Sensata Technologies

MANAGING NUISANCE TRIPPING AND PROTECTION NEEDS IN HIGH INRUSH APPLICATIONS

WHITE PAPER

At their core, circuit breakers are designed to trip when experiencing currents beyond their rated levels. But when managing power protection needs for some applications, high inrush currents create the potential for nuisance tripping if the circuit protection is not properly designed.

A maximum pulse, about 4 milliseconds in duration, can occur when switch closure coincides with the peak voltage point of the supply and the load is one that has low initial impedance such as an incandescent lamp bank, a high capacitive load, or a ferroresonant transformer.

Nuisance trips will result if pulse energy exceeds the energy needed to trip the protector.

The amplitude of tungsten lamp surges may be 15 times the rated steady state current at first – the following cycles are much lower. While protector inrush rating can be increased, that only occurs at the expense of overload protection.

In another example, capacitive input filter charging resembles an RC charge curve. At peak current it's limited by charge circuit resistance and the power supply itself. Here, surges are less troublesome; transient duration is very short.

Transformer inrush is the most common application problem. Its waveform is similar to that of lamp-load inrush. However, unlike a lamp-load inrush, the transient will not occur on every turn-on. But, like the lamp load, it has a maximum peak value when the circuit is closed near the maximum voltage point of the supply wave.

Currently, design trends demand a reduction in size and weight of system components, particularly transformers. Newer transformers having grain-oriented, high-silicon steel cores have serious "very high inrush current at turn-on" problems.

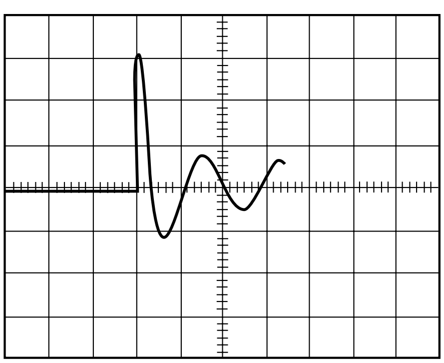

Fig. 1 - Example Tungsten Lamp Load Transient

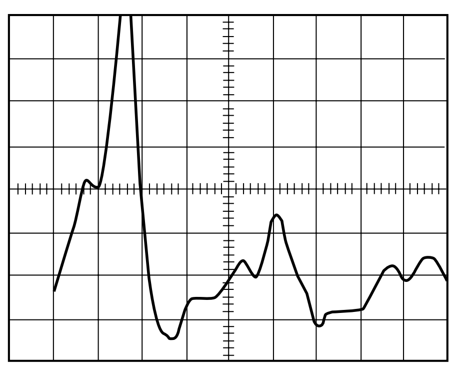

Fig. 2 - Transient from capacitive filter.

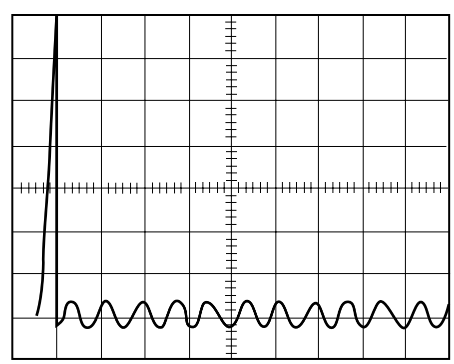

Fig. 3 - Transformer starting transient.

These currents can be as high as 30 times the normal rated current, compared with approximately 18 times for older transformers.

The "worst condition," highest spikes for 60Hz primary, are of approximately 4 millisecond duration. This turn-on transient is concentrated in the first half cycle with successive half-cycles depreciating in amplitude very quickly.

The transient is not very sensitive to transformer load; in fact, a loaded transformer may have slightly less severe transients than when under no load. At the instant of turn-on, the inrush of transient varies with the residual magnetism of the core and with the relative phase of the primary voltage at turn-on. The worst case transient will not occur at each equipment turnon, but more likely in 1 in 5 or 10 turn-ons.

Inrush transients are most severe when the power input is a low impedance source, and the line voltage is high. The maximum spike may be as much as 20 to 25 percent higher at 130 volts than at 120 volts with the same circuit.

MOTOR INRUSH PROTECTION

The starting energy requirements of AC motors are spread over seconds rather than milliseconds, and vary considerably with the type of load and with the inertia of the load. However, the peak amplitude of the starting current is generally within reasonable values.

The chart to the right provides some typical figures. Note that single-phase induction motors are the worst, usually having a starting winding which can draw 7 or 8 times the running current for the best part of a second. A 750-millisecond surge duration was observed on several of the various horsepower ratings.

(1) Motor Type	(2) Start Current Peak Ampl. RMS	(3) Duration of Start Surge in Sec.	(4) Load Second %1 x t Sec.	(5) APL Delay 62	(6) APL Delay 66
Shaded Pole	150%	2.0 sec.	.3	ok	ok
Series AC-DC	530%	.100	.5	no	ok
Series AC-DC	200%	.400	.8	ok	ok
Series AC-DC	333%	.167	.5	ok	ok
Split Phase	600%	.116	.7	no	ok
Split Phase	425%	.500	2.0	no	ok
Capacitor Load	400%	.600	2.4	no	ok
Capacitor No Load	300%	.100	.3	ok	ok
Capacitor Load	420%	.500	2.1	no	no
Induction	700%	.750	5.0	no	no
3 Phase	350%	.167	.6	ok	ok
Cap. Start. Split Phase Run	290%	.083	.24	ok	ok

Induction motors usually are protected by a thermal device imbedded inside the motor. Most protectors which will handle the starting surge will not trip out soon enough on lesser overloads to prevent damage to the motor. Here you are protecting the power wiring rather than the device.

