FUNDAMENTALS OF BUILDING A TEST SYSTEM

Automated Test System Power Infrastructure

CONTENTS

Introduction

Introducing Power to the System

Geographic Location Considerations

Elctromagnetic Interference or Line Filters

Power Budget

Power Distribution Unit

Uninterruptable Power Supply

Power States

Grounding

Best Practices for Components

Introduction

Powering an automated test system, or automated test equipment (ATE), is different from powering the PC and lamp on your desk. Test systems are composed of many heterogeneous internal components, some of which require large amounts of current and power, and these systems are often deployed globally into facilities with differing power sources and quality. Many test system components are sourced from multiple vendors and must be integrated by the test engineers, which complicates matters even more. Choosing the right components and making the right design decisions is much simpler when you follow best practices in power layout and equipment selection.

A power layout ensures all components operate properly by avoiding bottlenecks where a component may need more power than the power distribution can provide. This is especially important for components that could compromise operation of the whole system if starved of power. This guide covers test system power planning by listing the steps and considerations for creating a power layout.

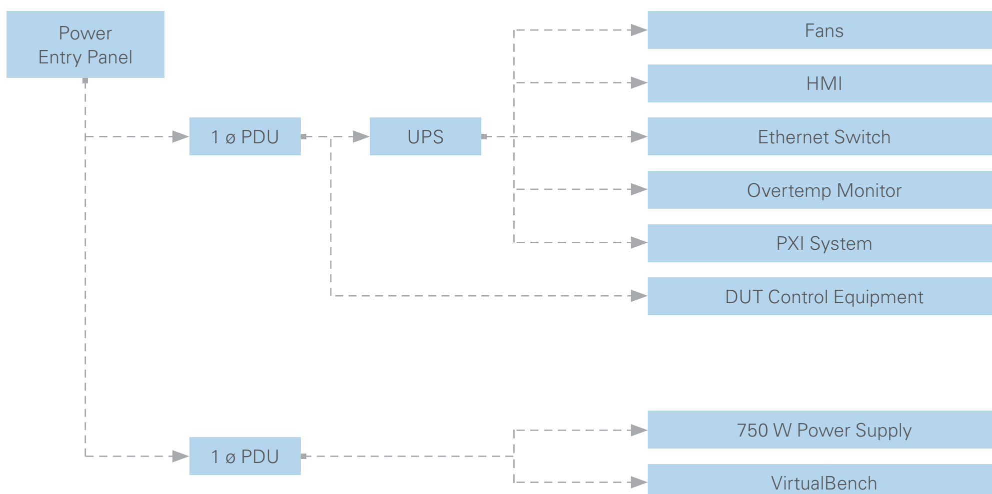
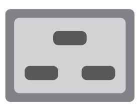


Figure 1. A power layout includes all equipment in the test system and maps the flow of power from the source to the test system to the end consumer.

Introducing Power to the System

A best practice for introducing power to the ATE system is to use a power entry panel, or power inlet panel. This allows you to isolate the internal power cabling from the point at which the main voltage is applied. With a power entry panel, you can outfit your test system with the proper power connector rated for the voltage and current that will be powering the system. NI power entry panels use a number of connector types and power ratings for a variety of power requirements and geographic coverage. Figure 1 shows examples of power panel connectors. A good power panel should also have built-in circuit protection, including a circuit breaker and fuses, which protects the system from power surges or incorrect supply power. A great power panel has a built-in electromagnetic interference (EMI) filter, surge suppression, and other connectivity to pass signals into the system.

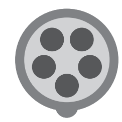


Low-Power Configuration

- IEC 60320 (C20)
- 1ø (16 A) 100-240 V

Medium-Power Configuration

- IEC 60309
- 1ø (32 A) 100-240 V



High-Power Configuration

- IEC 60309
- 3ø (16 A) 380-480 V (Red:3P+N+E)

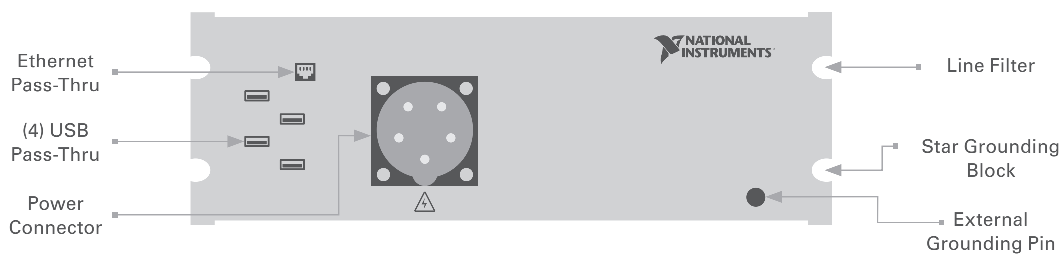


Figure 2. A power entry panel provides connectivity for incoming power to the system. Power entry panels can have one of a number of standard power connector types and good power panels have additional features like filtering or kill-switch relays.

Geographic Location Considerations

The geographic location of the tester or test facility is a critical detail in choosing the power panel for your test system. Additionally, when planning a new test system, consider the power standards and grid infrastructure, safety requirements, and ease of deployment, which are all factors that location can affect.

