Coordinated Circuit Protection for Electric Motors, Transformers and Control Units in Home and Professional Appliances

Although generally reliable, the electric motors used in home and professional grade appliances are subjected to mechanical overload, overheating, stalls, lost neutral, severe overvoltage humidity and other damaging factors.

The latest generation of Raychem Circuit Protection PolySwitch LVR devices is designed for operation at line voltages of 120 VAC and 240 VAC, and can help appliance designers meet safety and fire hazards requirements. These polymeric positive temperature coefficient (PPTC) devices reduce warranty return and replacement costs resulting from motor or transformer failure.

Protecting increasingly sophisticated and complex control boards from misconnection, power surges or short circuit damage is also of particular concern to the equipment manufacturer. The use of sensitive solid-state devices on the board necessitates improved overcurrent, overtemperature and overvoltage control even though appliance transformers, their enclosures and their connections are capable of withstanding some higher voltage transients,

Coordinating overcurrent and overvoltage protection will also help designers comply with safety agency requirements, minimize component count and improve equipment reliability. The Raychem Circuit Protection ROV overvoltage protection device, used in a coordinated circuit protection strategy with the PolySwitch LVR overcurrent device can help manufacturers meet IEC 6100-4-5, the global standard for voltage and current test conditions for equipment connected to AC input.

Device Type	Can provide OT/OC[1] in same device?	Resettable functionality?	Reset type	Tripped state leakage current?	Will cycle?	Latches once tripped?
Current fuse	No	No	Replace	No	No	Yes
Thermal fuse	Sometimes[2]	No	Replace	No	No	Yes
Bimetal	Yes	Yes	Self reset[3]	No	Yes	No
Push-button breaker	No	Yes	Manual reset	No	No	Yes
CPTC device	Yes	Yes	Self reset[4]	Yes	No	Yes
PPTC device	Yes	Yes	Self reset[4]	Yes	No	Yes

[1] Overtemperature and overcurrent protection.
[2] Thermal fuses are not designed for overcurrent protection, and generally require large currents to trip.
[3] Periodically attempts to reset until fault and/or power is removed, or resets to low resistance state when bimetal cools.
[4] Automatically resets to low-resistance state once the fault is cleared and power is removed.

Figure 1. Comparison of reset functionality and circuit conditions in fuses and resettable circuit protection devices.

Overcurrent Circuit Protection Technology Comparison

Protecting an electronic circuit from damage due to excessive current or heat is the primary function of many circuit protection technologies. In the past, this protection took the form of a fuse or fusible link, but in today's electric motor applications resettable devices such as PPTC devices, ceramic positive temperature coefficient (CPTC) devices, and bimetal breakers are the preferred solution. These devices do not require replacement after a fault event, and allow the circuit to return to the normal operating condition after the power has been removed and/or the overcurrent condition is eliminated. Figure 1 compares the reset functionality and circuit conditions of the most commonly used devices.

Technology Comparison—Thermal Fuses

Although the fuse is perhaps one of the simplest and lowest-cost solutions for motor protection, most appliance manufacturers find it easy to justify the cost of resettable protection if it helps protect the motor from overcurrent damage caused by electrical short, overloaded circuit, stall or customer misuse.

Tyco Electronics recently conducted comparison tests of its Raychem PolySwitch LVR devices as primary protection elements on a variety of transformers. The performance characteristics of the PolySwitch devices were compared to those of thermal fuses.

Testing was done by using a thermal fuse on a PolySwitch LVR device mounted near the center of the core of the transformer as the primary protection device. A primary input voltage of 253VAC was applied and a secondary short was simulated. Surface temperatures of the primary and secondary windings as well as that of the PolySwitch device were measured. The PolySwitch device started to trip when its external temperature reached approximately 95°C, at which time the primary coil temperature was about 95°C. Once it had tripped and limited the current, the coils began to cool.

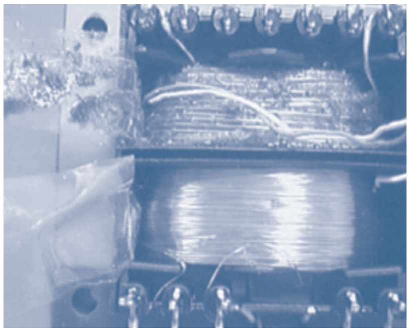


Figure 2. Effect of secondary short on 240 V_{AC} transformer utilizing a thermal fuse as the primary protection element.

