WHITE PAPER

Hybrid Power Generation System: A Safer On-site Storage & Power Architecture with Multiple Stacked Applications

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William Kaewert
Board Member, Strategic Advisor
Stored Energy Systems (SENS)

Stored Energy Systems
Longmont, Colorado USA
(303) 678-7500
Info@sens-usa.com

Abstract

Challenges to electrical power grid reliability and electricity prices are growing daily. In industrialized countries, particularly the US, these challenges are driven by the simultaneous combination of fast-growing electric loads and the replacement of dispatchable fossil and legacy nuclear power generation by non-dispatchable renewables.

This shift has led to new supply and demand strategies that include inverter-based resources (IBR) backed by battery energy storage systems (BESS). These systems can enable both backup power and the ability to support the grid with real power and fast-responding ancillary services such as frequency and voltage support. Unfortunately, BESS is not a panacea. In fact, the quest for ever-bigger batteries with longer discharge times is beyond impractical. This paper argues that such a quest is counterproductive. We propose a better solution.

BESS customers continue to search for a unicorn: longer run-time and lower cost, and lower fire risk, and less space consumption and longer life. Yet, these goals of cramming more energy into a smaller space, at lower cost, with greater safety are incompatible because of limitations inherent to the Periodic Table of Elements.

In addition to fire risk, there will always be a fundamental problem with grid-scale storage batteries. The battery's endurance will never be long enough to run through worst-case power grid emergencies. Sizing a battery for worst-case events, however, guarantees it will cost more than it needs to in 90+% of grid emergency events.

There is a more practical alternative than large BESS for supplying on-site power or augmenting the grid. A patent-pending hybrid battery/combustion power generation system, designed for bi-directional operation, would deliver both the fast-responding benefits of inverter-based resources (IBR) and blackout run-time limited only by fuel supply. Such a system equipped with a small (e.g. 10-minute), high-performance battery, plus inverter and fossil fuel generator would deliver the fast response characteristic of IBRs, at lower cost and with materially lower fire risk than an equivalent run-time BESS.

Introduction

Electric demand is skyrocketing due to a boom in energy-hungry data centers and aggressive electrification of transportation and heating, ventilation and air conditioning (HVAC). Electricity demand is facing unprecedented growth, while generation is increasingly reliant on the weather. The combination of higher demand and variable supply is a big problem. California's "Duck Curve" is an easy to grasp example of the mismatch between renewable energy generation and customer demand. In California, renewable generation mid-day displaces dispatchable generation. At sunset, however, dispatchable generation needs to ramp up quickly to meet the evening peak because photovoltaic (PV) systems shut down in the dark.

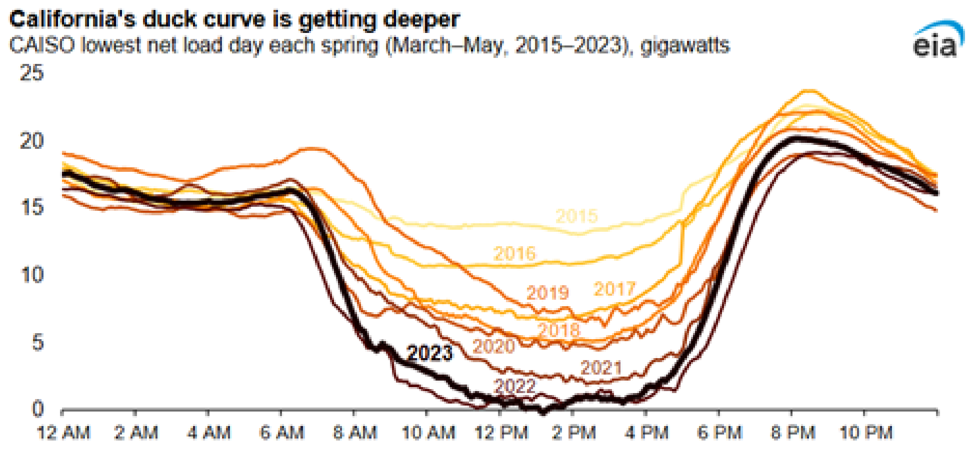

Figure 1 - California's Duck Curve

For additional insight and source data on these trends please see the 2025 Battcon paper by this author, *What Will the Mission For Critical Power Equipment Look Like In 2030, And Why?*

This problem of mismatch between electric supply and demand has led to the rise of several practices that fall into two categories: doubling down on the old model of centralized power generation and transmission; and shifting to distributed energy resources (DER) that include a myriad of technologies, including both fossil-fueled generators and battery-backed IBR with solar and wind as prime movers.

The limited capacity of most DERs means that demand management systems feature prominently in most DER. Demand management systems include many facets, such as employing DERs to reduce utility demand charges, minimizing consumption during peak price time of use (TOU) periods, and shedding lower priority loads to prevent overloading of the generating source, and maximizing battery run-time.

Why Distributed Energy Resources (DER)?

Doubling down on the old model of centralized, unidirectional power flow depends on delaying coal plant retirements and building more high voltage transmission. Both technologies suffer from serious public relations and financial resistance.

Most coal plants are either beyond, at, or near end of life. Even if environmental concerns were set aside there is only so long these assets can safely continue running. And although there are many attributes of coal power that are attractive (ability to store months of fuel on-site, plentiful domestic supply and low cost), it seems unlikely that coal will ever overcome the environmental and public relations headwinds it faces in the United States.

Multiple problems hinder even the most urgent new transmission projects. "Not in my back yard" (NIMBY) hinders transmission lines always and everywhere in Western democracies. More difficult to overcome than NIMBY, however, is a shortage of generator step-up (GSU) and step-down transformers, the lead-time for which is nearly a decade. Additional headwinds aggravate the transformer supply chain problem. Much of the existing US GSU fleet is either at or beyond end-of-life, meaning that replacements typically take precedence over new builds. In addition, hyperscale data center projects consume a large portion of the world's large transformer capacity, and will continue doing so years into the future.

More recently, policy changes are effectively mandating DER construction. Some states have already passed laws (e.g. Texas SB6) requiring new large loads to "bring your own power" (BYOP) and/or that the facility's connection to the grid can be severed in response to a grid emergency, or to avert one.
For all the reasons above, and because electric power supply is one of the most significant requirements to any new data center, many developers are choosing on-site power generation as either an interim or permanent solution.
The problem of mismatched power supply and demand will be solved with DER, not coal plant life extensions or massive new transmission build out.

Requirements for DER in Renewables-heavy Grids

The graphic below illustrates the fundamental problem with the Duck Curve:
mismatch between the supply of renewable generation and demand for electric power.

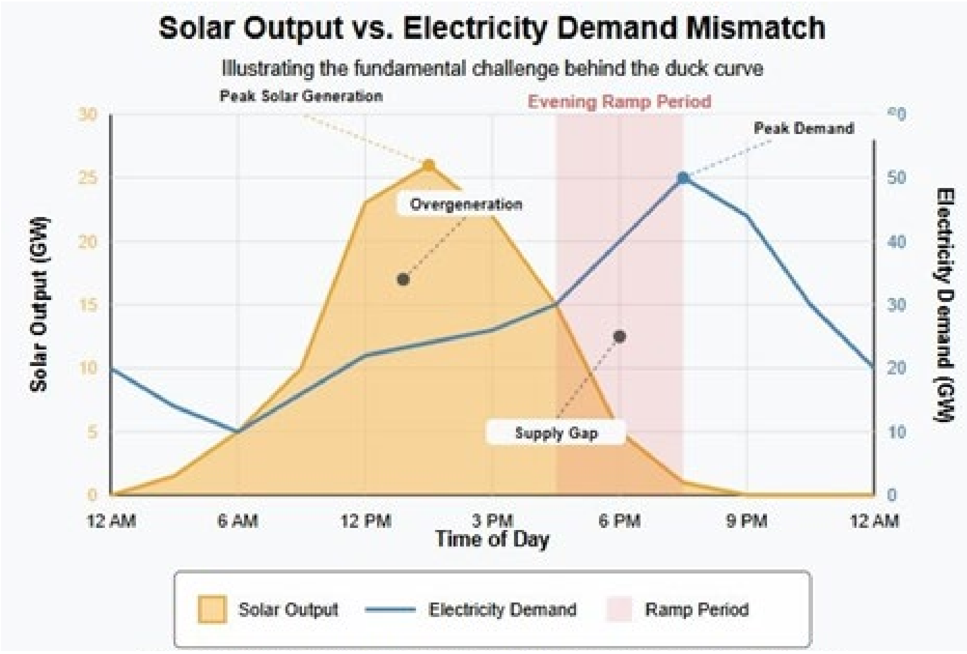

Figure 2 - Mismatch Between Renewable Generation and Electricity Demand

The supply/demand mismatch creates at least four problems:

1. Because we cannot command the sun to shine or wind to blow high, concentrations of renewables cause either under-generation or over-generation of electric power.

