Regenerative Power Supply

Addresses Efficiency, Safety, and Environmental Challenges

The diversification of the automotive market into HEVs (Hybrid Electric Vehicles) and EVs (Electric Vehicles) creates new challenges in design and manufacturing. The primary issue is the integration of high-voltage, high-power batteries in the 300 V range or higher on platforms traditionally using 12V. These high voltages generate additional costs and risks in ensuring smooth, safe power conversion for the various onboard electrical sub-systems.

Often the primary concern is the equipment cost, calibration, and maintenance. Although initial capital investments always command our attention, operating expenses can play an even more critical role in the total cost of ownership. Companies now must consider site preparation necessities, and safety requirements when transitioning from low power to high power. Having a commercial off-the-shelf solution that has a low cost of ownership would minimize your high-power test costs by reducing floor space usage, reduce heat dissipation, and maintaining uptime. Keysight can help you with the **RP7900 Series regenerative power system**.

KEYSIGHT TECHNOLOGIES

Bidirectional Regenerative Power Supplies (RPS) Overview

We have received several questions from customers about how you can have a DC power supply that can output up to 10 kW of power in Quadrant 1 (Figure 1) while running off a three-phase line; and then act like an electronic load in Quadrant 2 (sinking power) that puts power back on the three-phase line when it is sinking current.

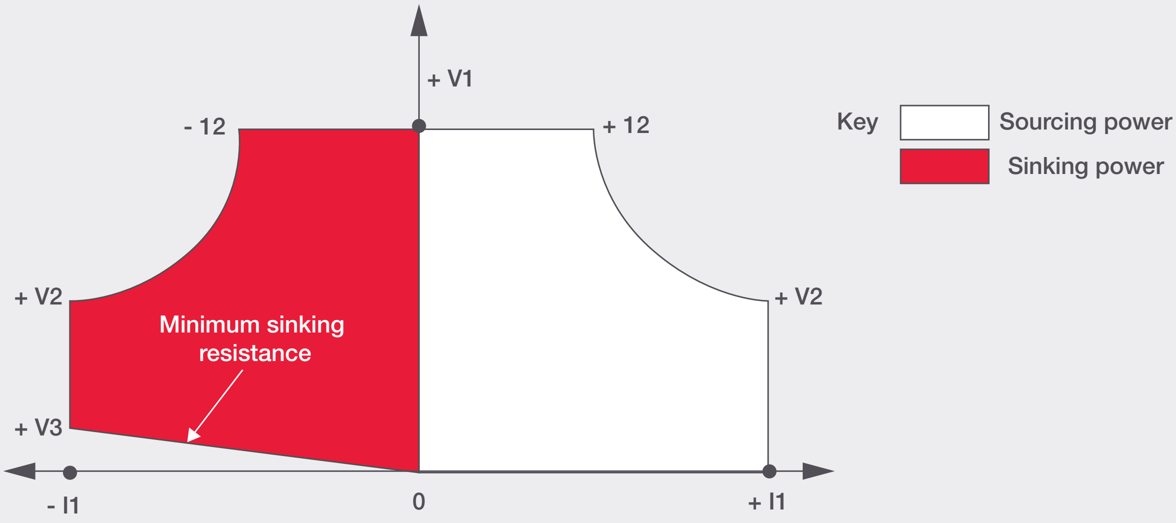
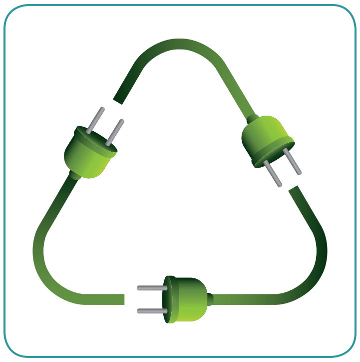


Figure 1. Regenerative Power Supply (RPS) Operating Range

Let's look back for a second to see how this design was implemented in the past. To operate in Quadrant 2 and sink 10 kW of power in the form of heat would require a large array of transistors, resistors, and heatsinks to dissipate all this power in Quadrant 2. In addition, to sink all this power would use a large volume of space for the fans to cool the heatsinks which typically require up to about 10 U (U = 1.75") of additional rack height. This doesn't include the power supply for Quadrant 1 operation which is typically another 3 U of rack height.