Some power supply designs utilize a single-use thermal fuse as a primary protection solution. Figure 2 shows an effect of overheating on such a transformer. In this test, a short on the secondary side resulted in coil temperatures exceeding 200°C. The thermal fuse—rated at 115°C and mounted near the center of the core—failed to open, and the insulation on the windings melted, destroying the transformer.

Tyco Electronics

Figure 3 illustrates the results of a test in which a similar transformer was tested with the PolySwitch LVR device installed as a primary protection element.

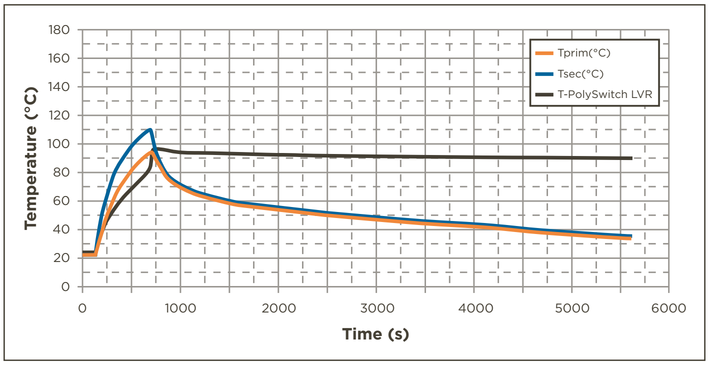


Figure 3. Effect of secondary short on 240V_{AC} transformer utilizing a Raychem PolySwitch LVR device as the primary protection element.

The performance characteristics of the PolySwitch devices versus thermal fuses studied in similar tests on a 120VAC transformer with a short on the secondary side are shown in the following table (Figure 4). These data demonstrate the advantages of the PolySwitch device's faster time-to-trip and its ability to limit the maximum coil temperature, thereby helping protect the transformer windings, as well as the secondary circuitry.

Device	Time-to-Trip/Open	Max Coil Temp (°C)	Max Current (mA)
Thermal fuse	>100 min	147	90
Thermal fuse	51 min	157	89
Thermal fuse	66 min	147	90
PolySwitch LVR Device	11 min	107	87
PolySwitch LVR Device	13 min	112	86
PolySwitch LVR Device	11 min	103	88

Figure 4. Comparison of performance characteristics of thermal fuses and PPTC devices used as primary protection elements on 120VAC transformer with a short on the secondary side.

Technology Comparison—CPTC Devices

CPTC devices help provide resettable protection; however, their application may be limited due to their relatively high operating temperature, high resistance and large size. The composition of the CPTC device tends to be brittle, which makes it vulnerable to damage from shock, vibration, and the thermal stress of heating and cooling found in many appliance applications.

Figures 5 and 6 show the results of comparison testing of CPTC and PPTC devices performed by Tyco Electronics. The Raychem PolySwitch PPTC devices were compared to CPTC devices as primary protection elements using two identical transformers. The PPTC and the CPTC devices were selected to have the same hold current. In this test, a fault was created with a secondary short while current, coil temperature, and time-to-trip were measured. As shown in Figure 5, the PPTC device reacted more quickly, and at a lower temperature.

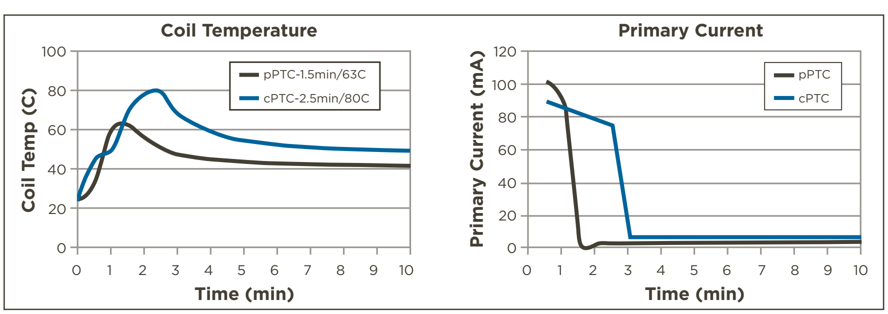


Figure 5. Comparison between a CPTC device and a PPTC device in a secondary short on a 120V_{AC} transformer.

Thermal images illustrate the difference in surface temperatures of the CPTC and PPTC devices in Figure 6.

Compared to the CPTC device, which had an approximate surface temperature of 75°C to 185°C, the PPTC device offered a lower surface temperature (approximately 100°C to 120°C) in the tripped state.

