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Applications & Cases

PTCs as charging resistors

July 2007

Fail-safe charging

Self-protecting charging resistors based on PTC ceramic are suitable for smoothing capacitors in power supplies. In the event of a short circuit, they limit the currents to safe levels.

Ohmic resistors are generally employed to limit the current when charging capacitors. This, however, is accompanied by technical risks. If, for example, the capacitor short circuits or the relay has a malfunction when short-circuiting the capacitor, the resistors will be subjected to high power levels continually. This can lead to the destruction of the resistor or the system. With the new J20X series of charging resistors based on PTC ceramic, EPCOS has developed a professional solution that is self-protecting despite its relatively compact size. As shown in the table, the J20X family consists of the J201, J202 and J204 products.

Table: Key data for PTC charging resistors

Type	Ordering code	V_{max} [V]	R_R[Ohm]
In phenolic resin plastic case:			
J201 *	**B59201J0140B010**	550	20 ± 30%
J202 *	**B59202J0135B010**	650	56 ± 30%
J204 *	**B59204J0130B010**	800	100 ± 25%
J105	**B59105J0130A020**	360	22 ± 25%
J107	**B59107J0130A020**	620	56 ± 25%
J109	**B59109J0130A020**	800	100 ± 25%
Leaded disks:			
B750	**B59750B0120A070**	360	25 ± 25%
B751	**B59751B0120A070**	360	50 ± 25%
B752	**B59752B0120A070**	360	80 ± 25%
B753	**B59753B0120A070**	620	120 ± 25%
B754	**B59754B0120A070**	620	150 ± 25%
B755	**B59755B0115A070**	800	500 ± 25%
Leaded disks, coated:			
C1412	**B59412C1130A070**	620	120 ± 25%
C1451	**B59451C1130A070**	470	56 ± 25%

* Not for new design

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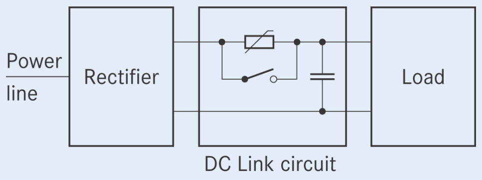
Applications & Cases

Typical applications for the J20X series are industrial power supplies, frequency converters and UPS systems in the power range from 500 W to 50 kW. In these applications a link-circuit capacitor is generally used to smooth the generated DC voltage or as an energy storage device in the link circuit.

In order to avoid impermissibly high current peaks when charging capacitors, as a rule it is necessary to limit the charging current by a resistor connected in series. This function is often implemented by fixed ohmic or NTC resistors. In most cases, the current limiting element is short-circuited after charging via a time or voltage-controlled relay. This limitation of the charging current is especially important for rectifier and converter systems, as the resulting inrush current peaks may otherwise trigger the fuses or expose the rectifier to impermissibly high currents. Fig. 1 shows a block diagram of a conventional rectifier or converter system.

FIGURE 1: BLOCK DIAGRAM OF A RECTIFIER UNIT WITH A SMOOTHING CAPACITOR



The ohmic resistor limits the charging current. As soon as the capacitor is charged, the resistor is shorted via a relay in order to avoid operating losses.

The combination of an ohmic resistor and a relay as described above is sufficient to limit the charging current under undisturbed operating conditions. However, disturbances occurring during or after charging can lead to total failure of these resistors and consequently to that of other system components.

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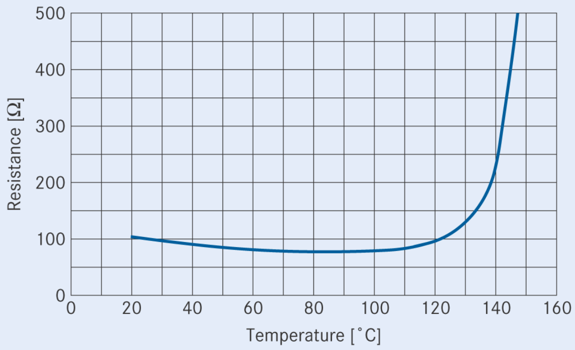
The use of self-protecting charging resistors of the J20X series is recommended in order to handle typical malfunctions such as short-circuiting the capacitor or failure of the short-circuit switch. In fault-free charging, these components act like a fixed ohmic resistor and limit the peak value of the charging current. In the case of a malfunction, the temperature and inherent resistance of the PTC ceramic increases in line with the increased ohmic losses (Fig. 2) and limits the current to a safe level.

