Capacitor bank discharge resistors

By Doug Millner

Fun Fact

This is an AI generated image.

AI just naturally knows that substation technicians look perpetually overworked, are prone to giving scowls, and saying things like:

"Good job Newbie"

"Good at letting the smoke out"

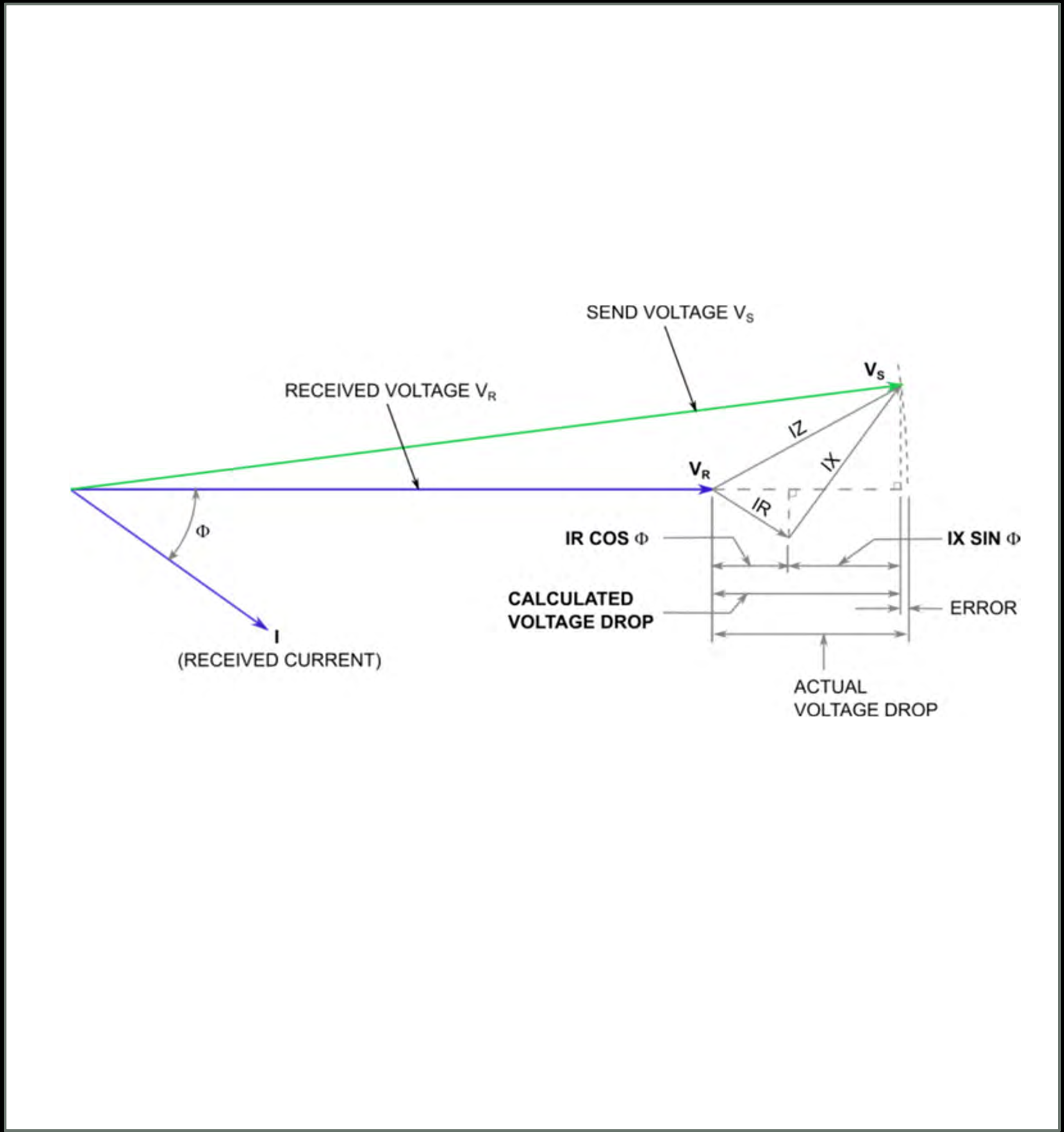
"Newbie, there are times when things go wrong and every blames you but your co-workers know that no one could have done better. This is not one of those times."