2. Because we can't control energy inputs into PV and wind systems, we don't have control over energy outputs either. Sudden variance in supply, e.g. clouds over solar panels or a sudden drop in wind velocity, tends to reduce both grid frequency and voltage. And because allowable variance from 60 Hz is quite small, when frequency drops below a standard value most existing grid-following IBRs trip offline, exacerbating under-frequency problems by removing more supply.

3. Because we don't control energy inputs into renewable energy systems, the addition or subtraction of large loads from the grid (e.g. hyperscale data center(s)) can generate large frequency excursions. This problem also exists in conventional grids with thermal or nuclear generation, but the effects are much less pronounced than in grids with lots of renewables. This is because the spinning generators in centralized fossil and nuclear plants are very heavy, and do not readily change speed when step loads are applied or removed.

4. A fourth problem with renewables-heavy grids is Dunkelflaute, or dark doldrums typically lasting for days. When such conditions occur, output from both solar and wind-driven renewables is typically a tiny fraction of nameplate rating for many days. If backup generation were not available Dunkelflaute conditions would cause widespread, long-duration blackouts.

While on-site emergency generators solved the problem of blackouts affecting mission-critical facilities decades ago, this paper's discussion revolves around the four new problems identified above.

What Today's DER Technologies Do, and Don't Do

Newer technology grid-forming IBRs offer the beneficial capability of helping to stabilize power grid frequency. Subject to battery state of charge, grid-forming IBRs can support grid frequency by quickly injecting power into the grid when frequency sags, and withdrawing power from the grid when frequency is too high. There is a marketplace for this stabilizing capability, known as "fast frequency response", in a few states.

Battery backed IBRs are also capable of delivering power to the grid when generating sources are under-performing, as solar PV does every night.

Battery-backed IBRs also enable reduction in the cost of grid-supplied electric power, in two ways. The first is time shifting of electricity demand, which is valuable in regions with time of use (TOU) tariffs. The second is shaving off peaks in demand, which reduces demand charges.

Yet, the wonderful capabilities of battery-backed IBRs suffer from constraints related to battery capacity:

1. There will always be worst-case outages that last longer than battery capacity.

2. 2. Especially during winter and/or during inclement weather batteries cannot support loads beyond a few hours.

3. 3. Ever-larger batteries present bigger fire risk, for a couple of reasons. Bigger batteries include more cells. More cells mean greater probability of failure. And, although safety systems exist to counter cell failure(s), battery fires still occur. And when they do, bigger batteries contain more combustible material than small batteries.

4. While a bigger battery brings the potential to reduce TOU and demand charges to beyond what's possible with a smaller one, the bigger battery is larger, more expensive, and represents a bigger fire risk.

The ideal onsite power system would have sufficient energy available to cut out all TOU and demand charges, but without the drawbacks related to large size. That ideal is one of the goals of the hybrid generator system discussed below.

Conventional on-site power generators, in contrast, offer different capabilities and suffer from shortcomings different from IBRs:

Diesel engines are well-understood prime movers for loads of nearly any size, but mainly as backup for some other prime mover. Their appeal is largely as reliable backup, rather than as prime power. One of their biggest advantages is that fuel is stored on-site, and thus not subject to interruption of pipeline-supplied fuel.

Shortcomings of diesel for longer-duration use, however, are overwhelming. Resupply of fuel depends on tanker trucks, which are impractical after most natural disasters due to fallen objects, floods and other road closures. Equally challenging are byzantine EPA exhaust emission rules that effectively forbid engines to run more than 100 hours per year except during blackouts. (So-called Tier 2 emission-controlled diesels used in almost all standby generator applications are governed by this 100-hour rule. Tier 4 engines, in contrast, are equipped with much more complex emission controls and are in theory freed from this operating hour restriction. Yet, Tier 4 generator sets (gensets) are very rarely specified, for two primary reasons: 1) Tier 4 generator sets typically cost 2.5 times as much as equivalent power Tier 2 gensets. 2) Tier 4 rules require that any emission control system malfunction shut down the engine. This hard requirement is an understandable deal-killer for most mission-critical applications.)

Gas turbines and gaseous-fueled reciprocating engines, in contrast, are excellent options to support long-duration operation. They more easily meet emissions regulations, and their endurance is nearly unlimited due to supply of fuel by pipeline. Moreover, supply of fuel via pipeline has in many cases proven to be much more reliable than diesel. Pipelines have proven to be largely immune to the effects of floods, hurricanes and other disasters that prevent diesel resupply due to impassible roads.

Yet, gaseous-fueled engines also suffer from some serious shortcomings. Most significantly, start-up and dynamic response is relatively slow. Compared with IBR, dynamic response of even the fastest responding gas gensets is slow.

Recently, end users have begun solving this problem of slow response time by operating gaseous-fueled turbines and reciprocating engines in series with a large BESS-backed inverter. This hybrid approach offers fast dynamic response typical of IBRs, coupled with the long endurance of a fossil-fueled generator. This series hybrid concept is one of many properties in the hybrid generator architecture discussed below.

What Other Problems Need Solving?

While the series connected gas generator and battery-backed IBR is a necessary first step toward behind-the-meter (BTM) power for data centers and other large loads, it leaves many other requirements of future power systems unsolved. This paper proposes solutions to these more complex requirements.

Referring to the Introduction, including Figures 1 and 2, Figure 3 below summarizes the future of electric power in the United States. The remainder of this paper shows how small storage batteries can do the same job as large BESS more safely, and proposes an architecture for hybrid power generation systems that will help solve the problems identified in Figure 3.

What's Coming (the Problem)	What It Means
Over the next five+ years wind and solar sources will continue to increase as a percentage of total MWh delivered to power grid customers	Increasingly variable electric output will lead to more variance in the price of electric power between peak and off-peak times. Demand charges will materially increase
More renewable energy will increase the incidence of either under-generation (shortage) of electric power, or over-generation (excess supply) of power	There will be periods when electric power prices are extraordinarily expensive. There will be other periods in which wholesale electric prices are negative
Commercial and industrial (C&I) customers, particularly those with large loads, will be incentivized by either price or legislation to invest in BTM onsite power generation	High electric prices will cause C&I customers to use their onsite power systems frequently to cut costs by responding to frequent grid emergencies, or for prime power
"Grid emergencies" will occur more frequently in the next five years	BTM powerplants will become an increasingly valuable asset to C&I firms
Data centers that are installing BTM power plants today will eventually connect to the power grid: 1. To increase reliability of electric supply by increasing diversity of supply 2. To improve their worsening public relations problem. Exporting power to the grid, either during grid emergencies, or under normal conditions to reduce electric power rates for local residents would be public relations wins	Electric power will alternately flow either into, or out of, facilities with large loads with regularity – perhaps several times per day

Figure 3 - Electrical Supply & Demand Issues In the United States 2026 - 2031

My home state of Colorado is a prime example of the changes that are occurring. By the end of 2031, Colorado utilities will have shut down roughly 3,800 MW of coal-fired power capacity. This includes nearly every big coal unit in the state. Colorado policymakers operate under the misapprehension that that this capacity can be reliably replaced by additions of wind (which doesn't always blow) or solar (which never works at night, under snow cover or under heavy cloud).