Since rack space, efficiency, and cost of ownership are becoming much bigger issues with customers, Keysight realized a Regenerative 2 Quadrant power supply, that can source and sink up to 10 kW of power, in a single 3 U high unit would be of excellent value to our customers. Not only does this power supply give you the ability to operate seamlessly between Quadrant 1 and 2, but it also efficiently returns more than 90% of the power back to the AC grid when operating in Quadrant 2.

Benefits of Regenerative Power



Being able to regenerate power back onto the line has several advantages. By doing this we can shrink the RPS (regenerative power supply) from 13U down to only 3U. You might ask what about all the dissipation in Quadrant 2?

This is where the benefits of regeneration come in:

- Allows you to reduce the dissipation of heat to under 1 kW while it is sinking 10 kW of power because the unit is over 90 percent efficient at regenerating power. The other 9 kW of power is being regenerated and returned to the AC power grid.
- Provides a 75 percent reduction in size because you don't have to dissipate 9 kW of power in the supply.
- Reduction in electrical utility costs because you are returning power back to the AC grid.
- Additional savings due to the reduction of new air conditioners and the associated cooling costs.

How do you get Bidirectional power transfer?

Let's start with a unidirectional buck mode DC-DC converter shown in Figure 2.

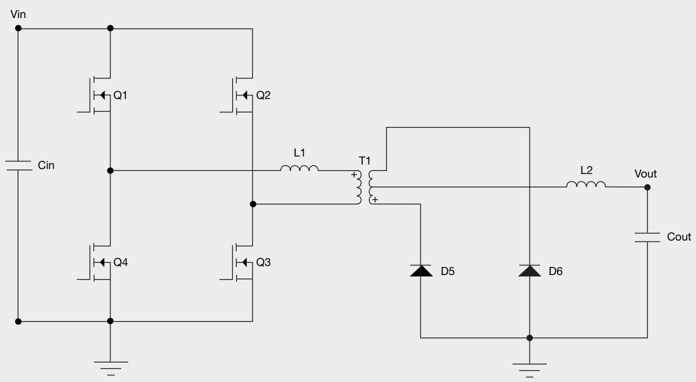


Figure 2. Buck converter

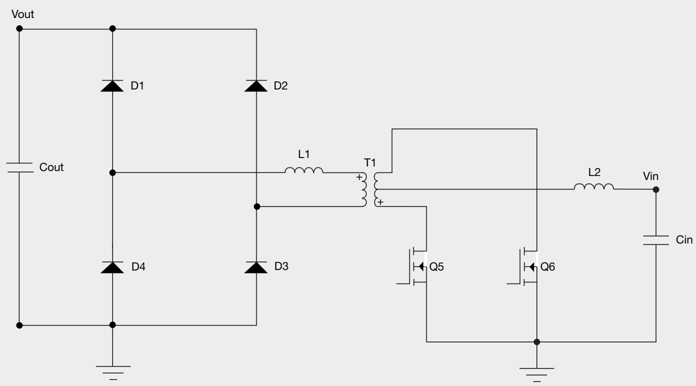


Figure 3. Boost converter

This is a standard buck mode power supply where the power is fed in on the left, and the output is converted to a lower voltage on the right. You can see on the left the standard H-Bridge and on the right, is the full-wave rectifying stage.

Next, let's look at a unidirectional boost mode DC-DC converter shown in Figure 3.

This is an example of a boost mode power supply. It is intentionally shown with the power fed in on the right, and the voltage is converted to a higher voltage on the left. You can see on the right the standard push-pull converter and on the left, you have a full-wave rectifying stage. The reason why it's shown this way is to demonstrate how you can go from two separate converters into a single bidirectional converter shown in Figure 4 by just superimposing the two converters one on top of the other.

