Protective Devices for Electrical Control Equipment

Fuses, Circuit breakers, Chop off Circuits, Crowbars, Thermostats

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In previous columns I have dealt with protection of the process and the product. Here we turn to protection of wiring, control panel components and various plant items.

Wiring and Loads. It is a given that your cables are properly sized for both steady-state current and predictable short term surges You have two choices for protection from short circuits and overloads.

Fuses. Common practice is to put in a fuse rated for 125% of the maximum load current – or the next standard size up. The voltage rating is important too because it affects arc extinction time and energy let-through. Check if the load is subject to high inrush **currents** and note their duration. Culprits are motors, transformers and heaters that have low cold resistance. They could, upon start up take some six times the steady state current but usually only for a few seconds.

This pattern is usually no threat to the wiring or the loads so you would choose a normal fuse, not a high-speed fuse. It would survive most common surges. You would use a slow blow fuse if your inrush were of unusually long duration. If you are on a high capacity low impedance supply with a high **prospective short circuit current** you will need a high rupturing capacity (HRC) fuse, designed to break that current. Some fuses come with a red flag that pops up when the fuse blows. This can save time when you are checking why the power went off.

Power semiconductors e.g. diodes and silicon controlled rectifiers, have a low thermal mass at their junctions compared with metal contacts so a relatively small dose of energy can destroy them under overload. This led to the design of special fast fuses having very low mass elements and a length that varies with rated voltage. I^2Rt represents the dose of heat delivered to a device and the energy tolerance of a semiconductor is expressed as its I^2t rating. This rating varies according to the **prospective short circuit current.** This in turn depends on the line voltage and the short circuit loop impedance, which includes that of the ac power source.

When selecting a matching semiconductor fuse (aka an I^2t fuse) use the I^2t rating based on your **prospective current** and make sure that its corresponding energy let-through (I^2t rating) is less than that of your semiconductor device. You will find curves and more detailed procedures in manufacturers' data sheets.

The 2millisecond Fuse

It is common practice to protect power semiconductor devices using standard semiconductor fuses (aka I^2t fuses) straight out of the catalog. Notwithstanding, at least one controls manufacturer states that such fuses cannot guarantee the limited current let-through and clearing times required for protection. One example cited is the delay time between **chop off** and the next zero crossing. Chop off is defined later in this article. Specially selected and tested fuses with a guaranteed 2 mS clearing time are therefore offered.

If your SCR's I^2t rating does not sufficiently exceed that of your fuse you are better advised to use a bigger SCR - rated for say three or four times your steady state load current. You do not need to uprate the heat sink; it can handle short duration overloads.

Circuit Breakers. Often there is not a lot to choose between a basic circuit breaker and a fuse, except that you can reset a breaker many times and buy it only once; whereas you have to buy a new fuse every time it blows and take more time replacing it. When you get down to applications a look through your catalog will tell you that breakers are offered in many designs and options.
The simplest and cheapest is the **thermal breaker** in which a built-in heater carries the load current and trips a bi-metal switch in series with the load. Like the fuse, higher the current faster a breaker acts.

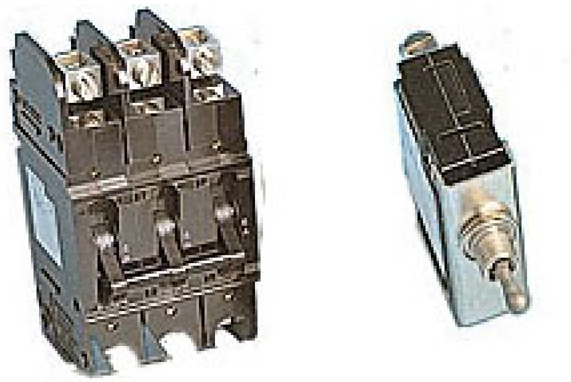

Fig 1. Circuit Breakers

They come either with a manual reset button or automatic reset that closes the contact when the bimetal cools. **Magnetic breakers** do not offer automatic reset. Note that unlike the magnetic breaker the thermal type needs a cool-off time before it can be reset. The current to trip is higher and less precise than the 1.25 times rated current of the typical magnetic breaker and it is somewhat ambient temperature dependent.
Some breakers are small enough to fit in a 3/8 inch hole in a panel and may incorporate a reset button. Sizes increase with the current-breaking capacity and voltage rating.

Magnetic Breaker. This is operated by a coil that carries the load current. Actuation may be combined with a heater and bimetal (thermal/magnetic) to add an element of time delay. Alternatively delay may be achieved by a **shunt plate** on the coil to retard growth of the magnetic field.
A more versatile design (hydraulic/magnetic) uses a damping-fluid filled cylinder with an **iron core** actuator. This design provides a wide range of speeds. Like most breakers, its operating time is inversely proportional to the square of the current magnitude. Variations of this law are offered.
Some magnetic breakers can act in a few milliseconds, fast enough for solid-state relay protection in selected applications.