NERX Power Consultants

Background

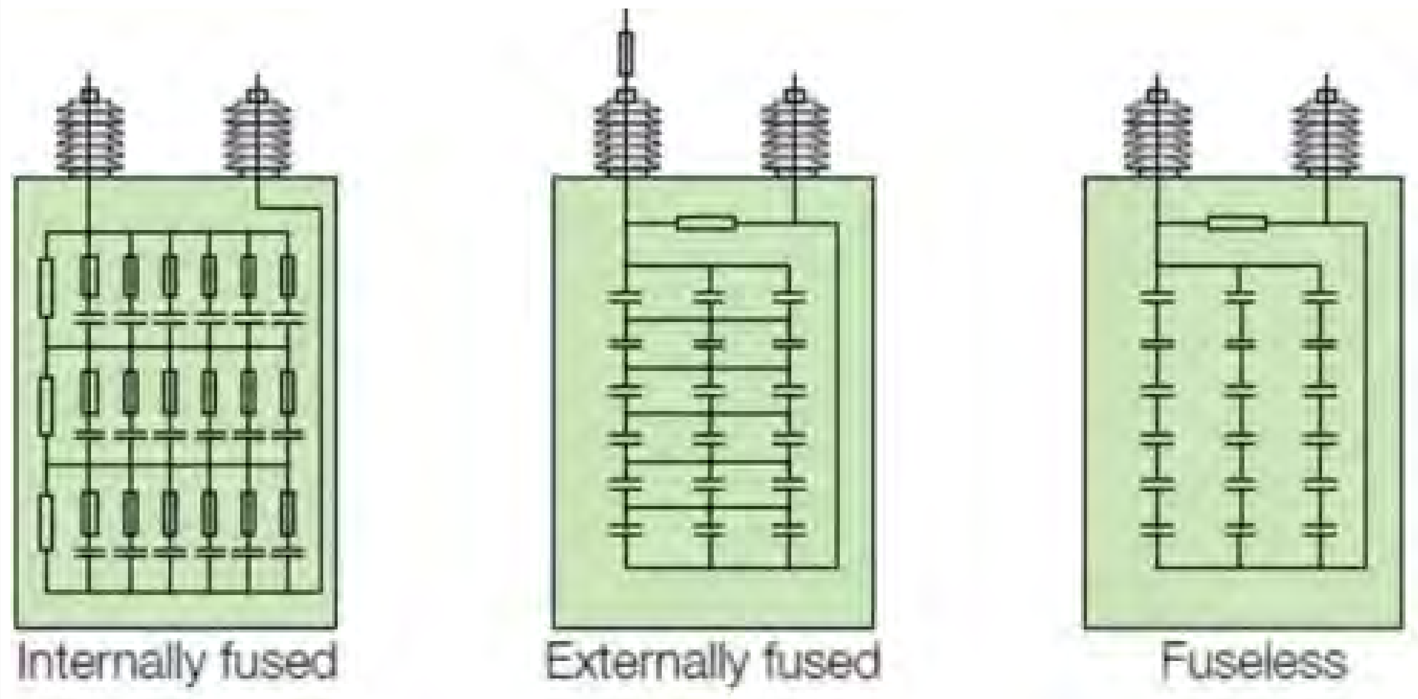
I am an electrical engineer with 15 years experiences in electrical design, protective relaying, transmission planning, and NERC compliance.

