ISCE

The Institute of Sound and Communications Engineers

Engineering Note 5.5

Fuses for mains primary circuits

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You need to have a fuse in the primary circuit of a mains transformer so that it protects against a fault in the transformer. Many times I see circuits like this with a 1 A fuse in the primary. It's quite safe - everything else will burn up before the fuse goes!

Working, as an example, through a 12 V/500 mA d.c. supply, assuming it uses a bridge rectifier, the r.m.s. secondary current will be around 800 mA (But measure it with a true-r.m.s. meter), and will not be anywhere near a sine-wave - hence the need for a true r.m.s. measurement. So the output volt-amps (VA) is 9.6. The input VA will be about 110% of that, i.e. 10.6 VA. With 230 V input, that means the primary current is 46 mA. We need to add about 10 mA for magnetizing current, but that is in quadrature, so the total is only 47 mA. A 50 mA fuse would do, then? WRONG!!!

When you switch on, the reservoir capacitor in the supply is fully discharged and initially looks like a short-circuit. In addition, when the transformer was last switched off, the core may have been left magnetized. (Although it's made of magnetically 'soft' material, the magnetic circuit is closed, especially if the core is a toroid, so it *can* stay magnetized.) Both of these effects cause an 'inrush current', which depends on the exact point on the supply voltage waveform at which the switch contacts close. This current is typically 5 to 10 times the full-load current, but it only last for a few cycles, and the highest value only lasts for one half-cycle. So the 50 mA fuse is going to zap, maybe not the first time you switch on, but soon.

To determine the fuse rating, you need to arrange to display the inrush current waveform on a storage scope (if you have one) and do the switch-on at least 25 times, to get a fair measure of the highest values. Because there are two causes of inrush - the capacitor and the transformer core, you get some weird current waveforms. Don't forget to discharge the reservoir capacitor before switching on again. Then, you should compare your worst-case inrush with the fusing-current/time curves of likely fuses. You will probably find that a 100 mA time-lag ('anti-surge') type is the best choice.

That fuse should also be a high-breaking capacity type, too. Ordinary fuses are rated only for prospective short- circuit currents of a few tens of amps, and the prospective current from the mains supply is in the order of hundreds of amps. Glass-tube fuses often explode if used in mains circuits.

If you don't have a storage scope, a peak-reading a.c. ammeter with a long discharge time-constant will do. You can't buy one, as far as I know, but you can use an audio-type PPM or an EMC-type quasi-peak voltmeter to measure the peak voltage across a 0.1 ohm resistor in the mains neutral lead to the transformer. You MUST feed the unit under test from an isolation transformer in this case. Another way is to build a dedicated instrument, which is not difficult. I may publish a design one day, but in principle, you feed the voltage across the 0.1 ohm resistor into a precision FULL-WAVE rectifier (a dual op-amp and four diodes), arranged to have a short charge time-constant and a long discharge time-constant. You feed the resulting d.c. into either an op-amp driver for a pointer meter or a digital meter module.

You can get an upper limit value for the peak inrush current just with an ohmmeter. The peak current can't exceed the peak mains voltage divided by the d.c. resistance of the primary winding (and anything directly in series with it). For example, if the resistance is 100 Ω, the peak current can't exceed 325/100 = 3.25 A (325 V being the peak voltage of 230 V mains). Now, we can reasonably assume that the inrush current waveform is half a sine wave, so the r.m.s. value over that half-cycle is $3.25 \times 2/\pi = 2.07$ A.