

**The ideal inrush-current limiting and charging resistor for power electronics –**

**Always precise, quick, robust and Fail-Safe**

**SQF – thermal protected power resistor from Ty-Ohm – the renaissance of the fixed resistor in power electronics**



Picture 1 – thermal protected power resistors of the SQF-series of Ty-Ohm

Resistors are used for limiting inrush currents when electronic devices are switched on. Commonly used are either temperature-dependent resistors (NTC's and PTC's) or resistors with a fixed resistance-value.

The current pulses which arise when switching-on electronic devices has to be limited with the resistor in a way that no components from the electronic circuit can be damaged (e.g. rectifier diodes). Furthermore, a smooth and complete charging of the DC-link capacitors must be assured.

Considering all possible conditions which might occur in the application, a correctly dimensioned wirewound resistor fulfills the requirements in the most precise, quickest and robust way. However, such wirewound fixed resistors have the significant disadvantage that in case of high currents due to a failure in the circuit, the wire can heat up to several hundred degree Celsius before opening, thus representing a risk to surrounding components and the PCB. Ty-ohm solves this handicap with the thermal protected power resistors from the SQF-series, thus meeting the requirements for the ideal charging resistor for sophisticated power electronics.

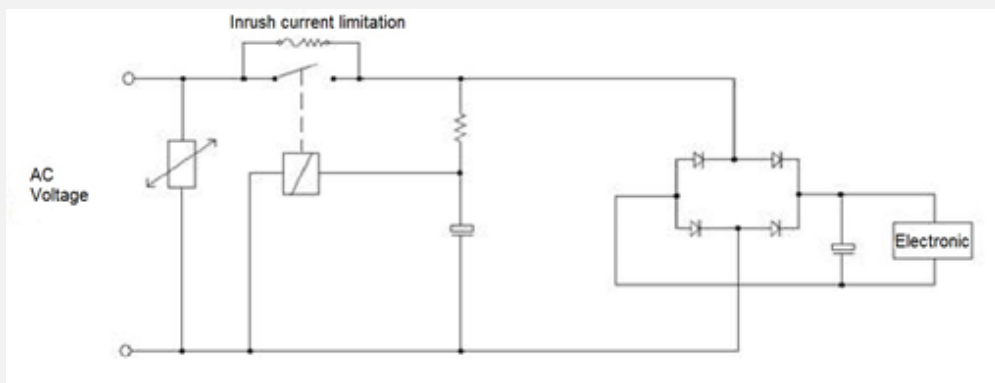
### Limiting inrush currents “passively” with a NTC:

In many power supplies with small or medium power-ratings, or in products where the best technical solution for the optimum energy-efficiency can be neglected, the “passive” usage of NTC’s has become the standard to limit inrush currents. The NTC is mounted into the AC-side of the power supply and remains there during operation. When switching on the electronic device under room-temperature, the NTC is high ohmic, thus limiting the inrush currents caused by the discharged DC-link capacitors. During operation the NTC heats up due to the current-loading and the related self-heating. The more the temperature of the NTC increases, the more the NTC gets low ohmic and the more it reduces its power consumption under operation. This passive way of limiting inrush current is simple and cost-efficient. However, there are disadvantages related to this solution:

