Why Can't You Put Electronic Loads In Series To Get More Voltage?

Electronic Design

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Mon, 2013-11-04 14:23

Many devices today operate at higher voltages, such as silicon-carbide semiconductors, dc distribution systems, electric vehicle batteries, and power subsystems. When devices can source power, they need an electronic load (e-load) to load them down during testing. But as voltages climb to 400 V, 600 V, or even 1000 V, there are fewer e-loads on the market rated for these high voltages. You may consider putting e-loads in series to construct a solution. But most, if not all, e-loads on the market cannot be safely put in series. For those of you wondering why, read on.

How Does An E-load Work?

The most basic e-loads can operate in constant current (CC) or constant voltage (CV). Some e-loads provide constant resistance (CR), constant power (CP), or even constant impedance (CZ), but all of these modes are generally derived from the basic CC or CV function. A CC e-load is used to load down a CV source, such as the output of a dc-dc converter. A CV e-load would be used to load down the output of a CC current source.

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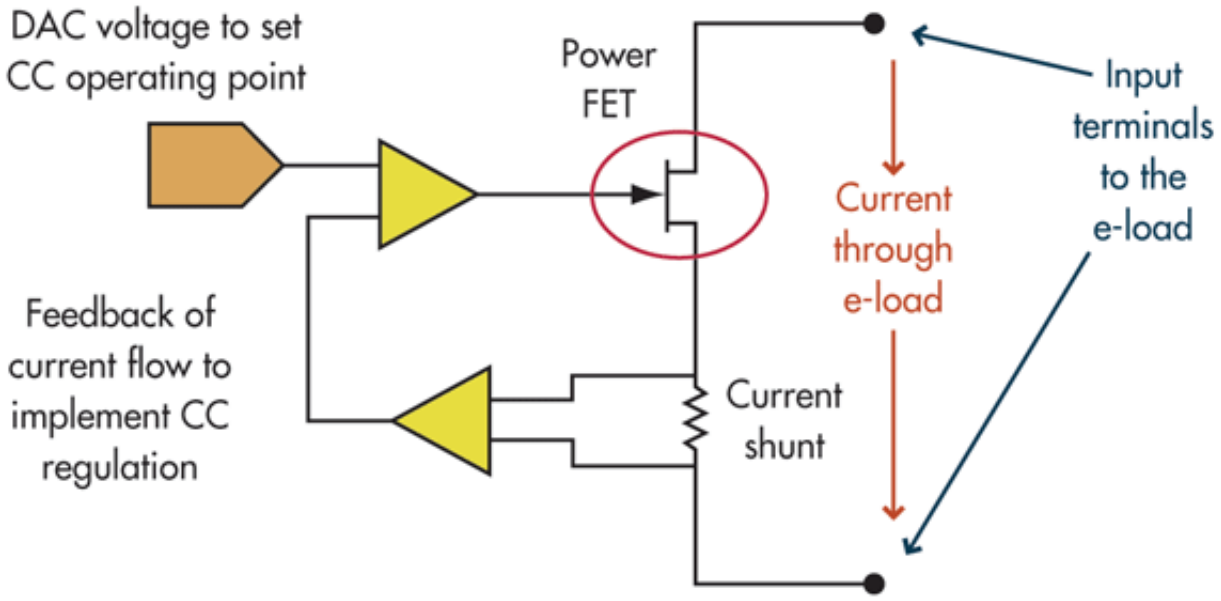
Looking more closely at the CC programmable e-load, the e-load controls the amount of current flowing by adjusting the R_{DS} of the FET *(Fig. 1)*. The series resistor (current shunt) senses the actual current. This signal across the shunt is amplified, compared against a digital-to-analog converter (DAC) voltage used to program the e-load to the desired CC level and fed back into the gate of the FET to create a regulated constant current.

