
PTC thermistors for inrush current limiting

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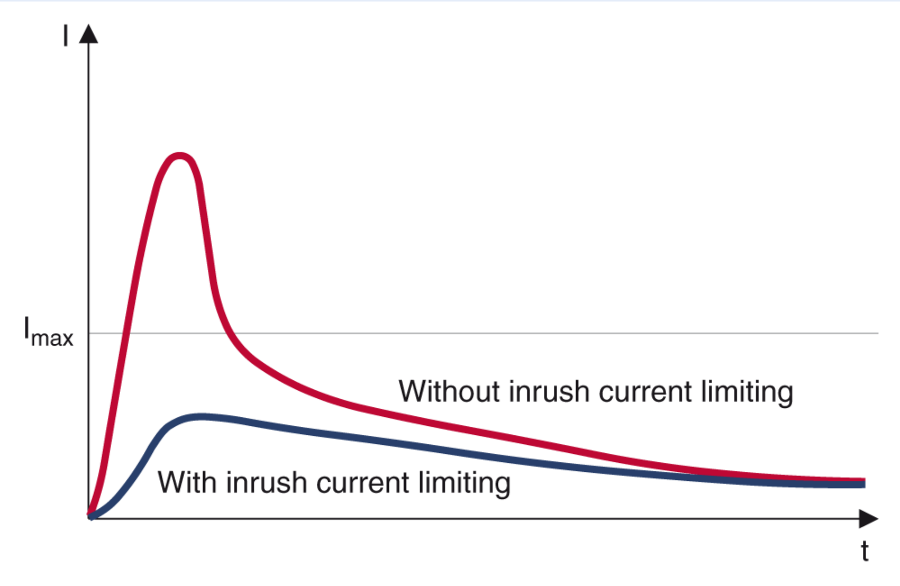
# Always on the safe side

**NTC thermistors are not always the solution of choice as inrush current limiters (ICLs) in power supplies. In certain cases with especially demanding temperature and power conditions, PTC thermistors are able to offer more reliable protection. An added benefit: EPCOS PTC ICLs also provide protection in case of short circuits.**

High currents are encountered whenever electrical equipment such as drive systems, inverters or power supplies are turned on. Because excessive inrush currents can damage or destroy the sensitive components such as the rectifier in a power supply or blow the fuse, for example, protection measures are needed (Figure 1). Two basic approaches to inrush current limitation are available: the simple insertion of a protection device as inrush current limiter (ICL) in the power circuit and the use of an active bypass circuit that is activated after the inrush current peak decays. These are also referred to respectively as passive and active ICL circuits. The choice of inrush current suppression technique that is suitable for a particular application depends on many variables. Most important are the power rating, the frequency at which the equipment is likely to be exposed to inrush currents, the operating temperature range, and system cost requirements.

Figure 1: Inrush current with and without ICL

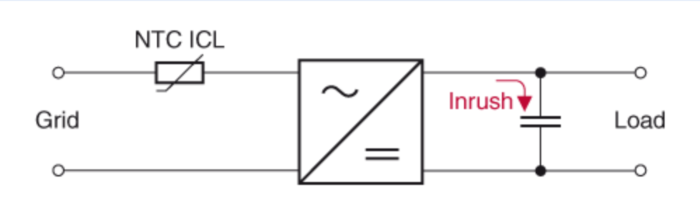



Inrush current limitation is needed to prevent the current from exceeding the critical level and either blowing fuses or destroying the rectifier.

### Passive inrush current limitation

For very small power supplies with power ratings of up to a few W, the easiest and most practical solution for inrush current limitation is simply to add an ohmic resistor in series with the load. In power supplies with higher power ratings, however, the power loss of a fixed resistance would significantly impair the overall efficiency. In these cases, NTC thermistors are the established standard ICL solution for passive current limitation (Figure 2).

Figure 2: Passive inrush current limitation with an NTC ICL




The fact that an NTC thermistor's initially high resistance drops to negligible levels once it becomes warm makes NTC ICLs the standard ICL solution for power supplies with power ratings of up to approximately 500 W.

NTC thermistors are high ohmic when cold and low ohmic when hot. In the cold state, the high initial resistance of the NTC ICL effectively absorbs the peak inrush currents. As a result of the current load and the subsequent self-heating, the resistance of the ICL then drops to a few percent of its value at room temperature. This special feature reduces the power consumption of the inrush current limiter in continuous operation and is, therefore, the reason why NTC ICLs can be left in the circuit even after the capacitor is fully charged. Finally, their cost is low and the solution is simple to realize.

