PRIMARY NEON SIGN FLASHERS AND ANIMATORS
HAVE YOU CONSIDERED POINT-ON-WAVE SWITCHING AND MAGNETIC REMANENCE?

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1. Introduction

With the sophisticated digital computers and power electronics available today we can create easily neon signs that can attract extra attention with the use of flashers and animators. Primary electronic controls today can flash or animate neon signs at rates much faster than what was ever possible with the old motor driven primary flashers. These controls can do this with minimum audible and electromagnetic interference and do it reliably if designed to switch the transformer primary properly. If the factors covered in this paper are ignored failures in the neon transformer and other components of the sign are certain to happen.

In designing animated neon signs with primary controls we must take into account the current inrush into the transformer every time its primary is connected to the supply source. A typical neon transformer when connected to the supply will draw a peak current of as much as 10 times its rated current for several cycles until its magnetic core and primary circuit stabilize. If primary switching is done at too fast a rate any or all of the following may take place:

a) The transformer primary will overheat and fail,
b) The electronic control may fail and
c) The branch circuit breaker may trip.

The factors that govern neon transformer current inrush are point-on-wave switching and magnetic remanence.

2. Point-on-Wave Switching

A neon transformer is an inductive load. In its simplest representation as a circuit component it can be thought of as a simple inductance in series with a resistance as in figure 1. The inductance represents the device that stores electric energy in its magnetic field and the resistance represents the losses in the transformer and the conversion of electric energy to light energy.

![Figure 1. Neon transformer simple equivalent circuit](image-url)
a) Zero cross switch-on

b) Switch-on at 45°

c) Switch-on at 90°
d) Switch-on at 135°

Figure 2 Simulated switching transients in transformers
Blue trace – Current
Red trace – Voltage

The behaviour of the circuit in figure 1 is simulated in figure 2 a, b, c, d and e for various switching angles for R=20 ohms and L=0.5 henries. The inductance is equivalent to a 15,000 V/30 mA neon transformer the resistance has been chosen at 20 ohms to speed up the decay of the transient for illustration purposes. In actual transformers the transient lasts longer than in the simulations above. Oscillograms a, b, d and e show that the nature of the transient inrush is a decaying DC offset current that adds to the normal AC current increasing its effective (rms) value.
This exercise shows that if the wrong point-on-wave switching is chosen transient current in the range of twice the rated current can be expected. If on the other
hand the correct switching angle is chosen, as in oscillogram c the switching transient in the input current can be virtually eliminated. For most neon transformers this angle corresponds to the arccosine of the power factor of the neon transformer. In non-trigonometric terms this corresponds to a switching angle of between 60 to 90 degrees.

3. Magnetic Remanence

The electrical circuit property described in section 2 is partially responsible for the inrush current generated at the time of switching-on the primary of the neon transformer. The other factor that governs the inrush current is remanence. Remanence is a property of the magnetic core of all transformers and it is the magnetic field that remains on the core after the removal of the power from the winding that magnetizes the core. Depending on the construction of the transformer, the residual magnetic flux density on the core after the interruption of power could be as high as 80% of the saturation flux density and it has a specific orientation. This flux remanence can stay on the core for a long time. On re-application of power if the voltage is applied such that the required flux to sustain it is of the same orientation as the remanence the core will saturate and the transformer acts similarly to an air core transformer. The excitation current as a result can take on values as high as 8 times rated.

Figure 4 illustrates the relationship between remanence and the excitation current inrush. If the core has no residual magnetism when the voltage is applied the flux traverses the BH curve of the core in the sequence O to Bs+ to Br+ to Bs- to Br- to Bs+ and the resulting excitation current is shown by the solid line. If on the other hand the core had a remanence of Br+ and the voltage is applied to require additive magnetic flux the traverse of the BH curve will be Br+ to Bair to Br+ to Bs- to Br- to Bair and the positive half cycle of the excitation current will be many times the rated current of the transformer, shown in dotted line.

After the core traverses the BH curve for several cycles the losses contribute to demagnetize the core and the current returns to normal levels.

The time taken for the demagnetization of the core depends on the size of the transformer. For large power transformers this can take minutes. Neon transformers generally will require about 30 Cycles or half a second.
4. Experimental Results

A 277V/15000 V, 60 mA neon transformer was loaded with 45 feet of 12 mm red neon and was connected to the source of supply using a CRYDOM HD6050 solid state relay. The relay was controlled by a variable frequency square wave from a WAVETEK function generator. The current input and the voltage to the transformer were recorded on a TEKTRONIX oscilloscope. A 0.01 Ohms non-inductive shunt was used for current measurement.

The solid-state relay consistently powered the transformer at the positive zero crossing of the line voltage. Oscillograms 1 and 2 are typical of the inrush current waveforms observed. In a few occasions the peak inrush of the first cycle was limited to 10 A, oscillogram 3, but in general the peak inrush of the first half cycle was in excess of 25 A, or approximately 8 times rated current.

The 15 A circuit breaker of the branch circuit powering the neon transformer tripped consistently when the HD6050 was used and the flashing frequency was at 0.5 cycles/second or higher.
With a homemade solid-state relay that allowed us to switch-on the primary at the desired angle of the voltage waveform, 90 or -60 degrees, no substantial transient inrush was observed, oscillograms 4 and 5. With this set up flashing the sign at a rate of 1 cycle/second did not trip the branch circuit breaker.

Oscillogram #1. Red trace, Inrush current of a 277 V/15000 V neon transformer. On at

Oscilligram #2. Red trace, inrush current of a 277V/15000 V neon transformer showing how magnetic remanence is established at switch off.
Oscillogram #3. Inrush current of a 277 V/15000 V neon transformer with zero remanence.

Oscillogram #4. Inrush current of a 277 V/15000 V neon transformer. Switch-on at $\theta = 90^\circ$. 
Oscillogram #5. Inrush current of a 277 V/15000 V neon transformer. Switch on at $= -60^\circ$.

5. Conclusions – Recommendations

The analysis and experimental results confirm that switching any transformer on “is a terrible thing to do”. Magnetic remanence and the natural transient response of the circuit combine to produce levels of current for several cycles that can damage the windings. If the switching is too frequent, as required in animated neon signs and not properly done, premature failure is certain. We can improve the situation considerably and get reasonable life expectancy from the neon transformer if we take remanence and point-on-wave switching into account. Follow the rules listed below.

- Use a solid-state relay that is non-zero cross switching and is preferably phase controllable. If phase controllable and the power factor of the neon transformer is known set the angle corresponding to the power factor of the neon transformer. If the power factor is not known ask the transformer manufacturer or choose an angle between $60^\circ$ - $90^\circ$.
- The transformer on time must be minimum 0.5 second to enable the DC offset transient to decay and the core to demagnetize to reduce remanence effects.
- Do not use a high power factor neon transformer in an animated application because the constant switching of the primary will degrade the power factor correction capacitor.
- After the transformer and the branch circuit breaker have been subjected to the high inrush switching current, a cooling off period is required. Allow an off
period of 5 to 10 times the on-time before switching on again. Failure to allow adequate cooling off time may cause the circuit breaker to trip and will definitely reduce the life of the primary winding.

♦ Again ensure that the primary is turned on for at least 30 cycles. Shorter on times are possible but the design of the antiremanence and the point-on-wave switching circuits become extremely critical.