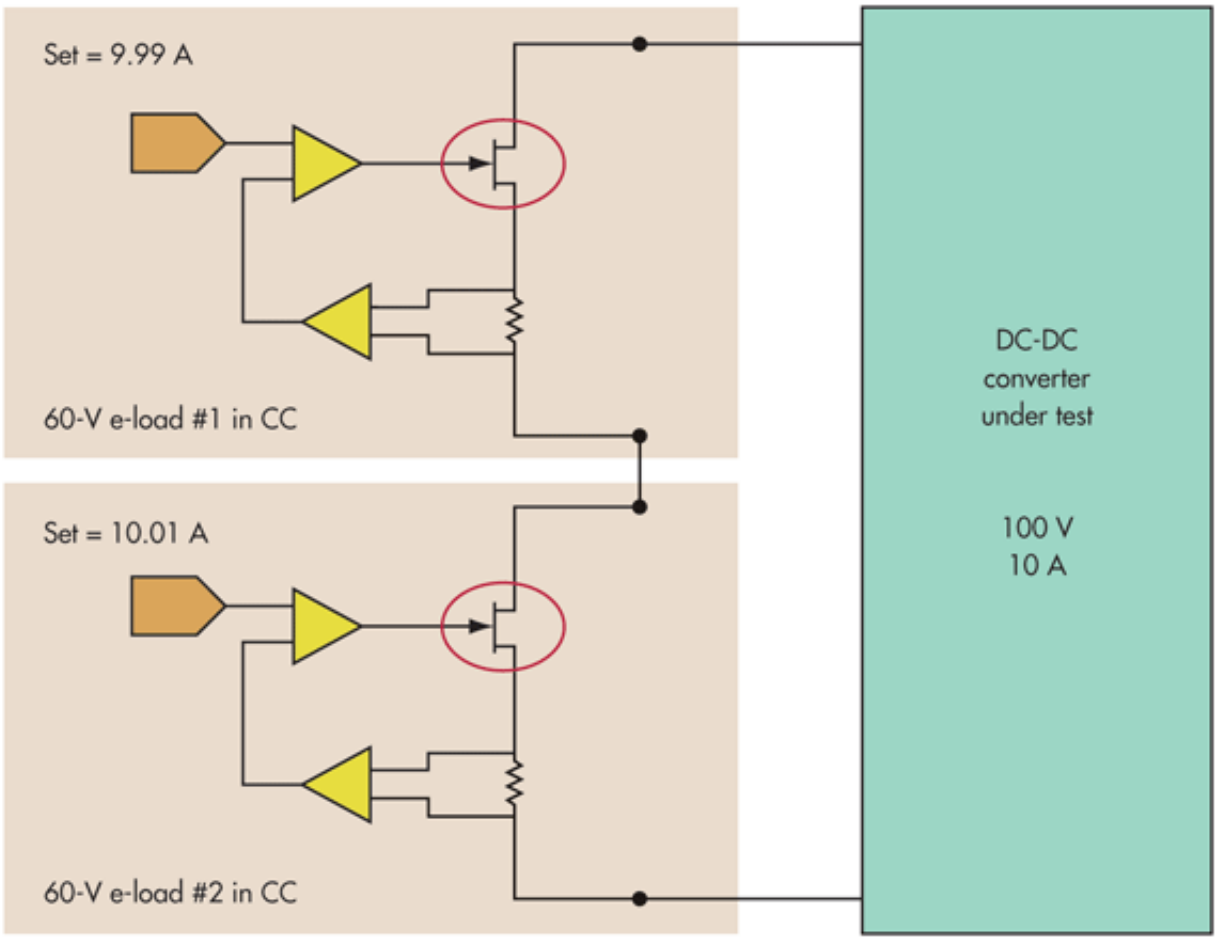


If too much current is flowing, the feedback circuit will adjust the gate voltage to increase the R_{DS} and reduce the current flow. If not enough current is flowing, the feedback circuit will adjust the gate voltage to reduce the R_{DS} and increase the current flow. If the e-load cannot pull enough current to achieve the CC value, the feedback circuit will cause the gate to turn on full and set R_{DS} to its lowest value, effectively turning the FET into a short.

The maximum current will flow based on I = V/R, where V = V_{Out} of the dc-dc converter and R = ($R_{DS(on)}$ of the FET + R_{shunt}). When this limit is hit, the e-load will not be in CC, as it can't drive the current to the programmed CC value. Instead, the e-load will go unregulated with a near short across its input terminals. This near short is the minimum resistance of the e-load, and it is often specified as the e-load's "minimum on resistance" or "short circuit resistance."

E-loads In Series

Every e-load is rated for a maximum voltage, such as 60 V. If the dc-dc converter has a 100-V, 10-A output, you might be tempted to put two 60-V e-loads in series *(Fig. 2)*. Each e-load must be set to pull 10 A because they are in series and the same current will flow through them. However, they will never be programmed to the exact same current level due to programming inaccuracies.



So, e-load #1 may go to 9.99 A and e-load #2 may go to 10.01 A. Now, current begins to flow. E-load #1, set to the lower current level of 9.99 A, will control the current and successfully operate in CC. E-load #2, set to the higher current, will try to pull more and more current by lowering its R_{DS}, but it will never achieve its programmed 10.01 A because e-load #1 is limiting its current to 9.99 A. Eventually, e-load #2 will become a near short and operate unregulated.

