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Extending PDN Peak Power Capabilities While Still Meeting Safety Requirements In IT Equipment

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Safety regulations set limits on the power and energy levels to which a user of IT equipment can be exposed. For example, one of the most common legacy standards, IEC-60950, which in 2021 was replaced by IEC 62368-1, specified anything beyond 240 VA of power or 20 J of energy as hazardous levels. As a result, the 240-VA/20-J threshold commonly indicated the boundary at which costly protective physical barriers were strictly required for users.

However, such protective covers can significantly affect PCB cooling in IT equipment. By restricting airflow, they can raise component temperatures and cause performance throttling. A preferable alternative is to implement electronic protection—overpower protection—preventing the equipment from exceeding the specified power and energy levels. At the same time, in real applications, a single PDN (power distribution network) channel is often required to support higher equipment performance associated with dynamically increasing CPU frequencies and peak power levels that significantly exceed the power safety boundary.

There are also applications where regular users do not have access to the PDN such as high-end servers with their multi-kilowatt PDNs, but which still impose safety limits to guard against fire hazards. In such cases the safety limits can significantly exceed the 240-VA/20-J threshold. Nevertheless, these applications have similarly conflicting requirements in meeting load peak power demands while still staying within the safety threshold.

One method to meet the aforementioned conflicting requirements is to use a delay in the overpower protection network. This article examines the amp-second limits that such a delay can support while meeting both energy and power safety requirements defined by the safety standard.

We begin with a brief overview of commonly used overpower protection circuits incorporating the high-side current sensing techniques offering better signal integrity performance. We then discuss peak power capabilities that the delay network can provide. The description of the delay network includes the limitations it has when power levels and the corresponding delay network's residual voltage, preceding the power spike, approach the safety threshold level.

We also recommend a solution that can expand the boundaries of peak power operation to the maximum that safety regulations allow. In this discussion we will be using the 240-VA /20-J guideline as an illustrative example for the implementation of the proposed protection technique.

Basic PDN Overpower Protection Circuits

Because voltage rails supplying power to the IT equipment are tightly regulated, providing overpower protection reduces to measuring current on each power delivery rail and initiating a power flow interruption when the current exceeds a predetermined threshold.

Since the selected current sensing method is not critical for the analysis we will be performing, the examinations below will apply to different linear sensors used for monitoring currents in power distribution networks. Just for the sake of clarity, we will be focusing on the most commonly used high-side sensing realized in multiple current monitoring ICs from different manufacturers.

High-side current sensing is known for several advantages when compared to low-side current sensing. The main advantage of such a technique is that it does not create ground disturbances which can cause issues when other PDN control circuits in a system are required to interface with the load (e.g., motherboard). Because the shunt resistor in high-side sensing is no longer positioned in the ground path, this arrangement prevents data errors and intermittent device glitches, i.e. provides better signal integrity performance.

Simplified schematic diagrams of the two basic high-side current monitoring arrangements are shown in Fig. 1. The first current monitoring network (Fig. 1a) is realized with a difference amplifier generating an output signal whose level is proportional to a voltage drop across the sense resistor R_{sense} . The second one, representing a current mirror circuit generating a similar signal across a terminating resistor R_{OUT} , is given in Fig. 1b.

The expressions for the output signal V_o in each of these sensors are given for reference in the corresponding diagram. As mentioned above, to enable safety protection in typical applications, the output signal of a sensor is fed to a comparator that shuts the power off when the power level crosses the safety threshold.