Colorado's planned (but not contracted for) replacement for this firm generation is a paltry ~478 MW of new gas-fired capacity by 2031. In other words, the state is removing ~8 MW of reliable power for every 1 MW it is considering building. The difference between planned and contracted construction is important: gas turbine power generator lead-time is in excess of five years. Because there is no firm plan and contract for new gas generation today the wait for new dispatchable generation will be beyond 2030.

Meanwhile, two hyperscale data centers are either in final planning states or under construction in Colorado. By any measure, Colorado's electrical power future is a slow-motion train wreck.

Solving the Coming Problems

The intuitive solution to the multiple problems listed above is simple in concept: just connect a bi-directional grid-forming inverter to the grid where the battery is infinitely large! Such a system, if it existed and if the battery were maintained at a partial state of charge (PSOC), would be able to either source or sink energy from or to the power grid instantly, and for as long as needed.

There is, of course, no infinitely large battery. Here are some more inconvenient facts about storage batteries:

- There will always be a grid emergency that lasts longer than even the biggest battery's capacity. The battery will therefore at some point become useless.
- Because the timing of grid emergencies cannot be predicted, there is no way to ensure that a battery used for regular cycling service would be at its maximum capacity, or charged at all, at the start of a grid emergency. The battery will therefore sometimes be useless.
- The severity of fire or explosion typically increases when potential energy is concentrated into smaller areas. All other things being equal, bigger batteries crammed into less space represent a bigger fire risk, in addition to greater cost. When large batteries are located on power utility premises, away from other assets, the fire risk appears to be manageable. When such batteries are placed on customer premises, such as mission-critical data centers, the consequence of fire typically becomes more acute.
- Batteries age, sometimes much faster than their makers' promise. The risks of failure and fire typically increase with age. Replacement of big batteries costs big bucks.

These inconvenient facts mean that the quest for ever-larger BESS is both impractical and a growing fire risk to life and property.

A small, high-performance battery is safer than a large BESS

Below we compare the fire risk of a hypothetical IBR equipped with an 8-hour BESS to a hypothetical hybrid generator that includes a 10-minute battery. The balance of 8-hour runtime in the hybrid system with 10-minute battery is achieved using a natural gas fueled engine generator (genset).

The onsite hybrid generator assumes a battery sized to support the system's full load output for ten minutes. Under normal conditions this battery is maintained at about 75% state of charge (SOC), so that it is able to both charge and discharge quickly.

We will consider two primary fire risk variables: battery chemistry and battery size.

Difference in battery chemistry – advantage small battery

State-of-the-art BESS systems are built using lithium iron phosphate (LFP), which is generally considered one of the safer lithium-ion chemistries available.

LFP batteries, however, are typically optimized for discharges longer than ten minutes. Therefore, the hybrid generator specifies lithium titanate oxide (LTO). For comparison purposes we will consider a leading LTO battery supplier's cell that is optimized for short, high-power discharge and equally high power recharge.

LFP cells use the same flammable carbonate electrolyte solvents as all other lithium-ion chemistries. When thermal runaway occurs, these solvents vaporize and release flammable and toxic gases including H_2, CO, CH_4, and electrolyte vapor.

The defining characteristic of a significant **LFP BESS thermal runaway event is that it cannot be extinguished**. The electrochemical reaction is self-sustaining as long as the cells retain energy. Fire departments have adopted a "let-it-burn" tactical posture — standing back, monitoring the perimeter, preventing spread to adjacent structures, and waiting for the battery to consume itself. Large BESS fire duration ranges from hours (single container) to multiple days (Melba, ID burned for three days; Lyme, NY burned for four days).[2] Although BESS fires are rare, the political and regulatory friction from each incident is out of proportion to the fire itself. Authorities Having Jurisdiction (AHJs) across multiple states have imposed BESS moratoriums, zoning restrictions, and heightened permitting requirements directly in response to these incidents.

Dendrite growth into the separator is the most common initiation mechanism for internal short circuits that cause fires in stationary LFP cells. In contrast, LTO anode construction fundamentally suppresses dendrite growth – inhibiting the primary short circuit mechanism.

The leading LTO manufacturer's documented mechanism in the event of an internal short circuit from any cause (manufacturing defect, external mechanical damage) is as follows: the LTO anode transitions from its conductive phase to a highly resistive insulating phase at the short-circuit point, actively quenching the runaway current rather than sustaining it. This is a passive, chemistry-inherent safety mechanism with no dependence on BMS or active suppression systems.[3]

There is no record of battery fire starting in anyone's LTO battery, despite shipments in excess of 100 million LTO cells over 15+ years from one of the market leaders (the total LTO cells in the marketplace is even higher).

While the safety advantage of LTO over LFP cannot be computed (the denominator of LTO failures is zero) battery experts generally agree that LTO is the safest of all lithium ion technologies. LTO is also the longest lived and performs best at extreme temperatures.
The 20,000+ cycle life of at least one commercially available LTO product materially reduces the calendar aging risk that contributes to LFP runaway. In large LFP systems degraded separators and breakdown of the solid layer (the solid-electrolyte interface [SEI]) that sits between the liquid electrolyte and the solid electrode after years of cycling are documented failure precursors. In contrast, an LTO battery cycling 5–10 times daily for frequency response would reach 20,000 cycles in approximately 5–10 years with documented capacity retention above 70–90%, without the progressive degradation mechanisms that make aging LFP systems progressively more dangerous.[4]

Difference in battery size – advantage small battery

To hold power (kW) constant while varying duration from 10 minutes to 8 hours, the LFP BESS must contain 48 times more stored energy than the LTO battery. This ratio, 48:1 in stored energy, is the primary risk multiplier. This multiplier is in addition to chemistry-level differences that favor LTO.

Total combustible inventory: An 8-hour LFP system at 500 kW continuous output requires approximately 4,000 kWh of stored energy. A 10-minute LTO system delivering the same 500 kW peak needs only ~83 kWh. The LFP system contains roughly 48 times more electrolyte solvent, more electrode material and more flammable gas precursor. It has much more stored electrochemical energy available to drive and sustain a thermal event. Fire intensity, duration, and suppression difficulty scale with total energy inventory.

In the hybrid generator we also need to consider the risk of fire in the combustion engine system. While such fires do occur, fuel isolation ends the hazard. This is the fundamental advantage natural gas shares with diesel over BESS, and it is significant. An automated gas shutoff solenoid, required by code in commercial generator installations, cuts fuel supply on detection of a fire or loss of pressure integrity. Once fuel supply is interrupted, the fire cannot sustain itself beyond the residual gas already in the enclosure. The incident has a finite and predictable end.

BESS, in contrast, offers no equivalent mechanism. The electrochemical energy distributed throughout thousands of cells cannot be "shut off."

Fire risk comparison summary

The failure mode making large LFP BESS fires so dangerous is the large amount of self-sustaining fuel that cannot be extinguished. This risk is directly addressed in the hybrid generator by keeping the battery small (10-minute duration) and choosing a chemistry (LTO) that does not readily support combustion and, in the worst case, releases far less flammable gas than equivalent size LFP cells that cause deflagration injuries.

The generator subassembly presents a very well-understood fuel fire risk that is manageable, extinguishable, and already governed by a mature regulatory framework that fire departments everywhere are trained to handle. In the hybrid system the total fire risk profile is more favorable than either a large BESS alone or a generator-plus-large-BESS combination. Even without the multiple other advantages over simple BESS systems presented below, favorable fire risk alone makes the hybrid system more attractive than large BESS for customer premise installation.

Integrated Hybrid Generator: Solving More Problems With Greater Safety

Elements of the hybrid generator system are identified below, along with several modes of operation that can work interactively with the grid, or as an island. Because several operating modes stack multiple applications, the hybrid power generation system offers a unique combination of functions that include **insurance** (facility backup power), **cost reduction** (lower utility bills) and **cash generation** (via payments or credits from the power utility).

The combination of prime power, backup power and grid support available from the hybrid generator architecture is new, and unavailable from any existing technology.

