Regenerative Power Supply

Addresses Efficiency, Safety, and Operation Costs

The consumer demand for electric vehicles (EVs) and hybrid electric vehicles (HEVs) continues to accelerate. Vehicle electrification in the automotive market brings with it new challenges in design and manufacturing. Consumers are looking for cars with a long-range, which means higher capacity batteries along with high-power electronics and chargers. Several newly designed EVs are using 800 V battery packs and chargers.

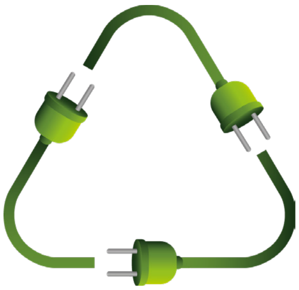
Using higher voltage chargers and batteries reduces the current required to deliver the same amount of power. Lower currents mean thinner cables, which provide an added weight savings benefit to the vehicle. Manufacturers need safe, reliable hardware to test their high-power, high-voltage electronics.

To meet industry needs, Keysight developed a regenerative two-quadrant power supply. The Keysight RP7900 Series regenerative power supply can source and sink up to 20 kW of power with an output of up to 2,000 V using a single supply. When testing energy storage systems, it is essential to switch between sourcing and sinking current.

The RP7900 Series enables you to make the transition seamlessly. While sinking power, regeneration returns energy to the grid eliminating the heat generated by a typical electronic load or power dissipater. A key benefit is higher power density, each 20 kW power supply only occupies three rack units.

KEYSIGHT TECHNOLOGIES

The Challenges



The primary budget concerns are the total cost of the equipment, along with operating, calibration, and maintenance costs. Operating costs typically outstrip the expense of the equipment. For example, there are additional cooling costs to remove the excessive heat in a test rack caused by a traditional power dissipater. Removing heat is necessary as it can cause measurement errors. At higher power levels, venting the heat into the lab becomes unpractical as it leads to a loud and uncomfortably warm work area.

An off-the-shelf solution gives you the best calibration and maintenance options compared to a custom solution. As an example, Keysight's global network makes it easy to replicate our solutions and provide maintenance to your installed equipment at various locations. Our on-site calibration services are available in many regions — as well as calibration and repair through global service centers.

How Regenerative Power Supplies Work

Traditional power supplies deliver a positive voltage and a positive current, as shown in Figure 1, quadrant 1. Similarly, a conventional power dissipator or electronic load accepts a positive voltage and a negative current shown in Figure 1, quadrant 2. The regenerative power supply operates in both quadrants. While operating in quadrant 1, the power supply draws power from the three-phase grid connection and then returns power through the same three-phase connection when operating in quadrant 2.

The RP7900 regenerative power supply gives you the ability to operate seamlessly between quadrants 1 and 2, while efficiently return more than 90% of the power to the AC grid when operating in quadrant 2.

