Unit 1.3: Transient Recovery Voltage

When short circuits are cleared by circuit breakers, then a second transient is initiated called the transient recovery voltage (TRV). The equivalent circuit is shown in Fig. 1.7. In this circuit the inductance represents the equivalent model for the power system and the capacitance represents the small amount of capacitance which exists at the circuit breaker bus. When a fault occurs, a large amount of current flows through the circuit breaker and the breaker capacitance is shorted out. When the fault is cleared, then there will be an LC circuit transient due to the interaction of the breaker capacitance with the system inductance. The fault clearing is assumed to occur at a current zero. Clearing the fault will create a large voltage across the capacitance, called the transient recovery voltage. Assuming that the fault looks like a zero impedance to ground, then the voltage across the circuit breaker will be the same as the capacitor voltage. This could cause the circuit breaker to fail, causing a fault current reignition.

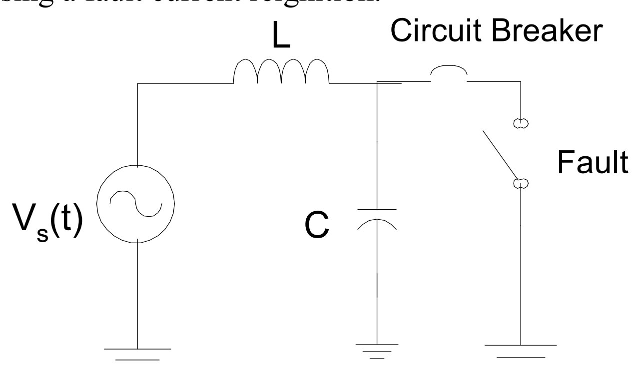

Fig. 1.7 Equivalent Circuit for Transient Recovery Voltage

Assuming that the source voltage can be represented by

$$v_s\left(t\right) = \sqrt{2}V_m \cos \omega t \tag{1.51}$$

then right after the fault is cleared, we can determine the capacitor voltage by writing a Kirchoff current law relationship at the breaker node:

$$C\frac{dv_C}{dt} + \frac{1}{L}\int_0^t \left(v_C - v_S\right)dt + i_L(0) = 0 \tag{1.52}$$

Taking the derivative of both sides leads to

$$\frac{d^2 v_C}{dt^2} + \frac{1}{LC}v_C = \frac{1}{LC}v_S = \frac{1}{LC}\sqrt{2}V_m \cos \omega t \tag{1.53}$$

The solution will have a steady-state and transient solution. The steady-state component can be found by applying a voltage divider

$$\tilde{V} = \frac{\frac{1}{j\omega C}}{j\omega L + \frac{1}{j\omega C}}\left(V_m\angle 0\right) = \frac{1}{1-\omega^2 LC}\left(V_m\angle 0\right) = \frac{1/LC}{1/LC - \omega^2}\left(V_m\angle 0\right) \tag{1.54}$$

where in the time domain

$$v_{Css}\left(t\right)=\frac{1/LC}{1/LC-\omega^2}\sqrt{2}V_m\cos\omega t \tag{1.55}$$

The transient portion of the solution is found by solving

$$\frac{d^2v_C}{dt^2}+\frac{1}{LC}v_C=0 \tag{1.56}$$

which has a solution of the form

$$v_{Ctr}\left(t\right)=A_1\cos\omega_o t+A_2\sin\omega_o t \tag{1.57}$$

where

$$\omega_0=\frac{1}{\sqrt{LC}} \tag{1.58}$$

Finally putting both components give us the total solution

$$v_C\left(t\right)=\frac{\omega_o^2}{\omega_o^2-\omega^2}\sqrt{2}V_m\cos\omega t+A_1\cos\omega_o t+A_2\sin\omega_o t \tag{1.59}$$

The initial voltage across the capacitor is zero due to the short-circuit. If we assume that the fault is cleared at a current zero-crossing, then the inductor current right before and after the fault will be zero.
Since the capacitor current is the same as the inductor current after the fault is cleared, then since

$$i_C\left(0^+\right)=i_L\left(0^+\right)=i_L\left(0^-\right)=C\frac{dv_C\left(0\right)}{dt}=0 \tag{1.60}$$

it follows that

$$\frac{dv_C\left(0\right)}{dt}=0 \tag{1.61}$$

Applying these initial conditions to (1.59)

$$v_C\left(0\right)=0=\frac{\omega_o^2}{\omega_o^2-\omega^2}\sqrt{2}V_m+A_1 \tag{1.62}$$

$$\frac{dv_C\left(0\right)}{dt}=0=A_2\omega_o \tag{1.63}$$

leads us to

$$v_C\left(t\right)=\frac{\omega_o^2\sqrt{2}V_m}{\omega_o^2-\omega^2}\left(\cos\omega t-\cos\omega_o t\right) \tag{1.64}$$

The transient solution suggests that the transient recovery voltage will appear as a high frequency transient superimposed on top of the steady-state voltage. In reality natural damping would rapidly cut the transient to zero.

If the natural frequency was much higher than the source voltage frequency, then the ratio

$$\frac{\omega_o^2}{\omega_o^2 - \omega^2} \approx 1 \tag{1.65}$$

and the source voltage could be approximated by a DC value so that

$$v_C(t) = \sqrt{2}V_m(\cos\omega t - \cos\omega_o t) = \sqrt{2}V_m(1 - \cos\omega_o t) \tag{1.66}$$

This shows us that the transient recovery voltage can reach twice the peak source voltage.

Additional damping could be introduced that would reduce this peak value. This can be accomplished using a preinsertion resistor as shown in Fig. 1.8. The auxiliary switch is used to introduce a resistance across the capacitor. When the transient is sufficiently damped, then the auxiliary switch is opened.

The differential equation which would need to be solved to include the resistance now becomes

$$C\frac{dv_C}{dt} + \frac{v_C}{R} + \frac{1}{L}\int_0^t (v_C - v_S)dt + i_L(0) = 0 \tag{1.67}$$

Taking the derivative of both sides leads to

$$\frac{d^2v_C}{dt^2} + \frac{1}{RC}\frac{dv_C}{dt} + \frac{1}{LC}v_C = \frac{1}{LC}\sqrt{2}V_m\cos\omega t \tag{1.68}$$

The solution with this additional damping will be left as a possible homework or test problem for the student.

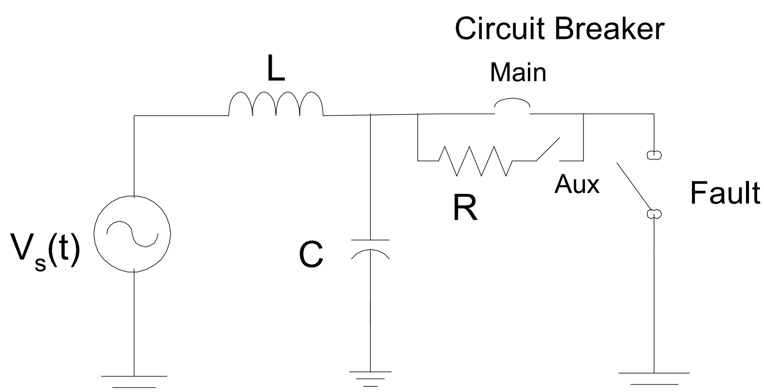

Fig. 1.8 Use of Preinsertion Resistance