Chapter Objectives:

- Define what is meant by a grid-tied PV system.
- Identify the various requirements surrounding rapid shutdown.
- Define the structure of a DC coupled and an AC coupled system.
- Discuss how to incorporate battery banks to address power outages, load shifting, and peak shaving.
- Identify trends and technologies available to assist in load management.
- Explore the various issues that arise when designing larger PV systems.
- Learn how best to incorporate subarrays in the design of large systems.
- Understand bipolar PV systems.
- Identify issues that can occur when integrating generators into a system.
- Discuss the role of microgrids in the distribution system.
- Explore how to integrate electric vehicle charging into a system as well as the grid.

Chapter 4

System Options

Determining the System Configuration

There are a number of ways a photovoltaic system can be configured to best meet the needs of a particular customer.

Some questions that need to be answered to help determine the system that best suits the situation include:

- Is the electrical grid available?
- How reliable is the grid? Are there frequent outages, for example?
- How critical are the loads being serviced by the system? For example, is the system being mounted on a hospital where power is literally a matter of life and death?
- Is shading an issue?
- How much space is available for the array?
- What is the billing structure from the utility, for example, is time-of-day pricing in place that would make battery systems attractive? Are there demand charges that could be offset with integrated storage?

Grid-Tied Systems

GRID-TIED SYSTEM

By far the most common system configuration installed in developed countries is the **grid-tied system**.

This configuration essentially uses the grid as a storage device. When more energy is generated by the system than is required by the load demand, the excess power is fed to the grid. When more load is

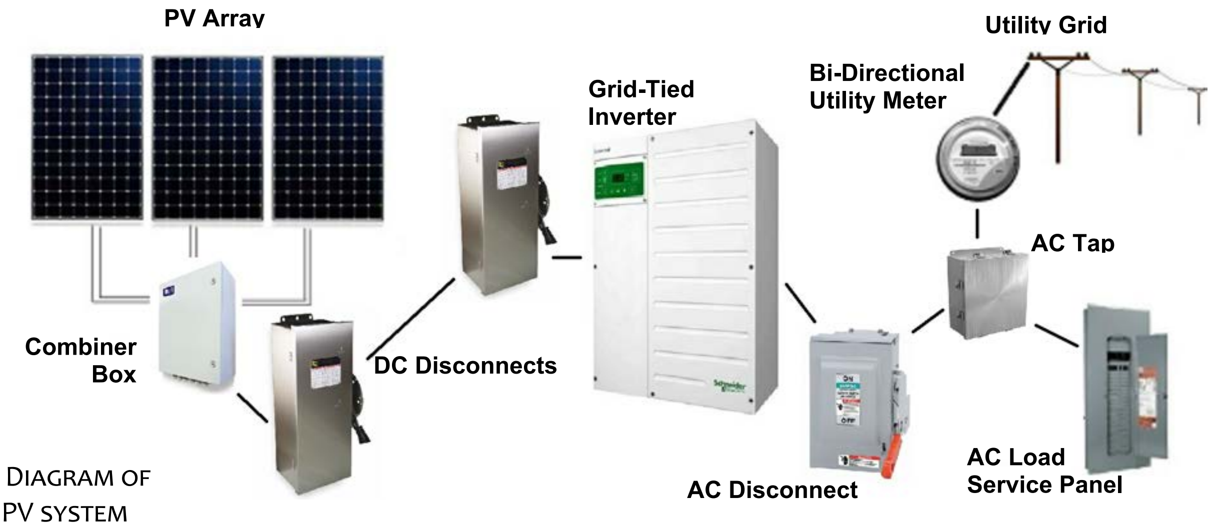


FIGURE 4-1: DIAGRAM OF A GRID-TIED PV SYSTEM WITH STRING INVERTER

required than the system is producing, the excess load demand is met by power drawn from the grid.

In effect, the electrical grid serves as a battery. "Storing" excess energy and then providing it when it is needed. This avoids the cost of a battery system (often more than half of the total system cost) and also avoids the maintenance issues required by battery banks.

A basic grid-tied system, can utilize a string inverter, such as the system depicted in Figure 4-1, or increasingly, incorporate microinverters or power optimizers that work in tandem with a fixed-voltage inverter.

Regardless of how it is configured, grid-tied systems have the advantage of avoiding the cost and maintenance issues involved when incorporating a battery backup system.

ISLANDING

One disadvantage, however, is that grid-tied photovoltaic systems are designed to shut down when the grid loses power. This avoids a situation where workers repairing the lines assume there is no power, only to find that the PV system is pumping electricity onto supposedly "dead" lines (known as **islanding**). In the past, workers have been killed or severely injured when a distributed energy system continued to operate while connected to a grid under repair.

As a result, a typical grid-tied system will only be as reliable as the electrical grid to which it is connected.

Rapid Shutdown of PV Systems on Buildings

Perhaps the most dramatic change in the 2014 NEC, from the perspective of PV design, was the incorporation of a provision (in Section 690.12) that all rooftop arrays must incorporate a method where they can be effectively shut down at the source.

The reason for this provision comes from the increasing risk faced by first-responders when responding to a fire at a structure where a PV system is installed. This risk is present in all occupied buildings - but not for ground mounted systems. So rapid shutdown requirements do not apply to ground mounted systems.

Historically, when a first responder disconnects power from the grid (by pulling the meter, for example), they can safely assume that they will not come into contact with any live electrical wires within the building.

However, if a PV system is present and the sun is shining, wires within the structure may still be energized, even when the main **AC disconnect** has been opened and the system is no longer operating (power can still be present from the panels to the string inverter where the anti-islanding feature has shut down the system).

AC DISCONNECT

2014 NEC Rapid Shutdown Requirements

To prevent this situation, the 2014 NEC required that when the PV system disconnect is turned off:

- conductors more than 1.5 meters (5 feet) inside the building structure and no more than 3 meters (10 feet) from the array be limited to a maximum of 30 volts and 240 watts within 10 seconds of system shutdown. 30 volts is considered “touch safe” in a wet environment,
- systems with rapid shutdown should be labeled as such,
- equipment that performs the rapid shutdown should be listed and identified as meeting the rapid shutdown requirements.

System designers could comply with this 2014 provision in a number of ways.

These include:

- use of microinverters, which disconnect at the panel when the grid is not present,
- use of power optimizers, which also disconnect at the panel when the grid is down,
- use of a **disconnecting combiner box** (must be located within 10 feet of the array) that is wired to an emergency shutoff switch located near the utility service entrance, an example is shown in Figure 4-2,
- or locate the string inverter within 10 feet of the array.

DISCONNECTING COMBINER BOX

FIGURE 4-2: EMERGENCY DISCONNECT SWITCH CONNECTED TO COMBINER BOX

(FROM BENTEK SOLAR)

2017 NEC Rapid Shutdown Changes

The 2017 NEC added some additional requirements. These include:

ARRAY BOUNDARY

- conductors within one foot of the **array boundary** (rather than 10 feet) must be energized to no more than 30 volts within 30 seconds (rather than ten seconds) of the main disconnect being turned off.

RAPID SHUTDOWN EQUIPMENT (PVRSE)

RAPID SHUTDOWN SYSTEM (PVRSS)

- the specific component parts used must be listed (by UL or some other listing agent) that they comply with rapid shutdown provisions (**rapid shutdown equipment**, or PVRSE) or as a system, when designed to work together (**rapid shutdown system**, or PVRSS),
- or, the array has no exposed wiring methods or conductive parts and is more than eight feet away from any grounded metal,
- or, within the array boundaries, there is no conductor with a voltage higher than 80 V when rapid shutdown is initiated. Under the 2014 rules, DC conductors could be up to 1,000 V inside the boundary of the array.

At the time, no standard existed that allowed compliance with these provisions. Also, few product systems were available that contained all wiring from the panel to the junction box in nonconductive raceways (a few non-metallic solar shingle systems).

MODULE-LEVEL POWER ELECTRONICS

The effect of these changes was that after 2018, all roof-mounted arrays must incorporate some type of **module-level power electronics (MLPE)**, such as power optimizers or microinverters, that reduced the conductor voltages to less than 80 V within the array boundary once rapid shutdown was initiated.

2020 NEC Rapid Shutdown Changes

In the 2020 NEC, rapid shutdown inside the array boundary was revised to address "PV hazard control systems". This is a change in terminology that replaced the rapid shutdown system provision as outlined in the 2017 code.

UL 3741

First published in December 2020, ***ANSI/CAN/UL 3741****: Standard for Safety for Photovoltaic Hazard Control* provides a means of evaluating photovoltaic (PV) hazard control components, equipment and systems that comply with the rapid shutdown requirements.

DC Coupled: Grid-Tied with Battery Backup

One of the critical disadvantages of a grid-tied PV system is that when the grid goes down - the system is designed to shut down due to islanding. To avoid the problem of loss of power when the electrical grid goes down, some grid-tied systems incorporate a battery backup system into their design.

DC-COUPLED SYSTEM

CRITICAL LOADS

This design, often referred to as a **DC coupled system**, as seen in Figure 4-3, might be practical if the installation is located in an area with an unreliable grid, or if there are **critical loads** within the building that absolutely must have power all the time (such as within a hospital, for example).

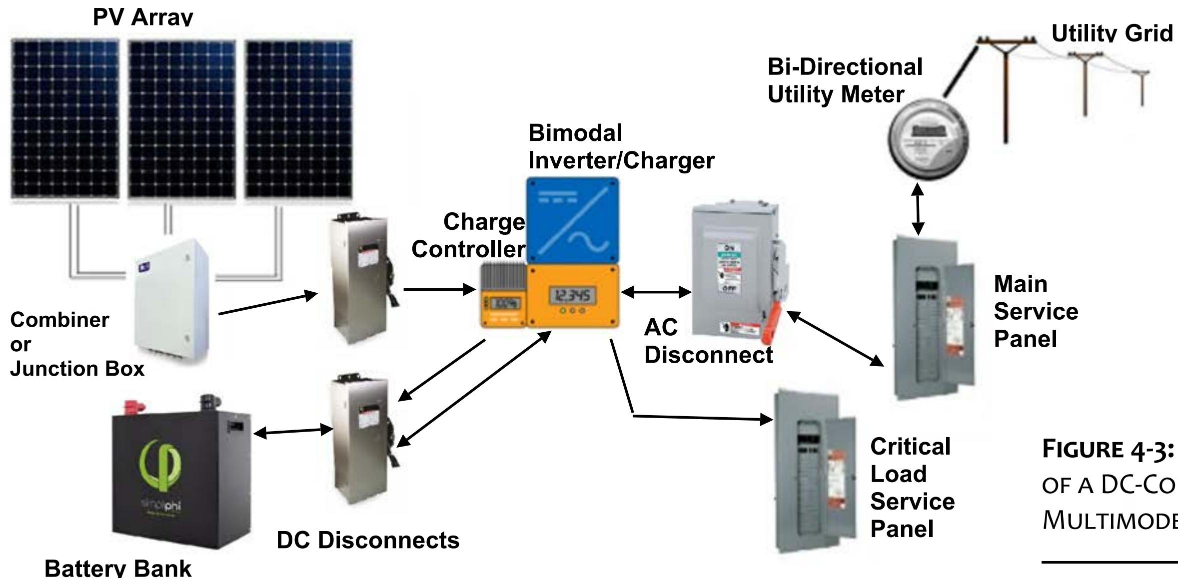


FIGURE 4-3: DIAGRAM OF A DC-COUPLED MULTIMODE SYSTEM

ESSENTIAL LOADS

For most facilities, there are two further classes of load. **Essential loads** provide secondary support services that may still be required for health and safety reasons, such as emergency lighting. These loads must still have some form of backup but do not require uninterrupted power, so can be allowed to fail or ride through the time it takes for a generator to start.