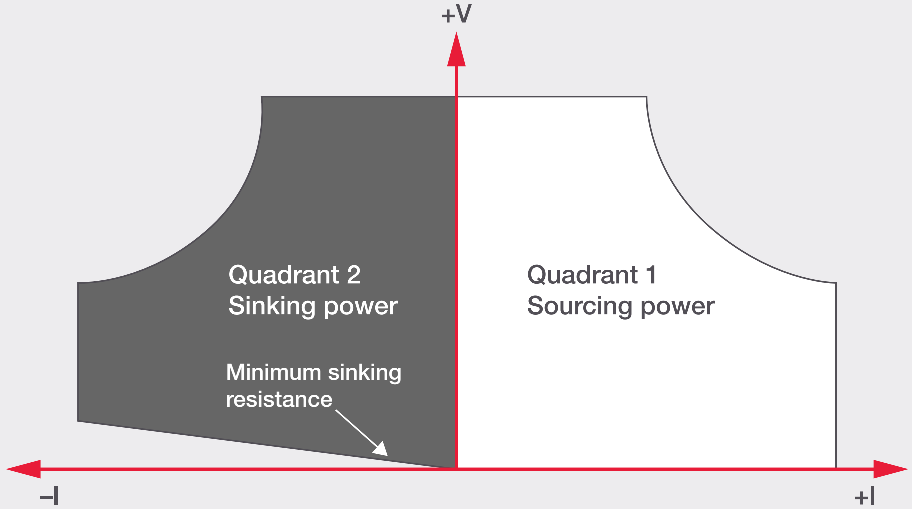


Figure 1. A regenerative power supply operated in quadrant 1 and 2

A traditional source, along with a power dissipater, requires much more rack space. A power dissipater uses an array of FET switches and resistors to convert current to heat. Fans keep the FETs and resistors within their normal operating temperatures. While power dissipaters work well at low power, they have to be physically large to disperse 20 kW of power. Keysight's advance power dissipater requires one rack unit, 1.75 inches tall, of space per kilowatt.

The Benefits

The ability to regenerate power back onto the grid has four key advantages:

- Uses one instrument to manage the sourcing and sinking of power.
- Reduces the amount of excess heat generated by 90%.
- Eliminates power dissipators which condenses rack space by 85%.
- Decreases or eliminates the need for additional cooling.

The RP7900 Series reduces operating costs while creating a work environment with less temperature rise and lower noise.