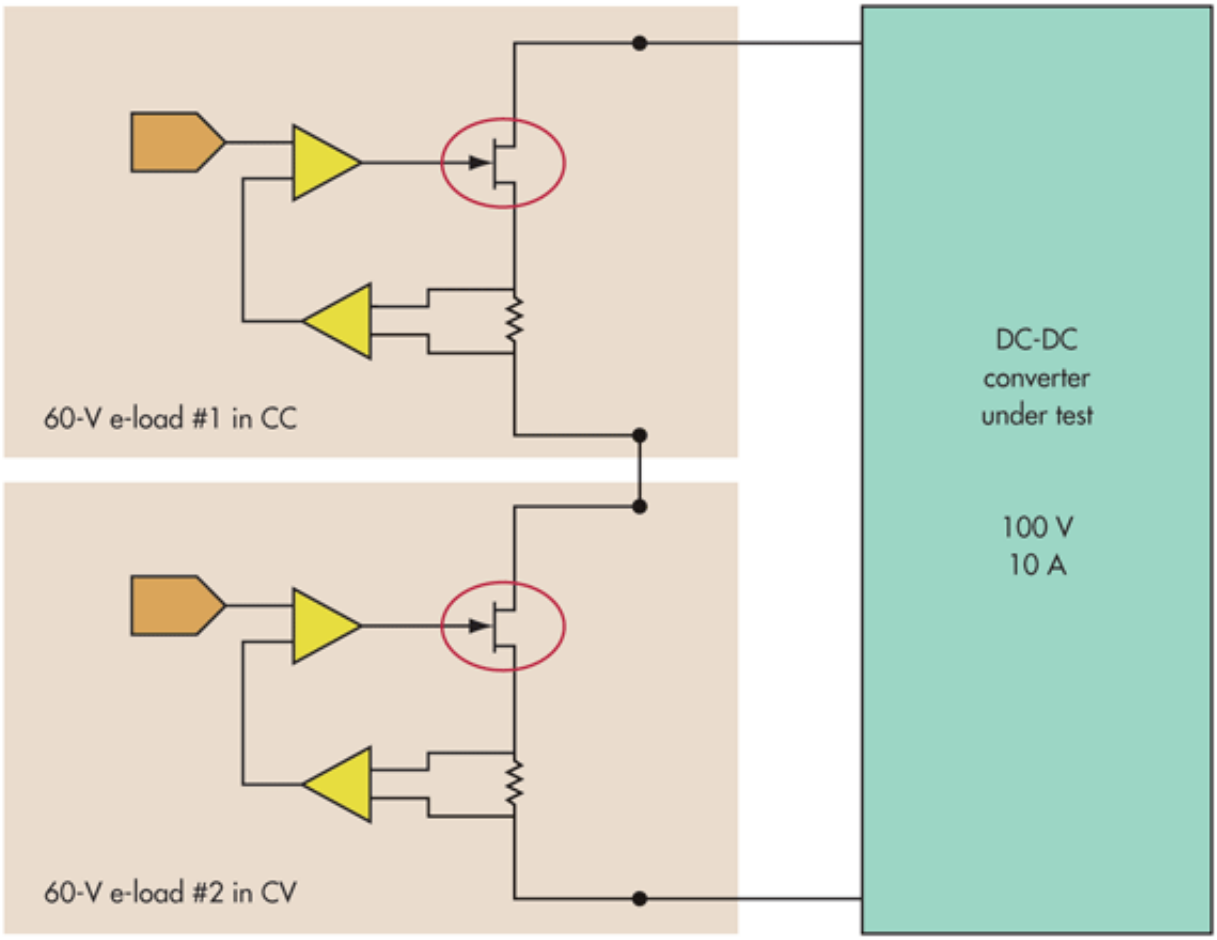
Since it is a short, the resulting voltage across e-load #2's terminals will be nearly 0 V. This means virtually all of the 100 V will appear across the terminals of e-load #1. This excess voltage will cause e-load #1 to shut down and could potentially damage the input circuits.

While this example is for two e-loads in series, the situation is the same for three or more. This only goes to prove that you can't have two or more devices both trying to control/regulate the flow of current through the same path.

You may be tempted to consider having one e-load in CC and the rest in CV so only one e-load is trying to control the current. But in this configuration, a problem will occur when intentionally turning the e-loads off or if one of the e-loads goes into protection and shuts off unexpectedly.

As soon as the flow of current is interrupted, any e-load set to CC will be driven to act as a short (lowest possible resistance) to try to pull as much current as possible. Meanwhile, any e-load set to CV will be driven to be an open circuit (highest possible resistance) to try to achieve the programmed CV voltage drop across R_{DS} of the FET even when there is no current flow. This will cause the dc-dc converter's high voltage to appear across the e-loads with the highest resistance

due to the voltage divider effect of the e-load resistances in series *(Fig. 3)*.



Summary

It is not safe to operate e-loads in series if the device under test can supply more voltage than the rating of any one e-load, as the whole voltage will eventually appear across one e-load. So, the only safe way to operate in series is to have every e-load be rated for the full voltage of the device under test. But if you have that, you don't need to put the e-loads in series after all.

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