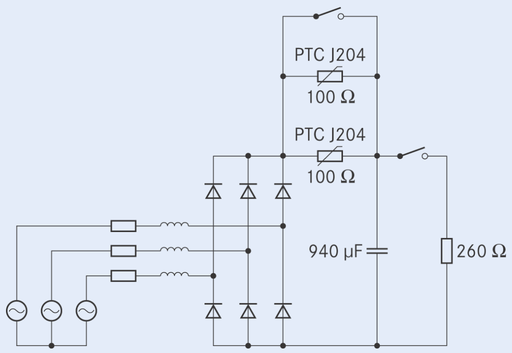
FIGURE 2: RESISTANCE OF A CHARGING RESISTOR BASED ON PTC CERAMIC



The high short-circuit current heats up the PTC ceramic and makes it highly resistive.

In contrast, when a fixed resistor is used as a charging current limiter, these malfunctions would produce a very high power dissipation at the resistor, thus requiring an uneconomic overdimensioning of the component. This functional principle is clearly illustrated by a specific example (Fig. 3).

FIGURE 3: RECTIFIER CIRCUIT



Typical configuration of a rectifier at the three-phase power supply system with a smoothing capacitor and self-protecting charging resistors.

A three-phase bridge rectifier connected to a power supply with a phase-conductor voltage of 400 V_{RMS} is assumed. The smoothing capacitor used has a capacitance of 940 µF. A parallel circuit comprising two charging resistors of type B59204J0130B010 is used to limit the inrush current. Also known as a zero-potential resistor, it has a rated resistance of 100 Ω at an ambient temperature of 25°C. The parallel connection of two components is needed in this case because the energy that must be transferred to the capacitor during charging would cause a single B59204J0130B010

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resistor to heat up to an undesirable extent and as a result become highly resistive. This should be avoided, as the link-circuit capacitor would otherwise not be completely charged.

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The number of required components from the J20X family may be calculated from the equation:

$$n \geq \frac{CV^2}{2C_{th} \; (T_{Ref} - T_{Amax})}$$

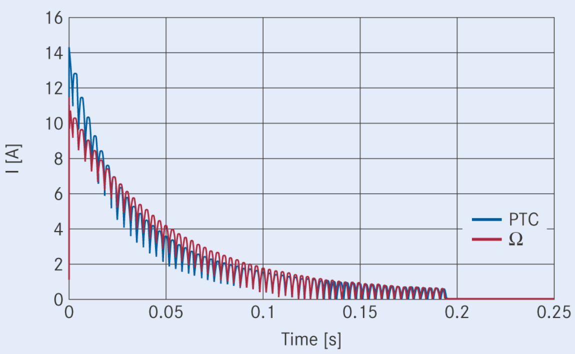
where:

n	the number of required J20X elements
C	the capacitance of the link-circuit capacitor in F
V	the maximum charging voltage of the capacitor in V
C_{th}	the heat capacity of a J20X charging resistor in J/K
T_{Ref}	the reference temperature of the PTC ceramic in °C
T_{Amax}	the maximum ambient temperature at the insertion point of the charging resistor in °C

The component B59204J0130B010, for example, has a heat capacity of approximately 2 J/K and a reference temperature of 130°C. The two components may be connected in either parallel or series. Satisfaction of the above equation ensures that the PTC ceramic does not exceed the reference temperature up to completion of charging and thus remains in the low-resistance range.

When 95 percent of the maximum charging voltage of the capacitor is reached, the parallel-connected J20X components are short-circuited and the load (represented by a 260 Ω fixed resistor) is connected in. Subsequently, the behavior of this parallel circuit of two J204 components is compared with that of a 50 Ω fixed resistor. A current-time diagram such as that shown in Fig. 4 represents fault-free charging.

FIGURE 4: NORMAL CHARGE WITH A PTC AN OHMIC RESISTOR



The currents flowing during charging are almost identical for the PTC ceramic (blue) and the ohmic resistor (red).

The time curve of the charging currents is almost identical in the two cases. The slight divergences of the current characteristic of the PTC ceramic from that of the fixed resister are due to:

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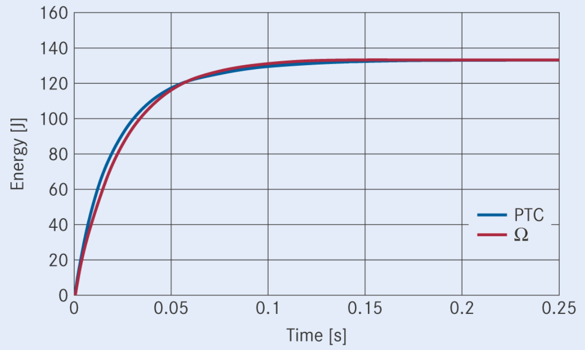
- the particular shape of the resistance-temperature characteristic of the PTC thermistor; and
- the voltage dependence of the PTC ceramic that is particularly strong during the turn-on process. This voltage dependence must be taken into account when dimensioning the peak inrush current.

