Here the current is not directly proportional to the voltage, though this condition may be approximated over limited ranges. The application of superposition must be restricted to these ranges. Nonlinear resistors are used from time to time, especially as protective devices. Again, the principle of superposition should not be applied where these are located. Finally, any type of rectifier is an extremely nonlinear device since it presents almost zero impedance to the flow of current in one direction, but an almost infinite impedance to current flow in the other direction. Superposition cannot be applied indiscriminately, although it will be shown that, with care, it can be used over certain intervals, even in circuits containing rectifiers.

**PROBLEMS**

1.1

![Fig. 1P.1.](image)

The current in Fig. 1P.1 has already reached a steady value when \( S \) is closed. Derive an expression for the current through \( L \) after the closing of \( S \).

1.2 If \( V = 500 \text{ V}, \ L = 20 \text{ mH} \) and \( R = 30 \text{ Ω} \), calculate the voltage across the inductance 1 ms after the switch \( S \) is closed in Fig. 1P.1.

1.3

![Fig. 1P.2.](image)

Initially, the capacitor \( C_1 \) in Fig. 1P.2 is charged to 100 kV; \( C_2 \) is uncharged. The switch \( S \) is closed and 40 \( \mu \text{s} \) later the gap \( G \) sparks over. What is the current in \( R_2 \) and the voltage on \( C_1 \) immediately after sparkover?
1.4 How much energy has been transferred to \( C_2 \) from \( C_1 \) at the time of gap sparkover? How much has been spent in \( R_1 \)?

1.5

\[ C_1 = 5 \text{ \( \mu \)F}, \quad C_2 = 0.5 \text{ \( \mu \)F} \]
\[ L = 10 \text{ mH} \]
\[ V_1(0) = 100 \text{ kV}, \quad V_2(0) = -50 \text{ kV} \]

Fig. 1P.3.

What is the maximum voltage attained by \( C_2 \) and the frequency of the current that flows in \( L \), after the switch is closed in the circuit of Fig. 1P.3?

1.6 What other natural frequency could be produced by the components of Fig. 1P.3 if they were configured differently?

1.7 A capacitor \( C \) charged to voltage \( V \) is discharged into an inductor \( L \). What is the voltage on \( C \) at the instant when its stored energy and that of the inductor are equal?
\[ 2.2 \] The transform of a certain voltage is given by:

\[
\frac{1.9 \times 10^{11}}{s^2 + 2.1 \times 10^5 s + 2 \times 10^{11}}
\]

Evaluate the transform and sketch its form with reasonable accuracy.

\[ 2.3 \] How much energy will be dissipated when the switch in the circuit in Fig. 2P.1 is closed.

![Fig. 2P.1.](image)

The capacitor \( C_1 \) in Fig. 2P.1 has an initial charge of 1.0 C; \( C_2 \) is discharged. Calculate the following:

a. The peak current

b. The current 200 \( \mu s \) after the switch closes

c. The ultimate energy stored in \( C_2 \)

d. The ultimate voltage on \( C_1 \)

\[ 2.4 \] If the resistor in Problem 2.3 is replaced by an inductor with the same 60 Hz reactance, calculate the following, once the switch is closed:

a. The instantaneous current

b. The peak current

c. The energy stored in the inductance 1 ms after the switch is closed

d. The energy stored in \( C_1 \) at the same instant.

\[ 2.5 \] Show that if one capacitor is discharged into another through a resistor, the energy dissipated in the resistor is independent of the value of the resistor.

\[ 2.6 \] Each phase of a 3-phase capacitor bank is rated 60 MVA at 13.8/\( \sqrt{3} \) kV. A second bank has a rating of 30 MVA at 13.8/\( \sqrt{3} \) kV. The two are to be paralleled by momentarily connecting them through a 100 \( \Omega \) stainless steel resistor (one for each phase), which will be subsequently shorted out. You are to design these resistors (determine the length and cross-sectional area of the wire to be used) if the temperature rise of a resistor is not to exceed 200°C, when the switching operation is made at a time when one capacitor is at positive peak voltage and the other at negative peak voltage.
The characteristics of stainless steel are: density $= 7.9 \text{ g/cm}^3$; specific heat $= 0.53 \text{ J/g per } ^\circ\text{C}$; resistivity $= 72 \Omega \text{ cm}$. Assume that no heat is lost to the surroundings during the switching operation.

What will be the weight of the resistor? What will be the peak current during the switching operation?

2.7

![Diagram](image)

Field coil: $L = 2 \text{ H}$, $R = 3.6 \Omega$

$R_2 = 10 \Omega$

Fig. 2P.2.

Figure 2P.2 shows the field coil of a machine. It is excited by closing switch $S_1$ onto an 800 V d.c. bus. Determine the energy stored in the coil, and the energy already dissipated in it, 1 s after $S_1$ is closed.

When the coil current has attained a steady value, $S_1$ is opened and $S_2$ is closed simultaneously. What will be the voltage across $S_1$ 0.1 s later? How much energy will eventually be dissipated in $R_2$?

2.8 We are often required to design test circuits which will generate surges of specific waveform. These are then used to apply surges to pieces of power equipment (transformers, generators, reactors, etc.) we wish to test. Sometimes we wish to simulate the effect of a lightning surge, sometimes a switching surge.

![Diagram](image)

$R_1 = 10 \Omega$  $C_1 = 2.0 \mu F$

$R_2 = 100 \Omega$  $C_2 = 0.05 \mu F$

Fig. 2P.3.

Figure 2P.3 shows a basic form of impulse generator. When $C_1$ has been charged and the gap $G$ is caused to spark over, an impulse voltage is generated at the output terminals $A$ and $B$.

Without solving the equation of the circuit, compute a good estimate of the following when the precharge voltage is 500 kV and the gap discharges.
a. The maximum current in $R_1$
b. The maximum voltage across $C_2$
c. The time when this voltage (b) is reached
d. The output voltage after 0.5 $\mu$s
e. The output voltage after 50 $\mu$s

2.9

Fig. 2P.4.

$V$ and $L$ in Fig. 2P.4 represent the resistance and inductance of the field winding of a machine. The switch $S$ has been closed and a steady direct current is flowing from the source $V$.

When $S$ is opened, an arc is established between its contacts which develops a voltage of 400 V, opposing the flow of current. Plot the current after $S$ opens.

REFERENCES