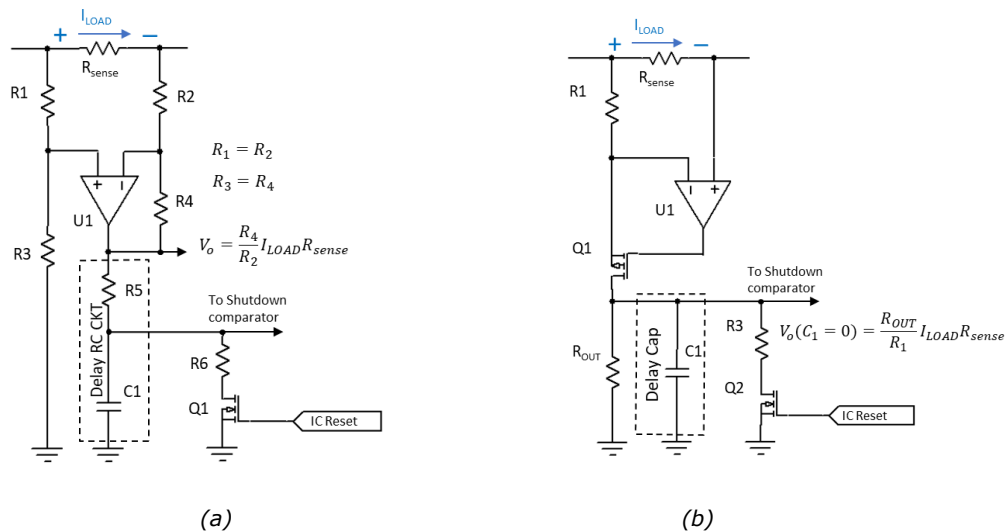


Fig. 1. Commonly used high-side current monitoring networks based on a difference amplifier (a) and current mirror (b) techniques. The delay circuit (a) and delay cap (b) allow for supporting operation at peak power levels exceeding the safety threshold. Initial condition reset networks maximize the energy available in the peak power mode.

If, under normal system operation, the peak power briefly exceeds this level, the protection tripping needs to be prevented. This prevention can be achieved by placing an RC-circuit between the sensor output and the comparator input for the circuit in Fig. 1a or just a cap in parallel with a terminating resistor R_{OUT} for the current mirror circuit in Fig. 1b. The delays that such networks provide allow for supporting peak power levels momentarily exceeding the safety threshold.

Since both current sensing networks' functions are similar, for clarity, we will be examining the behavior of the protection network shown in Fig. 1b as the most commonly used sensor providing a better accuracy than the difference amplifier network.^[1] The goal of this examination is to assess the delay network time constant that can guarantee not exceeding the hazardous energy level in a given PDN channel and to quantify the peak energy (power magnitude and timing) that the PDN with the protection delay network will be able to support without violating safety requirements.

Shutdown Time Delay And Peak Power Support

In practice, the PDN channels receive power from a common high-power source (a single power supply unit (PSU) or a power subsystem containing an array of paralleled PSU modules) whose power can exceed the 240-VA level manifold. This means that it's possible that the 240-VA limit can be briefly exceeded, and the 20-J limit requirement in IT equipment becomes dominant. In other words, in the case of power level crossing the 240-VA safety boundary, the rail to which a user has access must be deenergized within $20 \text{ J} / 240 \text{ VA} = 83.3 \text{ ms}$.

In our analysis, we will assume that the op amp in the current monitoring network in Fig. 1b has sufficient supply voltage so that it linearly mirrors the load current over the entire load operating range, i.e., has a fixed

gain defined by the R_{OUT}/R_1 ratio. In that case, we can use a linear network emulating the sensor circuit behavior. This network is shown in Fig. 2.

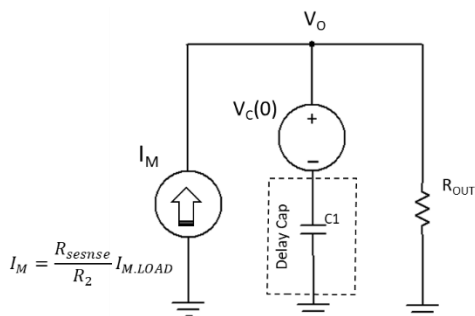


Fig. 2. Equivalent schematic of the current mirror sensor with a delay cap shown in Fig. 1b. The initial voltage $V_c(0)$ across the cap represents, either the idle power level preceding the peak power event, or the residual voltage after the power has dropped below the safety threshold.