How to perform bidirectional power transfer

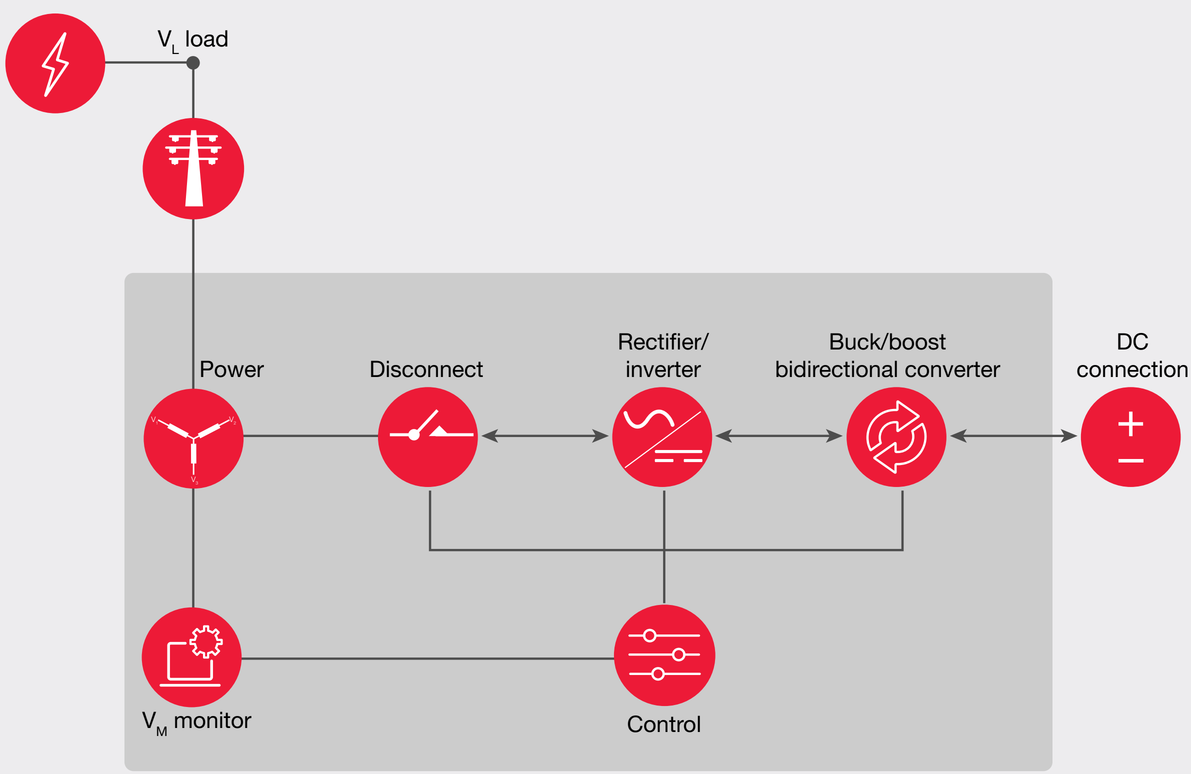


Figure 2. Overview of a regenerative power supply

Monitor and disconnect

Figure 1 shows how a regenerative power supply continually monitors the AC connection for safety purposes. If the AC connection has a fault or loss of power, the regenerative supply will disconnect. Disconnecting ensures the regenerative power supply does not back-feed energy into the building wiring or to the grid sending electricity to wires that should not be live. Disconnecting the power supply ensures electricians can work safely.

When the AC connection is working correctly, the monitor circuit determines the phase and voltage applied to the power supply. The controller synchronizes the power supply to the AC input. In its regeneration mode, electricity sent to the grid has the correct phase and voltage. A higher voltage V_m at the power supply's connections would allow current to flow to the lower voltage V_L at the load.

However, a miscalculation and a slightly higher voltage could cause a massive amount of current to flow to the grid. To avoid a voltage mismatch, the power supply transitions from a voltage source to a current source. Adding current to the grid allows the grid to remain at a highly regulated voltage. It is worth mentioning that an AC source or an uninterruptible power source cannot power a regenerative power supply as both solely supply energy and lack a load to absorb power.

Rectifier and inverter

Figure 3 shows a simple three-phase rectifier to convert AC power to DC power. Positive currents from each phase flow through a diode to the positive DC rail while the negative current flows through a diode to the negative rail. The rectifier in Figure 3 is a six-pole rectifier, and it captures the three positive cycles from each phase as well as the three negative cycles.

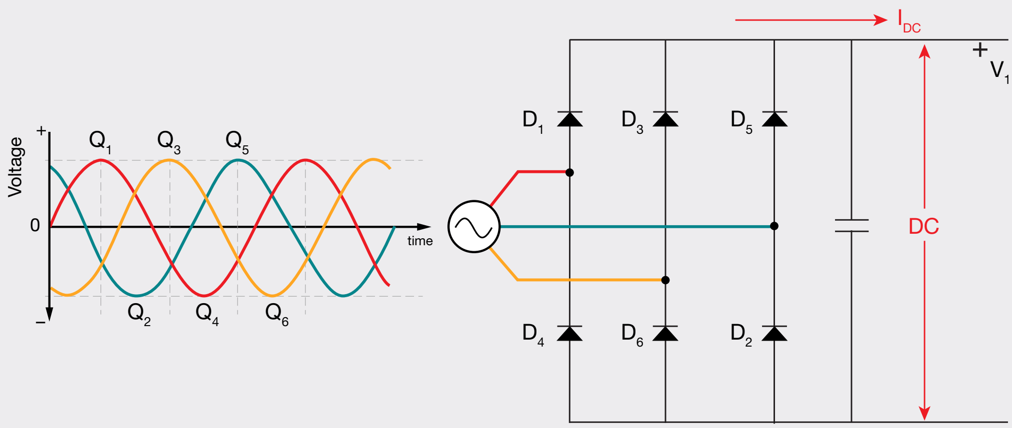


Figure 3. Six-pole rectifier converting three-phase AC to DC

In Figure 4, adding a switch to each pole allows the same circuit to convert direct current to a three-phase AC. The controller carefully times activating each switch so it can add the direct current back to each of the six cycles creating a three-phase AC waveform.

Figure 4 provides a simple illustration of a bidirectional rectifier / inverter. The RP7900 Series uses a more sophisticated circuit to generate a sinusoidal current waveform to put power back on the AC grid cleanly. Typical regenerated power has less than two percent Total Harmonic Distortion (THD) during full power regeneration.