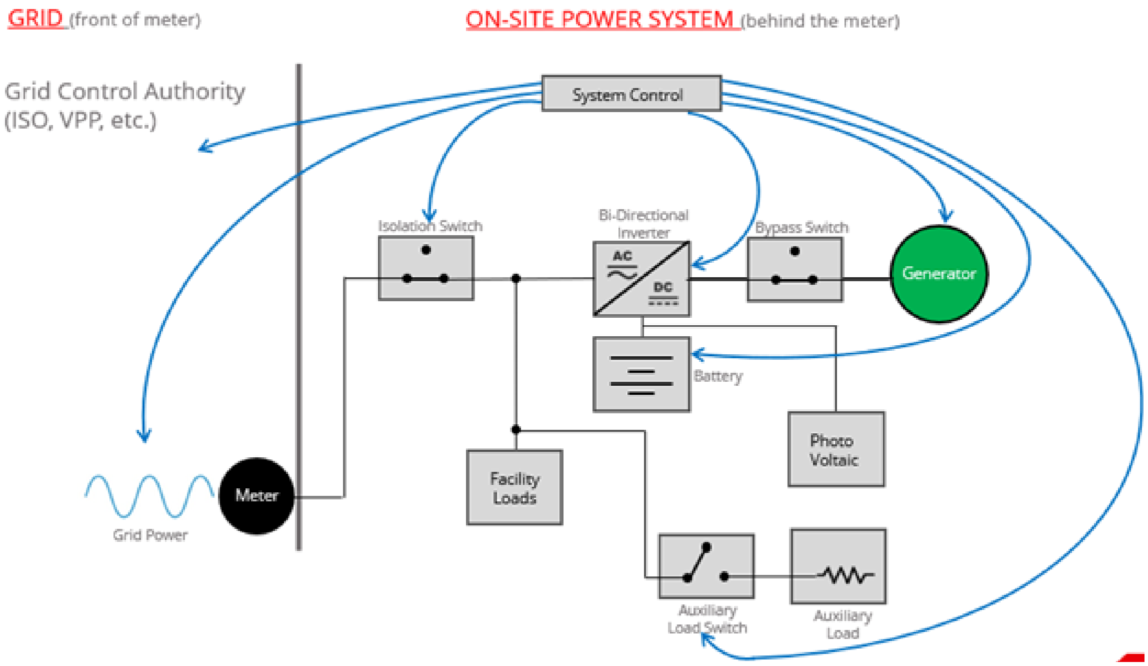

Figure 4 - Elements of the Hybrid Generator System

Grid Control Authority is an external controlling authority that typically dispatches DERs	**System Control** is an on-site controller in communication with all of the onsite power system elements shown by blue lines, including with the Grid to monitor frequency, voltage, power, etc., and with the Grid Control Authority.
Grid Power is nominal 60 Hz AC supplied by power utilities.	An **Isolation Switch** Isolates the onsite power system from Grid power at appropriate times, commanded either by its own logic or via command from the System Control.
The **Meter** is the facility's power meter that typically divides "front of" from "behind" the meter	**Bi-directional Inverter** is a grid-forming power inverter capable of importing from the Grid, or exporting power from the battery to the Grid.
	Bypass switch enables the Inverter and Generator to operate either in series or in parallel, depending on needs of the system.
	Generator is an internal combustion engine delivering AC power, some or all of which might be rectified when the Generator needs to power the Inverter.
	Battery is a high-power, short duration (e.g. 10-minute rated) storage battery, typically maintained at PSOC.
	Facility loads are what is powered by both the grid and on-site power system
	Photo-voltaic is an optional prime mover supplying power to the on-site power system
	An **Auxiliary load switch** connects Grid power to an Auxiliary Load at times determined by the System Control.
	An **Auxiliary load** is a large load that is independent of Facility Loads that may or may not perform useful work.

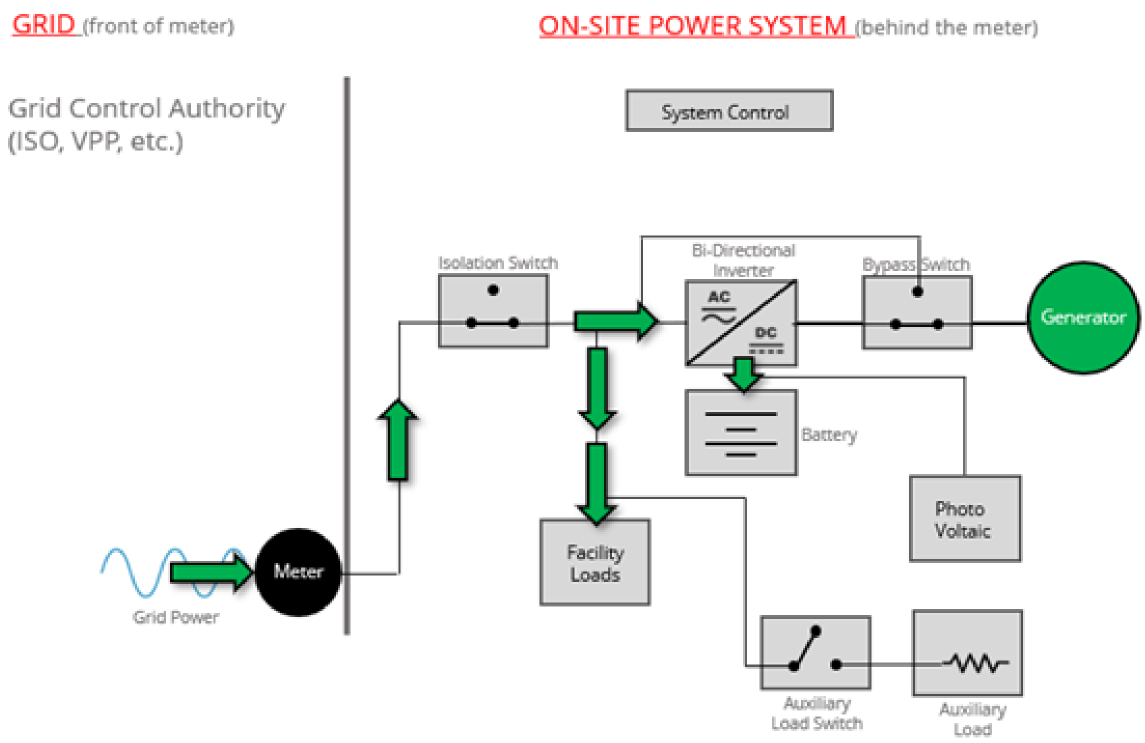

Figure 5 - Normal Operating Mode

Normal power to the facility is supplied to facility loads by the power grid. The battery is maintained at an appropriate state of charge by the bi-directional inverter.