A Laplace expression for the voltage at the op-amp output as a function of the current excitation $I_M(s)$ mirroring the load current is

$$V_o(s) = \frac{V_o(0)R_{OUT}}{s + \frac{1}{R_{OUT}C}} + \frac{I_M}{sC(s + \frac{1}{R_{OUT}C})}$$

Applying the inverse Laplace transform to $V_o(s)$, we find that in the time domain, the output voltage level depends on the natural and forced response components:

$$V_o(t) = V_o(0)e^{-\frac{t}{\tau}} + I_MR_{OUT}\left(1 - e^{-\frac{t}{\tau}}\right) \quad (1)$$

where τ is the RC time constant, $\tau = R_{OUT}C$. The forced one is formed by the excitation I_MR_{OUT} , the natural one depends on the initial voltage $V_o(0) = V_c(0)$ across the cap, which may represent, for example, the idle power level preceding the peak power event or the voltage across the cap even when the PDN supplied power was at the zero level and the cap was naturally discharging through the terminating resistor R_{OUT} .

Let's assume first that $V_o(0) = 0$ and the circuit is excited by the pulse with the cert level current magnitude $I_{M,240}$, corresponding to the 240-VA level. By equating $V_o(t)$ to the threshold voltage V_{thr} and by solving the last equation for the time t we find the trip time at zero initial conditions:

$$t(V_o(0) = 0) = \tau \ln I_{M,240}R_{OUT} / (I_{M,240}R_{OUT} - V_{thr}) \quad (2)$$

As mentioned above, the trip time at zero initial conditions must guarantee that the 20-J energy level is not exceeded. i.e.: $t(V_o(0) = 0) = 20/240 = 83.3 \text{ ms}$

Expression (2) shows that, to guarantee protection tripping, the threshold level must be selected so that the denominator in the fraction under the logarithm is always greater than zero. If an IC with a built-in threshold voltage is used, the condition $I_{M,240}R_{OUT} > V_{thr}$ must be met by properly selecting the R_{sense} value.

In real applications, $I_{M,240}R_{OUT}$ can be set equal to $1.1V_{thr}$. In addition to guaranteeing protection tripping, this setting provides a reasonable margin to accommodate sensor component tolerances. Substituting $I_{M,240}R_{OUT} = 1.1V_{thr}$ into (2) yields a simple expression for the RC time constant:

$$\tau = \frac{t(V_o(0) = 0)}{\ln 1.1V_{thr} / (1.1V_{thr} - V_{thr})} = \frac{83.3 \text{ ms}}{2.4} = 34.7 \text{ ms}$$

Now, using equation (1), let's determine how much time it will take the protection to trip when the power exceeds the safety level and the initial condition is away from zero.

$$t(V_o(0) \neq 0) = \tau \ln \frac{I_M R_{OUT} - V_o(0)}{I_M R_{OUT} - V_{thr}}$$

Dividing the numerator and denominator in the fraction under the logarithm by $I_{M,240} R_{OUT}$ and assuming $I_{M,240} R_{OUT}$ is set equal to $1.1V_{thr}$, we get

$$(V_o(0) \neq 0) = \tau \ln \frac{\widehat{I}_M \frac{V_o(0)}{I_{M,240} R_{OUT}}}{\widehat{I}_M \frac{V_{thr}}{I_{M,240} R_{OUT}}} = \tau \ln \frac{\widehat{I}_M \frac{V_o(0)}{1.1V_{thr}}}{\widehat{I}_M - 0.909} \quad (3)$$

where $\widehat{I}_M$ is the load current magnitude normalized over the safety (in our case 240-VA) current level: $\widehat{I}_M = I_M / I_{M,240}$.

As follows from this equation, the higher the initial cap voltage, the shorter the trip time, and therefore, the less energy is available under the peak-power condition. Load current and V_o waveforms of the tripping protection network illustrating this phenomenon are shown in Fig. 3 where two conditions ($V_o(0) = 0$ and $V_o(0) = 0.5V_{thr}$) are compared at the same excitation magnitudes.