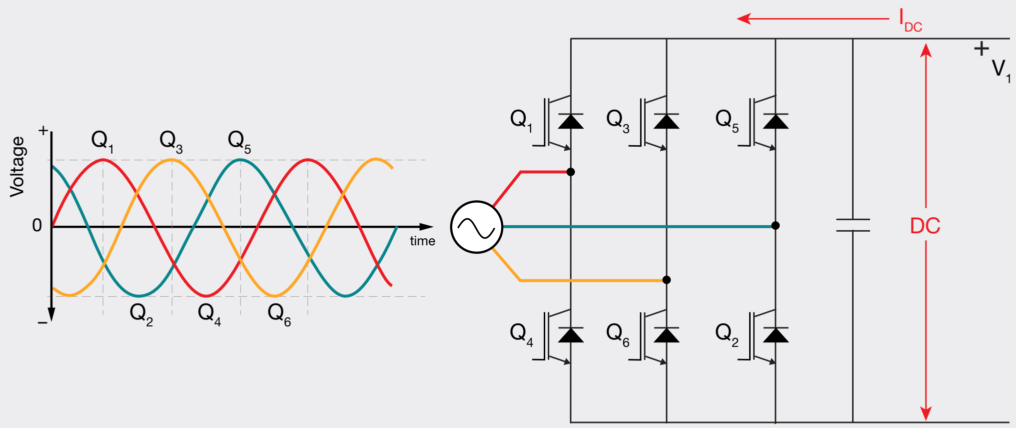


Figure 4. Bidirectional rectifier and inverter converting DC to three-phase AC

Bidirectional buck-boost converter

Figure 5 is an example of a buck converter which reduces the DC input voltage V_{in} to a lower DC output voltage V_{out}. A transformer efficiently steps-down the AC voltage to a lower AC voltage. An H-bridge circuit consisting of four transistors, (Q1, Q2, Q3, and Q4), converts V_{in} to AC voltage.

Transistor pairs Q1 and Q3 create a positive cycle, while Q2 and Q4 create a negative cycle of the AC waveform. On the opposite side of the transformer, a rectifier converts the lower AC voltage back to a DC voltage. The AC voltage from the transformer flows through the full-bridge rectifier, diode 5 (D5), and diode 6 (D6), converting the voltage to a DC V_{out}.

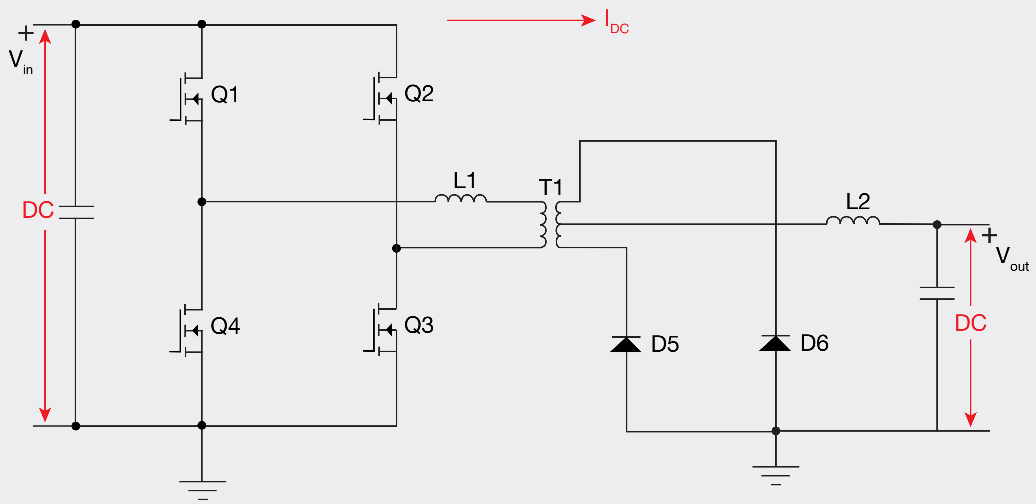


Figure 5. A buck converter reduces the DC input voltage V_{in}

Figure 6 is a schematic of a boost converter with V_{in} on the right-hand side. The transformer steps up the input voltage V_{in} to a higher output voltage V_{out}. The transistor pair Q5 and Q6 create the AC voltage for the transformer. Transistor Q6 creates a positive AC cycle, while Q5 generates a negative cycle. A full-bridge rectifier diodes D1 through D4 converts the output of the transformer to the DC voltage V_{out}.

