilment, Tesla will re-stock your local supply from Tesla Distribution Centers.

Even if not required, Tesla highly recommends ordering a Service Kit for microgrids in relatively remote locations. Having parts available on site will improve general system uptime compared to ordering on an as-needed basis due to shipping lead times.

Revision History

Revision	Date	Description
1.3	December 14, 2022	• Clarified role of spare Tesla Site Controller (*Computer Networking on page 26*) • Clarified battery meter requirement (*Battery Meter on page 59*)
1.2	June 29, 2022	• Restored topic (*Grid Form Retry Behavior on page 29*)
1.1	June 14, 2022	• Updated minimum battery SoE requirement to 10% (*Off-Grid SOE Range on page 31*)
1.0	May 16, 2022	• Added key terms (*Glossary of Key Terms on page 6*) • Corrected standard generator frequency droop values (*Generator Controller Requirements on page 54*) • Fixed placement of ATS to be downstream in the figure *Grid-Tied Microgrid With Solar and ATS Generator on page 20* • Added guidance for paralleling in dual-controller configurations (*Computer Networking on page 26*) • Corrected Islanding Architecture diagram (*Islanding Architecture on page 34*) • Added section that cites direct transfer trip and differential line protection considerations (*Microgrid Protection Considerations on page 66*) • Added details to island sequence subsections (migrated from *Tesla Energy Controls and Communications Manual*) (*Islanding Sequence of Operations on page 35*)
Preview Release	December 30, 2020	• Preview Release - subject to change