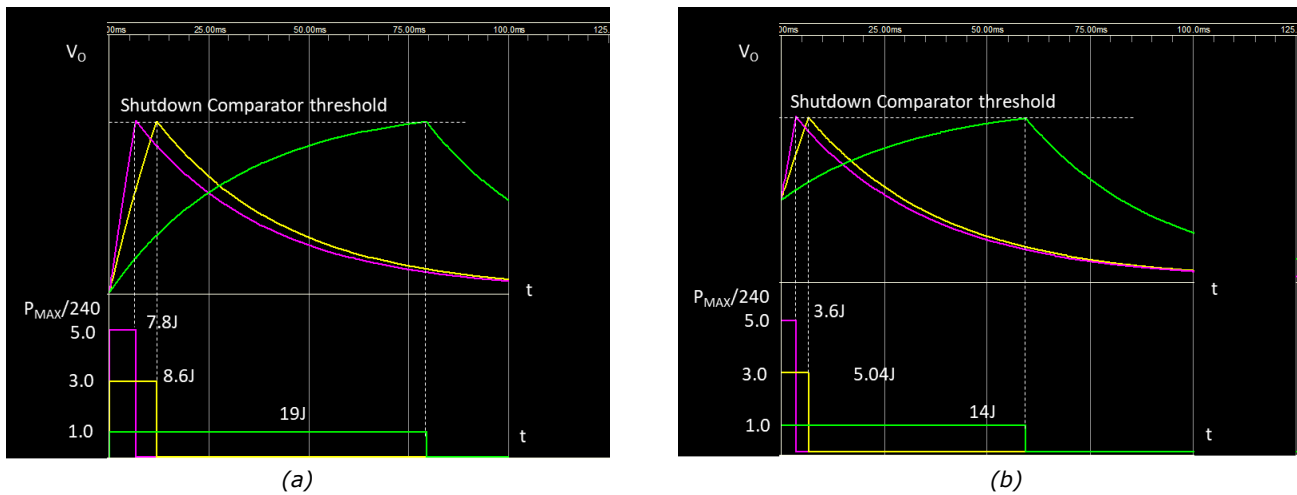


Fig. 3. Reduction of energy available under peak power condition when initial cap voltage increases from zero (a) to one-half of the 240-VA shutdown comparator (power flow interruption) threshold (b).

Ramping down voltage waveforms in Fig. 3 show the process of the cap discharge after the threshold is crossed and protection has tripped. However, the sensor output voltage can reach any level between zero and the shutdown comparator threshold also in normal operating conditions either because of the cap delaying the voltage decay or actual power lingering between the two boundaries (0 and 0.9×240 VA).

To determine the time available in the peak power state at any initial condition (i.e., residual voltage across the delay cap) and current magnitude, we need to use equation (3). A set of graphs illustrating such determination is given in Fig. 4 for different peak power magnitudes and the residual voltage varying from 0 to $0.9 V_{thr}$. For example, at peak power equal to 3×240 VA and residual voltage equal to $0.7V_{thr}$, the peak power time duration is equal to 4.3 ms. This example is illustrated by the blue dashed line in Fig. 4.