- It is impossible to predict the exact resistance value during operation of a NTC in power-supplies, as the temperature of the NTC depends on the current load and the occurring ambient temperatures. The exact calculation of the inrush-currents under all operating conditions is not possible.
- The tolerance of the  $R_{25}$ -value of a NTC is usually  $\pm 20\%$ , leading to a significant variance between the used parts.
- The cool-down period of a NTC varies between 30 seconds and 120 seconds, depending on the electronic device, the way of installation and the ambient temperature. If during this cool-down period the electronic device should be switched on again, the NTC is still in a low ohmic state. Then the NTC might not reliably limit the inrush currents which occurs by the new switching-on process. Therefore, in case of a quick switching-on of an electronic device which has just been switched off, there is a risk that e.g. the rectifier diodes are damaged or the power fuse may blow.
- A component which is used on the AC-side of the power supply should be robust against transient overvoltages. However, a NTC is not specified to withstand transient overvoltages. When affected by transient voltage impulses, the ceramic of a NTC might change its structure and characteristics. This leads the NTC into a very high ohmic state or to crack.
- The NTC is always in series with the load. During the operation the NTC reduces its ohmic value, thus causing fewer power losses. However, in the temperature-range between  $50^{\circ}\text{C}$  and  $100^{\circ}\text{C}$ , the resistance is still a few ohms. The occurring parasitic power losses are increasing with the power-rating of the electronic device and with its time in operation. If, for example, a NTC causes a power loss of e.g. 1.5% of the total power of the electronic device and the power supply has an efficiency of 92%, then about 16% of the total losses are created by the NTC. The less the NTC heats up during operation, the higher such parasitic power losses are.

### Limiting inrush currents “actively” with a PTC in a Bypass-circuit:

After the peak of the inrush current has decayed, there is also the option to bypass the inrush current limiting component with a switching element, e.g. with a relay or triac. Primarily, this concept is applied in electronic devices with a high power rating (> 500W), or to achieve a better energy-efficiency of electronic devices with a lower power rating. The total cost for such a Bypass-circuit is more expensive than a passive limitation of the inrush currents. But the energy-consumption of the electronic device can be significantly reduced, as well as less expensive switches and lower rated semiconductors can be used.



Picture 2: Bypass-system to limit inrush currents. The component to limit inrush currents can be e.g. a NTC, a PTC or a Wirewound fixed resistor.

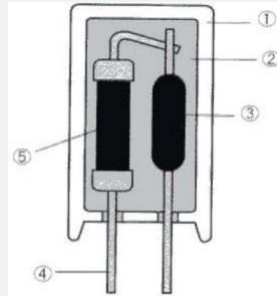
In such a Bypass-system, as the inrush current limiting component often PTC's are used.

The resistance value of the PTC can be selected so that the inrush currents are reliably limited under room-temperature when the electronic device is switched on. Once the DC-Link capacitors have been charged, the PTC will be bypassed by a relay or a triac. If the switching element fails to provide the bypassing-function or if there is a short circuit of the capacitor, then the current through the PTC increases accordingly. This leads to a heating of the PTC, resulting in a strong increase of its resistance value. As a result the current flowing through the PTC falls quickly to a non-critical value. This characteristic of a PTC is called “self-protection” in case of excessive currents.

After cooling down from such failures like short circuited capacitors or failed switching elements, the PTC can be used again.

### **The thermal protected wirewound resistor by Ty-Ohm's SFQ-series:**

As an alternative option to PTC's for inrush current limiting and charging applications, Ty-Ohm offers with the SFQ-resistors a series of thermal protected wirewound fixed resistors:



Picture 3: SFQ – thermal protected wirewound resistor from Ty-Ohm

A pulse-withstanding wirewound resistor (5) is connected by welding to a thermal element (3) and inserted into a ceramic case (1), which then will be filled with a non-flammable cement (2). The leadwires (4) define the pitch-distance.

In case of failure in the electronic circuit (e.g. defect switching element, a short-circuited capacitor or a short-circuit in one of the rectifier-diodes) the resulting high currents will heat up the resistor and cause the thermal element to open at a defined temperature.

The available resistance-values of the SFQ-series ranges from  $0.1\Omega$  to  $50K\Omega$ . The rated power covers a range from 1W to 12W, the rated current is from 1A to 10A.

The thermal element is available with different fusing-characteristics, e.g.  $132^{\circ}\text{C}$ ,  $145^{\circ}\text{C}$ ,  $185^{\circ}\text{C}$ , and on specific request. The thermal element is robust against surge-pulses and embedded to the resistor in the ceramic case so that it always detects precisely the temperature-change of the resistor.

Wirewound resistors are very robust electronic components and therefore they are very suitable to be used on the AC-side of a power-supply. The SFQ combines a wirewound resistor with a thermal element, both are embedded in a cement-filled ceramic case. In this way, a "Fail-safe" characteristics of this extremely robust components is assured.