Power Grid Standards

The line power available from the public grid differs from country to country. Countries around the world have standardized on different RMS voltage levels, AC power frequency, connectors, and current ranges in their power grids. There are several types of power configurations in public grids:

- **Single-phase power** uses a single active line that conducts an AC power and a neutral line. Common voltage levels of these lines vary from 100 V to 240 V. For instance, line power in Japan is 100 V, while power is delivered between 220 V and 240 V. The United States and Canada transmit power in public grids at 110 V to 120 V.
- **Dual- or split-phase power** is composed of two active lines that supply power at a given positive and negative offset voltage and one neutral wire. A common implementation of dual-phase power in the United States is 120 V with a 180 degree offset between active lines. Having two wires that are transmitting power with voltage levels of 120 V and -120 V allows you to have two single-phase sources of power with 120 V of potential by using each active line and the neutral line or one single-phase source with 240 V of potential by using the two active lines.
- **Three-phase power** is made up of three active lines that are 120 degrees offset from one another and one neutral wire. Most US buildings use 208 Y/120 V power, which has three lines that conduct 120 V power and a constant power circuit output of 208 V. Many industrial building use 480 Y/277 V, which provides 480 V for larger machinery.

Global Deployment

Test systems are often designed and deployed in separate or multiple locations. Having a single system deployed in multiple locations introduces new sets of system requirements. Deploying a system to Malaysia is different from deploying a system to a factory in the same country or even the same building. For example, you may build a test system for automotive engine control units at an R&D facility in Detroit but deploy it to factories in Mexico. Consider the power grid standards and quality when designing the system and confirm that all safety and regulatory certifications needed to deploy in Mexico are met before you ship the system. Here is a checklist of items to think through when designing a test system that will be globally deployed:

- Power grid voltage standard and configuration
- Power grid quality and reliability
- Materials compliance like RoHS
- Energy compliance like CE, PSE, or KC
- Trade compliance and import/export regulations

If you plan to deploy the test system to countries or regions outside the test system's country of origin, know the available power in the location(s) that the test system will be deployed and if you need to convert that power to operate the equipment in your test system. In the example above, the test systems were going to Malaysia and Mexico. Luckily, the power grids in both the United States and Mexico provide power at 110 V to 120 V and 60 Hz. This gets a bit more complex for a test station designed in Germany and deployed to Mexico where mains voltages are different.

Power converters and uninterruptable power supplies (UPSs) can help you to condition standard power to meet the needs of the system. For example, a test system that includes equipment that accepts only 120 V may need to include a power converter to turn 230 V single-phase power into a single-phase 120 V supply for the instrumentation. Better yet, evaluate and select equipment that has global input voltage to avoid the hassle altogether.

Certification

Many countries have specific required electrical safety standards like CE in Europe, PSE in Japan, or KC in Korea. Compliance testing for electrical test equipment usually includes emissions level and frequency, touch safety, and surge protection. The most important reason to get these markings is to be able to deploy systems to other countries or certify a factory for operation. Do the necessary research to know the required certifications in each country in which the test system will operate. Ignoring the certifications could make it problematic to service test systems in the future. Individual components cannot be imported unless they have these marks, so it is difficult to replace or repair parts that lack proper certification.

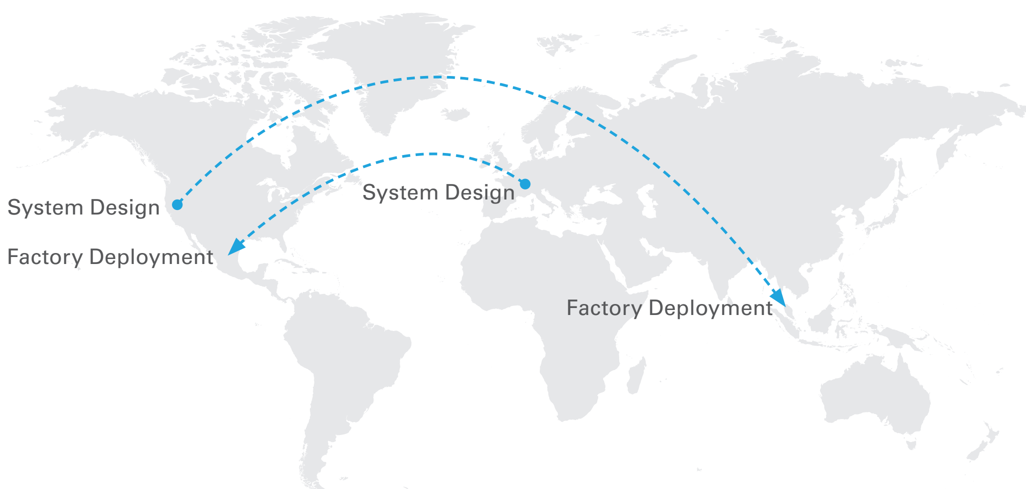


Figure 3. Designing and deploying test systems in multiple countries requires you to be flexible in designing your system. Consider power standards and certifications whenever you are developing a test system that could be used in multiple locations.

Electromagnetic Interference or Line Filters

Power grids carry high-energy signals that emit electromagnetic noise. Most noise from power lines is relatively consistent and you can plan for it in advance. No grid is perfect, however, so there will most likely be some nonstandard noise in the power signal. Nonstandard noise can affect the measurements taken by instrumentation in the system or cause the system to violate certification requirements. EMI and line filters are the most common ways to protect the test system from unexpected noise sources emanating from power transmission lines. A line filter is specified for a given voltage level, a maximum current level that should not be exceeded, and an operating range for frequencies it filters from the signal. For example, a line filter may be designed for 250 V, 10 A, and operate from 150 kHz to 1 MHz. Be sure to choose the right line filter for the power and unwanted noise frequencies in your test system. NI power entry panels include EMI/line filters to protect sensitive measurement equipment.