NON-ESSENTIAL LOADS

Finally, there are **non-essential loads** that are not required during brief periods when the grid is down, such as ceiling fans or printers.

When designing these systems, it is typical that specific critical circuits be identified to receive power from the battery bank (rather than the entire building), when the grid is down. These circuits must be disconnected from the grid (either physically, or electronically) before they can be energized.

CRITICAL LOAD PANEL

This is normally accomplished through the integration of a **critical load panel** - essentially a second service panel that connects to all critical loads but is not directly connected to the utility grid.

The main service panel and the critical load panel are connected to the bimodal inverter. During normal operations, both the main panel and the critical load panel are connected together to the array, battery bank and the grid through the inverter.

TRANSFER SWITCH

When the grid goes down, the bimodal inverter disconnects from the main service panel (isolating the system from the grid) through the use of an integrated **transfer switch**. It then redirects the system's power (array and battery bank) to the critical load panel only.

AUTOTRANSFORMER

Many commercially available systems, such as the system from SolarEdge, pictured in Figure 4-4, integrate multiple components into the inverter. For example, in this system the charge controller function and DC disconnect are integrated into the inverter unit. An added **autotransformer** unit must be connected to the inverter to monitor the grid and act as an anti-islanding transfer switch.

The inverter unit has two DC inputs (one from the array and one from the battery bank) and two AC outputs (one to the main service panel and one to the critical load panel. The monitoring (metering) system is handled in the cloud or an additional consumption meter may be added to the system..

Some charge controllers allow system owners to retrofit existing string-inverter grid-tied systems to incorporate battery backup (creating a DC-coupled system) by incorporating a charge controller with a manual transfer switch that avoids the necessity of replacing the existing grid-tied string inverter.

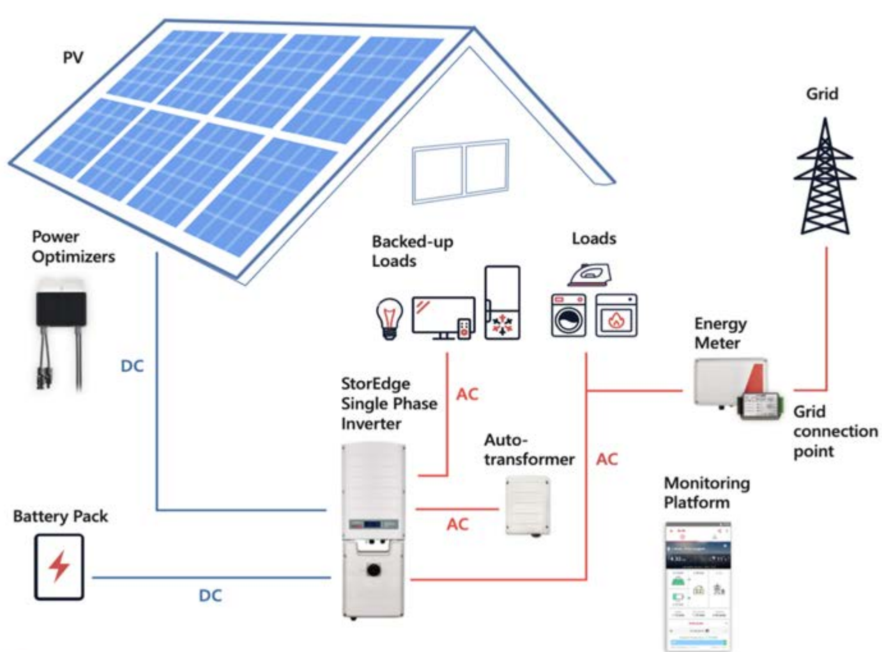
Incorporating a battery bank into a typical grid-tied system will add substantially to the overall cost and maintenance requirements of the system. However, as battery prices decline and the grid viewed as unreliable, grid-tied systems with battery backup have become increasingly popular. In 2020, over 20% of all systems installed in the US incorporated some sort of battery backup.

Other situations where DC-coupled systems may be appropriate include:

- time of use shifting (load shifting),

FIGURE 4-4: DIAGRAM OF DC COUPLED RESIDENTIAL INSTALLATION

(FROM SOLAREDGE)



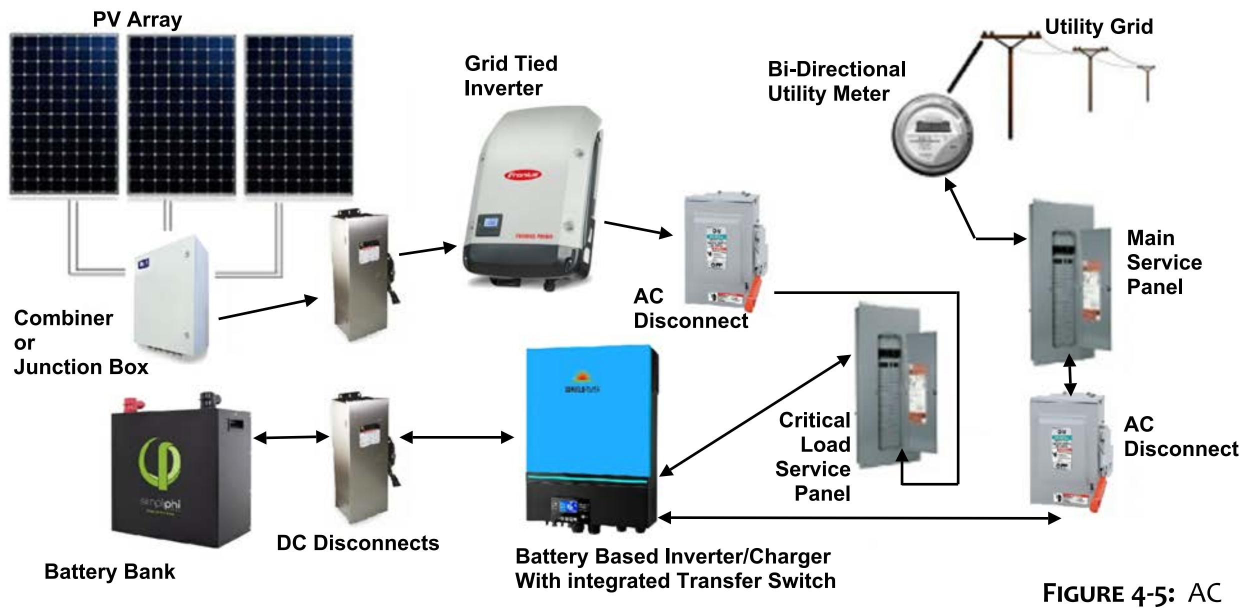


FIGURE 4-5: AC COUPLED SYSTEM

- peak demand reduction (load leveling or peak load shaving),
- where net metering isn't permitted.

AC-Coupled Multimode Systems

Systems that convert the DC power of an array into AC power, and then convert the AC power back to DC to charge a battery bank, are gaining in popularity.

At first glance, this may seem an unnecessary step and added complexity, but there are a number of advantages.

AC-COUPLED SYSTEM

AC-coupled systems allow owners of existing PV systems to add a battery backup without changing their installed system configuration.

In AC-coupled system illustrated in Figure 4-5, the grid-tied inverter is connected to the critical load panel (rather than the main service panel). A battery-based inverter/charger is also connected to the critical load panel, and then connected to the battery bank.

The battery-based inverter/charger can take AC power from the grid-tied inverter and/or from the grid and charge the batteries (converting it from AC to DC). It can also take DC power from the batteries (in the event of a power outage, for example) and convert it to AC power that is distributed through the critical load panel.

When the grid is operating, power flows from the critical load panel to the main load panel (and all the loads are energized and excess power can flow to the grid). When the grid goes down, an integrated transfer switch within the inverter disconnects from the main service panel, isolating the system from the grid.

There are a number of integrated systems on the market today (such as the Enphase Enpower system or the Tesla Powerwall 2) that offer components designed to work together and combine the battery bank with the inverter/charger in one unit.

Note that in all grid coupled systems (both AC-coupled and DC-coupled), a transfer switch must be located within the system. This transfer switch will sense when the grid goes down and disconnect the system from the grid to avoid islanding. In some cases the transfer switch will be a separate unit, or it may be integrated within the inverter.

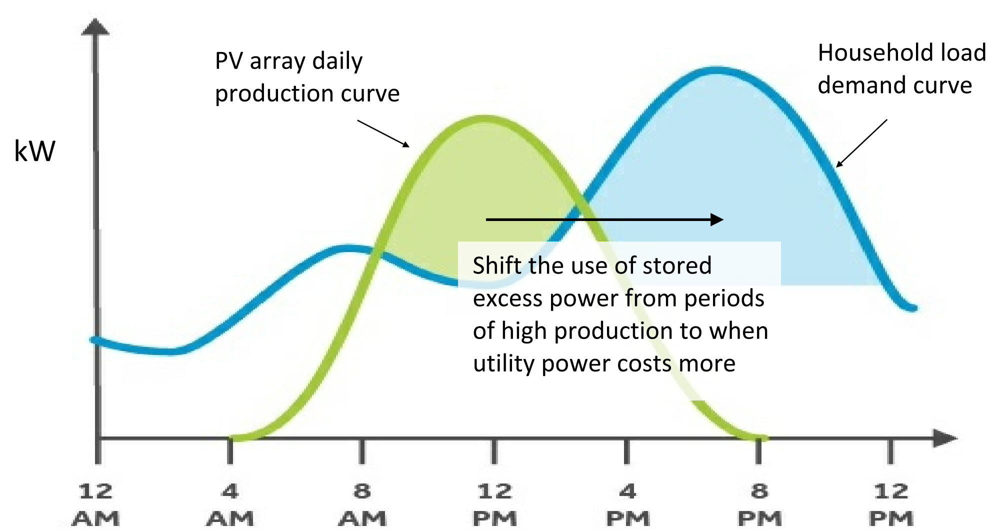
Designing AC Coupled Battery Bank Systems

AC coupled systems may be installed at a location for a number of reasons. In residential settings, these normally include:

- the originally installed system did not incorporate battery backup to serve critical loads when the grid fails.
- net metering isn't permitted at the location. A battery bank can be set to store excess energy (since it cannot be exported to the grid), and then offset power that might otherwise be purchased from the grid when the array is not producing sufficiently to service the loads (such as at night, for instance).