Founder of NERX Power Consultants LLC



Basic functions of a shunt capacitor banks

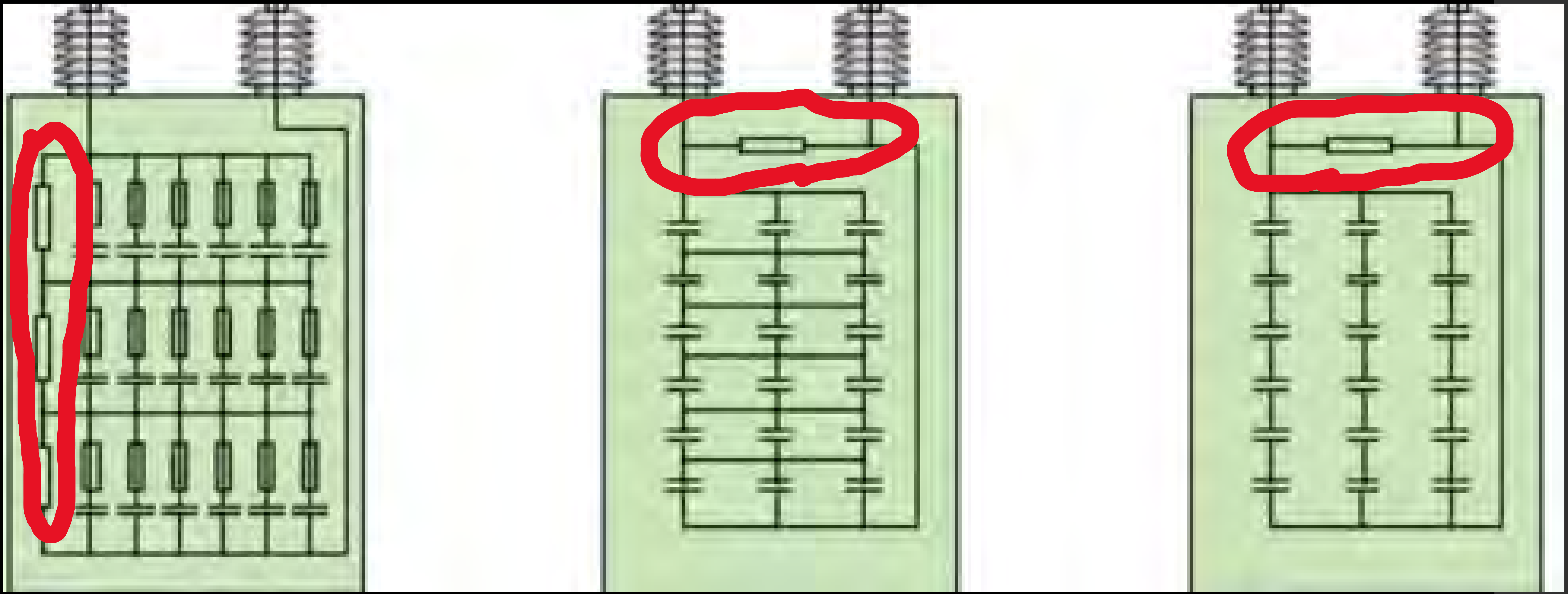
1. Var or voltage support
2. Harmonic filtering