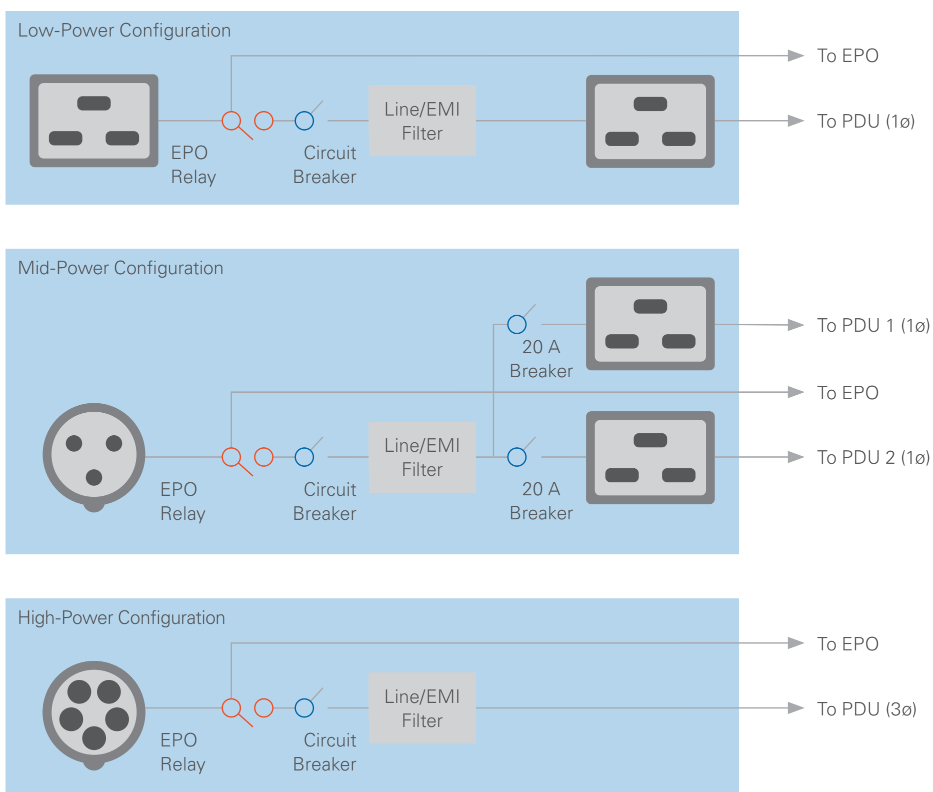


Figure 4. A circuit breaker and Line/EMI filter are critical to protecting the equipment in your test system and ensuring proper and accurate performance of your instrumentation. Example power entry panels are shown for low-power, mid-power, and high-power configurations.

Power Budget

A power budget is a critical part of planning resources and components for a test system. A given piece of equipment must have access to the proper amount of current at the correct voltage level. Budgeting must be performed for the entire system and at each point that power is distributed within the system. After determining the amount of power required, you can apply a few standard rules to the calculated values to right-size the power allocations in the test system.

System Power Budget

A system power budget begins with finding the maximum power requirements of all equipment included in the test system. The sum total should contain the expected power draw of all components in the test system, including voltage, current, and watts of power. In many cases the most important part of power budgeting is the current. Only a certain amount of current can flow through a given transmission line in the system, so current often has to be carefully distributed throughout the system using a power distribution unit (PDU).

The power draw of a given device is generally published in the user manual and sometimes includes a number of power requirements at different conditions. Occasionally, devices have specified typical power consumption and a maximum or worst-case power consumption specification. As a best practice, use the maximum power requirement as a conservative safety measure, and then subtract a given percentage, usually 30 to 40 percent, for a more realistic measure. Figure 5 shows the maximum power requirement of a stand-alone instrument that would be integrated into a test system.

Power Requirements

⚠ **Caution:** The protection providd by the VirtualBench hardware can be impaired if it is used in a manner not described in the *NI VB-8034 Safety, Environmental, and Regulatory Information* document.

Voltage input range	100 VAC to 240 VAC, 50/60 Hz
Power consumption	150 W maximum
Power input connector	IEC C13 power connector
Power disconnect	The AC power cable provides main power disconnect. Do not position the equipment so that it is difficult to disconnect the power cable. Depressing the front panel power button does not inhibit the internal power supply.

Figure 5. The VirtualBench all-in-one instrument specifies maximum power required at times of high-energy usage as opposed to typical or average power.

As a quick and simple example consider the test system in Table 1. First collect the maximum power consumption of each piece of equipment in the test system. Make sure to account for subsystems and bottlenecks. PDUs have a maximum current limit—in this case 16 A—so plan accordingly. The next step is to correct these values for typical power required as opposed to maximum. This means taking about 60 to 70 percent of that value. In this case, that gives you approximately 1,920 W for this test system using 70 percent as a conservative measure. It may also be a good idea to add about 20 percent of this full value as a means of expanding or adding new functionality to the system in the future without having to add more power to the system.