In commercial situations, utility billing practices may make AC coupled systems an attractive alternative for additional reasons that may or may not be a factor in a residential setting. These systems may or may not incorporate a solar array as part of their energy strategy.

FIGURE 4-6: LOAD SHIFTING FOR HOUSEHOLD LOCATED WHERE EVENING POWER FROM THE UTILITY COSTS MORE THAN AFTERNOON POWER



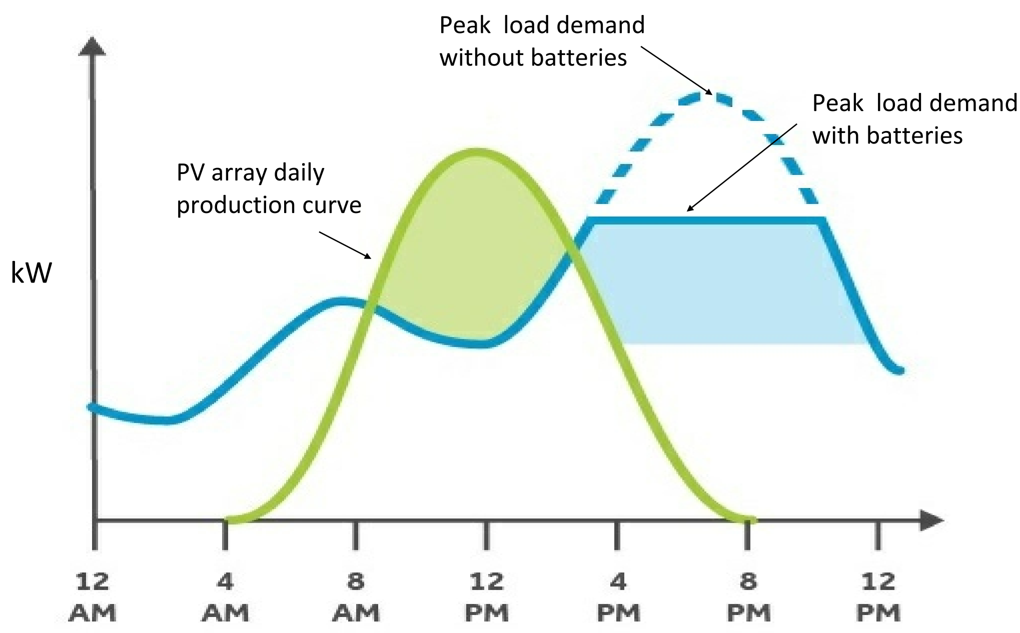


FIGURE 4-7: PEAK SHAVING AFFECT ON PEAK LOAD DEMAND BY INCORPORATING BATTERY BANK

These reasons include:

- time of use shifting. If the utility pricing scheme charges more for power during periods of high demand, the customer can shift their consumption by storing excess power generated by the PV array (rather than selling it back to the utility) and then using the stored power during periods of high-cost power (rather than purchasing it from the utility). This process is also known as **load shifting,** as illustrated in Figure 4-6.
- Peak demand reduction, commonly called **peak shaving**. Utilities often charge commercial customers a rate based on the 15-minute interval within the month where the most power was used. The higher the use, the higher the bill. Customers can reduce their peak usage, offsetting it with power from the battery bank, as illustrated in Figure 4-7. This can dramatically reduce their monthly bill from the utility company.

LOAD SHIFTING

PEAK SHAVING

PV systems that incorporate batteries designed to deal with load shifting and/or peak shaving are often referred to as **self-consumption grid-tied** systems.

SELF-CONSUMPTION GRID-TIED

Current Transformers

The sizing of self-consumption battery banks generally involves obtaining a detailed load-versus-time profile of home energy consumption with the use of energy-monitoring equipment.

Current transformers (CTs) are installed around the hot conductors in the solar production circuit (normally within the service panel). The arrow on the CT must be pointing toward the load, as illustrated in Figure 4-8. Load consumption data is collected and sent to a monitoring system.

CURRENT TRANSFORMERS

The data from the solar array must also be collected to determine how much excess power is sent back to the grid during peak generation times. Most grid-tied inverters collect and report this data.

This information can be used to size a battery bank within an AC or DC-coupled system. The battery bank is sized to store the portion of the PV array's daily energy. This energy would normally be exported to the grid in a net-metered system, so that it can be consumed onsite instead.

FIGURE 4-8: INSTALLED CURRENT TRANSFORMER (CT)

In order to properly size a battery bank, the system designer will need to know how much load will need to be offset to account for load shifting or peak shaving requirements, or to provide power during a grid outage. Designers often oversize battery banks, assuming power outages will last longer than they actually do.

Sizing Battery Bank for Power Outages

Eaton's *2015 Blackout Tracker* report found that of the more than 3,500 outages in the U.S., the average duration was only 49 minutes. The Electric Power Research Institute also estimated that 57% of U.S. power outages last less than five minutes. Depending on the client's system availability requirements, a relatively small battery bank can handle most grid outages.

For example, a typical home in the U.S. consumes about 30 kWh per day. This power is not consumed at a uniform rate (30 kWh / 24 hrs). An hourly load assessment could be conducted, but for this example, assume during waking hours the client consumes 2 kWh per hour.

A lithium ion battery bank designed to provide one (1) hour of emergency backup would be sized:

load demand / system voltage / depth of discharge / inverter efficiency, or
2 kWh / 48 volts = 41.66 Ah / 95% DOD = 43.85 Ah / 97% = 45.2 Ah

AC coupled systems are marketed in terms of kWh rather than the more traditional Ah rating of battery systems, and the DOD and inverter efficiency is already calculated into this rating. This system would need a 2 kWh battery bank to deal with any power outages less than one hour in duration.

Effectively, this system acts as an **uninterruptible power source (UPS)** for the entire house.

UNINTERRUPTIBLE POWER SOURCE (UPS)

Most AC coupled systems on the market are essentially plug and play. Follow the manufacturer's instructions. Some systems, such as Tesla's Powerwall, require they be installed by an installer that has been certified by the manufacturer.

Designing AC-Coupled Systems using Lead Acid Batteries

While most **energy storage systems (ESS**) available on the market for AC-coupled systems incorporate lithium ion batteries, it is possible to design an AC-coupled system using lead acid batteries.

ENERGY STORAGE SYSTEMS (ESS)

An AC-coupled system of this type has significant advantages over incorporating a generator into the system to deal with periodic power outages.

These include:

- reduced noise (generators can be very loud),
- reduced wear and tear on the generator, which must run the entire time the grid is down. Incorporating a battery bank into the system reduces significantly the amount of time a generator must operate during extended power outages.

Prior to adding a battery-based inverter and battery bank to an existing grid-tied system, it is common to add a critical load panel so the battery bank need not supply power to the entire load when the grid goes down.

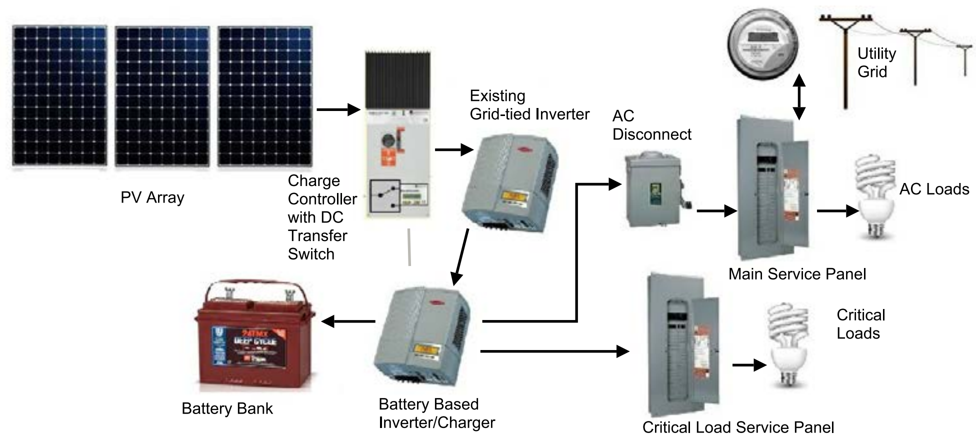
However, the existing solar array and the existing grid-tied inverter may have been sized to provide enough power to service all daily loads.

As a result, when designing an AC-coupled system, care must be taken to avoid overcharging the battery bank when production from the array exceeds load demand and the grid is not available to absorb any excess production.

If all the power flowing through the grid-tied inverter is to be captured, then the battery bank must be sized based on the grid-tied inverter's output. Generally this requires about 100Ah per 1kW of PV on a 48V system. Such a large battery bank may be much more than is required to service only critical loads during short term and/or infrequent power outages.

The battery bank required to service critical loads would be sized in a manner similar to sizing a battery bank for a stand alone system, with the daily critical load substituted for the total daily load demand.

FIGURE 4-9: POWER FLOW OF AC-COUPLED SYSTEM WITH CHARGE CONTROLLER WHEN GRID IS FUNCTIONING



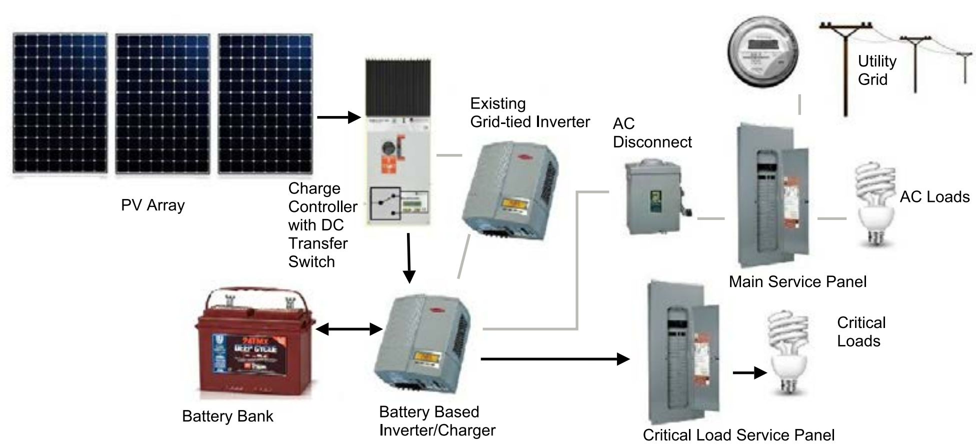
If a smaller battery bank were installed, however, then the power flowing from the array through the grid-tied inverter might severely overcharge the battery bank or charge it too quickly. It should be noted that charging rates faster than C5 can be harmful to lead-acid batteries and shorten their functional life.