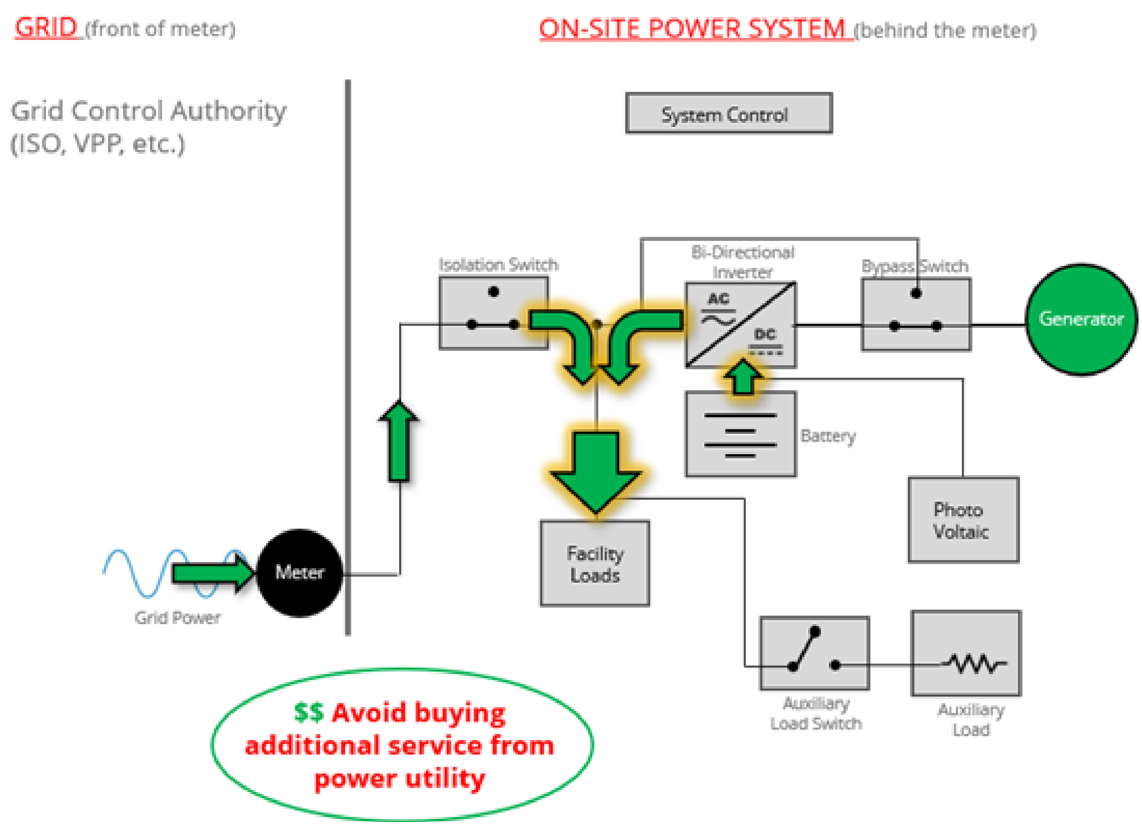

Figure 6 - Normal grid – Inverter augments grid to support large load surge

Normal grid conditions remain, but there is a large surge in facility load. This could be caused, for example, by a large motor starting load. Large load surges have the potential to trip facility input breakers or cause facility brownouts that are damaging to processes or equipment.

Figure 6 shows the inverter augmenting grid power to support an excessive facility load. This is possible because the inverter is in communication with the grid at all times, and remains synchronized with grid frequency.

The “revenue function” in this mode is to delay or eliminate the need to pay the power utility for expanded service as surge loads grow. Buying more capacity from utilities costs a lot, both initially and permanently with each monthly bill. The “grid augmenting” function of this system obviates or delays the need for additional utility service as facility loads grow.

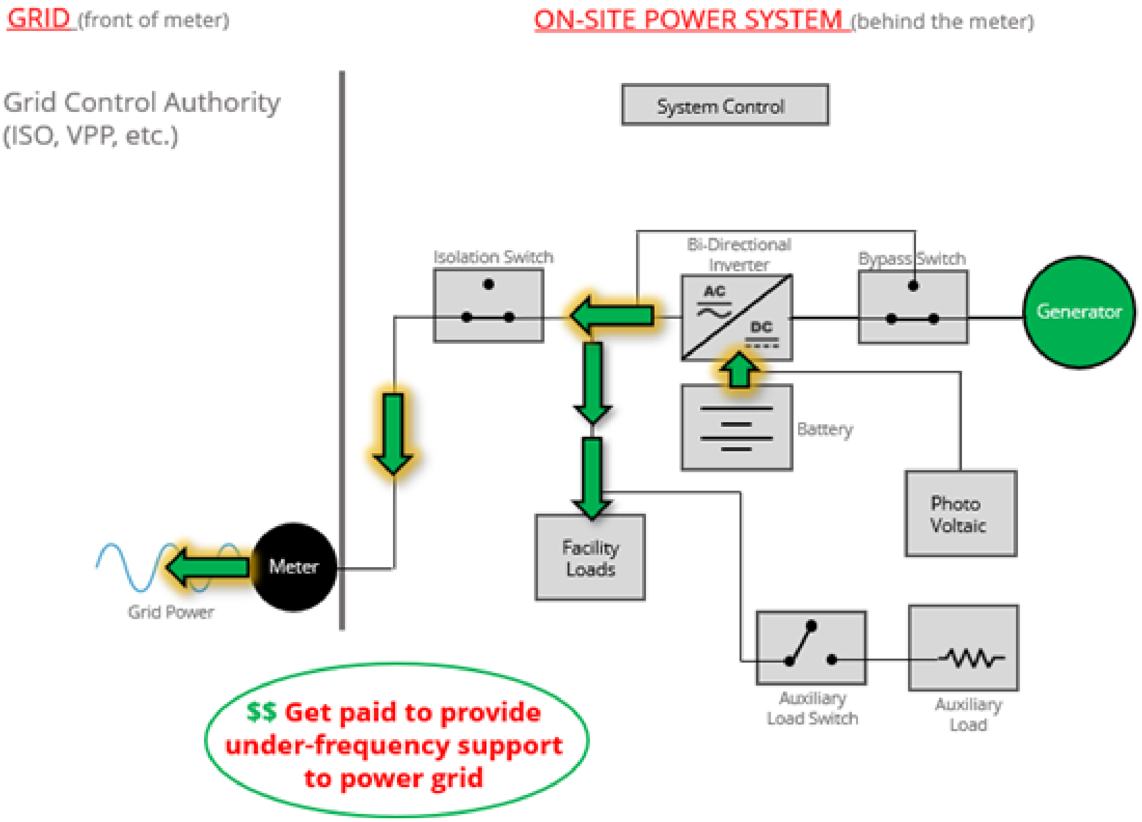

Figure 7 - Grid Support - Battery provides instant under-frequency response

High concentrations of renewable generation are often accompanied by under- and over-frequency excursions because there is little to no system inertia (i.e. “spinning reserve”) inherent to wind and solar generation as there is in coal or nuclear power plants.

In Figure 7, the inverter responds nearly instantly to grid under-frequency by converting battery DC into AC that is fed to the power grid and facility loads. The inverter and/or system controller detect and respond to the under-frequency event. In some cases the inverter could be dispatched in response to a signal from the grid control authority.

The inverter delivers either real or reactive power, as determined by the system controller or the grid control authority.The generator would start operating before the battery is fully discharged to support under-frequency events lasting longer than the battery's capacity.

A building management system (not shown) could simultaneously reduce optional facility loads, such as air conditioning, to maximize the proportion of power exported from the on-site power system to the grid.

The "revenue function" in this mode is to get paid by the utility for providing fast frequency response. At least two U.S. states offer fast frequency response payment programs. Additional states are likely to do the same in the future.

