ECE 524

TRANSIENTS IN POWER SYSTEMS

SESSION no. 17
ECE 524: Homework #3

Due Date: Session 20 (February 28)

Problem 6-3 in text book: Neglect the loads for analytical calculations.

Problem 6-4 in text book: Neglect the loads for analytical calculations.

Problem 6-5 in text book: Neglect the loads for analytical calculations. Choose the resistance such that the series R-L-C circuit for energizing the capacitor is critically damped for the case with the bus tie breaker open and round up to the nearest 0.5 ohm.

Instead of recalculating the resistance with the tie breaker open, evaluate the response with the same resistance and the bus tie breaker closed.
Switch in capacitor 2 through a resistance:

Eliminate the source resistance again. Suppose the bank 2 is energized through a resistor with bank 1 already in the system. Determine the resistance needed to limit the peak line to ground voltage on either bank to 33.5kV

\[ C_{eq} := \frac{C_1 \cdot C_2}{C_1 + C_2} \quad C_{eq} = 14.33 \cdot \mu F \]

Simulation Results

With \( R = 25.01 \) ohm, switching at \( t = 15.61 \)ms. Results identical with \( L_1 \) ignored.
Analytical Solution:

\[ C_1 = 40.11 \, \mu F \quad C_2 = 22.29 \, \mu F \quad L_1 := 19.2 \, \mu H \]

\[ V_m = 28.17 \, kV \quad \text{Actual value with C1 in the system} \]

Undamped resonant frequencies:

\[ f_{01} := \frac{1}{2 \pi \sqrt{L_s (C_1 + C_2)}} \quad f_{01} = 439.35 \, \frac{1}{s} \]

- Start from estimate from analytical soln
- Repeat simulation with different + close
- Adjust R
- If ignore 60Hz term can close at voltage peak
- Add 60Hz term you get bigger voltage if close before peak

V & 1 voltage
\[ \omega_d = \sqrt{(2 \cdot \pi \cdot f_0)^2 - \alpha^2} \]

Find maximum voltage that can be added to source:

\[ V_{\text{maxAdded}} := 33.5kV - V_m \quad \text{or} \quad V_{\text{maxAdded}} = 5.33kV \]

So we want the positive peak of the damped sine wave to be:

\[ V_{\text{maxAdded}} = -V_{\text{drivingpoint}} \cdot e^{-\alpha \cdot t} \cdot \sin \cdot \omega_d \cdot t \]

Or with the numbers added:

\[ 5.33kV = (10.06kV) \cdot e^{-\alpha \cdot t} \cdot \sin \cdot \omega_d \cdot t \]

Positive maximum occurs when:

\[ \sin \cdot \omega_d \cdot t = -1 \]

This implies that:

\[ t_{pk} \cdot \sqrt{(2 \cdot \pi \cdot f_0)^2 - \alpha^2} = \frac{3\pi}{2} \]

or:

\[ t_{pk} = \frac{3\pi}{2 \cdot \sqrt{(2 \cdot \pi \cdot f_0)^2 - \alpha^2}} \quad \text{Equation #1} \]

The damped amplitude requires:
\[ f_{02} := \frac{1}{2 \cdot \pi \cdot \sqrt{\frac{L_1 \left( \frac{C_1 \cdot C_2}{C_1 + C_2} \right)}}} \quad f_{02} = 9596.15 \, \text{s} \]

Likely to be damped severely by a resistance that can damp the lower frequency, so neglect this resonant circuit.

Driving voltage for \( f_{01} \):

From charge balance:

\[ C_1 \cdot V_{C_1}(0) = (C_1 + C_2) \cdot V(\infty) \quad \text{Assume near voltage peak when switch} \]

\[ V_{\infty} := V_m \cdot \frac{C_1}{C_1 + C_2} \quad V_{\infty} = 18.11 \, \text{kV} \]

\[ V_{\text{driving point}} := V_m - V_{\infty} \quad V_{\text{driving point}} = 10.06 \, \text{kV} \]

Damped resonant voltage will be:

\[ V_{f01} = -V_{\text{driving point}} \cdot e^{-\alpha \cdot t} \cdot \sin \cdot \omega_d \cdot t \]

Where:

\[ \alpha = \frac{1}{2 \cdot R \cdot \frac{C_1 \cdot C_2}{C_1 + C_2}} \]
Then, taking a square root

\[
\alpha := \sqrt{\frac{\left(\text{Exp}_\text{\alpha t}_{pk}\right)^2 \cdot 4 \cdot (2 \cdot \pi \cdot f_{01})^2}{9 \cdot \pi^2 \text{sec}^2 + \text{Exp}_\text{\alpha t}_{pk}^2 \cdot 4}}
\]

\[
\alpha = 368.71 \cdot \frac{1}{\text{sec}}
\]

Recall

\[
\alpha = \frac{1}{2R \cdot (C_1 + C_2)}
\]

\[
R := \frac{1}{2 \cdot \alpha \cdot (C_1 + C_2)}
\]

\[
\omega_d := \sqrt{(2 \cdot \pi \cdot f_{01})^2 - \alpha^2}
\]

\[
\frac{\omega_d}{2 \cdot \pi} = 435.42 \cdot \text{Hz}
\]

However, there is a problem with this result. This result assumes that the transient happens so fast that the 60Hz waveform is not varying. It turns out that the transient will be worse the switching transient occurs prior to the 60 Hz peak with a tradeoff between the driving point voltage and the sum of the resonant response plus the 60 Hz response.
If instead we wanted critically damped

\[ \sqrt{\left(\frac{R}{2L}\right)^2 - \frac{1}{LC}} \]

\[ = 0 \]

\[ \frac{R}{2L} = \frac{1}{\sqrt{LC}} \]

\[ R = \frac{2L}{\sqrt{LC}} = 2\sqrt{\frac{L}{C}} \]
Switch Opening Transients

Ch 8 in book

L12 8/12

Vs

M

L

R

Vb

Fault

If we simulate this, then command action on open command action on Vb

V3
If simulate this in ATP numerical oscillation

EmTP - Like programs use the Trapezoidal rule for numerical integration - 1st order, implicit method for numerical integration - 1st order, implicit method.
Both responses are incorrect
- model is over simplified...

\[ V_s(0) = V_m \]

\[ V_{c}(0^-) = 0 = V_{c}(0^+) \]

C_{para}

Potasitic capacitance
C_{para} on the order of nF

L on the order of mH or 100's nH

Natural freq is 10's to hundreds kHz

Response called Transient Recover Voltage (TRV)
Concerns are

1) damage from overvoltage (grounding matters)

2) Breaker restrike
   - starting conducting again
   - voltage rises faster than dielectric "insulation" recovers

$\text{Rate of Rise of Recovery Voltage (RRRV)}$