EQUIPMENT	MAXIMUM POWER CONSUMPTION	AVERAGE POWER UTILIZATION	CURRENT AT 110 V
PDU 1			
Fans	50 W	35 W	.03 A
HMI	100 W	70 W	.06 A
Ehternet Switch	25 W	17.5 W	.02 A
Overtemp Monitor	10 W	7 W	.01 A
PXI System	526.9 W	369 W	3.4 A
DUT Control Pumps	1,000 W	700 W	6.4 A
PDU 1 Total		**1,198.5 W**	**11.0 A**
PDU 2			
VirtualBench	150 W	105 W	1.0 A
750 W Power Supply	1,100 W	770 W	7.0 A
PDU 2 Total		**875 W**	**8.0 A**
System Total		**2,073.5 W**	**19.0 A**

Table 1. Start calculating a power budget by collecting the maximum power consumption of all system components, applying an average power utilization factor, and adding them together. Remember to account for bottlenecks and subsystems.

Three easy best practices can significantly simplify power budgeting:

- 1. Base your system power requirements on about 60 to 70 percent of the maximum required power of each component.
- 2. Add about 20 percent to the final power calculation from rule one as a safety buffer to account for high-activity periods and any necessary future expansion of the test system.
- 3. Remember that some items connect through PDUs and UPSs, so there are power subsystems within the larger system.

Subsystem Power Budget

A step not included in solving for the power budget above is how to account for subsystems within the large test rack. A subsystem can be any subset of the equipment in the larger test system that all share a common power source. This may be a number of instruments using a single bank of a PDU or a modular instrumentation system like PXI.

A benefit of modular instrumentation is that it can simplify power management. If all the instruments included in the PXI chassis were separate in the test system, you would have to account for each of them individually. PXI chassis provide high-quality and safe power to all instruments in the chassis and come in several power and instrumentation slot options. When adding a PXI system to your power budget, you can take one of two options:

- 1. Use the maximum power consumption of a full PXI system as specified by the PXI chassis. For example, the maximum power consumption of a PXIe-1085 PXI Chassis is 791 W, which would translate to a budgeted power consumption of 554 W after applying an average utilization factor of 70 percent.
- 2. Add the maximum power consumptions of all modules in the PXI system to get a very accurate power budget number. See Figure 6 for an example of performing a detailed PXI system power budget.

Additionally, a modular instrumentation system is significantly more efficient than a traditional set of instruments because it removes the shared components like monitors and cooling that would have to be powered within a test system.

As an example of an accurate power budget for a PXI system, consider a PXIe-1085 PXI Chassis with 24 GB/s system throughput that includes a PXIe-8880 PXI Controller, six PXIe-4139 precision system source measure units (SMUs), two PXIe-5162 PXI Oscilloscopes, a PXIe-6570 digital pattern instrument, two PXIe-4081 7 ½-digit digital multimeters (DMMs), and four PXIe-2527 multiplexer switch modules. See a representation of how the PXI system power budget is calculated in Figure 6.

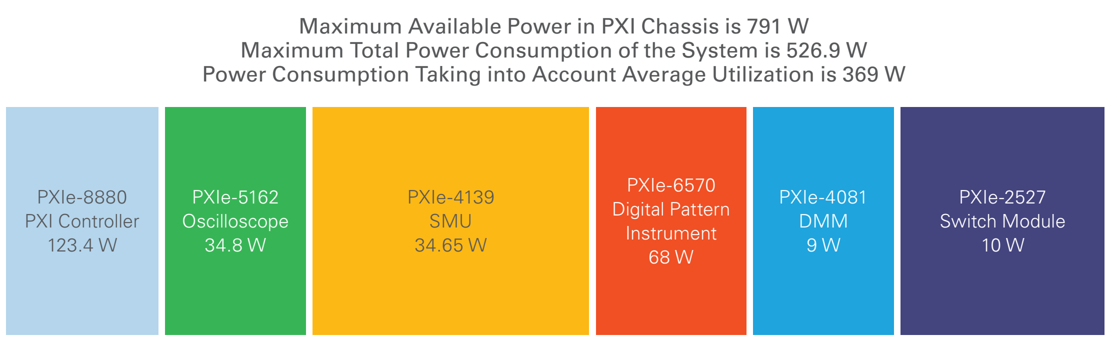


Figure 6. The total power consumption of a PXI chassis is the sum of all modules in the chassis. You can see above a full chassis of instrumentation that will, in the worst-case scenario, consume 526.9 W.

Power Distribution Unit

A PDU's main purpose is to take an input power signal and distribute it to a number of outputs that power components of the system. These internal power outlets from the PDU have a rated voltage and current and are often available for both alternating and direct current. The best PDU options have a number of features:

- Remote on/off gives operators the ability to make changes in the power state with the power mechanism and EPO. In this way, the operator has full control of the system state from an easily accessible location. Operators also can disable the power in the system from the local and global EPO mechanism.
- Built-in circuit protection like fuses can protect valuable and fragile equipment from unexpected power events, which could save tens, or even hundreds, of thousands of dollars.
- Bank sequencing can ensure that specific equipment powers on first before other banks power on. For instance, a PXI chassis that is connected to an external controller, or extended from another master PXI chassis, needs to start before the host controller. In this case, the PDU should enable a bank of outlets that include the slave PXI chassis before starting the bank that includes the master PXI chassis.
- Multiple banks that handle a given amount of power allow you to balance power loading on the PDU to prevent over-current conditions that could damage equipment in the test system. For instance, a PDU that has three banks of power outlets that can deliver 16 A on each bank prevents any one piece of equipment connected to the PDU from experiencing more than 16 A. It also means that you must be aware to distribute the current required for the equipment across multiple banks.
- DC supplies can provide power to items like status LEDs or cooling systems that run off of DC power with remote on/off and bank sequencing as well. Some of the items are even useful in the enable power state of a system, making a remote powering function necessary.