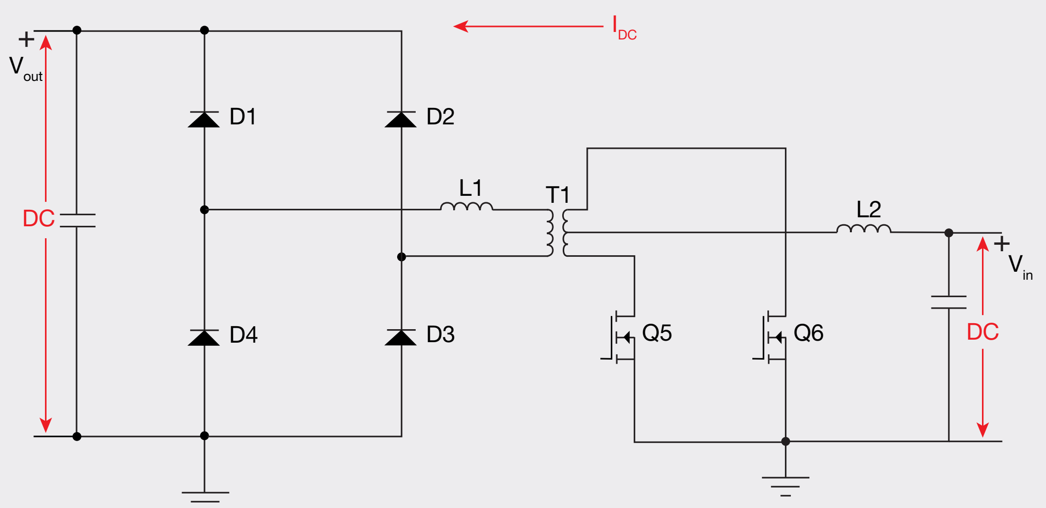


Figure 6. A boost converter raises the DC input voltage V_{in}

Superimposing Figure 5, the buck converter with the boost converter in figure 6 creates a bidirectional converter as represented in Figure 7. The transistors control the flow of current as well as create an AC waveform for the transformer.

Turning off transistors Q5 and Q6 allow the converter to function as a buck converter. Turning off transistors Q1 through Q4 enables the converter to act as a boost converter. Combining the two converter topologies now lets the current to flow in either direction.

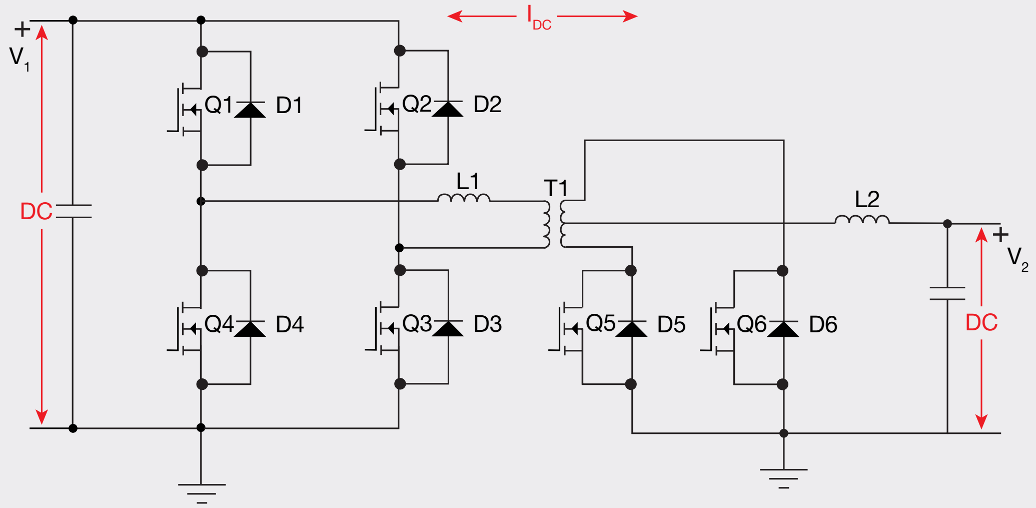
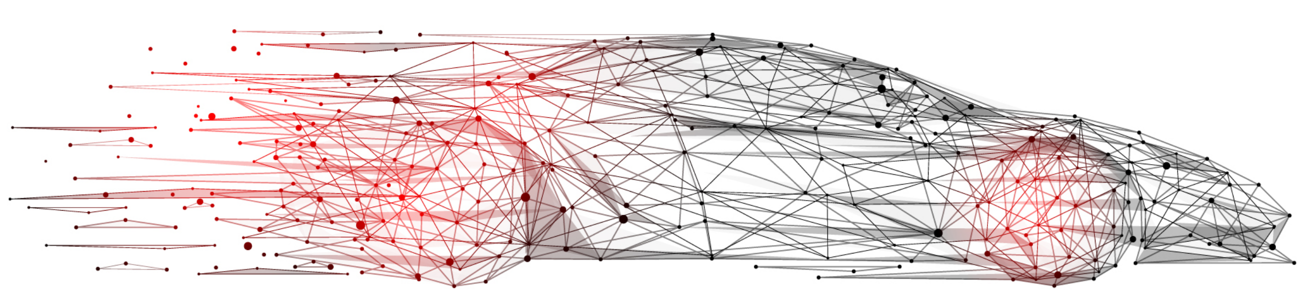