Designers can avoid this problem by incorporating a diverted load (such as a hot water heater) in a manner similar to that used when designing a stand-alone system.

Or a charge controller with a DC transfer switch can be incorporated into the system. When the grid is operational, power flows through the charge controller from the PV array to the grid-tied inverter, as indicated in Figure 4-9.

However, when the grid goes down, the transfer switch within the charge controller redirects the array's power to the battery-based inverter, as demonstrated in Figure 4-10. The charge controller then limits the amount of power going to the battery bank, avoiding overcharging.

FIGURE 4-10: POWER FLOW OF AC-COUPLED SYSTEM WITH CHARGE CONTROLLER WHEN GRID IS DOWN



Rapid Shutdown Issues with Battery Systems

The rapid shutdown provisions of the NEC are designed to ensure that power is not present within the building when the main PV disconnect is turned off (disconnected from the grid).

However, one of the main advantages of incorporating batteries into a PV system is to ensure the array remains functional and power is available, even when the grid goes down. Obviously these two goals are in conflict.

In grid-tied systems that do not incorporate batteries, the AC disconnect is considered the **rapid shutdown initiator (RSI)**. In other words, when the main AC disconnect is opened (turned off), shutdown takes place at the array. With systems that incorporate batteries, a second RSI is required.

RAPID SHUTDOWN INITIATOR (RSI)

Most AC-coupled and DC-coupled systems incorporate a manual RSI with the battery-based inverter unit. However, since the RSI must be accessible by first responders, this means the inverter must be mounted outside (normally within 10 feet of the meter), or an auxiliary RSI (for the battery system) must be installed.

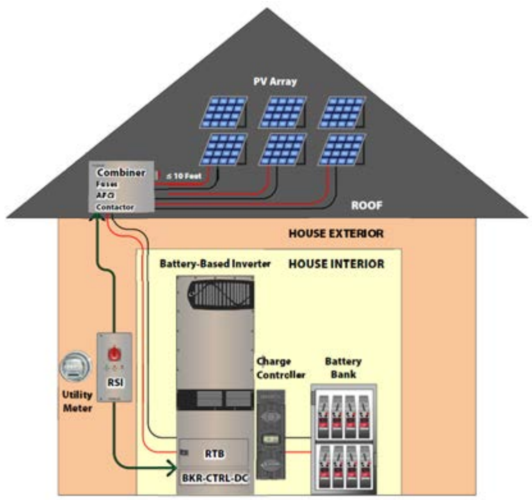


FIGURE 4-11:
REMOTE BATTERY RAPID SHUTDOWN INITIATOR

FROM OUTBACK POWER

Most battery-based inverters will offer a remote disconnect switch designed to integrate into their unit, such as the optional switch offered by Outback Power for their system, as illustrated in Figure 4-11.

Load Management

Batteries are often introduced into a system as a tool that allows better management of the load. Load shifting, peak load shaving and power outages are all reasons cited for incorporating batteries at a site. But batteries are expensive, so load management devices are often incorporated to reduce the size of the battery bank required to accomplish these goals.

LOAD MANAGEMENT

Load management, often called demand-side management (DSM), is the process of balancing the supply of electricity available with the electrical load by adjusting or controlling the load rather than the supply.

This can be achieved by the direct intervention of the utility in real time, or by the consumer managing how they use loads either manually or through a number of automated devices.

A very early load management device might be a timer placed on a water heating circuit to turn off the heater during periods of peak load demand. Over the years, the technical nature of these load management devices has changed dramatically.

Frequency-based Decentralized Demand Control

Excessive loads on the grid physically slow the rotors of a grid's synchronized generators. This causes service throughout the grid to have a slightly reduced frequency.

Inexpensive electronic devices can easily and precisely measure the frequency present and turn off sheddable loads. Most electronic electric power meters internally measure frequency, requiring only simple demand control relays to turn on and off equipment.

Ripple Control

RIPPLE CONTROL

Ripple control is another common form of load control. With ripple control, the grid operator superimposes a high-frequency signal (usually between 100 and 1600 Hz) onto the standard 50–60 Hz of the main power signal. A receiving device attached to non-essential loads receives this signal, shutting down the load until the signal is disabled or another frequency signal is received.

Plug and Process Load Management

PLUG AND PROCESS LOAD (PPL)

Plug and process loads (PPL) include all plugged-in and hardwired electronic devices that are not associated with other major building end uses such as heating, cooling, ventilation, and lighting. PPLs in commercial buildings account for almost 47% of U.S. commercial building electricity use.

Automated systems exist for homeowners to control and manage energy consumption at the appliance level. These systems rely on the technology inherent in the Internet of Things (IoT) that provides the ability of devices to send and receive data via the Internet.

However systems required to provide effective load control within commercials structures are much more complex. Commercial buildings generally have multiple occupants, many more devices, multiple impressions of what is or is not a critical load - so uniform management systems are often quite difficult to implement.

An effective load management system must have five main capabilities:

- location identification of the load,
- communication processes,
- control of the load,
- energy metering, and
- data storage.

One PPL solution is to install a "smart outlet." A **smart outlet** can be installed at the electrical outlets of a building either as plug-through receptacle or embedded into the outlet itself, such as the example pictured in Figure 4 -12.

FIGURE 4-12: COMMERCIALLY AVAILABLE SMART OUTLET

SMART OUTLET

Typically, a smart outlet measures the power consumption of the device that is plugged into it and transmits the data wirelessly to a central monitoring system. Building managers can view the data and turn devices on or off, either manually or through pre-determined settings.

Load control can be scaled up to include the entire branch circuit, rather than a single outlet. With the use of an **energy management circuit breaker (EMCB)** the owner or building manager can control a complete circuit rather than a single device. For example, during a power outage the system operator may wish to shed non-critical loads to extend the useful capacity of the battery bank. Circuits can be prioritized and sequentially shed based on the length of the outage.

ENERGY MANAGEMENT CIRCUIT BREAKER

Larger Systems Using Microinverters

For larger arrays that incorporate microinverters, an AC-rated combiner box will be required.

For smaller systems, the PV output circuit can run (in conduit) directly to the building, connecting to either a meter or an AC disconnect (or both). Increasingly larger PV installations are incorporating microinverters.

Advantages of this system design include:

- zero risk of **arc fault** as the entire system incorporates standard AC wiring. All modern inverters incorporate arc fault detection, however it remains a risk with high voltage DC systems.
- automatic rapid shutdown compliance, as the microinverter ensures the current is terminated within the array boundary since the inverter is connected directly to the panel.
- increased system efficiency and shading mitigation.
- increased system reliability as there is no single point of failure, as in a larger string inverter system.
- increased power quality. microinverters will automatically correct **phase imbalance** within a three-phase system. Voltages at the site can become unbalanced due to the unequal system impedances, the unequal distribution of single phase loads, asymmetrical three-phase equipment

ARC FAULT

PHASE IMBALANCE

and devices, unbalanced faults, or bad electrical connections. An unbalanced three-phase system can cause three-phase motors and other three-phase loads to experience poor performance or premature failure.

AC Combiner Box for Microinverters

Since microinverters generate AC current at grid voltage (240 Vac single phase or 208 Vac three phase) rather than DC, when connected together they are connected in parallel rather than series. So multiple microinverters connected together are a **branch circuit,** rather than a string. Each microinverter added increases the amps on the circuit.

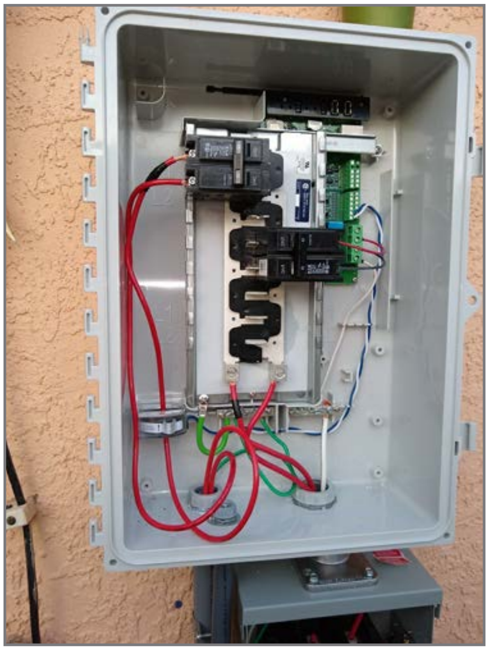


FIGURE 4-13: ENPHASE IQ COMBINER 3 CONNECTED TO A SINGLE BRANCH CIRCUIT

BRANCH CIRCUIT

The limiting factor on the number of microinverters in each branch circuit is the maximum ampacity of the proprietary cabling used in the system (generally limited to 20 amps).

For example, the Enphase IQ7+ microinverter generates 290 VA of continuous power. Each microinverter in a single phase system will add 1.21 A to the branch circuit (290 VA / 240 V) and 1.39 A in a three phase system (290 VA / 208 V). So branch circuits are limited to 13 microinverters for a single phase system (13 x 1.21 A= 15.73 A x 1.25 safety margin = 19.66 A) to stay under the 20 A limitation of the cable. Three phase systems are limited to 11 microinverters for each branch circuit.

When designing a system that incorporates more microinverters than can be accommodated in a single branch circuit, a combiner box is required.

Enphase, the industry leader in microinverters, offers a combiner box as shown in Figure 4-13 that integrates overcurrent protection as well as the monitoring hardware for the system.

This combiner box has space for four 20 A double-pole circuit breakers connected to four branch circuits from the array or battery bank. The monitoring hardware is also incorporated into the unit and can be paired with the site's wireless Internet service (or to a mobile phone network).

Multiple combiner boxes can be used for very large systems.

Battery-less Coupled Systems

Enphase made headlines in early 2022 with the announcement of their IQ8 series of microinverters. The groundbreaking feature of these systems is that they can provide power to critical loads even without a battery attached to the system.

When the grid goes down, the system will disconnect from the grid in a manner similar to all AC-coupled systems. Then the array will provide power directly to the loads, but only to the extent that solar power is available at any given instant.

Due to the variability of solar power (clouds passing overhead, for instance) the available power rises and falls from moment to moment. With no battery incorporated to even out this variability, the system is designed to shut down if the load demand is too high.

The system incorporates a load controller to manage loads, shedding predetermined circuits as needed.

While this is the first product to incorporate battery-less backup capability, it is highly likely that more systems will begin to incorporate similar features.