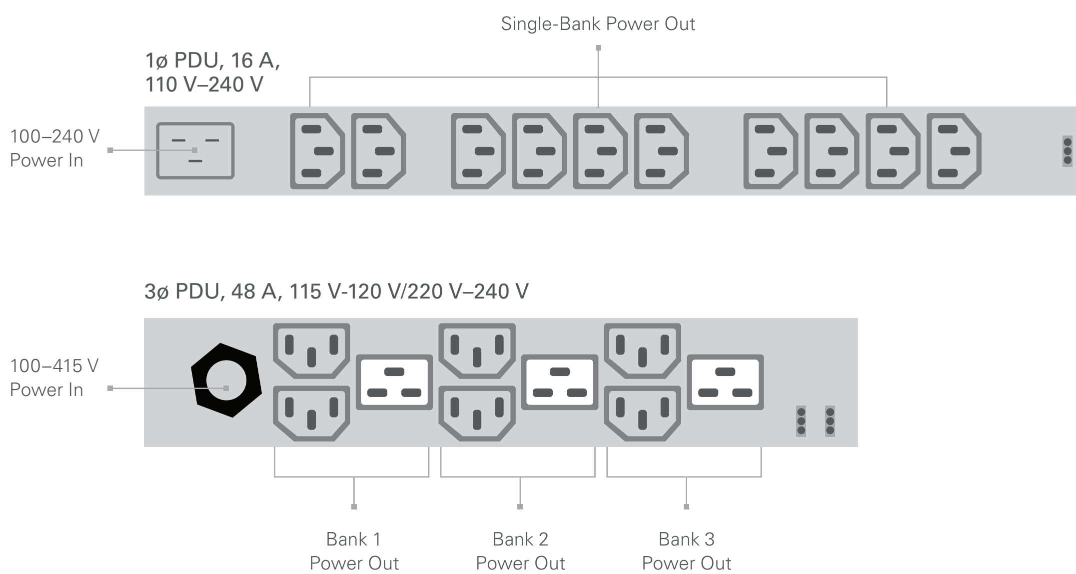


Figure 7. PDUs can have different connectivity and architectures. The PDU above has a single bank that can supply devices with up to 16 A, and the PDU below has three banks that can supply 16 A each for up to 48 A.

Powering Critical Components in the Test System

Make sure that critical components like the host controller and sensitive instrumentation in your test system get power from the UPS. Some components of the test system are more important than they might seem at first glance. Without the cooling systems continuing to run after a power incident, the host controller may overheat. Without power to the touch panel monitor on the test system, a technician has no way of troubleshooting the failures or logging data of the power incident. Think about the items that you want to be operational, even after a power outage or emergency.

Powering System Overhead and Support

Remember overhead and infrastructure like temperature control, network connectivity, and user interface elements of the test system when allocating power. Having an outage in your production because of overheating or lack of network connectivity is just as detrimental as failures in test instrumentation.

Uninterruptable Power Supply

A good test system designer takes into account the quality of the grid and designs the system to avoid undefined behavior during power loss and brownouts. You can use UPSs to power critical components in the test system during these events and sometimes during normal operation as well.

A UPS can deliver power with a dependable voltage and current supply. It can also act as a battery power supply after a power outage or significant brownout. A UPS is a critical part of a rugged test system, especially one in a location with an unreliable power grid.

There are two major types of UPSs:

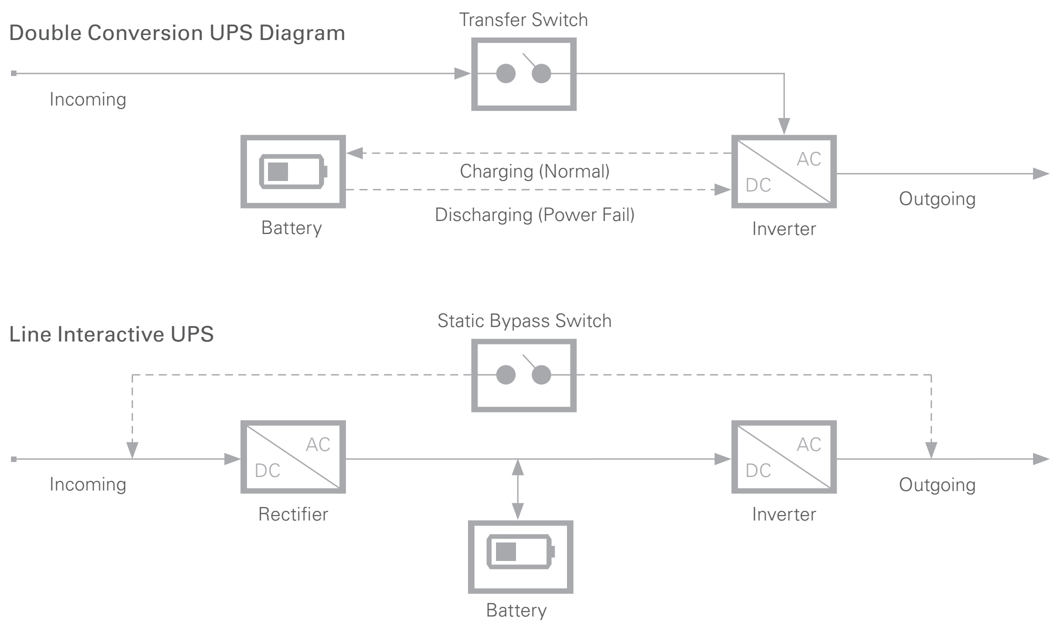


Figure 8. A UPS is used to provide clean, reliable power that also allows for graceful shutdown in the case of a blackout or brownout. A double conversion UPS is always charging a battery that provides consistent power to the system.