In this comparison of a 220VAC trip, the CPTC device reached a maximum temperature of 184.5°C, whereas the PPTC device reached a maximum temperature of 118.9°C. The PPTC device also had lower resistance in the circuit, was lower in capacitance and was less frequency dependent.

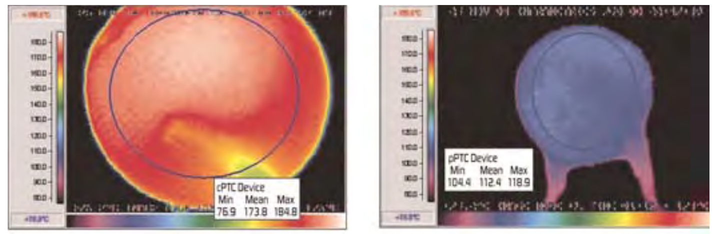


Figure 6. Comparison of maximum surface temperatures of CPTC device and PPTC device in tripped state.

Technology Comparison—Bimetal Circuit Breakers

Conventional bimetal circuit breakers, although widely used to help protect the electric motors found in appliances, do not latch and require additional action to interrupt their on-off cycle. The bimetal strip is constructed of two different metals bonded together. When the bimetal's switch temperature is exceeded, the bimetal strip bends and opens a set of contacts to stop current flow. With no current flowing the device cools and the bimetal returns to its normal shape, closing the contacts so current flow may resume. The bimetal circuit breaker continues to cycle until power is removed or the fault is corrected.

The cycling nature of this device has several disadvantages. Among those are material fatigue and a tendency to damage contacts, spark or weld shut. If the device "fails closed" it can cause overcurrent damage to the motor as well as sensitive follow-on electronics. Potential noise or "chatter" and electromagnetic interference (EMI) can also make bimetal circuit breakers incompatible with advanced electronic control systems.

Recent testing by Tyco Electronics compared the thermal and electrical characteristics of a popular bimetal thermal protector and the Raychem PolySwitch LVR device, each installed on an icemaker motor. The protection devices were coupled to the motor winding and the motor shaft was locked during the test period. The voltage, current, and temperature of the winding, the core, PPTC device, and the bimetal protector were recorded during the test.

Figures 7 and 8 illustrate the results of the two tests. In the test using a bimetal circuit breaker, the motor winding reached a temperature of approximately 129°C at 60 minutes. This was significantly higher than the test that used a PPTC protection device, where the motor winding reached a temperature of 44°C within the same time frame.

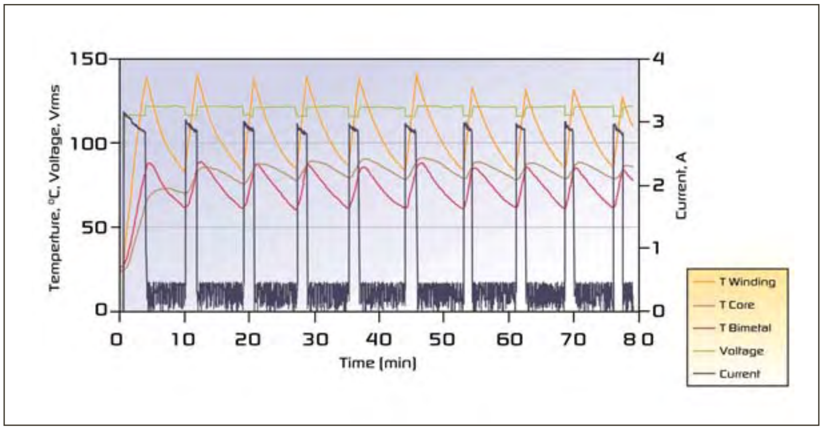


Figure 7. Icemaker motor (rotor locked) test results with bimetal device protection.

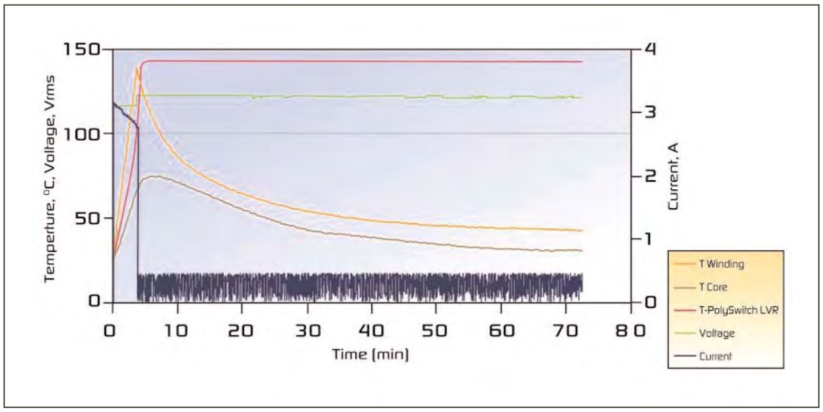


Figure 8. Icemaker motor (rotor locked) test results with PPTC device protection.