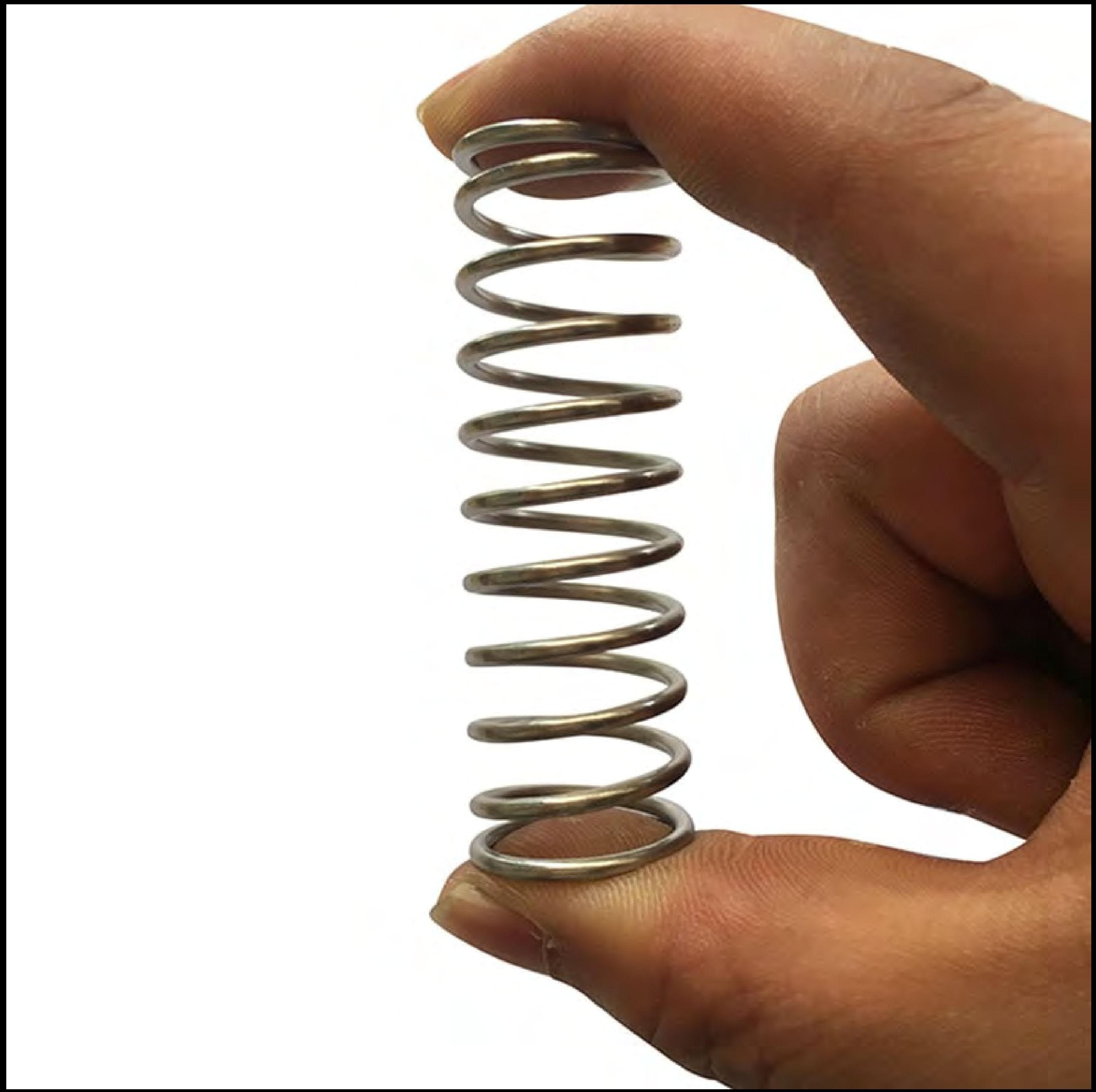
Three types of capacitor banks

Two basic functions

1. Internally fused
2. Fuseless
3. Externally fused



Discharge resistors



Why do we need discharge resistors?

1. Stored energy sources are an inherent hazards

2. Differences between capacitor bank residual and grid voltage can result in inrush, overvoltages, and ringing

Why do we need discharge resistors?

1. Energy stored on the capacitor bank $E = .5*C*V^2$

2. $0.5*(21.5\mu F)*(30kV)^2$
   $= 9675$ Joules

3. Low source impedance of the capacitors means that all that energy is discharged incredibly fast.

SHUNT CAPACITOR BANK SWITCHING TRANSIENTS: A TUTORIAL AND CASE STUDY

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INTRODUCTION

Transient disturbances in power systems may damage key equipment, potentially having a great impact on system reliability. These transients may be introduced during normal switching operations, interruption of short circuits, lightning strikes, or due to equipment failure. Phasor analysis or other simplified analysis methods are usually inadequate due to system frequency dependencies and nonlinearities. Therefore, time-domain computer models are typically developed as a means of predicting the severity of the transient occurrences. The simulations are typically performed using simulation software such as the Electromagnetic Transient Program (EMTP). In this work, a royalty-free version of EMTP, called the Alternative Transients Program (ATP) was used.

During the switching of shunt capacitor banks, high magnitude and high frequency transients can occur [1, 5, 6, 7]. In earlier years, shunt capacitor banks have been more commonly installed at distribution and lower subtransmission levels. However, there has

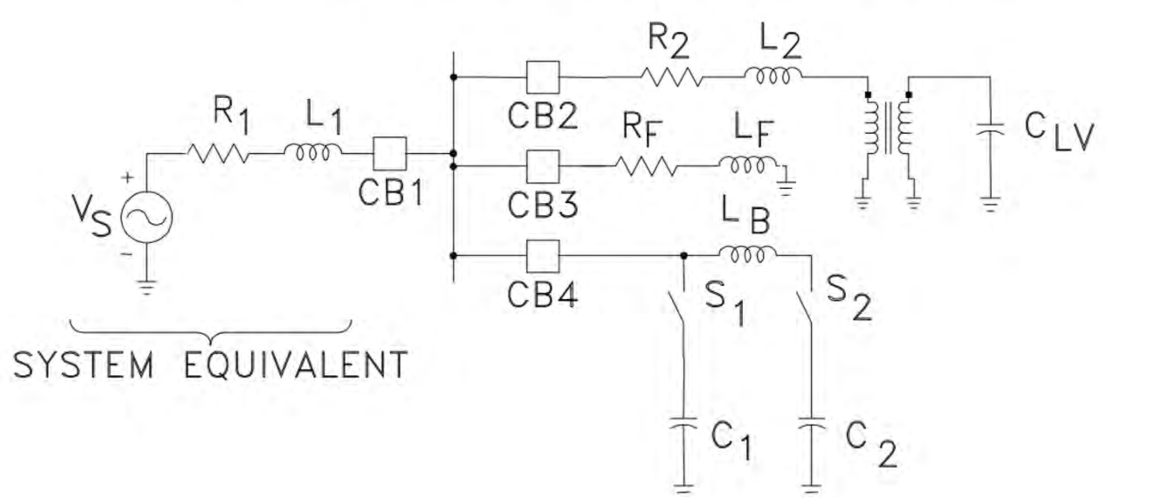


Figure 1. A simple 34.5-kV per-phase system used to illustrate capacitor bank transients.