Commercial Systems

In many respects, most of the same design issues that apply to smaller residential systems also apply to larger commercial systems. The same components are utilized, but scaled up for larger systems.

The chief difference when determining the design options for a larger system (10 kW and up - in 2016 the average commercial system was 217 kW) lies in the selection of the inverter and how it is connected to the electrical grid.

The designer of a commercial PV system must decide whether to install one large inverter, capable of handling the power generated by the entire array, or to install a number of smaller inverters and then combine their AC output.

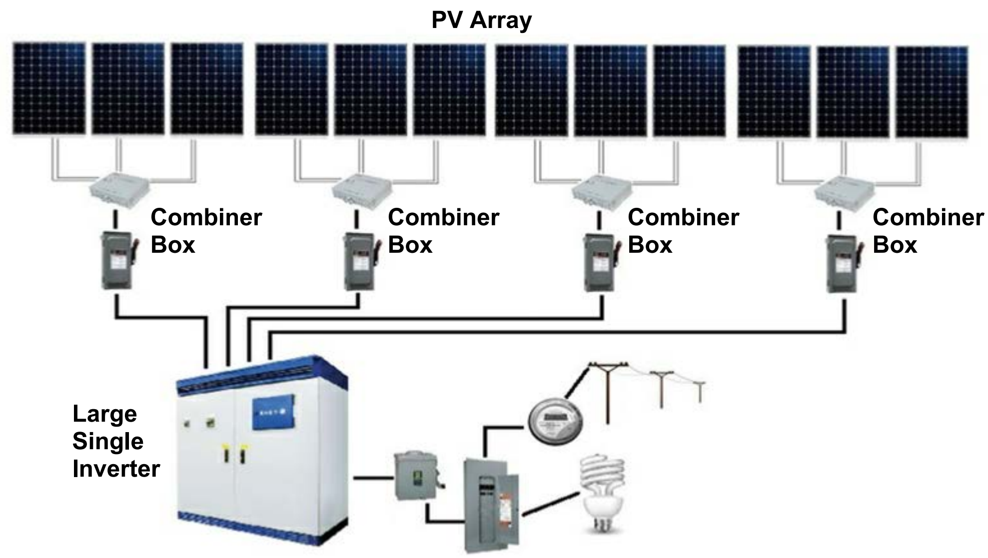
Note that many of the advantages/disadvantages between a single large inverter and multiple string inverters in a commercial installation are quite similar to the issues involved when determining whether or not to use microinverters or a string inverter in a residential installation.

Large commercial inverters typically have connection points for multiple **subarrays**, as indicated in Figure 4-14. A subarray that has two output conductors, one positive and one negative (which is typical) is referred to as a **monopole subarray**.

SUBARRAY

MONOPOLE SUBARRAY

FIGURE 4-14: SYSTEM DESIGN WITH SINGLE COMMERCIAL STRING INVERTER



Larger systems can alternatively be designed to incorporate many smaller string inverters. These are essentially smaller PV systems combined together on the AC side of the inverters, as shown in Figure 4-15.

Advantages and disadvantages of these configuration options are detailed in Table 4-1.

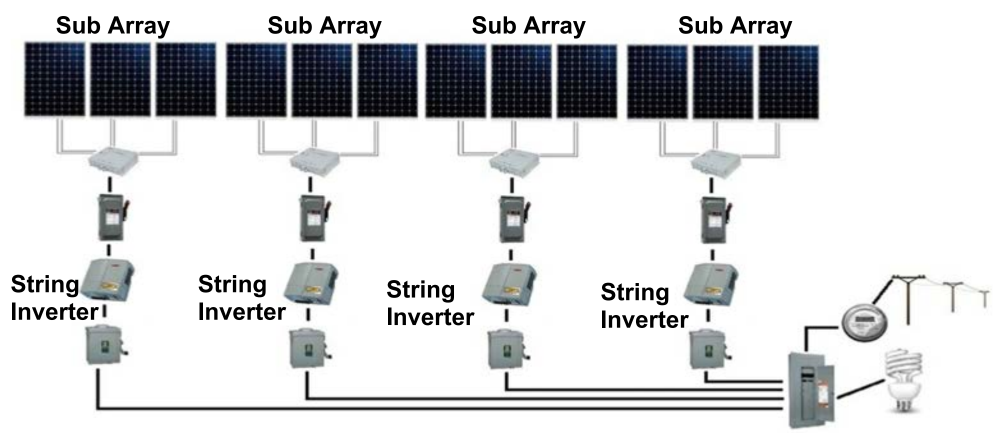
Larger Power Optimizer Systems

Many larger commercial installations are moving away from a single large inverter to installations that feature multiple optimizer-based sub-arrays coupled together.

The advantages of this design choice include:

- no single point of failure within a large inverter,
- module level monitoring and efficiency,
- a greater workforce is available to install and service the smaller systems, as large inverter systems may require specialized training.

FIGURE 4-15: LARGE SYSTEM DESIGN WITH MULTIPLE STRING INVERTERS



	Single Inverter	Multiple Inverters
Equipment Cost	Less Expensive	More Expensive
Installation Cost	Less Expensive	More Expensive
DC Wiring	More Complex	Less Complex
AC Wiring	Less Complex	More Complex
Unit Weight	Very Heavy, requires lifting equipment	Lighter, no special equipment required
System Availability	Single point of failure	Entire system is not affected when one inverter goes down
MPPT	Single MPPT for entire array	MPPT adjusted for each inverter
Array Orientation	All panels in the array must be oriented in the same direction	Each inverter can have unique orientation
Array Configuration	Each string must be of the same length	Each inverter can have unique configuration
Module Selection	All modules in the array must be identical	Each sub-array can have unique modules
Fault Detection	Difficult	Less Difficult
Performance Monitoring	Difficult	Less Difficult
Output	—	1% to 1.5% higher
Grid Connection	Must match grid exactly	Often field configurable
Warranty	Usually 5 years	Usually 10 years
Service	By trained technician	By installers

TABLE 4-1: ADVANTAGES AND DISADVANTAGES OF A SINGLE COMMERCIAL STRING INVERTER COMPARED WITH MULTIPLE STRING INVERTERS

Products have recently come on the market that seek to capitalize on the advantages offered by both systems. These products incorporate multiple string inverters in a single cabinet, enabling the installation at a single point (like a centralized inverter) but with the modularity of multiple inverters.

Bipolar PV Systems

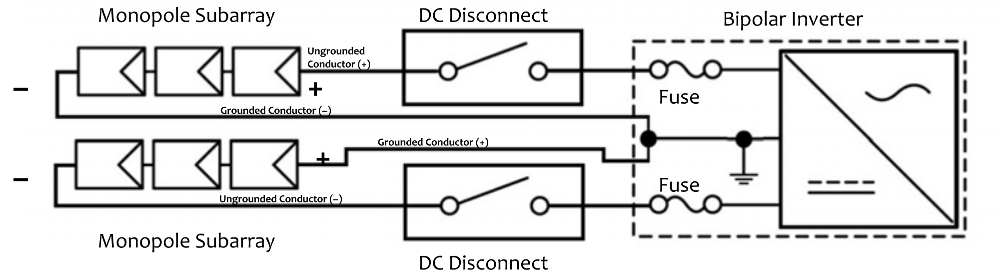
BIPOLAR SYSTEM

While rare, **bipolar PV systems** do exist and present a number of challenges to the installer/designer when and where they are employed.

In PV systems, the DC power output from the array generally arrives at the inverter on two conductors, one positive and the other negative. There may be multiple pairs of power output from the array, but they leave and arrive in this familiar pattern.

A bipolar system, however, "has two outputs, each having opposite polarity to a common reference point or center tap." (NEC 690.2) So what does this mean?

FIGURE 4-16: BIPOLAR PV SYSTEM CONFIGURATION



BIPOLAR SUBARRAY

A subarray that has two output conductors, but their output polarities are in reference to a common (neutral), is called a **bipolar subarray**. This wiring configuration is similar to service coming from the utility to a home in a 120/240 Vac split-phase system. In that system there are two hots, each sharing a common or neutral. In a bipolar array, the positive and the negative share a common neutral.

Outputs from two monopole subarrays can be combined in a combiner box, or, if by combining the voltage the system would exceed the ratings of the conductors and/or equipment located outside the inverter, then the conductors from each subarray must run separately to the inverter for termination, as illustrated in Figure 4-16.

In a bipolar system, the subarrays are effectively connected in series, increasing the voltage of the system above the limitations of each array.

For example, if each subarray had a voltage limit of 600 Vdc, then the output from the combiner box when the two subarrays are combined in a bipolar configuration would be 1,200 Vdc.

Such a configuration can only be used with combiner boxes and inverters that are specifically designed for bipolar systems. The monopole subarrays feeding the combiner box must also be balanced (configured in an identical manner).

In general, the higher the voltage of a system, the lower the cost (smaller wire, disconnects, breakers, etc). The NEC currently limits residential systems to 600 volts DC. PV system DC circuits on or in commercial and multi-family buildings are limited to a maximum voltage no greater than 1000 volts. While there is no set limit on ground-mounted commercial systems, the availability of product effectively limits commercial systems to 1,000 Vdc. By configuring a system using bipolar subarrays, the designer can raise the system's voltage while still using products with lower-voltage ratings within the monopole subarrays.

System Monitoring

One big advantage of systems that incorporate module-level power electronics (MLPE) is that energy production can be monitored and tracked on a module-by-module basis (as shown in Figure 4-17).

As more and more utility customers are integrating battery banks into their systems to minimize demand charges or adjust load demand to time-of-day pricing, there is a need to monitor load demand as well as PV energy production. This is done with the use of current transformers, or CTs.

CTs measure current passively, without interrupting the circuit in any way. They are placed around the conductor and use the magnetic field to measure current flow.

They are then connected to the monitoring system through sensor wires. The monitoring system can be programmed to draw power from or send power to the battery bank, depending on instantaneous load demand.

System monitoring can be handled in house, or subcontracted to firms that specialize in this service.

A simple residential system may be configured to send the homeowner an e-mail if the MLPE fails to report or is performing outside the expected range of operation. It will also track and report daily, weekly, monthly and lifetime power and energy output from the panels.