SWITCHING POWER SUPPLIES AND INRUSH PROTECTION

Switching power supplies (commonly called switchers) have different characteristics than the familiar linear types.

When compared with linear type power supplies, switchers are smaller, lighter, and more efficient. They can tolerate a much greater range of input voltage and frequency than the linear types. On the other hand, switchers do not have as fast a recovery time, have slightly higher ripple content and a little less regulation factor than linears. Switchers also require a minimum load current of 20 to 25 percent for proper operation, whereas linear supplies are designed to operate from no load to full load.

The peak value of current at turn-on of linear supplies is in the range of 10 to 20 times RMS rated load values depending on the type of input transformer used. Switchers, almost without exception, do not use an input transformer but rectify the source power directly. This can produce a peak turn on current as much as 40 to 100 times the rated RMS value of current.

For this reason, most switchers include some circuitry in series with the input line to limit this high peak value of current. Most of the smaller units up to 350 watts use a thermistor for this purpose. The thermistor has an initial cold resistance that is high, which quickly decreases to a very low resistance when hot. This limits the cold turn on peak current quite adequately, however, if the circuit is turned off and turned back on while the thermistor is in its low resistance condition the limiting characteristic is much less and can allow a high peak current that may cause nuisance tripping if the circuit protector is rated too low.

Larger wattage supplies use a resistor paralleled with a triac or some other “soft start” means to limit the high initial inrush current to the order of 20 times the rated RMS value of the supply. Though this inrush is quite high it is of short duration, usually from 3 to 5 cycles of 60Hz or 50 to 80 milliseconds and in a decaying amplitude. This high value of current is destructive to on-off switches that do not have contacts designed to resist these stresses.

The steady state input current of switchers is a train of pulses instead of a sinusoidal wave. These pulses are two to four milliseconds duration each when on 60Hz power, with peak values two to three times the RMS value of the input current. This high peak pulse train has a tendency to advance the delay tube core of magnetic circuit protectors and can cause a buzzing sound or nuisance tripping if the current rating of the protector chosen is too near the rated input current of the power supply.

One of the features of most switchers is the inclusion of fold-back circuitry that shuts off or limits the pulse width modulator in the event of an overload in an output circuit. This feature protects against overloads on the output and leaves the circuit protector to afford protection for the input circuitry.

By choosing a protector 2 to 3 times the rated input current with a high pulse tolerance delay you have eliminated the possibility of nuisance tripping, protected against potential faults and provided an on/ off switch with suitable contacts, all in one component. If the circuit protector has a load in addition to the switcher, the total load current and its waveform must be taken into consideration in sizing of the protector.

Since the inrush currents of switchers are typically 50 to 80 ms in duration and in a decaying pattern, the switcher can best be protected with a fast delay with high pulse tolerance. If you select a protector of less than 2 times the rated load you may encounter a buzzing or nuisance tripping from the protector.

MEASURING AND MANAGING INRUSH CURRENTS

In order to properly tailor delays for protection against nuisance tripping, precise measurement of inrush current is needed.

Because the duration of inrush currents may be measured in milliseconds, typical current meters do not provide the level of fast response which is needed, so an oscilloscope must be used. Oscilloscope current probes will saturate and distort wave forms above a value 12 to 14 times the rated currents, giving the impression of a much lesser value than actual. So it is advised to insert a current meter shunt in the primary circuit and then sense voltage drop across the shunt with a calibrated scope. This provides a visual readout of time duration amplitude and wave-shape of the turn-on currents.

Engineers should also perform a repeated turn-on, turn-off exercise. This will help verify that the breaker selected is one that will avoid nuisance tripping. Also, the exercise should be conducted with the highest line voltage that is anticipated in the circuit.

Pulse tolerant protectors must accept the first surge of current without tripping, while still providing maximum equipment protection. This is accomplished either by shunting high flux peaks away from the armature or using an inertial device to damp the armature from short duration pulses.

Each method requires a compromise. Shunts distort the trip time curve in the area of 600 to 1200 percent overload, which may make trip time unacceptable. Inertial dampers are effective only in the area of the first half-cycle of high overload currents. If the high current persists past the first cycle, the inertia wheel will tend to aid trip out to provide the necessary protection.

Airpax hydraulic magnetic circuit breakers feature an inertial wheel to provide an armature delay. The high-inrush construction, which is designed for short-duration, high-amplitude pulses, up to 30 times rated current for about 4 to 8 milliseconds, impacts only the armature has no particular effect for long-duration, lower-amplitude overloads (such as experienced during motor starting). For detailed inrush pulse tolerance, please refer to each product datasheet.

Airpax breakers are available with a variety of custom delays and trip time curves to manage inrush currents. Pulse tolerances are specified for each product line, as well as the delay curve for each configuration.

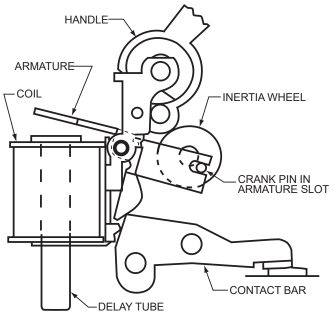

Fig. 4 - Inertial integration against nuisance tripping.