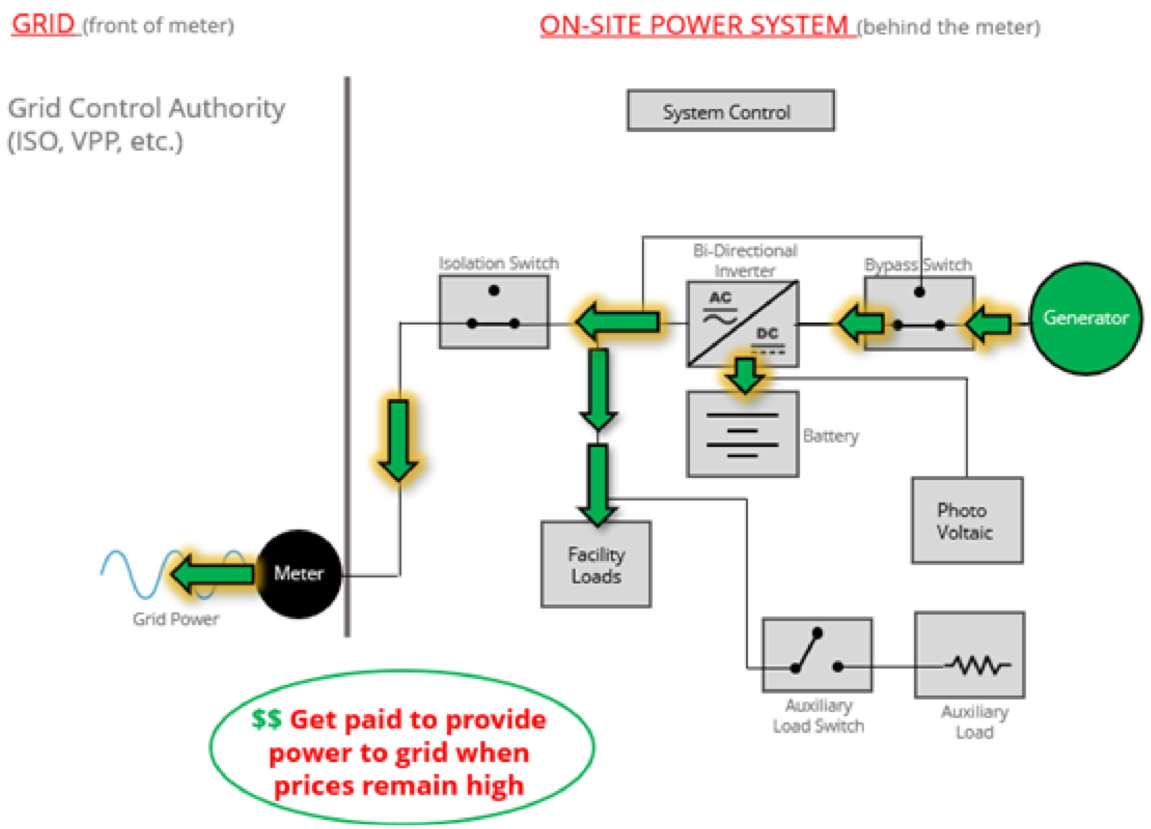

Figure 8 - Grid support - Generator provides long duration grid support

This mode is similar to that shown in Figure 7. The on-site power system is exporting electrical power to the grid in addition to supporting facility loads. In this mode, power to the inverter is supplied by the on-site generator instead of the battery. The generator is simultaneously recharging the battery.

Although the diagram shows generator power being supplied to the grid via the inverter, the generator could also be connected around the inverter via the bypass switch.

The "revenue function" in this mode is payment by the utility for providing kilowatt-hours. During grid emergencies power is scarce, and thus prices paid by the utility for power exported from the onsite power system could be quite high, making it very attractive to export every KWh possible.

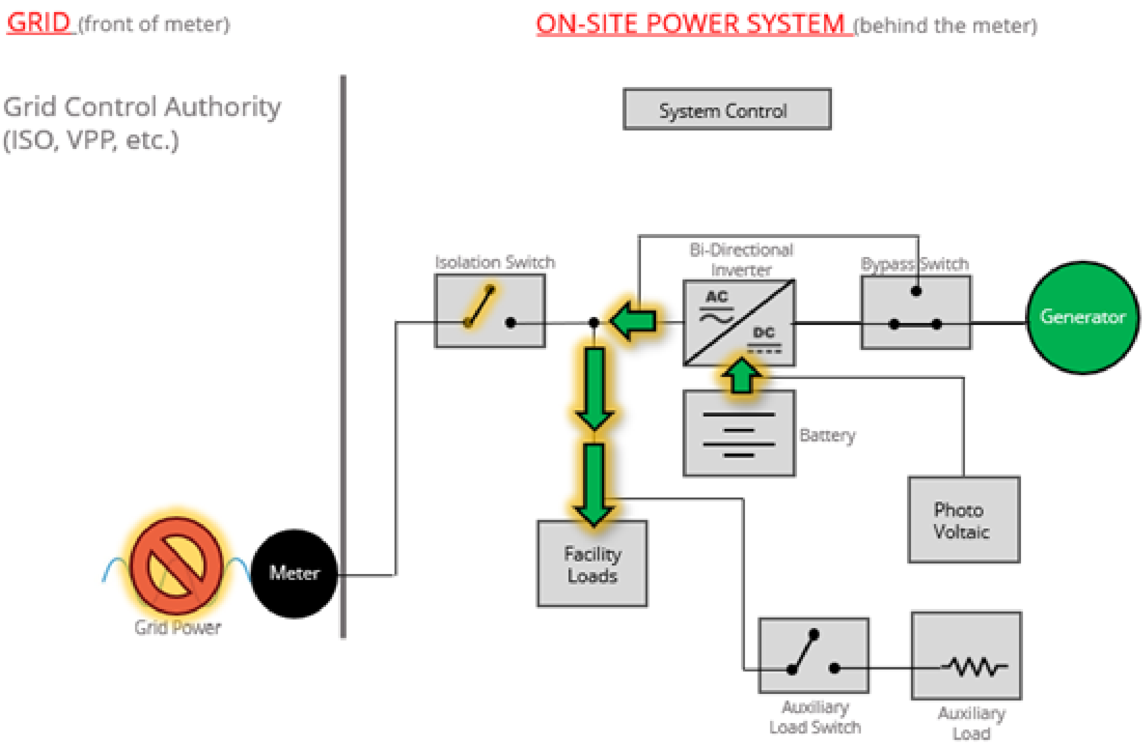

Figure 9 - Grid Failed – Battery provides instant on-site load support like UPS

Note that the inverter remains in operation and in communication with the grid under all circumstances. When a blackout occurs the battery, via the inverter, powers facility loads. The system controller determines that a blackout has occurred and immediately opens the isolation switch so that the on-site power system operates as an island, away from the now de-energized grid.

Upon restoration of the grid, the system controller determines if reconnection is safe, resynchronizes the inverter to the grid, and reconnects the on-site power system to the grid. At that time, operation reverts to “normal” as discussed in Figure 5.

This is a pure “insurance” mode, like a conventional UPS.

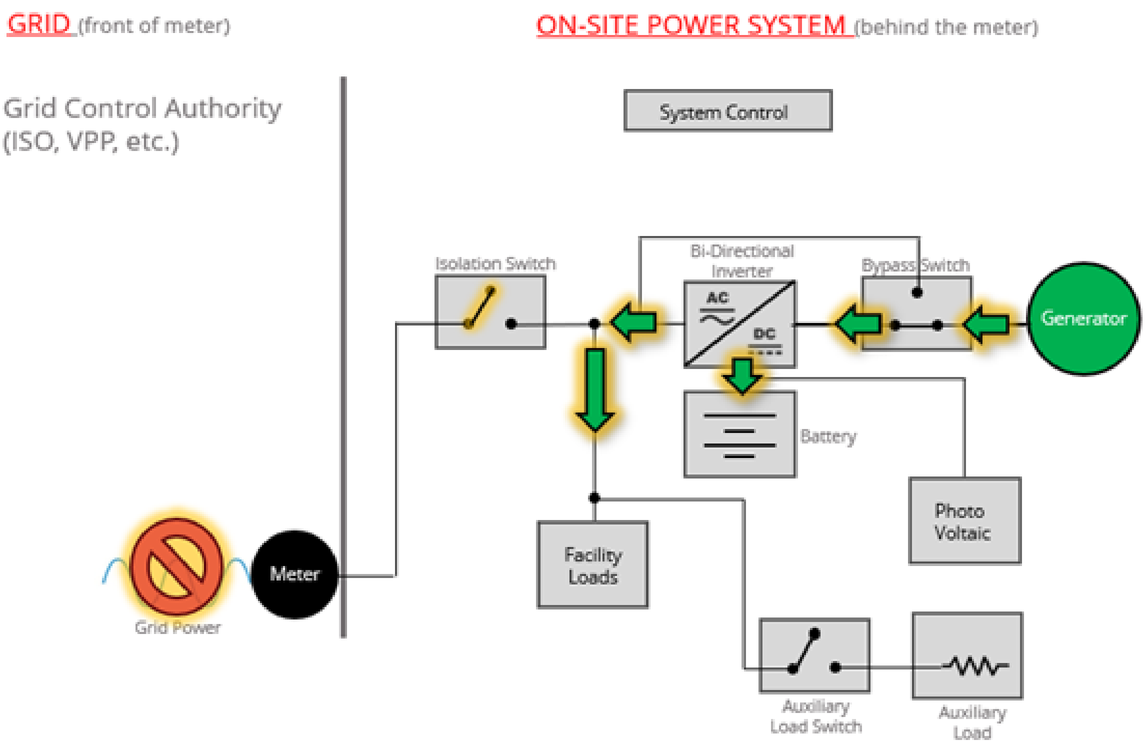

Figure 10 - Grid Failed - Generator provides long duration on-site load support

The function provided in this operating mode is like that provided by a traditional genset: backup power for facility loads during a blackout.

In this mode the generator also recharges the battery to an appropriate state of charge.

This is a pure “insurance” mode, functioning like a conventional genset.