After about 190 ms, charging is completed and the charging resistors are short-circuited. The energy absorption curves and thus the degree of heating are also almost identical (Fig. 5). Their maximum corresponds to the energy in the capacitor at the time of the short circuit.

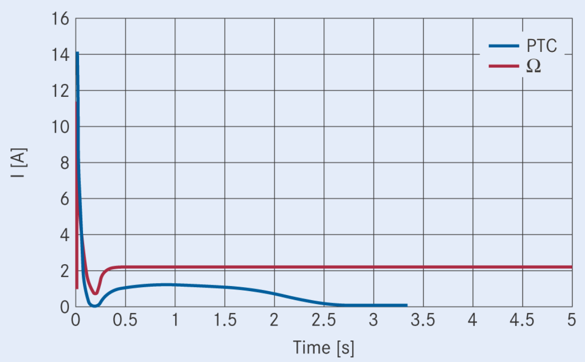
FIGURE 5: FIGURE 5: ABSORPTION DURING CHARGING



The energy absorption of the PTC ceramic (blue) and the ohmic resistor (red) are almost identical during normal charging.

The advantage of a PTC thermistor as a current-limiting element becomes evident in the event of malfunctions. If the relay fails to close, the load current flows via the charging resistor and produces a high thermal stress that would require corresponding dimensioning of the resistor. When a charging resistor based on PTC ceramic is used, its resistance rises to several 10 kΩ due to the high initial power dissipation and accordingly limits the current flowing during this malfunction (see Fig. 6). After about three seconds, the current flowing through the two resistors and thus through the entire circuit has dropped to a few 10 mA. A comparison of the energies absorbed is shown in Fig. 7.

FIGURE 6: CURRENT FLOW WITH A DEFECTIVE RELAY



With a defective relay, the PTC ceramic heats up and the current drops to safe levels after about three seconds (blue)

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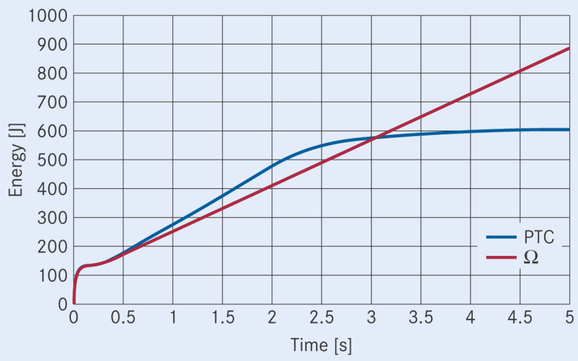
FIGURE 7: ENERGY ABSORPTION WITH A DEFECTIVE RELAY



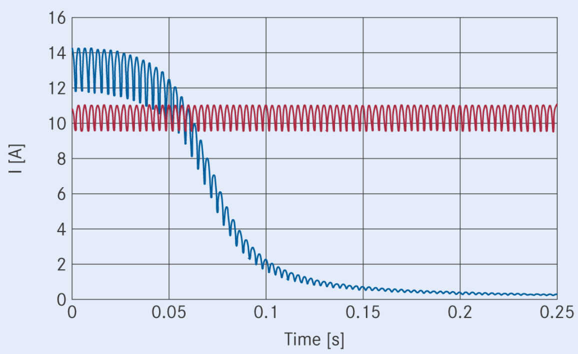
After about four seconds, the energy absorption of the PTC ceramic is constant, whereas it increases at the ohmic resistor (red).

By going into the high-resistance state, the PTC ceramic limits its energy absorption to a non-critical value, whereas the fixed ohmic resistor shows a linear rise of the absorbed energy. In the above example, the fixed resistor must have a rated power of above 200 W in view of the temperature derating in order to avoid overheating and subsequent destruction.

Malfunction – short-circuited capacitor at the start of charging

The high inrush current makes the two self-protecting charging resistors highly resistive after about 150 ms so that they restrict the current. The current flowing through the fixed resistor is limited only by the very low power line impedance and thus causes a very high power conversion in the fixed resistor (Fig. 8).

FIGURE 8: 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).

After a short time, both parallel-connected self-protecting charging resistors are in thermal equilibrium with their surroundings and the energy absorbed rises only slightly due to the high resistance of the PTC ceramic. The resulting energy absorption is similar to that shown in Fig. 7.

The above-mentioned malfunction, “short-circuited capacitor at the start of charging,” represents a very high load on the charging resistor. Therefore, J201 charging resistor requires an additional fixed resistor to limit the short circuit

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current. The charging resistors J202 and J204, however, can be used without any additional protection by a fixed resistor.

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