As an option, the SFQ is also available without resistor as a protected thermal-fuse. In this case, the thermal element alone is placed into the ceramic housing, which then is filled with non-flammable cement.

In the same way, also protected current-fuses can be offered.

Compared with a PTC, the fixed power resistors of the SQF-series provides following advantages for the application as a charging resistor:

- By using the specified temperature-coefficient of the SQF, it is possible to calculate exactly the inrush currents under all operating temperatures.
- The energy amount which must be transferred to the DC-link capacitors during the charging-process could cause a PTC to heat up, thus getting highly resistive. In this case there is a risk that the DC-link capacitors will not be charged completely. A possible prevention method is to connect 2 PTC's in parallel, so that the energy amount can be split between both PTC-elements.
- With a correctly dimensioned SQF, this situation can be excluded, as the resistance remains fixed for all operating temperatures. The charging current and time can always be calculated exactly, an incomplete charging of the capacitors can be excluded. Only about 50% of the pieces of the comparable SQF are needed to bear with the transferred energy amount and to assure a complete charging of the capacitors.
- A doubling of the PTC elements is also taken into account when it is allowed to switch on the electronic device twice. In this way the individual PTC-element heats up less during the switch-on process, thus avoiding to get into a very high ohmic state before the capacitor is completely charged. For a SQF, even in case of repetitive switch-on processes, it is not necessary to double the amount of pieces to assure a complete charging of the capacitors.
- Unlike a SQF, a PTC has a voltage dependence which is particularly strong during the switch-on process. This voltage dependency of the PTC must be considered for evaluating the maximum peak of the inrush current.
- Due to the particular resistance/temperature profile of a PTC the charging-current is not as linear as with a SQF.
- The tolerance of the  $R_{25}$ -value of a PTC is  $-/+25\%$ , therefore the used parts may show a significant variance.
- In applications which can already be very warm during start-up (e.g. circulator-pump for hot water) using a PTC could result in lower charging currents and longer charging times. For a SQF this concern is not relevant.
- The SQF is significantly more robust against overvoltage-impulses (Surge) than the ceramic element of a PTC. This aspect is only important for the time when the inrush current limiting element is not bypassed. However, the power quality is continuously getting more polluted with temporary overvoltages and transient overvoltages caused by the switching of inductive loads, frequency converters etc. For a component without sufficient robustness against overvoltage-impulses even a short period of time on the mains might be enough to suffer irreversible damages.
- The SQF combines a wirewound resistor and a thermal element in a ceramic case which is filled with non-flammable cement. A burning of the component can be excluded.
- In case of failure (e.g. the switching element has a malfunction or the capacitor short circuits or there is a short-circuit on one of the rectifier-diodes) a PTC gets highly

resistive, thereby protecting itself. After cooling down the PTC gets low ohmic and can be used again. However, the root-cause of the failure still exists and can lead to even bigger damages in the circuit.

- The SQF, however, triggers in case of failure and disconnects the electronic safely from the mains. Subsequently, there is a chance to analyze the root-cause of the failure before bigger damage occurs.

## **Summary**

Saving energy and increasing the energy-efficiency is getting more and more essential. Therefore also for small and medium power-rated electronics it should be considered to apply Bypassing-concepts for the inrush current limiting components, in order to minimize potential losses during operation.

The ideal component to limit inrush-currents while charging the capacitor can be described as follows:

An exact calculation of the maximum inrush- and charging current is possible under all operating conditions. An incomplete charging of the DC-link capacitors can be excluded. The required characteristics are available without delay at all operating conditions. For the application in power electronics with a long lifetime-expectancy it is very robust. The End-of-Life behavior is always Fail-safe.

The thermally protected power resistors by Ty-Ohm's SQF-series meet these requirements very well. With the SQF there are inrush current limiting and charging resistors available, which under all operating conditions are not only precise, quick and very robust, but which in case of failure, disconnect the electronic safely from the mains.

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