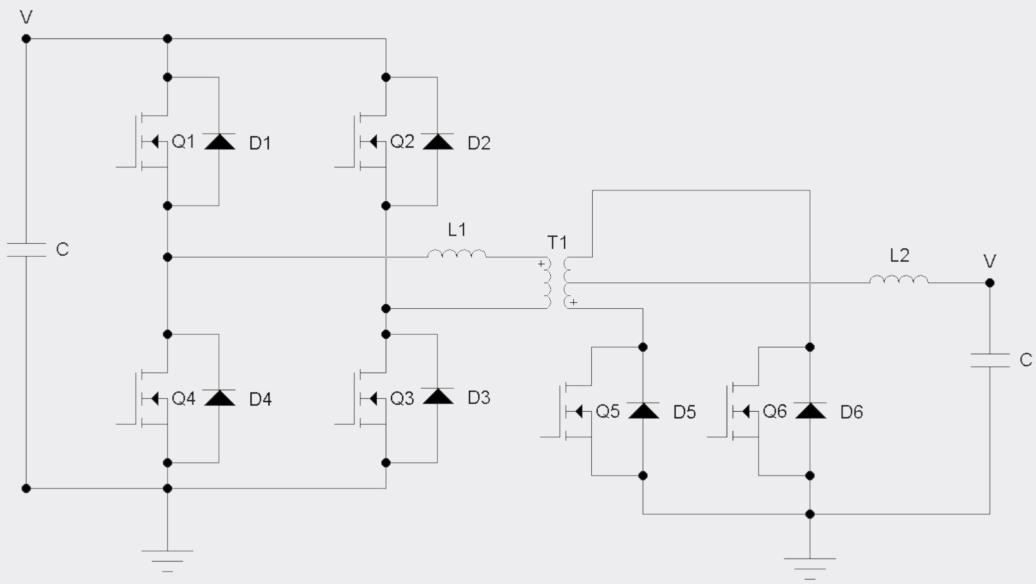


Figure 4. Bidirectional buck-boost converter.

By superimposing the two circuits, you now have a parallel combination of transistors and diodes on both sides of the transformer. You can see that this converter can now run as a bidirectional power supply by controlling which FETs (field-effect transistor) are turned on and which are turned off.

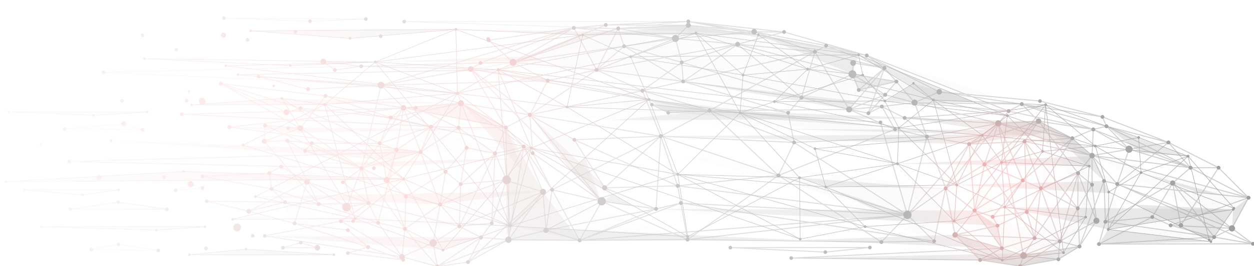
If you turn off Q5 and Q6 and leave the other transistors active, you have a buck converter. Conversely, if you turn off Q1 thru Q4, and leave Q5 and Q6 active, it is now a boost converter. You can use this same superposition for the PFC (power factor correction) stage which converts AC-DC by replacing the rectifying diodes on the DC output with FETs. This provides a bidirectional supply which can be both a PFC and an inverter which will take the DC rail and convert it back to AC, which can then be fed back onto the AC grid.

Returning Power to the AC Grid

The next step in regenerating power back to the line is where it becomes a little trickier. You need first to establish the AC power grid frequency and voltage are stable before you can put power back onto the grid. This is to ensure you are not putting power back into a faulted circuit or creating an island where the RPS (regenerative power systems) is energizing equipment that was already disconnected from the AC grid. If power were to be put back onto the line without first doing these checks, it could injure workers who have come to repair the fault and aren't expecting circuits to be energized.