- **Line interactive UPS**—In a line interactive UPS, the active power line input is connected directly to the power output. The UPS then monitors incoming power to ensure that the power does not sag below a given threshold. If the power line does sag too low, it switches to a battery that is charged by running the UPS in reverse to power the output signal. In this case, the test system is receiving line power during operation without any conditioning and the UPS takes over power delivery in the case of a power failure.
- **Double conversion UPS**—Double conversion UPSs connect the incoming power line to a battery that charges continuously and then supplies power to the output line of the UPS. The power supply of a double conversion UPS is very consistent because it is delivering power from the onboard battery. A double conversion UPS has the added benefit of always being prepared to act as a backup power supply with a fully charged battery to allow critical systems to shut down gracefully if a blackout or significant brownout occurs without having to switch power supplies. Although these UPSs are slightly less efficient, they provide an added value of always providing stable and accurate power inside the test system, which makes double conversion UPSs good choices for ATE applications.

Power Quality and Reliability

No power grid is perfect, yet most electrical devices are designed to operate under ideal power conditions. When the power from the grid varies from the power the system is designed to use, the system behaves in an unexpected manner. Instruments can take bad measurements or source incorrect signals. Devices and systems can switch on and off and lose important settings or default to incorrect settings. This unexpected behavior can lead to bad test results, damaged devices under test (DUTs), or worse. A double conversion UPS has the added benefit of constantly providing filtering by charging the internal battery with incoming power and providing a highly reliable, clean power source.

Blackouts and Brownouts

Blackouts occur when the power that the grid supplies completely turns off. Blackouts are fairly rare where there are well-developed power grids, and managing behavior of a system during these conditions can go two ways: (1) run some or all parts of the system off of a battery for a short time so that it can shut down properly or (2) let it turn off because of the lack of power.

Brownouts and power surges are far more common in the grid, especially in facilities like factories with large power consumptions, and are more difficult to handle because they can cause indeterminate behavior in the system. A brownout can be any sag or glitch in voltage or current in the grid that causes less power to be delivered to the test system. A surge is a momentary instance of additional voltage difference or current than the grid normally provides.

UPSs have an internal battery that allows for time between a blackout, or severe brownout, and a new power source, like a generator, coming online to provide enough power for essential equipment in the test system. Essential equipment includes the host controller and user interface and any other critical equipment. The time that the battery provides allows the system to maintain essential data and avoid corruptions or unsafe software states.

Power States

It is often necessary for a test system to have multiple running statuses to allow for debugging maintenance, power saving, and safety. A good approach to test system design is to implement four states of operation:

- **Off**—A system is entirely disabled with no power passing through the line filter or any internal test system components.
- **Enabled**—Power is passing through the line filter and into any directly powered equipment. Usually, all equipment is powered through a PDU. In the enabled state, only primary or master outlets on the PDUs would likely be activated. In some cases, DC supplies on the PDUs are also activated to power system support and other components. For example, in the enabled state, an Ethernet router and real-time system controller could power on so that technicians can monitor the health of the test system.
- **On**—A change to this state begins the main power on sequence of the test system. All PDUs receive power and enable outlets to other system equipment. In many cases, it is helpful or necessary to stage the power sequence when certain system components depend on others to be running when they start. Read more about PDUs in the Power Layout section.
- **Emergency Power Off (EPO)**—The EPO immediately cuts power to the test system when a user or system monitor recognizes an unacceptable operating condition.

- System Power Disabled
- No Facility Power to the Line Filter

- System Power Enabled
- PDU Master AC Outlets Enabled
- PDU DC Outlets Enabled (Individually Controllable)
- PDU Standard Outlets Disabled
- UPS Disabled

- System Power Enabled
- PDU Master Outlets Enabled (DC Supplies—Fans, System Controller, ENET Router)
  – Individual DC Outlets Enabled (2 Bank Power-Up Sequence)
- PDU Standard Outlets Enabled (2 Bank Power-Up Sequence)
- UPS Enabled

- System Power Disabled
- No Facility Power to the Line Filter

Figure 9. A test system requires multiple power states including off, enabled, on, and EPO to ensure efficient operation.

Emergency Power Off

When a test system encounters a serious issue or an emergency is taking place in the facility, operators need the ability to quickly and cleanly power off the test system. EPO mechanisms are included on test systems to simplify connectivity and inhibit power switching. Operators might use an EPO to reset a system in an error state, prevent damage to a DUT, or even prevent harm to themselves. EPO functionality is also required by the safety standards bodies such as IEC and UL.