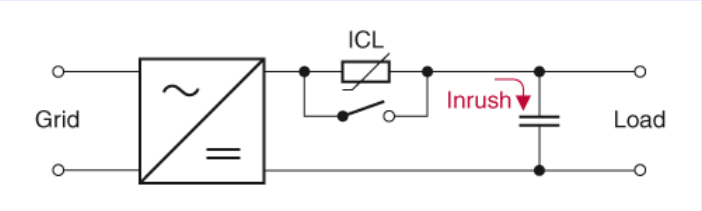
### Focus on low-loss solutions for higher power levels

Increasingly, the design of power supplies focuses on eliminating power losses wherever possible. Once the power rating exceeds a level of around 500 W, the drawbacks of the passive circuit solution become evident. If the ICL is always in series with the load, the power losses it causes become too high. The higher the power rating of the device and the longer its typical run time, the more significant the parasitic power losses become. For example, assuming that an NTC ICL generates a power loss of 1 percent of the total power of the device and the power supply has a 92 percent efficiency rating, about 12.5 percent of the overall losses are due to the NTC.

### Active inrush current limitation

At the higher power levels, it is, therefore, standard practice to bypass the ICL once the inrush current peak has decayed using relays or triacs. Depending on the application requirements, this active inrush current limitation circuit can employ a power resistor, an NTC thermistor or a PTC thermistor (Figure 3) as the ICL component. PTC thermistors, for example, are commonly used in on-board chargers (OBC) of plug-in hybrids or of electric vehicles, where the power rating is typically a few kW. While the benefits of active inrush current limitation are most evident for power ratings higher than 500 W, the approach may be necessary to achieve improved performance even for applications at lower power levels. Although the system cost for active inrush current limitation itself is somewhat higher, this approach reduces power losses and enables the use of less costly switches and semiconductors with a lower rating.

Figure 3: Active inrush current limitation




In active inrush current limitation an ohmic resistor, an NTC thermistor, or a PTC thermistor can be used as an ICL component.

### When to use PTC thermistors as ICLs

In certain applications, PTC thermistors offer superior performance as ICLs. The resistance of an NTC ICL when the power is switched on depends on the ambient temperature. At very low ambient temperatures the NTC thermistor's resistance is higher, leading to lower charging currents and resulting in longer charging times. High ambient temperatures, on the other hand, can limit the ability of the NTC ICL to suppress inrush currents because the NTC is already in a low ohmic state. This temperature dependency can pose a problem especially for applications with a wide operating temperature range. For example, a power supply used outdoors in a northern winter may never warm up enough for the NTC resistance to drop enough.

Conversely, a circulator pump for hot water can already be very warm during startup, causing the NTC thermistor to fail to limit the inrush current. An NTC thermistor's cool-down time varies typically from 30 s to 120 s after the system has been switched off, depending on the particular device, its mounting method and the ambient temperature. Only after it has completely cooled down is the NTC ICL ready to limit the charging current again. In many cases, the cooling period is quick enough; however, effective inrush current limitation is sometimes required before the NTC has cooled down sufficiently. This is the case in applications where a quick active discharge of the DC link capacitor is possible, for example, in inverter-driven home appliances such as modern washing machines and dryers. The necessary cool-down time can also be critical after short power outages. Consequently, active inrush current limitation designs must always take into account all possible situations where an inrush peak can occur while the NTC ICL is still in a low ohmic state. In both of these cases, EPCOS PTC thermistors offer an effective inrush current limiting solution.