Other features of magnetic circuit breakers.
Manual reset is the standard option and you normally reset only after you have diagnosed and cleared the over-current problem that tripped the breaker. Like all breakers, holding in the reset will not prevent a re-trip if the over-current condition persists.

Auxiliary contacts can be provided to indicate the condition of the breaker. The coil's actuating current can be from a different source than that in the interrupting contacts.
A shunt trip breaker has a volt coil which when energized operates the trip mechanism. It can act alone from a voltage source, commonly signalling some condition that calls for a shut-down, usually not a current overload. A volt coil can also be fitted on the same core as an over current breaker, enabling a trip to be initiated for some other reason. Since a shunt trip breaker needs the **presence** of a signal to trip, it does not have the fail-safe integrity of a magnetic contactor whose shut-down operation depends on the **absence** of a voltage on the hold-in coil.
There are too many combinations of the various features to mention here but you can find them in your manufacturers' catalogs.

Over Voltage Protection
Equipment can be damaged by voltage surges and spikes from various sources; power factor capacitor switching, utility switching, and lightning - among other things. Some are unpredictable and can come and go unseen. These can only be observed by special instruments that record the time, duration and peak value of such transients.
A simple form of over voltage protection uses high-energy, transient clamping devices placed across the ac power source. When they encounter a transient instantaneous voltage higher than a certain value they behave like a near short circuit to the excess portion of the voltage. They depend on the ac power source having some finite impedance so that voltage divider action of the low resistance of the clamping device acts to achieve voltage clamping action.
The metal oxide varistor (MOV) is one form. A pair of zener diodes in series, back to back is another. Different clamping voltages and **joule ratings** are offered; so you need a device with a joule rating greater than the clamping voltage times the prospective diverted current times its duration.
You will often see the ashes of such devices that have received excessive joules due to the low impedance of the ac power source. There are purpose built protection devices that include a series current-limiting inductor and other circuitry upstream of the clamping device to take account of low source impedance and duration of the transient.

Silicon controlled rectifiers can fail when line voltages exceed their maximum forward blocking voltage or their peak inverse voltage rating. In the normal inverse-parallel connected pair used for AC control each one can be arranged to protect its threatened partner by switching on and passing the transient power on to the load. The gate is connected to sense the instantaneous line voltage and will switch on when it is excessive.

Transient Overloads
Some SCR controlled heaters are subject to sudden overloads that can clear quickly. Two examples come to mind:

- silicon carbide heaters in glass melting furnaces where conductive molten glass splashes the elements occasionally, causing a flashover.
- the metal workpiece in an induction heater accidentally touching and shorting the bare copper induction coil

Often the fault will clear with no harm to the SCR or fuse and the process can continue.

Other times the transient over-current will blow your fast I^2t fuse and you suffer down time. Current-limiting circuits are not fast enough to defeat sudden short circuits and two other techniques come to mind.

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Chop-Off. See Fig 2.This is a feature that can head off a destructive overload, save your fuse and let you continue operating right away provided the fault clears itself.
When the current exceeds a preset value, the control circuit initiates an instant cut-off of the trigger pulses to the SCR. Load current ceases at the next zero crossing (this can be up to 8.3 mS later at 60 Hz).The current stays off until you push the reset button to initiate a restart. You will rarely lose a fuse in this short time. If chop-off recurs when you reset, it means that the fault did not clear and the process needs your attention.

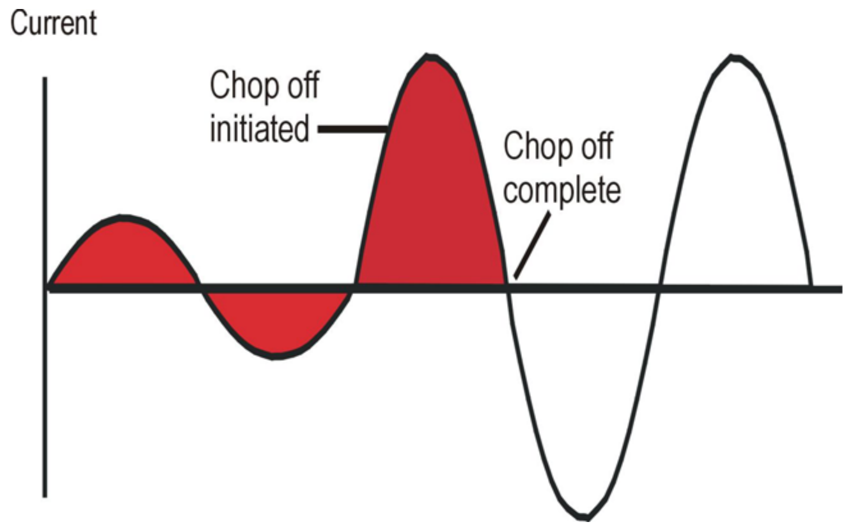

Fig 2 Chop Off

The Crowbar Circuit. Sounds crude? You bet. It is the equivalent of dropping a low-resistance metal bar across the power lines just downstream of the fuse.
In place of a bar, an extremely robust SCR pair is connected across the lines and triggered into conduction immediately the load current hits a preset value. This quickly blows the fuse - not the crowbar SCR or the load SCR - and spares the circuit downstream from damage. Unlike chop-off, crowbar action works instantly without waiting for the next zero crossing. You waste a fuse and have to put up with a shut down but you head off further damage.