A more complex monitoring system will, in addition to the above, also:

- assess the PV system's overall technical and financial performance,
- display data at the module, string and system levels, for a single system or for multiple PV arrays,
- monitor the PV system's production, as well as load consumption over multiple circuits and sites,

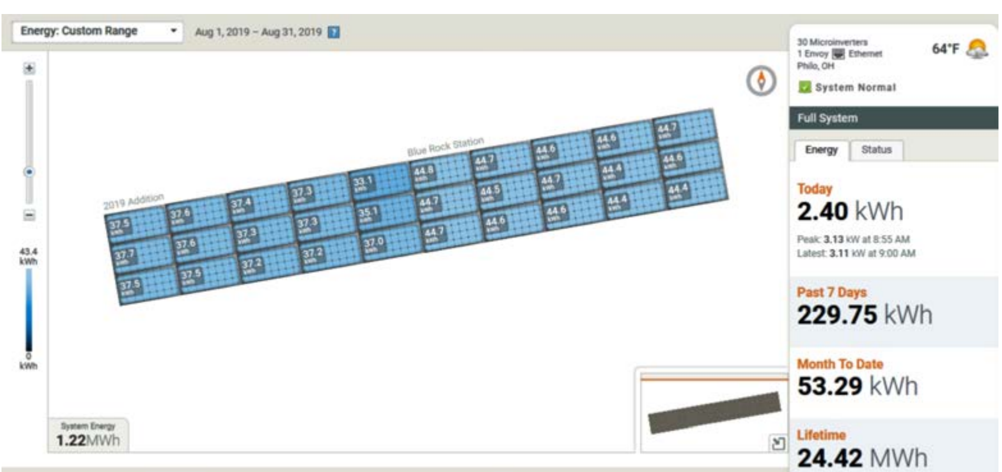


FIGURE 4-17: ENPHASE ENLIGHTEN PRODUCTION MONITORING SYSTEM

- provide prompt analysis and reporting tools based on real-time events,
- allow for easy and convenient management from a computer, tablet or phone,
- provide instant alerts regarding system issues (panel or inverter performance drops),
- integrate real-time weather data to predict system performance,
- allow access to real-time and historical system data with the ability to compare across sites,
- provide comprehensive billing analysis,
- dispatch repair crews in the event of a system malfunction.

Integrating Generators

GENERATOR

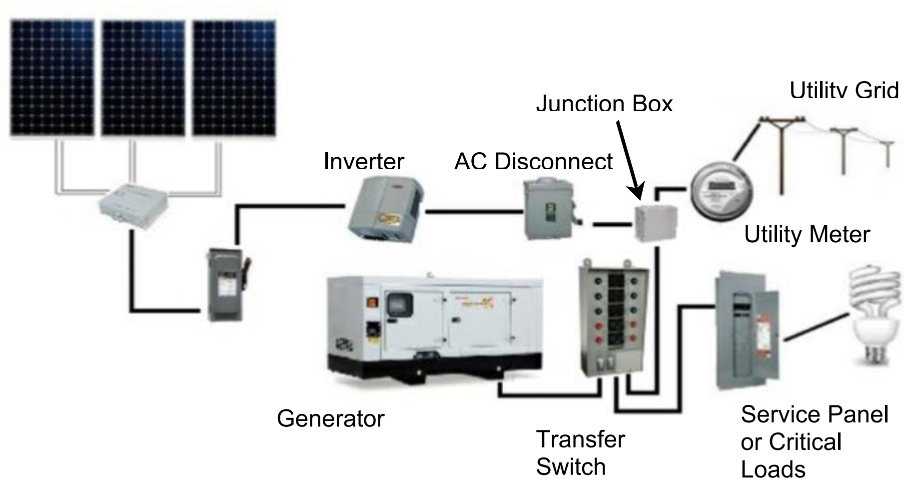
Many commercial businesses have **generators** in place that provide emergency power when the grid goes down. Increasingly, residential customers are installing them as well in areas where the grid is unreliable.

It is possible to connect a PV inverter to an electrical system that incorporates a generator if the output from the generator is stable and of high quality. The inverter will monitor the generator's output voltage, frequency and waveform, just as it does with power from the grid. If the AC waveform from the generator is grid quality, the inverter will attempt to synchronize with the generator.

If the AC input to the inverter does not dip, sag or surge when the PV system comes on line, then the inverter will remain online. But if the generator's output falls out of normal operating ranges, the inverter will shut off.

But assume the inverter remains operational. If more power is available from the PV system than is required to service the building's loads, then it will seek to go somewhere (normally onto the grid when the grid is connected).

FIGURE 4-18: CONNECTING A GRID-TIED PV SYSTEM WITH A GENERATOR



Since the grid is down (which has caused the generator to kick on), the excess power from the array, with no place to go, will cause a rise in the system voltage. This will in turn cause the inverter to shut down, as the system is now out of operational limits. So unless the generated power from the array is always less than the load demands of the business or home, a PV system connected in this fashion has no chance of working properly.

That is the best case scenario. Worst case, the inverter may damage the generator by feeding power into the unit, or the generator may damage the inverter by backfeeding power into that device.

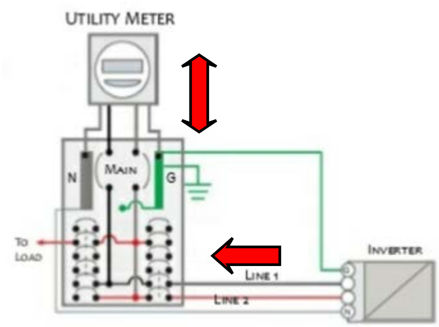


FIGURE 4-19: GRID-TIED SOLAR ARRAY INVERTER LOAD-SIDE CONNECTED TO THE MAIN SERVICE PANEL

Normally the best method of connection when a generator is present is to connect the grid-tied PV system ahead of the generator transfer switch and the subpanel feeding the critical loads. Make the connection between the meter and the generator's transfer switch as illustrated in Figure 4-18.

A typical load-side connected grid-tied PV system is connected to a breaker within the existing service panel, as shown in Figure 4-19. The inverter is designed in such a way that it cannot be backfed by the utility.

If a generator is installed as shown in Figure 4-20, by incorporating a transfer switch between the meter and the main disconnect, the generator as well as the array can work together in powering loads. However there is a possibility the generator will backfeed power to the PV system when the system is isolated from the grid.

Alternatively, if the array is producing more power than the loads can handle, the system may attempt to backfeed the generator. Either situation may result in damaged equipment.

By moving the PV connection to the supply side of the transfer switch, as illustrated in Figure 4-21, the PV array and inverter are physically isolated from the generator when it is in operation.

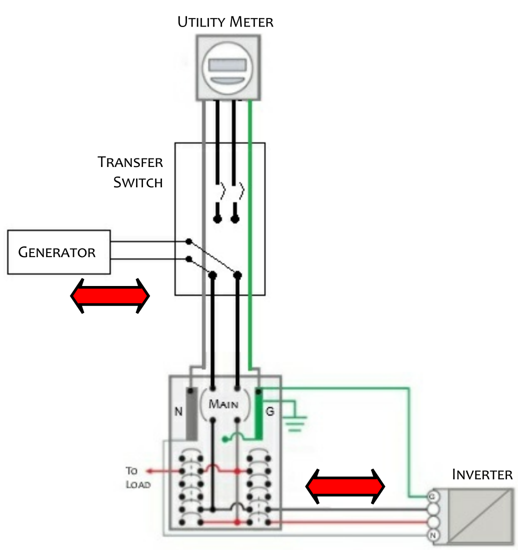
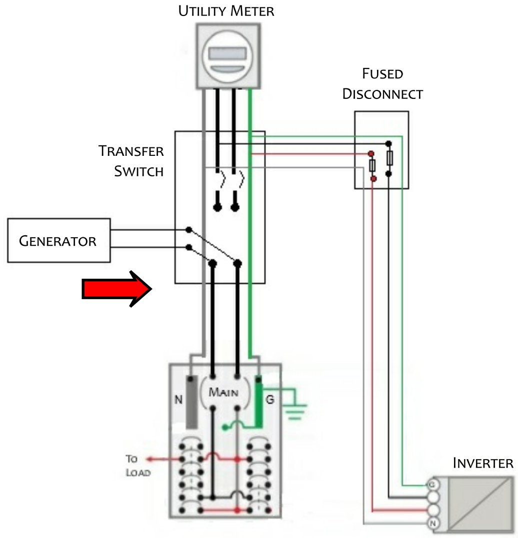


FIGURE 4-20: GENERATOR HOOKED UP TO A TRANSFER SWITCH. NOTE THAT WHEN CONNECTED IN THIS FASHION, THE PV ARRAY AND THE GENERATOR CAN BACKFEED.

A fused disconnect should be located between the inverter and the supply side connection in the transfer

FIGURE 4-21: GENERATOR AND PV ARRAY CONNECTED WITHIN TRANSFER SWITCH SO THEY ARE ISOLATED FROM EACH OTHER



switch. The rating on the fuse will be the same amperage as the load side connected breaker.

When connected in this manner, when the grid goes down, the PV system goes down as well. The transfer switch disconnects the building from the grid, and in this case, from the PV system. The generator will service all the loads while the grid is down.

A standby generator may be the best alternative at sites that regularly experience multi-day power outages, as generators generally offer more available energy than a typical battery bank. Generators also tend to be less expensive than a comparable solar battery storage system.

However, for short duration outages, load shifting and peak shaving, an integrated battery storage system is a better choice. Plus, a battery can operate in tandem with a solar array when the grid is down - something a generator cannot do.

Many inverter/chargers now incorporate generator connection options. However generator controls (for loads and/or charging batteries) are controlled by battery voltage - so batteries are still required in these systems.

Microgrids

MICROGRID

Another system configuration that will transform the way energy is distributed is the **microgrid**.

A microgrid normally refers to small power systems that use local generation resources to meet local electricity needs. This definition could apply to any PV system that services a home or business, but in microgrids the concept is expanded over a wider area, such as a campus, military outpost, industrial center or even a community or village.

In practice, microgrids are typically developed and owned by a single entity, such as a university. But they may have multiple owners installing and controlling various pieces of the system.

Microgrids can and often do interact with the larger grid - or they may operate as their own separate mini-utility (a remote off-grid microgrid). The later is common when installed on islands or remote villages that have no access to the grid.

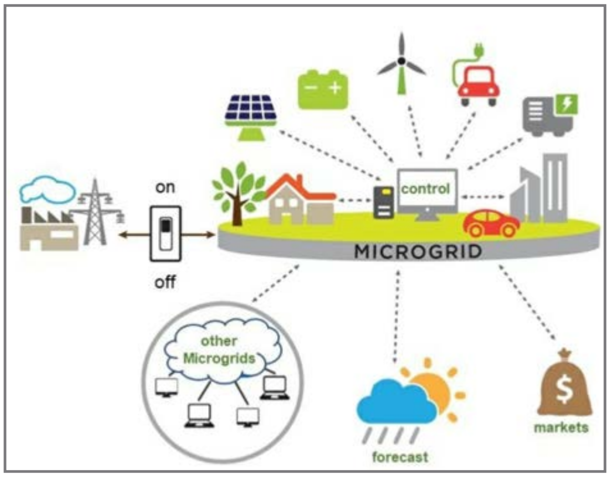


FIGURE 4-22: GRID CONNECTED MICROGRID

(SOURCE: BERKELEY LABS, USDOE)

If the microgrid interacts with the grid (as illustrated in Figure 4-22), its purpose will likely be similar to that of a PV system installed in a home or business; that is to provide power to the campus (or industrial park, or sub-division, etc.) while the grid is operational as well as supply emergency backup power when the grid goes down.

The microgrid is the logical extension of an electrical system that is transitioning from large centralized power sources to smaller distributed energy sources.

The electrical grid can be described in three large subsets. First is power generation. Then the transmission system, high-voltage lines that take power from the centralized power stations to the distribution system. And finally the lower-voltage distribution system that distributes bulk power to individual customers.

In a microgrid the power generation is localized, so the transmission system is unnecessary. Without any large infrastructure to maintain or repair, a microgrid is effectively hardened against widespread disruptions or natural disasters.

POINT OF COMMON COUPLING (PCC)

The **point of common coupling (PCC)** is where a microgrid connects to the main grid. In connected mode, the two systems operate in parallel, with the PCC maintaining equal voltage signals in both.

Like a grid-coupled PV system installed on a single building, the microgrid can import and export electricity from the parent grid in response to price signals or load demand. When the grid goes down, the microgrid can operate independently, drawing on local generation and storage capacity.

Benefits of microgrids include:

- resilience, as microgrids can temporarily disconnect from the central grid. Each microgrid can continue supplying power from their own generation sources or battery storage meeting local energy demand during widespread outages.
- local control over access to energy sources,

- easy integration of renewable energy generation sources - reducing global carbon emissions,
- reduce the need of the utility to invest in transmission and distribution infrastructure,
- increase local energy demand and response efficiency,
- enhance power reliability and quality,
- reduce transmission and distribution line losses,
- more rapid implementation of the Internet of Things (IoT) technologies into the facility's operations.

Electric Vehicles

ELECTRIC VEHICLE (EV)

Many consumers who are early adopters of solar energy are also drawn to the **electric vehicle**, or EV market for many of the same reasons. This technology, like solar, promises a low carbon alternative at an increasingly affordable price.

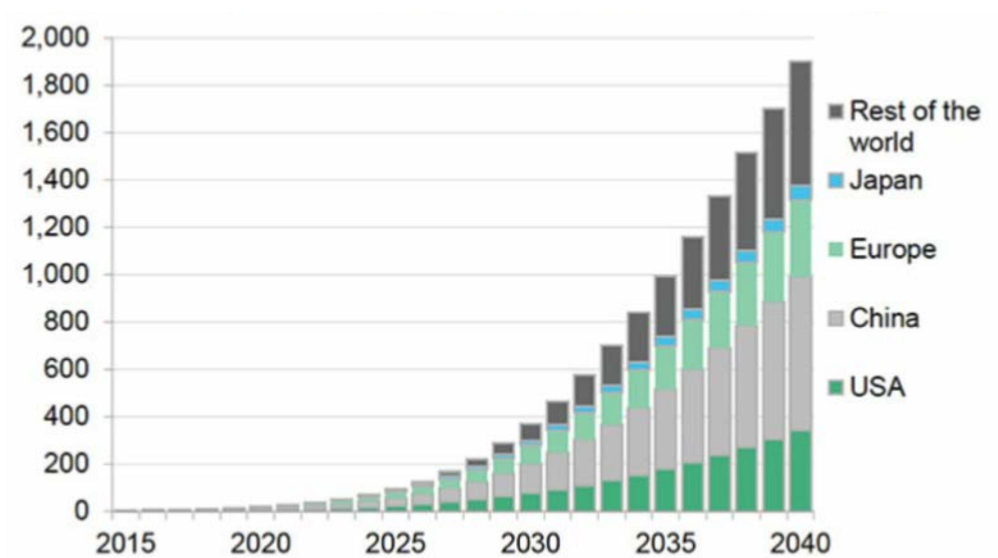
Purchases of EVs doubled in 2020, however total EVs on the road still represent a small portion, only 2.8% of all the vehicles registered. This is poised to change, however.

Nearly every major auto manufacturer has announced plans to transition their passenger car line to electric. Projections show that by 2025, sales of EVs will likely climb to 10% of all vehicles sold in the US with prices at or below the cost of internal combustion vehicles. By 2040 it is estimated EVs will account for more than a third of all vehicles purchased worldwide.

As the vehicle fleet transitions from oil to electric, increased electrical demand (projected in Figure 4-23) will place even more strain on an already stressed electric grid.

FIGURE 4-23: ANNUAL GLOBAL ELECTRICITY DEMAND FROM ELECTRIC VEHICLES (TWH)

(SOURCE: BLOOMBERG NEWS ENERGY FINANCE)



The average EV uses about 30 kWh of charge to travel approximately 100 miles. And according to government statistics, the average American drives about 30 miles per day. So it is fair to assume charging an EV will add about 10 kWh to the facility's daily load demand (per vehicle). This increased load demand should be factored in when designing a PV system.

EV Charging Stations

Recharging electric vehicles (EVs) is accomplished by connecting to **electric vehicle supply equipment (EVSE)**. From the perspective of the PV installer/designer, these charging stations often simply represent one more load in the system.

ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE)

These charging stations can take a number of forms.

Level 1, 120-Volt Charging

This option is the simplest form of charging and requires nothing but an ordinary 120 Vac outlet on a 20 amp circuit. These units, similar to that pictured in Figure 4-24, are supplied by the vehicle's manufacturer. **Level 1 charging** stations normally draw about 1.4 kW when charging.

LEVEL 1 CHARGING

These systems are typically located in homes or employee parking lots and take 6-10 hours to fully charge a vehicle.

FIGURE 4-24: LEVEL 1 EV CHARGING CONNECTOR

Advantages

- low installation cost,
- low impact on utility peak demand charges.

Disadvantages

- charging is slow - around 3-5 miles (5-8 km) of range added per hour of charging.

Level 2, 208/240-Volt Charging

Level 2 charging is much faster than Level 1 charging, but requires a 208 Vac three-phase or 240 Vac single-phase power connection.

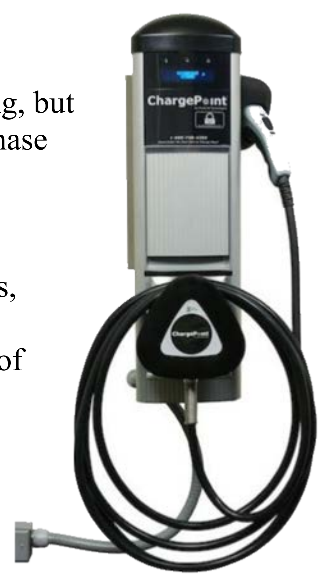


FIGURE 4-25: LEVEL 2 EV CHARGING STATION

Level 2 charging stations, such as Figure 4-25 can theoretically provide up to 80 amps of current to EVs, although most operate only at about 30 amps. The rating of the unit will determine the ampacity rating of the circuit to which it is connected.

LEVEL 2 CHARGING

These systems are typically located in homes, shopping centers, or commuter parking lots and take 1-3 hours to fully charge a vehicle.

Advantages:

- charge time is significantly faster than Level 1. EVs will get between 10-20 miles (16-32 km) of range per hour of charge,
- more energy efficient than Level 1.

Disadvantages:

- installation costs are much higher than Level 1. This may potentially impact utility peak demand charges by creating a significant spike in demand.

DC FAST-CHARGING

DC Fast-Charging

DC fast-charging (sometimes called Level 3) equipment delivers high power directly into an EV's battery system, bypassing the need for a rectifier (that converts AC power from the grid to DC power that can be used in batteries). Charging speeds can be very fast, normally about 80% charge within 30 minutes.

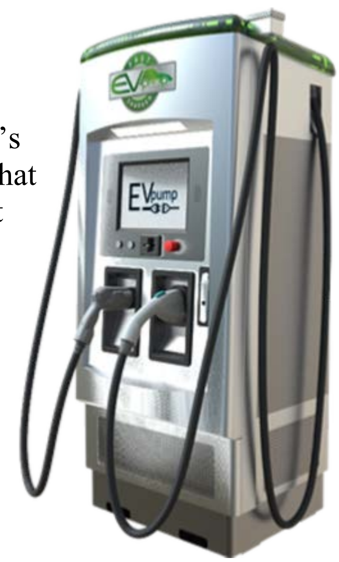


FIGURE 4-26: DC FAST-CHARGING EV CHARGING STATION

These systems, as shown in Figure 4-26, are typically located in designated charging facilities and take about 30 minutes to fully charge a vehicle.

Advantages:

- charge time is dramatically reduced.

Disadvantages:

- much higher equipment and installation costs, ranging from $20,000-$100,000.
- potential for higher demand charges.
- competing standards are confusing to EV buyers and charging station operators.
- cold weather may require increased charging time.

Level 1 & 2 EV Charging Station Connector Types

Unfortunately, not all EVs use the same plug type while charging. Tesla and auto makers in Japan and Germany each use different plugs and communication protocols to link batteries to chargers, as illustrated in Figure 4-27.

SAE J1772 (Type 1)

This connector is the industry standard for all electric vehicles from North America and Japan performing Level 1 or Level 2 charging (home use).

Mennekes (Type 2)

The Mennekes Type 2 charger is the standard within Europe and most of the world outside North America and China. It is also used for Level 1 and Level 2 charging of Tesla models.

GB-T

The Level 1 and Level 2 charger is the standard for vehicles manufactured in China. After 2019, Tesla vehicles sold in China also are compatible with this charging standard.

Level 3 Fast Charge Connectors

Level 3 charging stations provide fast charging using DC current. Not all EVs are equipped to accept this form of charging.

CHAdeMO

This is the first of fast charging connectors originally implemented to be the industry standard. It was developed through the collaboration of five different Japanese automakers. As a result, the **CHAdeMO** (an abbreviation of CHArge de Move) connector remains the standard in Japan and on EVs from Japanese manufacturers. This includes automakers such as Toyota, Mitsubishi, Subaru, and Nissan.

CHADEMO

Combined Charging System (CCS)

Shortly after the CHAdeMO was introduced, a second Level 3 connector called the **Combined Charging System (CCS)** was developed. The CCS connectors differ from CHAdeMO in that they allow for AC/DC charging on the same port. CHAdeMO-equipped EVs require an additional J1772 connector cord to achieve Level 1 or 2 charging. This connector is the preferred mode of Level 3 charging for European and American vehicles, including BMW, Ford, Jaguar, GM, Volkswagen, and Tesla.

COMBINED CHARGING SYSTEM (CCS)

Tesla SC (SuperCharger)

This proprietary connector exists on all Tesla models in North America, although Tesla does offer CHAdeMO and CCS adapters for certain markets.