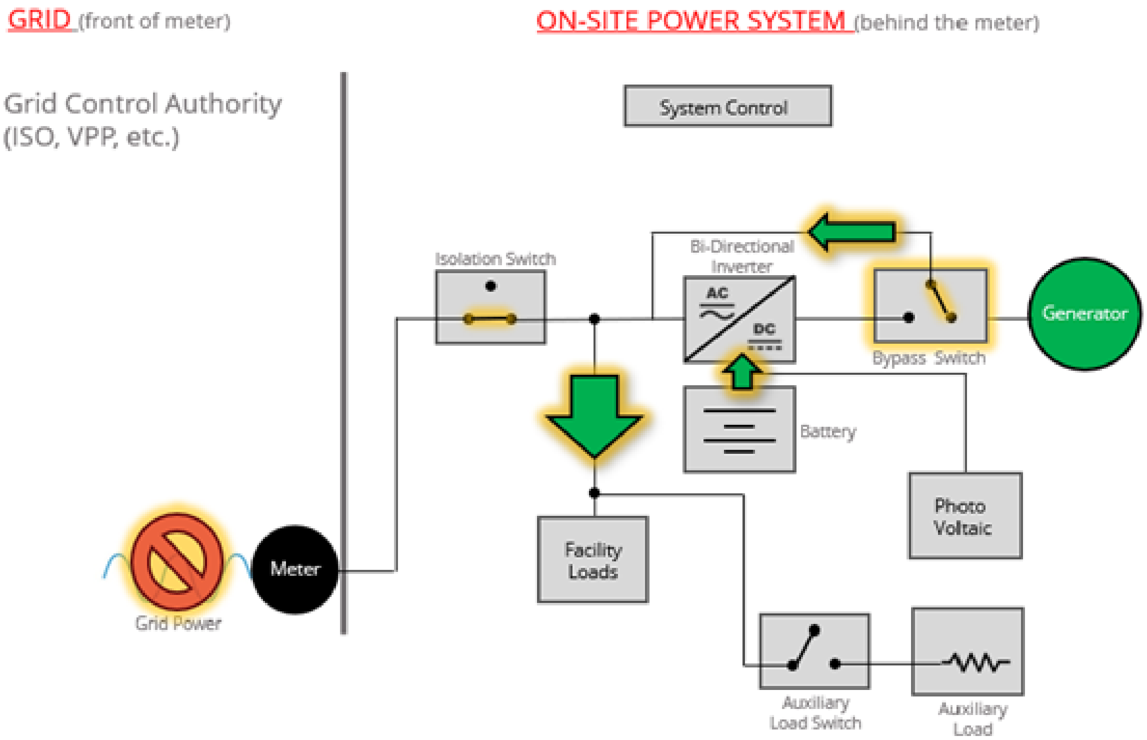

Figure 11 - Grid failed – Generator & inverter in parallel to provide surge power

In Figure 9 on the previous page, the generator is powering the facility load in island mode. The generator's limited capacity and relatively slow response time have the potential to create power quality problems, including dropping of the load.

These problems can be solved by operating the inverter in parallel with the generator.

Figure 10 shows a "parallel hybrid" inverter/generator in which the generator and inverter augment each other to supply surge power. This operating condition would only occur when the grid is unavailable, and only for a duration limited by the battery's capacity.

As with other operating modes, the system control would coordinate synchronization between inverter and generator prior to paralleling these sources.

There would be no need to operate the inverter and generator in parallel when the grid is available.

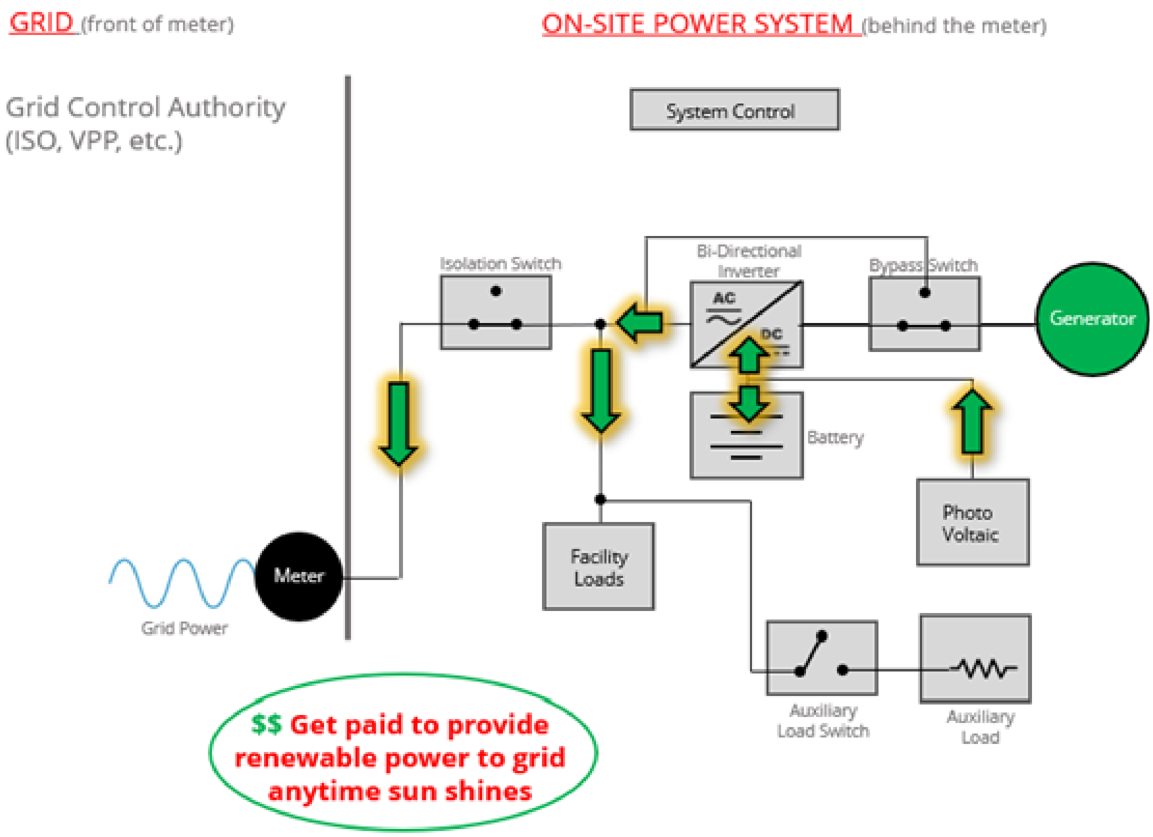

Figure 12 - PV system contributes power to on-site load & exports excess to grid

Renewable energy, e.g. from a PV system, is fed to the facility AC bus by the inverter. When power available from the renewable source(s) is greater than facility loads the excess is exported to the grid. When renewable power is less than facility loads the excess energy is exported to the grid.