Figure 7. A bidirectional dc to dc converter allows current flow in both directions

Regenerative operation

Applying a negative current to the power supply will cause the regenerative operation. For example, setting a negative constant current -4 amps while testing a 500 V supply will send 2,000 W of DC power back through the bidirectional converter. Internal converter voltage V_1 (Figure 3 & 4) will start to rise, which causes the current to flow back through the rectifier / inverter. Most of the 2,000 W will move back to the grid, allowing V_1 to return to a steady-state condition.



Safely returning power to the grid

The monitor circuit continuously confirms that the power supply has a grid connection, and the AC voltage is normal. If the grid voltage drops, the regenerative power supply will recognize the fault and not put energy back onto the grid. The primary concern is that the back-feed energy could cause an electrical shock to an electrician while fixing the fault.

The monitor circuit has a second safety feature for detecting a fault when the power supply and other electrical equipment are sharing a branch circuit. Segmenting a power lab into several branch circuits allows a dedicated breaker to turn a group of equipment on and off. For our example, a branch circuit powers an equipment rack containing a regenerative supply and other electrical equipment. And, the breaker is set open removing power from the branch circuit. Under normal circumstances, any regenerated power will not be enough to power the other equipment on the rack's branch circuit. The open breaker will cause the branch circuit voltage to drop, and the monitoring circuit will recognize the fault.

Similarly, the monitor circuit will detect a fault based on a rise in voltage if the regenerative power is greater than the consumed power. So, what if the regenerated power is precisely enough to power the other equipment on the rack's branch circuit? In this case, the voltage would remain constant. For this condition, the monitor circuit also measures the regenerated power's frequency and can detect a fault based on frequency drift when not connected to the grid.

Summary

The RP7900 Series regenerative power supply returns over 90% of the energy to the grid while acting as a load. The energy returned is clean, with less than 2% total harmonic distortion. Constant monitoring of AC power allows the safe return of energy to the grid.

When working with high-power, a regenerative power supply has several advantages over a traditional electronic load or power dissipator:

- Saves up to 85% of rack space and gives you a full 20 kW load.
- Reduces cooling costs by eliminating 90% of the heat generated.
- Uses a single instrument to simplify power and load operations.
- Conserves energy by returning excess energy to the grid.

The RP7900 Series comes in 18 different models to accommodate your output voltage and current needs. Voltages up to 2,000 V or 800 A are available. Units can be parallel using a master / slave connection to achieve even higher power.

Learn more at: www.keysight.com

For more information on Keysight Technologies' products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus