Adjustable Line Voltage Limiter Uses Ground Fault Circuit Interrupter

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Electronic Design
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Designers commonly use varistors in voltage limiters targeting short-duration voltage spikes typically lasting less than 10 ms. But for protection against long-duration overvoltages, where the line voltage reaches more than 130 V for seconds or minutes, another solution is required. Examples include an erratic connection of the neutral wire at the distribution panel, voltage bumps on the distribution network, and overvoltage protection on ac generators.

The circuit provides such overvoltage protection using a ground-fault circuit interrupter (GFCI), which has a response time of less than 25 ms when responding to ground currents over 5 mA. The circuit is connected between the GFCI load side and ground (Fig. 1). An overvoltage will cause the circuit to draw an ac current above the 5-mA trip limit of the GFCI and trigger it, disconnecting its own outlet and the remaining downstream outlets.

At normal line voltage, typically 120 V, transistor Q1 is barely conducting. This residual current (about 0.7 mA) comes from resistors R4, R8, R2, and R3. If the line voltage exceeds 120 V, Q1 starts to conduct a small fraction of every half cycle of the line period. Capacitor C1 and diode D1 stretch these current pulses. Resistors R4, R8, R2, and R3 make up a voltage divider with R2 allowing adjustment of the limiter voltage. The divider's total resistance is a compromise between low residual current and a sharp knee in the circuit's voltage-versus-current curve.

Typically, Q1 will start to conduct just above 120 V and trigger the GFCI at 133 V (Fig. 2). Q1's collector resistors—R5, R6, and R7—limit the current to less than 20 mA peak. They are series-connected to increase power dissipation and divide the peak voltages so the maximum allowable voltage across the resistors is less than 200 V under line-transient conditions.

The varistor at the circuit's input will clamp any short-duration pulse to less than 400 V, protecting Q1. Zener diode D2 sets Q1's threshold level of conduction. The Zener is a 1-W diode having a 40-Ω dynamic impedance to minimize reduction of the transistor's effective current gain. Capacitors C2 and C3 shunt the D1 and Q1 base-emitter junction to prevent false activation by stray RF fields.

This circuit is easily implemented on a small printed-circuit board (PCB) at the rear of the GFCI. It can also fit in an electrical enclosure connected to an existing GFCI outlet using a standard three-prong plug. Note that this circuit will not prevent the GFCI from performing its normal protection against ground faults. Additional details may be found at http://ve2azx.net/technical/VoltageLimiter.pdf.

Anoop's Analysis

This Idea for Design is good. I would only correct one mistake—the wattage rating of resistors R5, R6, and R7. The peak current passing through these resistors can be as high as 17 mA (120 V × √2 – 30 V)/(3 × 2.7 kΩ) when the transistor is conducting and the GFCI has not yet tripped. A simple calculation shows that the power dissipation in these resistors is about 780 mW (17 mA × 17 mA × 2.7 kΩ). The figure shows 1/4-W ratings on these resistors, which means they may burn out. A 1-W or higher rating with suitable heatsinking would be preferable.

The Author's Response

I agree that the peak current could reach 17 mA (at 120 V input) when the transistor is saturated. Before this happens, the GFCI will have trigged. I tried two GFCIs and based my design on the less sensitive one, which triggered at 14 mA peak, or about 7 mA rms. However, the GFCI would have a 5 ±1-mA spec for triggering.

An important point to remember is that the transistor only starts to conduct for voltages above 120 V rms (Fig. 2). The transistor current waveform will be close to zero for the first 80°, then quickly rise to its peak value and start decaying after 110°. This gives a measured average total power in resistors R5, R6, and R7 of 1/2 W at 130 V and 0.95 W at 133 V input (the GFCI trigger level).

This distorted current waveform gives a 4-to-1 peak to average power ratio, instead of the usual 2 to 1 for sine waves. Based on this I would recommend changing the resistor rating 1/2 W on Figure 1, providing 1.5-W total dissipation capability. This should cover the case where the input voltage stays just below the trigger point for a long period of time. It's also a good idea to verify the peak trigger current of the GFCI, since they are not all the same.

Anoop's Reply

My calculation resulting in 780 mW was based on peak current, and I was only trying to indicate that 1/4-W resistors will not work. But the exact way of calculating power dissipation is by summing up instantaneous power at different points of the sine wave and averaging it. Average current will be much smaller because the transistor conducts during only a part of the sine wave (either side of the peak) as the author pointed out.
So, 1/2-W resistors will work fine. But the user should still make sure that there is a good way of

conducting away that 1/2 W each from three resistors. (Surface-mount resistors would require large copper areas to act as heatsinks. Through-hole resistors may use copper areas or convection air currents.) The 1/2 W is quite a bit of heat for a small resistor to dissipate effectively.

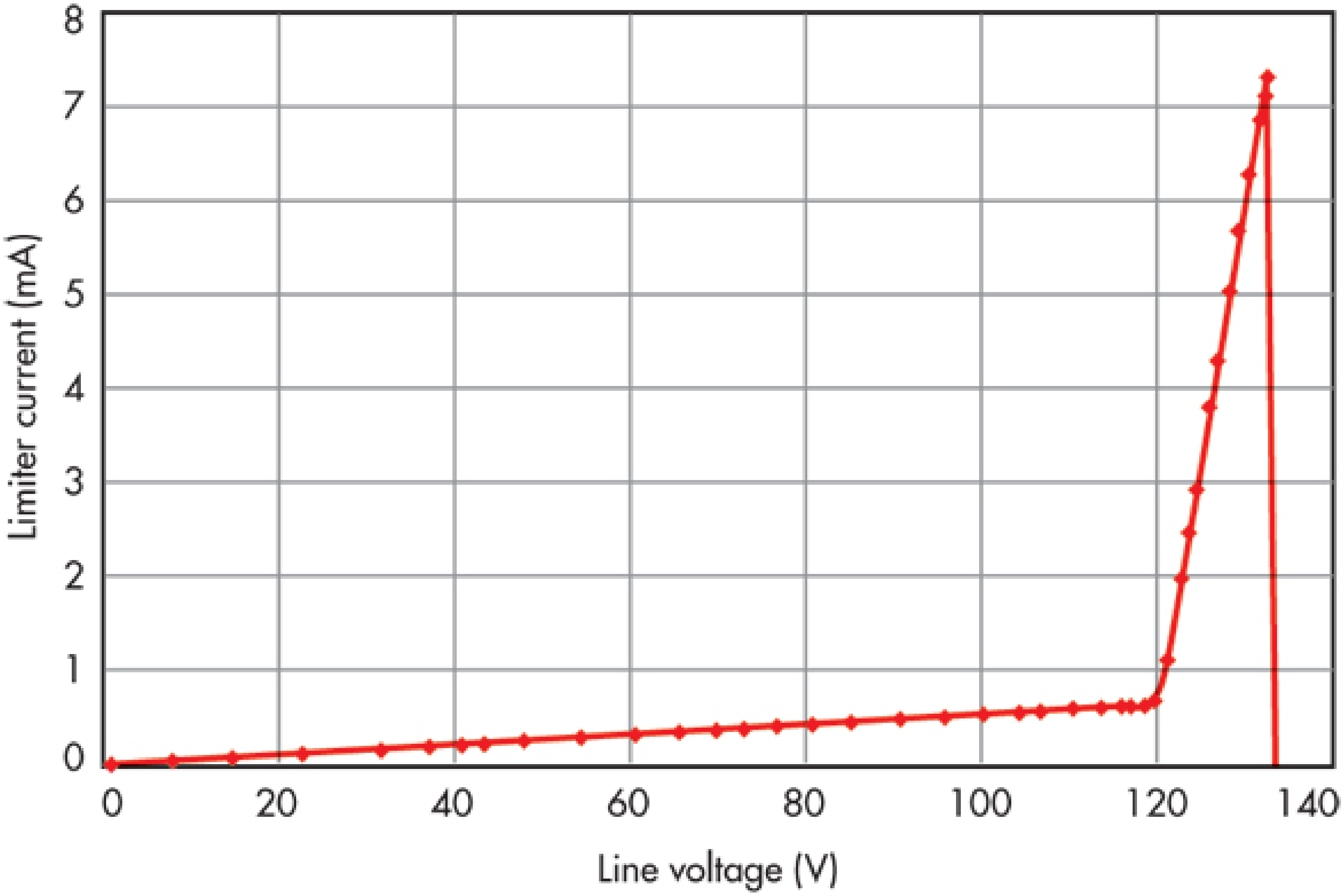

Fig 2. With the trip point set at 133 V rms, the circuit draws less than 1 mA at 120 V rms and approximately 7 mA at 133 V rms, which triggers the GFCI.

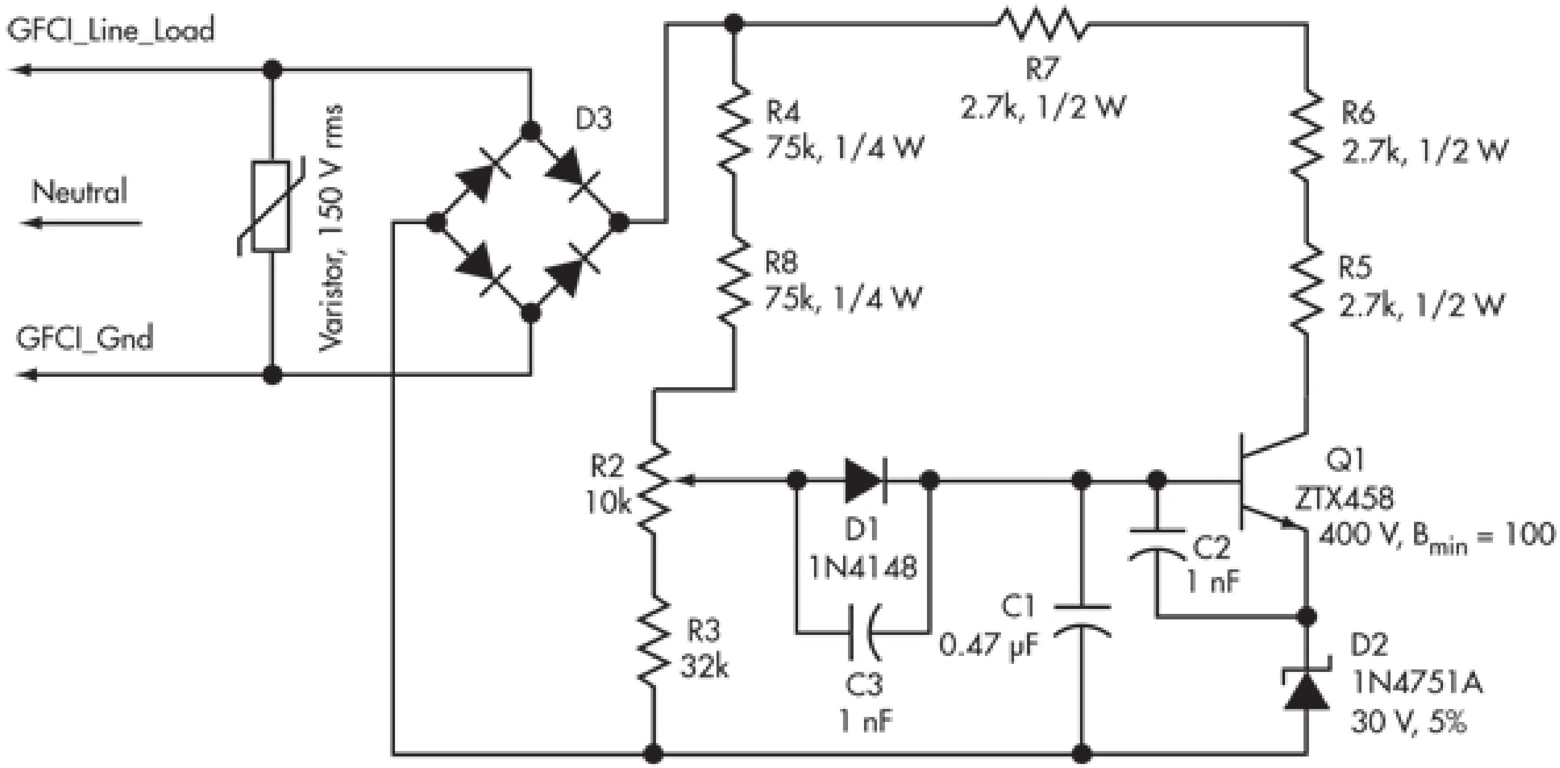

Fig 1. Placing this two-terminal circuit between a GFCI line-load terminal and ground creates an adjustable line-voltage limiter.