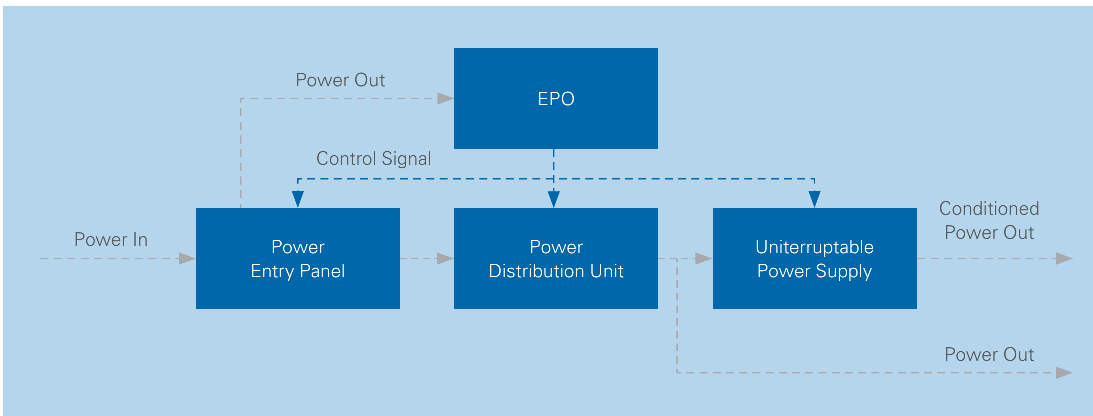


Figure 10. The EPO is connected to all equipment in the test system and can disable all connected equipment when necessary to maintain safety.

An EPO is generally a physical mechanism like a button or switch that is easily accessible to an operator and, when pressed, cuts power to all test system equipment. Ideally, the EPO panel has connectivity with all equipment in the test system to ensure that everything is powered off quickly. Most EPOs put systems into an off state that requires them to be reset to the enabled state before they can be reactivated and all equipment can power on. This prevents systems from unexpectedly restarting after a power off when there is an unsafe condition.

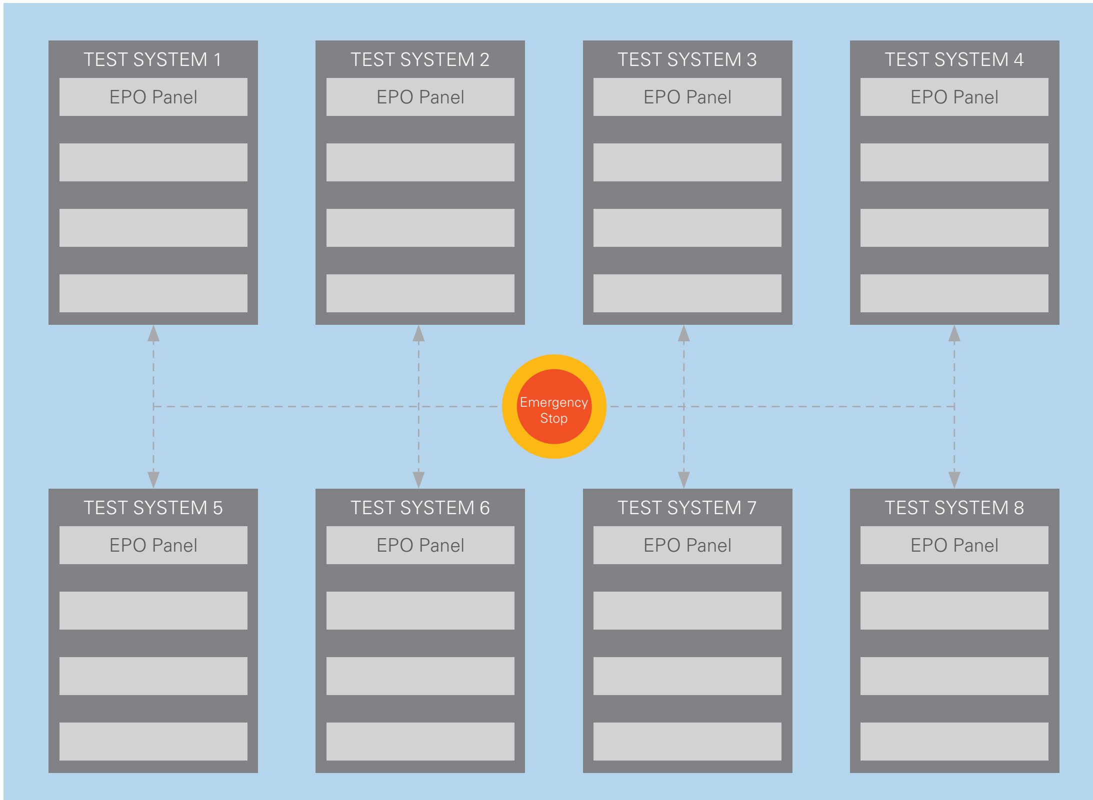


Figure 11. In some cases, a global EPO is necessary to disable all test systems and equipment in a facility. A global EPO is a single power off mechanism that enables the local EPOs of all individual systems.

Grounding

Grounding is a critical part of test system design for two main reasons: safety and measurement quality.

Ensuring that your test system has proper grounding to guarantee safety means giving all equipment in the test system a proper path for current to flow to a true or earth ground. The power entry panel must be connected to a power source that has a proper ground. You should then be able to choose any piece of equipment in the test system that is an end power consumer and follow its path to ground back to the power entry panel. Follow the ground current path for the Ethernet switch in the power layout of the example test system in Figure 1. The Ethernet switch ground is connected to the UPS ground, which should be connected to the ground of the PDU, which should be connected to the ground of the power entry panel. By creating a path for current that forms as a product of ground loops to flow to ground, you avoid building up dangerous charge in the system that could arc and cause damage or discharge into an operator or DUT.