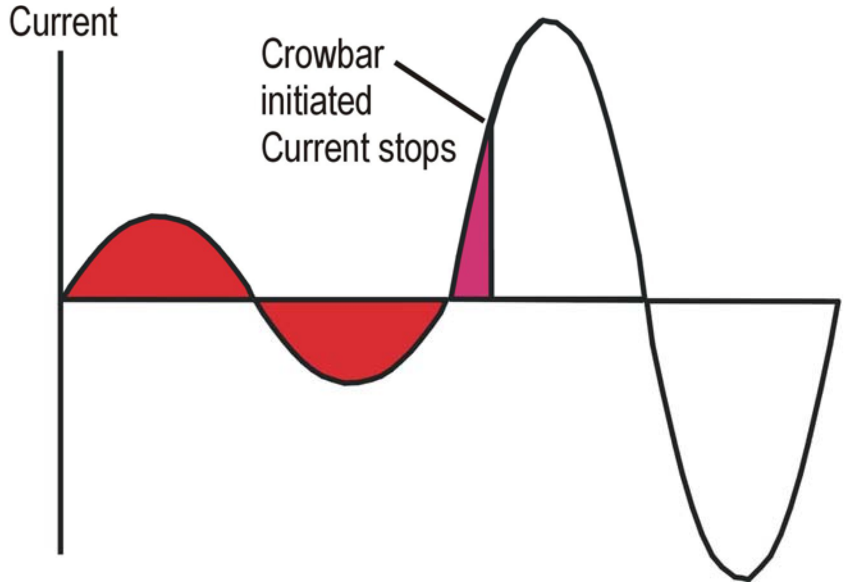

Fig 3 Crow Bar

OTHER DEVICES

Thermostat. Common types are, in ascending order of cost: bimetallic, liquid-filled expansion type. Use them on motor windings; SCR heat sinks; inside control enclosures, ovens, plastic machinery, gearboxes, hot air ducts and in heat transfer fluids. Speed often is not a requirement because of the slow changes in most thermal processes. So here, bimetal and liquid-filled thermostats are acceptable. Bear in mind that a leaky liquid-filled thermostat is fail-safe low, not fail-safe high; i.e. it senses that the temperature is lower than it actually is. Neither one can be validated without removing it and taking its temperature up through its trip point; also slow and inaccurate if you impatient.

Electronic thermostat For speed and ease of installation, consider a thermocouple actuated electronic thermostat. This is virtually an on/off temperature controller with added features such as; it stays tripped after the temperature has returned to normal It can have manual-acknowledge-and-reset capability that you cannot cheat and its action can be validated quickly and frequently without taking the temperature up to the trip point.. You can consider back-up of this kind to be mandatory protection in processes where your regular controller or its power-controlling device could fail and allow the temperature to run away.

Flow-Failure Protection. There are processes where liquid, gas or air-flow can stop and result in over-temperature. Air ducts or heat exchangers are examples. Use a flow switch or thermostat - or both - set to the minimum safe flow or maximum safe temperature. Connect them to cut off the heat source when they trip.

Thermal Cutoff or Thermal Fuse

See Fig 4.This is small non-resettable temperature sensitive device that interrupts the circuit when its environment temperature exceeds its temperature rating. One design uses an internal organic pellet that undergoes a phase change allowing spring activated contacts to part. Another design uses a metal link that melts and breaks the circuit when the predetermined temperature is reached.

A disadvantage of these devices is that, unlike the electronic thermostat you can only verify their action by heating them to their trip point after which they are not reusable.

Fig 4 Thermal Fuse

Arc Fault Circuit Breakers. Arc fault circuit breakers have already made their way into home wiring. In addition to tripping on overcurrent, they will trip on sensing the noisy signature of an arc fault current caused by a bad connection. Current of normal magnitude passing through an intermittent open circuit acts like an arc welder, so it has good igniting potential. Let's look at the worst-case figure on, say a 40A 240V load. A bad connection making kissing contact of say 1 mm^2 could deliver 2.5kW into that very small area. It could be a lot worse than 2.5kW if you had an inductive or a tungsten filament load.

Home wiring is a first priority market for breaker manufacturers because there is a lot of combustible material around, teamed up with a lot of unsupervised and ill-maintained wiring, appliances and connections.

Though industrial plants, aircraft and ships are more strictly regulated than homes, they can all benefit from arc fault protection.