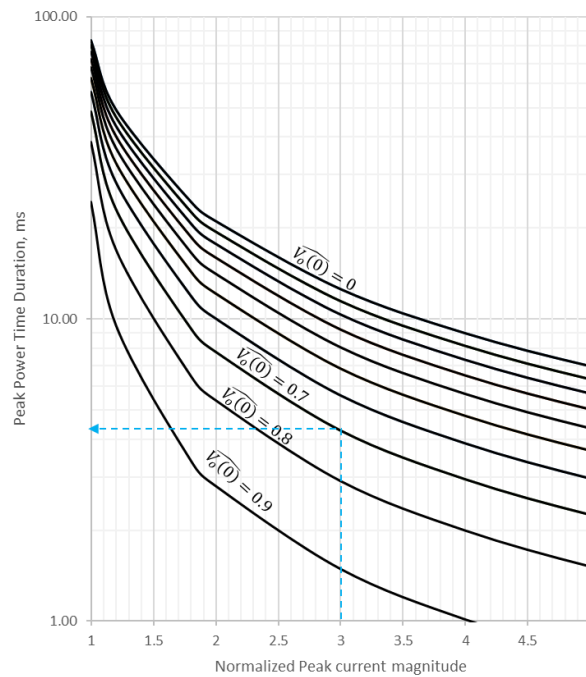


Fig. 4. Available peak power condition time interval vs. normalized peak current magnitude.

The graphs in Fig. 4 show the boundaries of protected PDN operation for given initial and peak power levels. The delay network for supporting the peak power operation can be validated through actual system testing.

The process of characterizing the suitability of this network can also start by acquiring the typical (benchmark) workload power profile, which is essentially a continuous output power signal $P_o(t)$ over some validation time interval sufficient for the workload characterization. Specifically, the benchmark needs to be focused on producing real application peak power levels and power levels that precede the power spike.

Expanding The Peak Power Operating Boundaries

If the power profile stays within the envelope defined by equation (3), the 240-VA protection network is good to be used as is. However, if the workload profile crosses this boundary, i.e., the power spike duration or magnitude exceed the levels defined by the graphs in Fig. 4 at the projected $V_o(0)$, it can activate the safety protection and prematurely deenergize the PDN, causing a system fault.

As mentioned in the previous paragraph, such an issue can be uncovered during validation testing. With reference to the example cited above, it means that either the actual peak power duration exceeds 4.3 ms or the power level preceding the spike exceeds 0.7×240 VA. In such cases, the PDN operating boundaries need to be expanded. But how do we do this?

Raising the operating envelope to the top curve in Fig. 4, corresponding to the zero initial condition, represents the maximum energy the PDN will be able to provide in the peak power mode while still meeting the safety regulations. Such an expansion can be achieved by resetting the delay circuit (i.e., by forcibly zeroing the initial condition) each time the safety (in our case, 240-VA) level is momentarily crossed. Such a reset acts similarly to adaptive voltage positioning in voltage regulators, expanding a leeway for the output sensor signal.

The functional block diagram of the network realizing the reset feature is shown in Fig. 5a; the timing diagram illustrating its operation is shown in Fig. 5b. This network uses the second no-delay current sense channel, used for the delay cap reset. It trips its comparator each time the power level crosses the safety level.

The signal in the reset control path is not used for the power flow interruption, but for quickly (in a few microseconds) discharging the delay cap in the first channel. Such an arrangement can be realized, for example, by using a dual-or quad-channel current monitoring ICs, such as LTC6103, MAX34406,^[2] or similar devices.