After ensuring there is a stable power line available and then synchronizing the AC output of the DC-AC inverter with the line, you can start to put power back into the AC grid, much like a solar power inverter does. To enable power to flow back into the AC grid, the output of the DC-AC inverter needs to be higher in voltage than the AC line to reverse the current flow. The amount of power is regulated by configuring the AC output from the inverter to operate in current control mode instead of voltage control mode. This is done because the AC line is a regulated voltage source. Since we know two voltage sources cannot be put in parallel with each other because even a small error in voltage can cause a large amount of current to flow between them. The inverter generates a sinusoidal current waveform to cleanly put power back on the AC grid. By doing this you can maintain less than two percent THD (total harmonic distribution) (typical) during regeneration at full power. The regenerative supply will then put as much power back into the grid as needed to create the amount of loading being called for by the RPS.

In other words, if Quadrant 2 operation calls for 500 volts at -4 amps, then the loading would be 2000 watts. The power mesh will first put this power back into the DC-DC converter which will cause the rail voltage to start climbing. To keep the rail voltage from climbing above the predetermined level, the DC-AC inverter will put the same amount of power back into the AC grid to keep the rail voltage steady minus the losses in the converter and inverter. The two converters will regulate to keep just the right amount of power being put back onto the line to keep everything in equilibrium. If Quadrant 2 settings are changed, the same correction in power transfer will take place automatically.



What happens if the AC grid drops out (Anti-Islanding)

There are several reasons the AC grid might drop out:

- There has been an AC power failure outside the building. In this case, the building has become an island from the AC grid and the RPS will not be able to maintain the AC grid for the entire building and will shut down.
- Another condition that can cause loss of the AC grid is a local breaker has tripped or a disconnect may be turned off. The local island can be thought of as instruments that may be in the same test set hooked up to the same AC line inside the rack which has been disconnected from the AC grid. This is the condition that you are more concerned about, because the small local island (test rack) may be drawing about the same amount of power as the RPS is returning to the test rack.
  - The first two conditions are when the local island draws more power or less power than the RPS is putting out. If either of these conditions exists, the internal rail voltage will either climb above or fall below the predefined limits and shut down the RPS.
  - The third condition is the one that is a little more difficult to detect. This is where the power being drawn by the local island, exactly equals the power being put back onto the AC line inside the test rack. In this case, the RPS has no external AC grid to synchronize with, and it will start to drift in frequency. If this drift is more than a few hertz from the line frequency when the RPS was turned on, the unit will shut down. This drift only takes a few seconds to happen so the unit will shut down in less than 10 seconds from losing the AC grid.

Can I use this if my AC line is from an Uninterruptable Power Source (UPS) or AC source?

The simple answer is no. The reason is most AC sources and UPS are not able to act as an AC grid. The AC grid can both source and sink where an AC source and UPS can only source power. This goes back to the quadrants of operation (Figure 5). AC sources and UPS only source power so they operate in Quadrant 1 and 3. When the RPS starts regenerating power, it puts this power back onto the grid in Quadrants 2 and 4. Since the AC source and UPS have no way of sinking power, they can easily be damaged by power flowing back into their outputs. Therefore, we never recommend using them to power up the RPS.

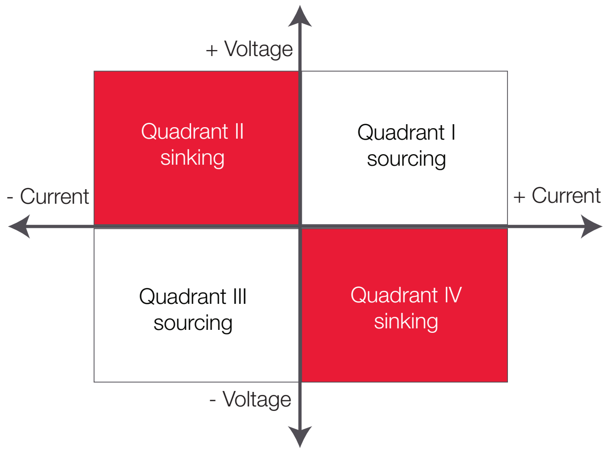


Figure 5. Four quadrants of operation.

Conclusion

I hope this has helped to explain the advantages of using an RPS in your test system. They can simplify, reduce wiring complexity and improve the performance of your test system while significantly reducing form factor. In the long-term, it also reduces the cost of operation and ownership. **Learn more.**

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

KEYSIGHT TECHNOLOGIES