Unit 3.1: Current Chopping

Up to this point, we have assumed that a switch cleared a fault or load current on a zero crossing. However there are situations where a small amount of current may be abruptly interrupted, and this scenario is referred to as current chopping. One instance where this could occur is when a transformer is being deenergized. The equivalent circuit is shown in Fig. 3.1. The inductance represents the magnetizing reactance of the transformer while the capacitance could be due to interwinding capacitance.

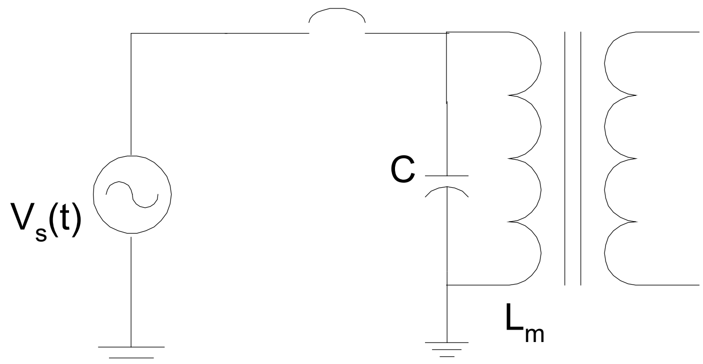

Fig. 3.1 Current Chopping Example

Suppose that the amount of current chopped is given by I_o. Then the amount of energy initially stored in the magnetizing reactance at the time of switching is given by

$$E_o = \frac{1}{2} L_m \left(I_o\right)^2 \tag{3.1}$$

The value of current may be small, but since the inductance is large, then this could represent a large amount of energy.

When the switch opens, the transformer inductance will interact with the capacitance. Assuming that no damping exists, then this energy will be transferred to the capacitance in this oscillatory circuit.

The amount of energy transferred to the capacitance will be found by equating the energy as follows

$$\frac{1}{2}C\left(V_{peak}\right)^2 = \frac{1}{2}L_m\left(I_o\right)^2 \tag{3.2}$$

where the peak voltage can be found by

$$V_{peak} = \sqrt{\frac{L_m}{C}}I_o \tag{3.3}$$

This expression shows us that a current chop can result in an increase in current voltage as the capacitor gets charged up by the inductor.

As an example of how much of a voltage rise we might see, suppose that we had a 1 MVA, 13.8 kV three-phase transformer that was drawing 1.5 A (rms) of magnetizing current. This would correspond to a magnetizing inductance of

$$L_m = \frac{V}{\omega I_m} = \frac{13{,}800/\sqrt{3}}{377\left(1.5\right)} = 14\ Henries \tag{3.4}$$

For an equivalent capacitance of 5000 pF, interrupting this no-load current will result in a peak voltage of

$$V_{peak} = \sqrt{\frac{L_m}{C}}I_o = \sqrt{\frac{14}{5000\times10^{-12}}}\left(1.5\sqrt{2}\right) = 112\ kV \tag{3.5}$$

Not all of this energy is transferable and there will be losses, so this peak will not actually occur. However this relationship shows what factors will determine the potential rise in voltage.

To determine the impact of damping we need to write and solve the appropriate differential equations. Suppose that we now factor in damping due to a load or core losses as shown in Fig. 3.2.

The voltage across this parallel combination is found by writing a current law relationship

$$C\frac{dv}{dt} + \frac{v}{R} + \frac{1}{L}\int_0^t v\,dt + i_L\left(0\right) = 0 \tag{3.6}$$

Differentiating both sides of (3.6)

$$\frac{d^2v}{dt^2} + \frac{1}{RC}\frac{dv}{dt} + \frac{1}{LC}v = 0 \tag{3.7}$$

The solution only involves a transient response of the form

$$v(t) = K_1 e^{s_1 t} + K_2 e^{s_2 t} \tag{3.8}$$

with

$$s_1, s_2 = \frac{-1}{2RC} \pm \frac{\sqrt{\left(\frac{1}{RC}\right)^2 - \frac{4}{LC}}}{2} \tag{3.9}$$

For the case of imaginary roots

$$\alpha = \frac{1}{2RC} \quad ; \quad \beta = \frac{\sqrt{\frac{4}{LC} - \left(\frac{1}{RC}\right)^2}}{2} \tag{3.10}$$

then the voltage has the form of

$$v(t) = e^{-\alpha t}\left(A_1 \cos \beta t + A_2 \sin \beta t\right) \tag{3.11}$$

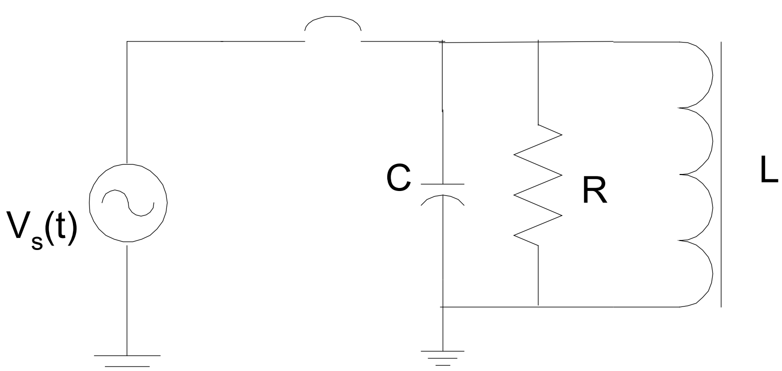

Fig. 3.2 Current Chopping with Damping

The initial conditions are a function of the chopped current and the voltage across the capacitor at the time of switching.

The voltage across the capacitor will be about equal to the source voltage for a light-load condition.

The derivative of the voltage will correspond to the chopped current.

Since the current through the inductor cannot change instantaneously and since the capacitor voltage is holding the current through the resistor fixed, that means that

$$i_c(0) = C\frac{dv_c(0)}{dt} = -I_o \tag{3.12}$$

Applying these initial conditions to (3.11)

$$v_c(0) = e^0\left(A_1\cos(0) + A_2\sin(0)\right) = A_1 \tag{3.13}$$

$$\frac{dv(t)}{dt} = \frac{-I_o}{C} = -\alpha e^0\left(A_1\cos(0) + A_2\sin(0)\right) + e^0\left(-A_1\beta\sin(0) + A_2\beta\cos(0)\right) = -\alpha A_1 + A_2\beta \tag{3.14}$$

This gives us a final form for the voltage solution of

$$v(t) = e^{-t/2RC}\left(v_c(0)\cos\beta t + \frac{1}{\beta C}\left(-I_o + \frac{v_c(0)}{2R}\right)\sin\beta t\right) \tag{3.15}$$