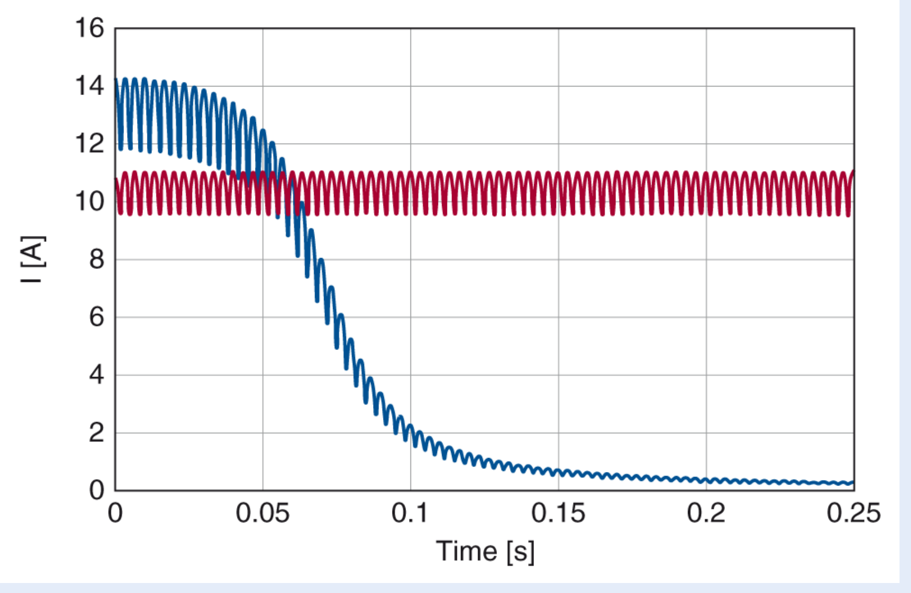
### Built-in self-protection

Under normal operating conditions, a PTC ICL functions as an ohmic resistor. When the power is switched on and the temperature of the component is the same as the ambient temperature, PTC ICLs have a resistance of between 20 Ω and 500 Ω, depending on the type. This is enough to limit the inrush current peak. Once the DC link capacitors are sufficiently charged, the PTC ICL is bypassed.
If there is a malfunction in the charging circuit, the specific property of the PTC thermistor serves to protect the circuit. When current flows through the component, it heats up and its resistance increases significantly. Thus, thanks to their self-protecting properties, PTC thermistors have a built-in advantage under the following failure modes:

– Short circuit of capacitor
– Current limiting element not bypassed after the DC link capacitor is charged (failure of switching element)

All these failure modes have one thing in common: thermal stress to the current limiting device. There are two ways to effectively ensure that the ICL component is not destroyed by such events: the use a power resistor with a sufficient power rating or the use of a PTC thermistor. EPCOS PTC ICLs are designed to survive being directly connected to the supply voltage even at their maximum rated voltage. No additional current limitation is required because these PTC ICLs are self-protecting. In case of excessive currents such as short circuits, the temperature of the PTC increases, which in turn leads to a significant rise in the device's resistance. Consequently, the PTC thermistor itself limits the current to uncritical levels (Figure 4).

Figure 4: Current curve with shorted capacitor




With a shorted capacitor, the current flowing through the PTC ceramic drops very quickly to non-critical values (blue). With the ohmic resistor, however, the current flow remains constant at high values (red).

Thus, EPCOS PTC thermistors offer key benefits when used as ICL components for active inrush current limitation in certain applications:

– Their ICL functionality is not affected by extreme operating temperatures.
– Effective inrush current limiting as soon as load is turned off, cooling already takes place during normal operation.
– They are self-protecting against current overloads caused by circuit malfunctions.

Thanks to the broad portfolio of EPCOS PTC ICLs power supplies can be reliably protected from high inrush currents and short circuits under demanding temperature conditions. The Table shows a representative selection of PTC ICLs which are included in the sample kit, Inrush Current Limiters – Self-Protecting Power Resistors (ordering code B59003Z0999A099).

EPCOS PTC inrush current limiter in a robust plastic case

Table: Key data for EPCOS PTC ICLs

| Ordering code | $V_{max}$ [V AC] | $V_{link}$, max. [V DC] | $R_R$ [Ω] | $C_{th}$ [J/K] | In sample kit | AEC-Q200 |
|---|---|---|---|---|---|---|
| **In plastic case** | | | | | | |
| B59213J0130A020 | 280 | 400 | 33 | 1.1 | | x |
| B59215J0130A020 | 280 | 400 | 22 | 2.3 | x | x |
| B59217J0130A020 | 400 | 620 | 56 | 2.3 | x | x |
| B59219J0130A020 | 560 | 800 | 100 | 2.3 | x | x |
| B59105J0130A020 | 280 | 400 | 22 | 2.3 | | |
| B59107J0130A020 | 440 | 620 | 56 | 2.3 | | |
| B59109J0130A020 | 560 | 800 | 100 | 2.3 | | |
| **Leaded disks, coated** | | | | | | |
| B59770C0120A070 | 260 | 370 | 70 | 0.4 | | |
| B59771C0120A070 | 260 | 370 | 120 | 0.6 | | |
| B59772C0120A070 | 260 | 370 | 150 | 0.6 | | |
| B59750C0120A070 | 280 | 400 | 25 | 1.0 | x | x |
| B59751C0120A070 | 280 | 400 | 50 | 1.4 | x | |
| B59752C0120A070 | 280 | 400 | 80 | 1.4 | | |
| B59451C1130B070 | 440 | 620 | 56 | 2.1 | x | x |
| B59753C0120A070 | 440 | 620 | 120 | 1.4 | x | |
| B59754C0120A070 | 440 | 620 | 150 | 1.4 | x | |
| B59773C0120A070 | 440 | 620 | 500 | 0.6 | x | |
| B59774C0115A070 | 440 | 620 | 1100 | 0.6 | | |
| B59412C1130B070 | 480 | 680 | 120 | 2.1 | x | x |
| B59755C0115A070 | 560 | 800 | 500 | 1.4 | | |