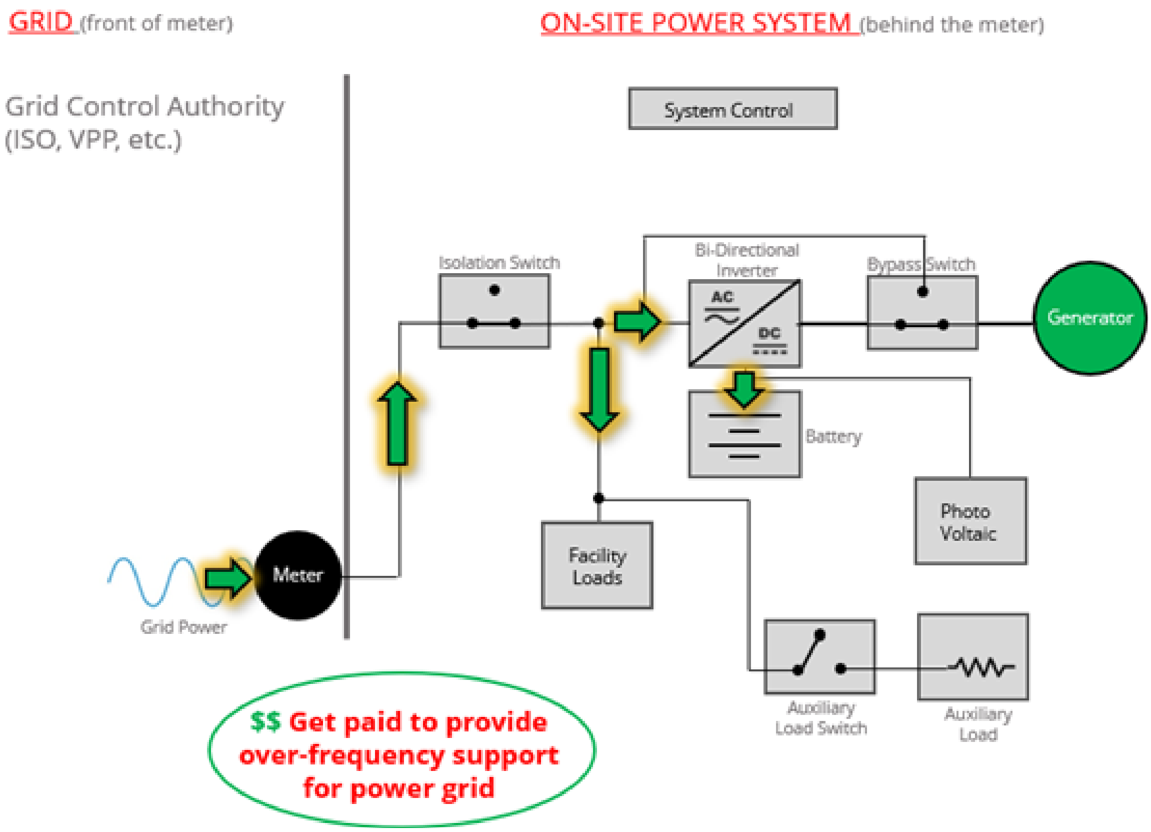

Figure 13 - Grid support - Battery provides instant over-frequency response

This mode is similar to that depicted in Figure 7, except that the battery serves as a short-duration energy sink that loads the grid.

The inverter responds nearly instantly to grid over-frequency by converting grid AC into DC to charge the battery. This is possible since the battery's normal condition is at partial state of charge (PSOC).

The "revenue function" in this mode is to get paid by the utility for providing fast frequency response. At least two states offer fast frequency response payment programs. Additional states are likely to in the future.

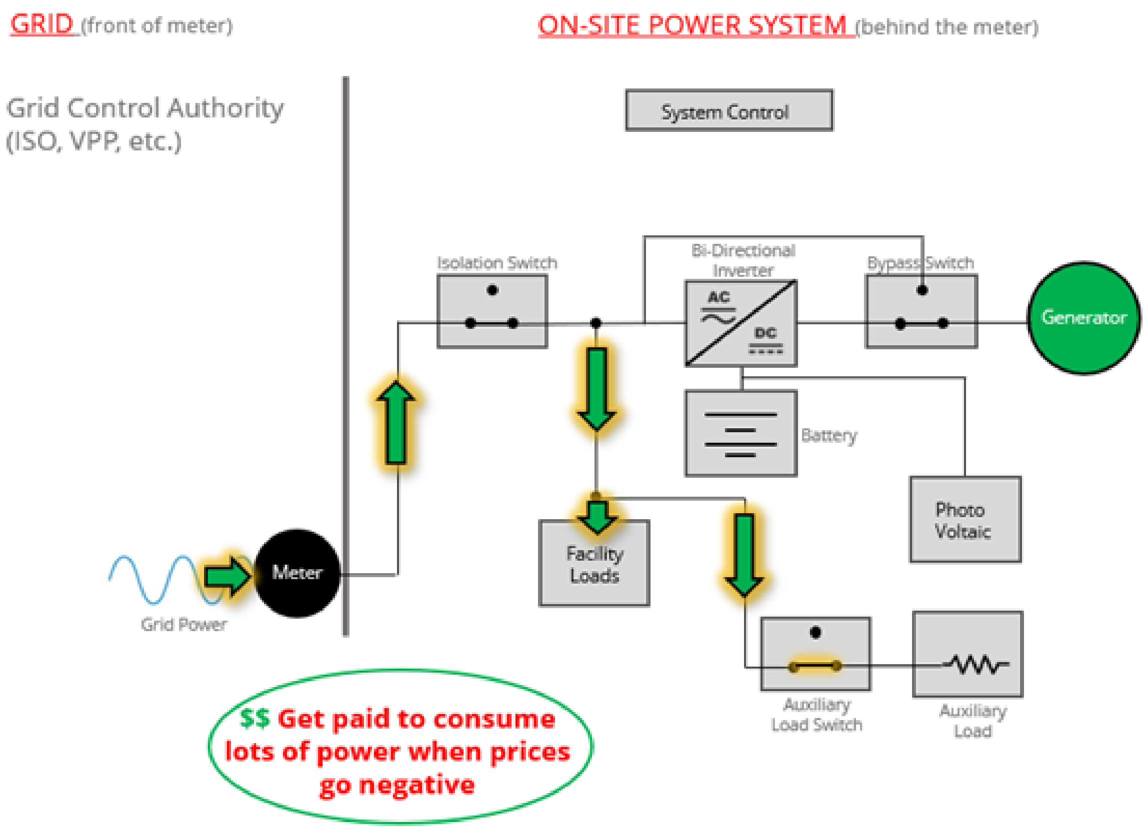

Figure 14 - Grid support - Load bank enables response to negative pricing

When the over-frequency event lasts longer than the battery has capacity to absorb the excess, additional load(s) are connected to the grid. Note that the auxiliary load provides absorption capacity that is not limited by battery SOC. Examples of such loads are heating, air conditioning, or computing tasks that aren't time-critical. When electricity prices are negative, the bigger the load, the better.

The scale of the "revenue function" of this mode is surprisingly large. CAISO experienced negative 5-minute prices in 15.66% of all 5-minute intervals in April 2025.[5] That is one in every six 5-minute dispatch intervals in a given month when the onsite power system could be importing power at zero or negative cost. In ERCOT West Texas nodes, negative pricing is structural during high-wind periods, occurring hundreds of hours per year.

A fleet of 1,000 onsite power systems, each absorbing 250 kW during negative-price events averaging -$20/MWh for 400 hours per year, would collect $2 million annually across the fleet from the negative price payment alone, before accounting for the value of work performed by the energy consumed in the auxiliary loads.

Summary

The national energy landscape is changing rapidly. Massive new loads are being added at the same time dispatchable generation sources are being retired and “replaced” by renewables. The result will be an increase in the frequency of mismatch between supply and demand for electric power.

This supply/demand mismatch will, in turn, cause more frequent blackouts and much more variability in electric power pricing. A combination of government policy and inability to obtain grid power will force many new large loads to BYOP. Over time, however, these BTM power systems will be forced to connect to the power grid by either policy, economics or a desire to improve community relations.

On-site energy storage or power generation will be critical to maintaining non-stop power for mission-critical applications. The paper discusses the multiple shortcomings of large BESS, and proposes a new hybrid power system architecture to replace large BESS.
The proposed hybrid power system architecture builds on pre-existing hybrid architectures, such as UPS and generator systems that work together to deliver both instant and long-duration power for mission-critical applications.

There are three primary differences between older technologies and this hybrid architecture. The first is close integration of subsystems including inverter, generator, auxiliary load and the control module. The second is close integration with balancing authorities and/or virtual power plant (VPP) companies to coordinate operations with the power grid. The third is the multiple different operating modes that enable backup power generation, plus utility cost avoidance, plus revenue generation. The opportunity to run in any of these modes boosts the value of the onsite power system beyond anything possible today.

References

1. Assessment-of-Potential-Impacts-of-Fires-at-BESS-Facilities_FINAL_Se p-2025.pdf
2. Toshiba_SCiB_catalog_202504
3. SCiB™ Cells | SCiB™ Rechargeable battery | Toshiba
4. April 2025 Monthly Renewables Report, California ISO

SENS®
STORED ENERGY SYSTEMS

Contact
Stored Energy Systems LLC
www.sens-usa.com
(303) 678-7500
info@sens-usa.com