Applications for Raychem PolySwitch LVR Devices

From small countertop appliances to professional grade ovens, increasing complexity and functionality are driving the industry toward circuit integration and board size reduction. Protecting sensitive electronic components from voltage transients, short circuits and customer misuse is of primary concern to manufacturers.

In the past, control board designs often used no overcurrent protection on the primary or secondary side, relying on the transformer to sink sufficient heat to prevent control board damage in the event of a fault condition. However, the increased use of sensitive solid-state devices on the board now requires that voltage levels be limited.

A number of Raychem Circuit Protection products can be used to help provide overtemperature, overcurrent and overvoltage protection for the electric motors and fans, controllers, touchpads, displays and interface circuitry required by sophisticated appliances.

Intermittent Operation Motor Protection Technique

Intermittent operation motors, such as those used in blenders and food processors, are usually designed to operate for a limited time and, generally speaking, operating them for longer than the designed maximum limit usually results in stalling, overheating, and ultimately failure. Fault conditions arise when the switch is held on, either because of contact failure or customer misuse.

To prevent overheating, the circuit protection device used here must "trip" quickly, but not sooner than intended, to avoid creating a nuisance condition for the user. Developing a protection scheme that effectively protects the motor without nuisance tripping is the design challenge.

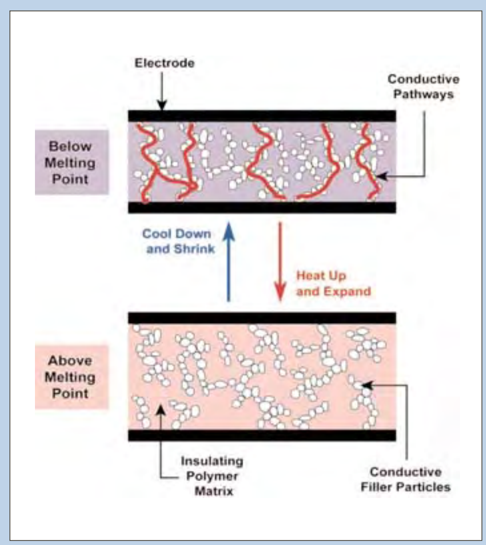
Figure 9 shows how a Raychem PolySwitch LVR device can be installed in a motor circuit to help protect against overcurrent/overtemperature damage. When the device is enclosed within the motor housing it reacts

PPTC Device Principle of Operation

PPTC devices are made from a composite of semi-crystalline polymer and conductive particles. At normal temperature, the conductive particles form low-resistance networks in the polymer. However, if the temperature rises above the device's switching temperature (TSw) either from high current through the part or from an increase in the ambient temperature, the crystallites in the polymer melt and become amorphous. The increase in volume during melting of the crystalline phase causes separation of the conductive particles and results in a large non-linear increase in the resistance of the device.

The resistance typically increases by three or more orders of magnitude. This increased resistance helps protect the equipment in the circuit by reducing the amount of current that can flow under the fault condition to a low, steady state level. The device will remain in its latched (high resistance) position until the fault is cleared and power to the circuit is removed - at which time the conductive composite cools and re-crystallizes, restoring the PPTC to a low resistance state as well as restoring the circuit and the affected equipment to normal operating conditions.

Because PPTC devices reset when a fault condition clears and power is removed from the circuit, they do not generally require replacement or service and can be placed in relatively inaccessible areas within the product.



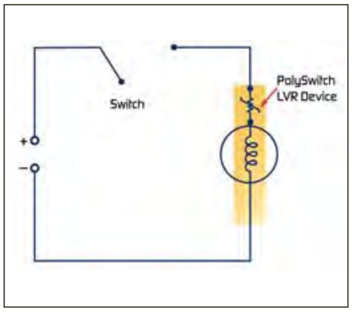


Figure 9. Typical PolySwitch device application in a motor circuit.

to the current flowing in the motor, as well as any temperature rise that may occur during a fault condition.

