Problem 1: Capacitor switching:
(30 points) A three-phase 2,100kVAR capacitor bank (700kVAR/phase) is installed on a three-phase distribution feeder with a nominal voltage of 12.47kV line-to-line. The three-phase short circuit duty at the capacitor bank location is 41MVA. For this problem assume that the system impedance is entirely inductive.

1a) (5 points) What is the expected steady-state voltage rise in percent when the capacitor bank is energized?

1b) (10 points) What will be the frequency of the oscillatory transient when this capacitor bank is switched on?

1c) (5 points) What will be the peak amplitude of the inrush current when this capacitor is switched on?

1d) (5 points) What is the largest three-phase capacitor bank that can be installed at this location using only 200kVAR capacitor "cans" if the steady-state voltage rise that occurs when the capacitor is switched on cannot exceed 3%?

1e) (5 points) What will be the frequency of the oscillatory transient when the capacitor bank selected in problem 1d is switched on?

Problem 2: Short answer:

2a) (5 points) Why does the PSQ text recommend placing an arrestor at open terminals of a distribution line?

2b) (5 points) What is nuisance tripping, as the term applies to adjustable speed motor drives? Give a brief example of a cause of nuisance tripping and a possible solution to this problem.

2c) (5 points) What is the fundamental distinction between a crowbar circuit and a clamp circuit from the perspective of the downstream load? In your explanation, give a brief example of each.

2d) (5 points) A small relay has contacts rated to carry 5A of resistive load. To help reduce the wear on the contacts due to arcing, what would be a suitable current limit for this relay's contacts with an inductive load, such as other relay coils? (Reference: LIttelfuse Application note EC638.)

2e) (5 points) "Snubbers" (resistor and capacitor in series) are used to help prevent arcing of relay contacts. The application note above describes adding a varistor in parallel with a snubber to prevent arcing of relay contacts. What are <u>three</u> separate advantages of including a varistor in parallel with the basic snubber compared to using the snubber by itself?

2f) (5 points) List the three necessary conditions for ferroresonance as described in the lectures.

2g) (5 points) Capacitors are employed for voltage support in electric utility systems. Utility capacitors have a small internal resistor connected between the terminals. Without this resistor, when such capacitors are switched off line they would tend to retain a voltage near the peak of the voltage that was applied to the capacitor. This is true even for all three capacitors in a three phase system. Explain why the capacitor retains a voltage that is near the peak value and why all three phases would retain this peak voltage if there were no internal resistors in the utility capacitors.

2h) (5 points) Briefly describe the two power quality problems discussed in lectures and the PSQ text that are associated with current from lightning strokes traveling in the grounding system.

2i) (5 points) A voltage transient appears between the "hot" or "line" conductor and the neutral conductor, but during this transient the voltage between the neutral and the grounding conductors remains very low. Is this a "common mode" transient or a "normal mode" transient?

Problem 3: Low-side surge:
(25 points) Consider the circuit shown in Figure 4.38 in the PSQ text. An impulsive current transient with a 200 Ampere peak appears due to the lightning shown at the left side of the diagram. The pulse is characterized as an 8 microsecond x 50 microsecond transient. This means that the virtual front duration (see figure 1 below) is 8 microseconds and the pulse decays to half of its peak by 50 microseconds from the virtual start of the pulse. Both ground resistances are 3 ohms and ground lead inductance shown is 160 uH. The neutral wire has a series reactance of 200 uH. The distribution transformer is 4160V / 240V with a center tapped secondary winding. Assume that the arrestor behaves as a low-impedance arcing fault.

3a. (10 points) Determine the peak voltage, relative to ground, at the center tap of the transformer secondary.

3b. (10 points) Determine the peak current in the neutral wire between transformer and load.

3c. (5 points) Determine the peak voltage at the neutral-ground bond of the load.

Figure 1 - current transient