FIGURE 4-27: CONNECTOR CONFIGURATIONS FOR VARIOUS EV CHARGING

SMART CHARGING (V1G)

Smart charging is where the rate and/or time at which a vehicle is charged can be controlled while the vehicle is plugged in and involves the one way flow of energy from the charger to the car. This is referred to as uni-directional or V1G.

The rate or time of the charging can be modified based on user settings to charge when electricity is cheapest, cleanest or in response to signals from the utility.

Vehicle to Grid (V2G)

VEHICLE-TO-GRID (V2G)

Vehicle-to-grid (V2G) is a charging system in which plug-in electric vehicles can not only draw power from the utility, but can also export power from the vehicle to the grid. The vehicle can either return electricity to the grid (selling power during periods of peak load demand) or throttle their charging rate during periods of high energy cost (as is also possible using V1G).

Different terms are used to describe the various options where systems can draw energy from EV batteries.

Often referred to as V2X (to describe the concept in total) examples include:

- V2G: Vehicle-to-grid
- **V2H: Vehicle-to-Home**
- **V2B: Vehicle-to-Building / Business.**
- V2V: Vehicle-to-Vehicle
- V2X: Vehicle-to-everything

VEHICLE-TO-HOME (V2H)

VEHICLE-TO-BUILDING (V2B)

PLUG-IN HYBRID (PHV)

Vehicle-to-Home (V2H) or Vehicle-to Building (V2B) taps into the battery bank in the electric (EV) or **plug-in hybrid (PHV)** vehicles, using them as a replacement for a stationary energy storage system for a grid interactive system.

The fleet of electric vehicles can serve as a distributed storage system, since most vehicles are parked (and therefore could be connected to the grid) for about 23 hours each day.

V2G storage capabilities can also enable EVs to store and discharge power from solar arrays, serving as the battery backup for the home or business. Not only can this storage resource allow utilities to respond to fluctuations in load demand, the charging and discharging of EV batteries can assist in frequency regulation.

The Rocky Mountain Institute (RMI) has estimated that electrifying all of the light duty vehicles on US roads today would increase annual electricity demand by about 25%. This figure does not take into account all the medium and heavy-duty transportation needs, such as freight and public transit.

The rapid addition of such a significant load demand and changing load demand profiles present significant challenges to utilities. One projection by the consulting firm Wood Mackenzie, for example, predicted that just a quarter of a percent of Texas' cars charging simultaneously could crash the grid.

While the electrification of transportation will dramatically increase load demand on the grid, it also represents a tremendous potential storage resource.

It is estimated that by 2040 there will be around 200 million EVs in use worldwide, representing approximately 7 TWh of storage capacity.

Globally, loads draw about 15 TW of power at any one moment - so the combined storage capacity of EVs could, in theory, provide backup to approximately half the current loads (at least for a brief period of time).

V2X requires four things to function properly:

- a V2G enabled vehicle,
- a bi-directional charger,
- a communication system or 'protocol', such that the grid can communicate to the EV and vice versa, and
- a control system.

Challenges Facing V2G

While the advantages of tapping into the emerging EV storage resource are profound, so to are the challenges the industry faces if this is to become a reality.

Challenges include:

- Warranty issues. A significant barrier to V2G is the lack of **original equipment manufacturer (OEM)** support. Not all EVs and PHVs are compatible with V2G. The auto and utility industries have not agreed on standards. As of 2020, only two vehicles, the Nissan Leaf and Mitsubishi Outlander were equipped with V2G capability. In September 2020, Tesla unveiled a new EV battery design that allows for adaptation to the V2G technology. However, the V2G-compatible batteries are not anticipated to be in production until 2023.

ORIGINAL EQUIPMENT MANUFACTURER (OEM)

- Standardization. To export the energy, the EV battery and the charger must communicate with each other, as well as with the grid. This is done using standardized communication protocols. At present there are at least four communication standards and protocols used widely in the EV market for DC charging. These are ChaDeMo (Japanese), CCS (EU and US), GB/T (Chinese) and Tesla (worldwide) Of these, only the ChaDeMo protocol currently supports V2X. The CCS protocol is planned to support V2H from 2020 and V2G from 2025, with testing ongoing on a draft form of the protocol.

- Lack of harmonization within the electric utility industry. EVs are mobile while utilities are not. Utilities and wholesale power markets must define what services they want, simplify rules for participation, and provide adequate compensation.
- Lack of EV owner interest. Most EV owners will likely not educate themselves as to the value of V2G or will be unwilling to risk their expensive EV by connecting it to the grid.
- Expensive charging stations. Early V2G-capable chargers are significantly more expensive than standard units. For example, the Wallbox residential V2G-capable L2 unit retails for around $4,000, compared to a V1G-capable EnelX Juicebox, which sells for approximately $650.
- AC or DC? Batteries store and export DC power. The grid and typical loads generate or use AC power. So power must be converted to DC when charging an EV and inverted to AC when exporting power from the EV. This can either be done in the charging station or within the vehicle itself. Currently different vehicles handle this process in different ways. Without a standard process, an effective V2G system will be difficult to achieve.
- Range Anxiety. EV owners are concerned that the use of the vehicle's storage capacity may drain the battery of the vehicle to a point where its range may be limited when needed. With this in mind, these systems typically limit discharge so the battery will always be charged to 70-90% of its capacity.
- Impact on battery life. The impact of V2X on EV batteries is a concern for vehicle owners. Many studies have been conducted on this issue, and most studies show that with proper controls, the life of the battery will not be significantly impacted by V2X.

Chapter 4 Review Questions

1) The situation where a distributed energy system is exporting energy to the grid when the grid is “down” or not functioning is known as:
   a) net metering
   b) decoupling
   c) phase unbalance
   d) islanding

2) Rapid shutdown provisions require that:
   a) all PV systems be equipped with MLPE devices on each panel
   b) all PV inverters must stop generating power once they sense that the grid is “down”
   c) all conductors leading from the array must have zero voltage present within 30 seconds of the main disconnect shut down
   d) no conductor within the array boundary can have a voltage greater than 80 Vdc once rapid shutdown has been initiated

3) A PV system that incorporates batteries and is designed to run critical loads only when the power from the grid is interrupted is called a:
   a) DC coupled system
   b) grid coupled system
   c) stand alone system
   d) critical load system

4) The transfer switch that automatically disconnects the PV system from the grid in the event of a power outage is often referred to as a:
   a) rapid shutdown initiator
   b) autotransformer
   c) current transformer
   d) DC/AC coupler

5) Which of the following is **NOT** a situation where incorporating an AC-coupled or DC-coupled system may be the appropriate solution?
   a) time of use shifting
   b) peak demand reduction
   c) where net metering is not allowed
   d) to improve the efficiency of the system

6) When batteries are incorporated into a system to store energy during periods when power from the grid is less expensive to be used when power from the grid is relatively more expensive is known as:
   a) peak shaving
   b) self-consumption
   c) load shifting
   d) time-of-use pricing

7) The device used to monitor the amount of energy flowing through a conductor is referred to as:
   a) current transformer (CT)
   b) module-level power electronics (MLPE)
   c) voltage regulator (VR)
   d) maximum power point tracking systems (MPPT)

8) A customer wishes to install a battery backup system that will provide 6 hours of backup power to critical loads should the grid go down. A load assessment has been conducted and it has been found that the critical loads draw 3.5 kWh per hour when operating. The following also apply:
   - the total system derate is 87%
   - the array receives 3.78 hours of insolation each day
   - the monthly load demand is 1,525 kWh
   - the nominal voltage of the battery bank to be configured is 48 V
   - the site has a power factor of .96
   - the depth of discharge of the battery bank will be set to 90%
   - the array is 35 kW in size
   - the inverter used is 98% efficient
   - The lowest temperature ever experienced on site is -35°C

   To what size (in amp-hours) should the battery bank be configured?
   a) 385.87 Ah
   b) 437.5 Ah
   c) 496 Ah
   d) 502.87 Ah

9) Lead acid deep cycle batteries should be charged at a rate no faster than _____ to avoid damaging them and shortening their functional life.
   a) C1
   b) C5
   c) C10
   d) C20

10) When designing an AC or DC coupled system, rapid shutdown provisions require:
   a) that a rapid shutdown initiator be installed within 1 foot of the array boundary
   b) that no more than 30 volts be present on the battery output circuit within 30 seconds of disconnecting the system from the grid
   c) that a second rapid shutdown initiator be installed that shuts down the battery bank
   d) rapid shutdown does not apply when the system is operating as a stand alone system.

11) Which of the following is **NOT** a form of load management?
a) critical load panels
b) frequency-based decentralized controllers
c) ripple control
d) plug and process loads

12) Which of the following is **NOT** an advantage of incorporating micro inverters into a large array?
a) no risk of arc faults
b) no risk of ground faults
c) automatic compliance with rapid shutdown requirements
d) automatic phase imbalance correction within 3-phase systems

13) A subarray that has two output conductors, one positive and one negative is referred to as a:
a) monopole subarray
b) bipolar subarray
c) DC coupled subarray
d) branch circuit subarray

14) Which of the following is **NOT** an advantage of designing a system with multiple inverters rather than one single larger inverter?
a) no single point of failure
b) component performance monitoring is less difficult
c) each subarray can have unique panels (not all panels need to be uniform)
d) AC wiring of the system is less complex

15) A PV system that combines the lower voltages of multiple subarrays to provide a higher total system output voltage is known as a:
a) monopole subarray
b) bipolar subarray
c) DC coupled subarray
d) branch circuit subarray

16) Which of the following is **NOT** a typical function of a commercial-scale remote monitoring system?
a) monitor the system's technical and financial performance
b) provide real time data about individual components performance
c) allow for remote rapid shutdown and anti-islanding control
d) dispatch repair crews in the event of a system malfunction

17) In order to avoid the risk of backfeeding a generator connected to a PV array, the designer of the system should:
a) select a generator that incorporates a diode to prevent backfeeding
b) connect the PV system on the supply side of the transfer switch
c) connect the generator to a separate breaker on the service panel
d) incorporate a fused disconnect between the inverter and the generator

18) A microgrid connects to the main grid at the:
   a) point of common coupling
   b) distribution transformer
   c) distribution sub-station
   d) transmission sub-station

19) Which of the following is **NOT** a common Level 3 charging station connector configuration?
   a) SAE J1772
   b) CHAdeMO
   c) Combined charging system (CCS)
   d) Tesla SuperCharger

20) The smart charging of electric vehicles is sometimes referred to as:
   a) V2X
   b) V1G
   c) V2G
   d) V2B

21) Which of the following is **NOT** a major challenge that must be overcome if V2G is to gain widespread adoption?
   a) lack of industry standardization
   b) the technology is not yet ready to handle bi-directional charging
   c) EV manufacturer's warranties may not support bi-directional charging
   d) lack of EV owner interest in and/or understanding of V2G technology