ECE 524: Homework #1

Due Session 8 (January 29)

Solve each of these problems analytically and then simulate them using a transient simulation program. Compare your results and comment.

Problem 1. Do the following for the circuit below:

![Circuit diagram](image)

\[ \begin{align*}
C_1 &= 60 \mu F \\
C_2 &= 40 \mu F \\
R &= 5 \text{ ohm}
\end{align*} \]

The capacitor \( C_1 \) in the figure has an initial charge of 1.0 Coulomb; \( C_2 \) is discharged. Calculate the following:

A. The peak current through the switch
B. The current 200 microseconds after the switch closes
C. The total energy dissipated in the resistor
D. The ultimate energy stored in \( C_2 \)
E. The ultimate voltage on \( C_1 \)
F. Verify that energy is conserved

Problem 2: Given the simple LC network with the conditions given below find the following:

![Circuit diagram](image)

\[ \begin{align*}
C_1 &= 60 \mu F & Q_{C1} &= 1 \text{C} \\
C_2 &= 40 \mu F & Q_{C2} &= 0 \text{C} \\
X &= 5 \text{ohm} & \text{at 60Hz}
\end{align*} \]

A. Find the instantaneous current when the switch closes.
B. Determine the peak current
C. Find the energy stored in the inductor at \( t = 1 \text{ms} \)
D. Find the voltage across \( C_1 \) at \( t = 1 \text{ms} \).
**Problem 3.** The figure below shows the field coil of an electric machine. It is excited by closing switch $S_1$ onto an 800V d.c. bus. Determine the energy stored in the coil, and the energy dissipated in the coil resistance, 1 sec 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 sec later? How much energy will eventually be dissipated in $R_2$?

![Diagram of field coil with switches $S_1$ and $S_2$.]

- $R_2 := 10\text{ohm}$
- Field Coil:
  - $R_f := 3.6\text{ohm}$
  - $L_f := 2\text{H}$

- You need to have the system in steady-state before opening $S_1$
- Note: when simulation this, $S_1$ needs to be set to interrupt the steady-state
- load current
- $S_2$ needs to be commanded to close at the same time $S_1$ opens.

**Problem 4:** A 230kV:69kV, 100MVA three phase transformer (wye grounded-wye grounded) has per unit leakage reactance of 10% with an $X/R$ ratio of 15. This is supplied by a source impedance of $j0.05\text{pu}$. No change of base calculations are needed.

A. Calculate the worst case peak fault current for a fault at the low voltage terminals. What is the angle of inception compared to the voltage waveform (assume a cosine voltage source)? Include the resistance.
B. Using simulation only, repeat part A if the $X/R$ ratio of the transformer is 7.

- Model the system referred to the low voltage winding for your simulation, do not use the built-in transformer models yet. We will learn to use the transformer models in the simulation later in the semester.

\[ i(t) = k\left[\cos(\omega t + \varphi) - e^{-\frac{t}{\tau}}\cos(\omega t - \varphi)\right] \]
EMTP Variants

- Original version mainly modeled RLC elements, switches, ideal sources and lines
- Many extensions and several versions
  - ATP: Alternate transients program (http://www.emtp.org)
  - EMTP-RV (http://www.emtp.com) latest from DCG
  - EMTDC: student version available free from their web site (http://www.pscad.com)
  - RTDS: Real time digital simulator
  - OPAL-RT: Real time digital simulator
  - SimPowerSystems blockset for Matlab

EMTP-like Programs

- Designed to study transient phenomenon from a few hundred Hertz to hundreds of kHz
- Switching surges, faults studies, insulation coordination, power electronic interactions with power systems
- EMTP can also model dc systems and electromechanical interactions
- Trapezoidal integration scheme \( \rightarrow \) astable
  - Stable results if transient response modeled is stable
ECE 524: Transient RC Response

Define units:
\[
\text{MW} := 1000 \text{kW} \quad \text{MVA} := \text{MW} \quad \text{MVAR} := \text{MW} \quad \text{kJ} := 1000 \text{J}
\]
\[
\text{ms} := 10^{-3} \text{sec} \quad \mu\text{s} := 10^{-6} \text{sec} \quad \text{pu} := 1
\]

Each phase of a 3-phase capacitor bank is rated at 60MVA at 13.8/\sqrt{3} \text{kV}. A second bank has a rating of 30 MVA at 13.8/\sqrt{3} \text{kV}. The two are to be paralleled by momentarily connecting them through a 100 ohm stainless steel resistor (one for each phase), which will be subsequently shorted out.

What will be the peak current during the switching operation?

**Analytical Solution**

Known parameters:
\[
V_{\text{rated LL}} := 13.8 \text{kV} \quad \omega := 2\pi 60 \text{Hz}
\]
\[
Q_{c1 \_1\text{phase}} := 60 \text{MVA} \quad R_{\text{limiting}} := 100 \text{ohm}
\]
\[
Q_{c2 \_1\text{phase}} := 30 \text{MVA}
\]

Since the banks appear to be Y connected:
\[
X_{c1} := \frac{V_{\text{rated LL}}^2}{3Q_{c1 \_1\text{phase}}} \quad X_{c1} = 1.06 \Omega
\]
\[
X_{c2} := \frac{V_{\text{rated LL}}^2}{3Q_{c2 \_1\text{phase}}} \quad X_{c2} = 2.12 \Omega
\]
\[
C_1 := \frac{1}{\omega X_{c1}} \quad C_1 = 2507.17 \mu\text{F}
\]
\[
C_2 := \frac{1}{\omega X_{c2}} \quad C_2 = 1253.58 \mu\text{F}
\]
\[
V_{pk} := \sqrt{\frac{2}{3}} V_{\text{rated LL}} \quad V_{pk} = 11.27 \text{kV}
\]

Initial voltages:
\[
V_{c1 \_0} := V_{pk} \quad V_{c2 \_0} := -V_{pk}
\]