Although the grounding path described is usually sufficient, grounding each piece of equipment in the test system individually can guarantee safety. A power entry panel from NI has a star grounding block, as seen in Figure 2, which is connected to other ground blocks throughout the rack. The grounding stud on the outside of the power entry panel can then be attached to a true earth ground outside the chassis. Additionally, each piece of equipment will generally have a grounding stud that can be directly connected to a ground. You can see the grounding screw of an NI PXI Chassis in Figure 12. Attaching each piece of equipment to the distributed grounding blocks throughout the chassis ensures that each one is grounded safely and that all ground leads are very short, which leads to less electromagnetic noise.

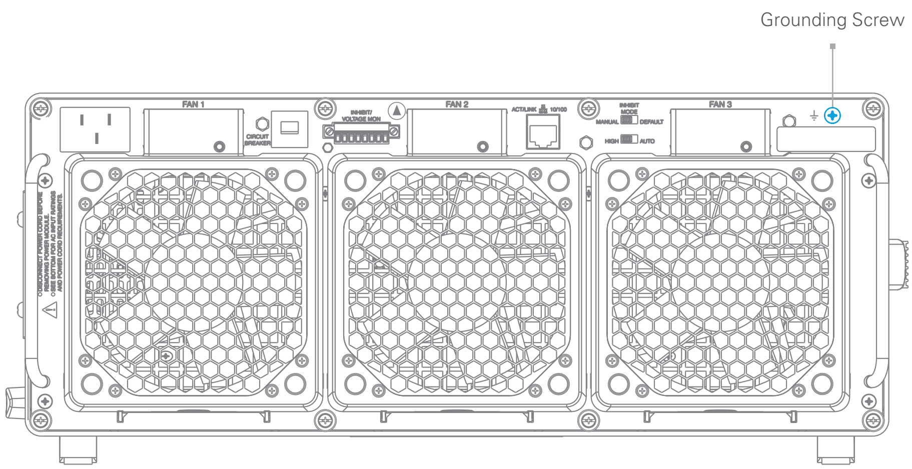


Figure 12. The PXIe-1085 PXI Chassis has a ground screw that allows you to directly ground the chassis and all instruments to an external grounding block. Grounding each piece of equipment in a rack is a best practice for guaranteeing safety.

Make sure that electrical connections to ground plains are short. Long ground loops can cause standing waves that result in radio frequency emissions within the system. If long transmission lines are needed to connect to ground plains, couple the signal with the ground signal in a twisted pair configuration to cut down on electromagnetic noise. Include both the positive and negative references of the signal if it is floating, or not referenced to ground.

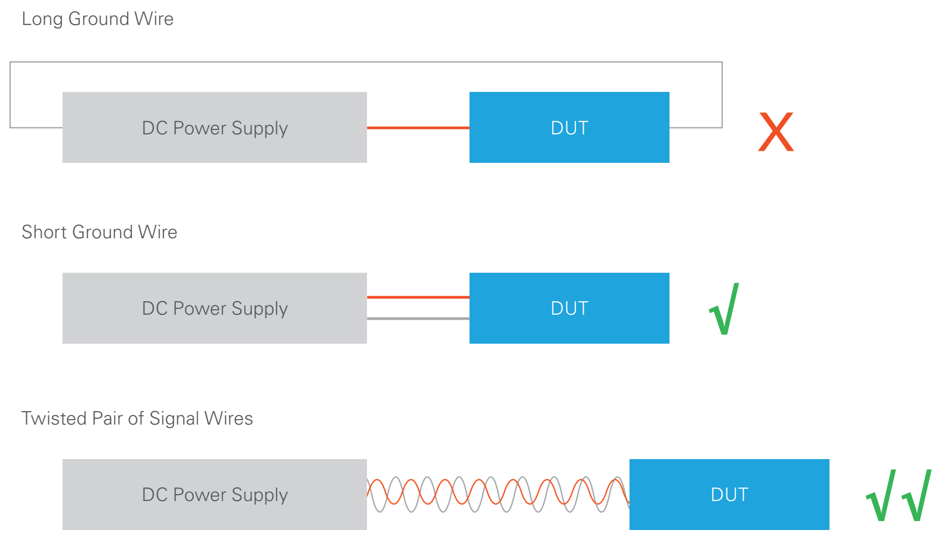


Figure 13. Having long, unmatched ground wires in your system can cause significant ground loops and act as an antenna for noise signals. Using short ground lines is better, but still has the possibility of picking up unwanted noise. For the best performance, use twisted pairs of signal and ground wires in your system.

Learn all you need to know about making the right connections for your measurements by reading the white paper Comprehensive Guide for Field Wiring and Noise Considerations.

Best Practices for Components

There are nearly infinite ways to source materials and construct a test system. When building a system that you have to maintain over time, consider long-term support and the extensibility of the system to add future requirements. To achieve these results, it is best to source system components from commercial vendors that support products and consumers with long-term supply strategies. It can seem like commonsense to work with a vendor for items like PDUs, UPSs, system controllers, and instrumentation, but that same strategy can pay off long term on smaller items like interconnects and cables. A committed vendor that can supply connectors along with vendors supplying test instrumentation can keep your system running with reasonable effort for a decade.

On the rare occasion that special requirements or extenuating circumstances make using a commercial product impossible, many companies are experts in custom equipment and solutions for test systems. Keep in mind that these solutions are often for a single consumer and are more likely to change or become obsolete over time.