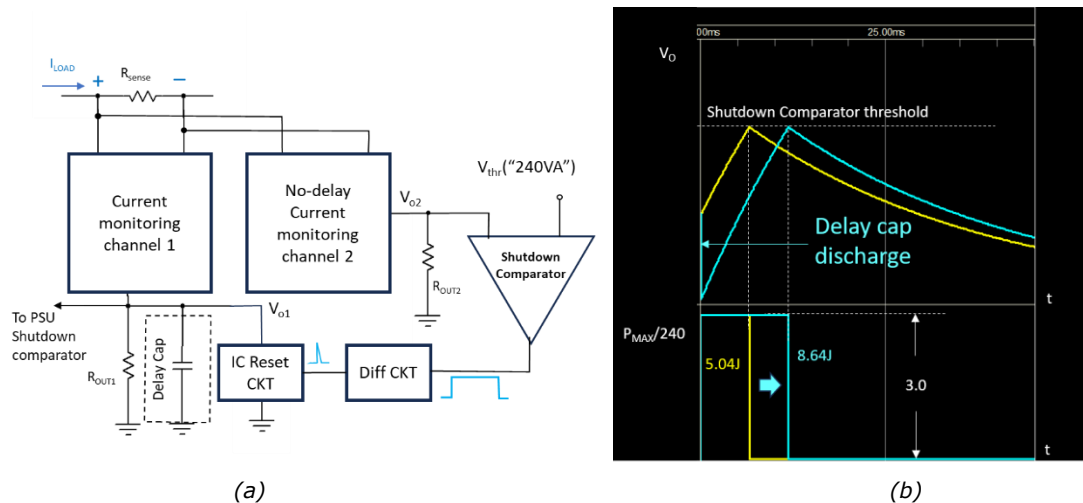


Fig. 5. Network realizing the protection reset feature (a), and the timing diagram illustrating its operation (b). With the reset feature, the residual voltage ($V_o(0) = 0.5V_{thr}$) across the delay cap drops to zero (blue trace in the top timing diagram). This allows for more than 60% increase in the energy available in the peak power mode.

To do so, the comparator signal is fed to the differential circuit input, shortening the pulse duration to a few microseconds. This signal activates the reset circuit (e.g., a MOSFET switch Q2 with a series resistor R3—Fig. 1b, repeated below), which momentarily discharges the delay cap without any noticeable impact on the safety 20-J threshold.

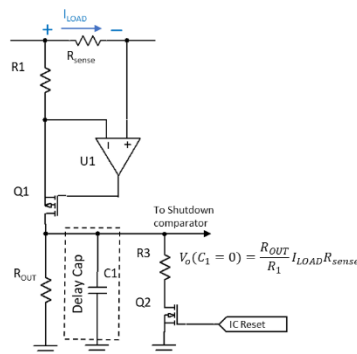


Fig. 1b (again). High-side current monitoring network based on a current mirror with a delay cap supporting operation at peak power levels exceeding safety level. The reset network momentarily discharges the delay cap to maximize the energy available in the peak power mode.

Higher-power (multikilowatt) distribution networks are usually sealed off from regular user access and are required to prevent fire hazards in case of load faults. This means that the threshold power and energy levels for such PDNs will be set higher (selected R_{SENSE} and R_{OUT} values will be lower), and the use of the technique shown in Fig. 5 will differ from the examined 240-VA/20-J case only quantitatively.

Fig. 5b compares two conditions: one with no-reset delay circuit (yellow traces), which replicates the 3 x 240-VA peak power condition in Fig. 3b, and the same circuit with a delay-cap reset (blue traces). With the reset enabled, the energy available in peak power mode increases by more than 60%. The higher the residual voltage, the greater the relative energy increase the reset feature provides.

Summary

This article presented an analysis of the operation of a high-side PDN overpower protection network. It determined the operating boundaries of the network with a delay cap for given initial and peak power levels in order to stay within the specified energy limit. A solution was then proposed that can expand the boundaries of peak power operation corresponding to the zero initial condition, supporting the maximum energy the PDN will be able to provide in peak-power mode while still meeting the safety regulations. The proposed technique is also suitable for high-end servers with hardware compartments sealed off from regular users and protected against fire hazards at higher power and energy limits.

References

1. "[High-Side, High Current Sensing Techniques Renesas Electronics](#)," AN1827 Rev.1.00, Feb 7, 2022 (better accuracy).
2. "[Quad Current-Sense Amplifier with Overcurrent Threshold Comparators](#)".

About The Author



Viktor Vogman is currently retired from [Power Conversion Consulting](#) where he applied his skills as an analog design engineer specializing in the design of various power test tools for ac and dc power delivery applications. Prior to this, he spent over 20 years at Intel, focused on hardware engineering and power delivery architectures. Viktor obtained an MS degree in Radio Communication, Television and Multimedia Technology and a PhD in Power Electronics from the Saint Petersburg University of Telecommunications, Russia. Vogman holds over 50 U.S. and foreign [patents](#) and has authored over 20 articles on various aspects of power delivery and analog design.

For more on power protection in power supply design, see How2Power's [Design Guide](#), locate the "Design area" category and select "Power Protection".