The major advantage of the PolySwitch device in this application is that it can be specified with a trip current substantially below the normal operating current of the motor, but with a time-to-trip that is several times longer than a full system operating cycle. This means that the device will trip after a number of system cycles but will operate much more quickly in the event of a stall situation, where the motor current is several times that of the PolySwitch device's trip current.

Continuous Operation Motor Protection Technique

Continuous-operation motors, such as those used in refrigerators and air conditioning equipment, are designed to optimize size and cost. Since they often drive fans, some airflow can be diverted through the motor to allow operation under more stress than would otherwise be possible. As a result, the stall current of fan motors is usually only two times the run current, compared to a ratio of three or four times run current that is common in other applications. This complicates finding and sizing a fuse that will open reliably if the fan becomes blocked, yet not nuisance-blow when the motor is first switched on.

As noted in the discussion on intermittent-operation motors, Raychem PolySwitch devices offer significant advantages in motor protection schemes. By altering their characteristics as the motor's vulnerability changes with temperature, they can help provide a slower response when desired.

In applications where a fan is driven, both the PolySwitch device and the motor can benefit from being placed in the air stream. With this method, the trip current of the PPTC device will be greatly increased because the airflow tends to prevent it from reaching its trip temperature. However, if the fan stalls for any reason, the cooling effect of the airflow ceases, causing the overrated motor and the PPTC device to heat up quickly.

This condition causes the PolySwitch PPTC device to trip and limit current flowing to the motor.

Unlike a single-use fuse, the PolySwitch device helps prevent damage where faults may cause a rise in temperature with only a slight increase in current draw—providing both overcurrent and overtemperature protection with a single installed component.

Coordinating Protection for AC Input Applications

Electrical equipment can be exposed to risk from large voltage or power transients on the AC inputs caused by lightning strikes or power station load-switching transients. IEC 61000-4-5 is the global standard for voltage and current test conditions for equipment connected to AC input.

Coordinating overcurrent and overvoltage protection at the AC input can help designers comply with safety agency requirements and minimize component count and cost.

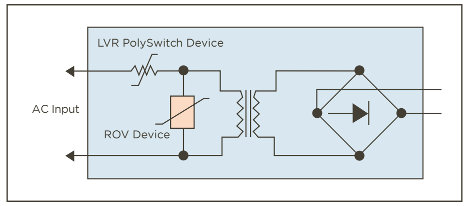


Figure 10. Coordinated overvoltage and overcurrent protection on AC input.

Figure 10 illustrates how Raychem Circuit Protection's ROV series metal oxide varistor is used in combination with the PolySwitch LVR device to improve equipment reliability in the harsh AC environment, and help meet the IEC-61000 test requirements.

The ROV device's high current-handling and energy absorption capability, fast response and low cost make it suitable for overvoltage protection in power supplies, control board transformers and electric motors. The PolySwitch overcurrent protection device is UL rated at 240 VAC, can interrupt maximum voltages of up to 265 VAC and can be installed with the ROV device in the AC input lines.

Unlike a single-use current fuse, the resettable PolySwitch device helps protect against damage under conditions where faults may cause a rise in temperature with only a slight increase in current draw. When installed on the primary side of the circuit, in proximity to potential heat-generating components such as magnetics, FETs, or power resistors, the PolySwitch device helps provide both overcurrent and overtemperature protection with a single installed component.

The Raychem PolySwitch and ROV devices chosen for a particular application depend on the IEC 61000-4-5 class rating for the equipment as well as the operating conditions of the equipment itself. When selecting a PolySwitch device, the primary consideration is to match the hold current rating of the device to the primary current drawn by the electrical equipment under normal operating conditions.

Summary

Coordinating overcurrent, overtemperature and overvoltage protection can help designers minimize component count and reduce warranty returns resulting from failed motors and control board transformers. The low resistance, fast time-to-trip, low profile, and resettable functionality of the Raychem PolySwitch LVR device helps circuit designers provide a safe and dependable product and comply with regulatory agency requirements. PolySwitch devices are qualified for and widely used in appliance designs, compliant with the UL 1434 standard, CSA and TÜV approved, RoHS-compliant, and are compatible with lead-free solders and high-volume assembly processes.

Raychem Circuit Protection Products
308 Constitution Drive
MS R21/2A
Menlo Park, CA USA 94025-1164

Tel (800) 227-7040
(650) 361-6900
Fax (650) 361-2508

www.circuitprotection.com
www.circuitprotection.com.hk (Chinese)
www.circuitprotection.jp (Japanese)