Problems made worst by voltage left on a capacitor bank

1. Inrush into capacitor bank on energization to match the grid voltage
2. Back to back capacitor bank switching. The energized capacitor bank discharges into the capacitor bank just switched in. High frequency ringing.

Capacitor Bank Inrush

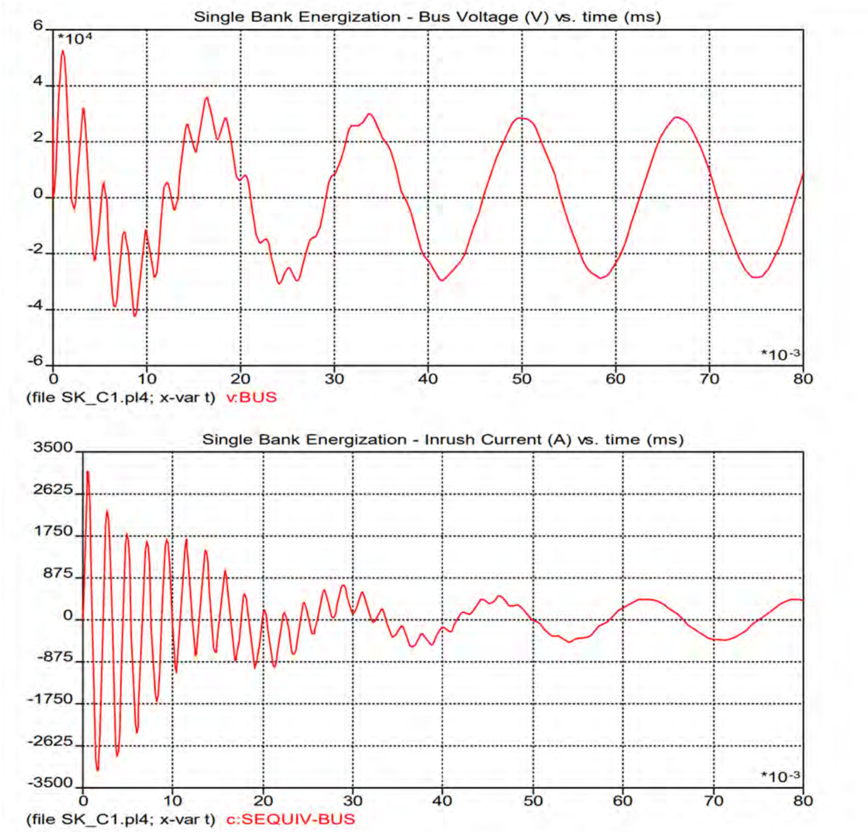


Figure 2. Energization inrush. Peak bus voltage = 1.87 pu. Peak current = 3041 Amps.

Back to Back Capacitor Bank Switch

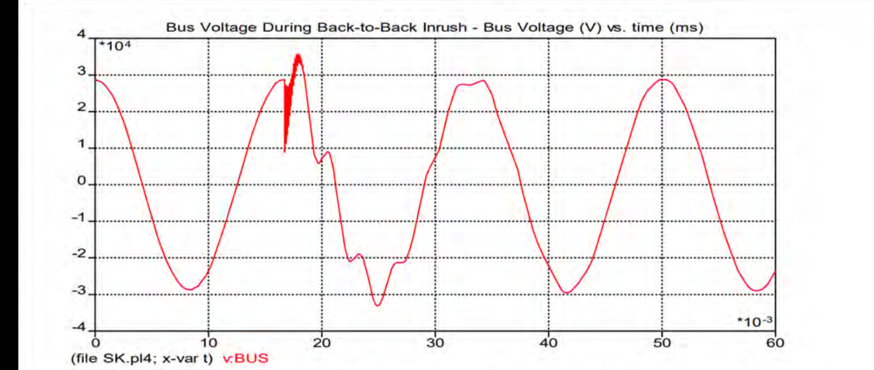


Figure 4. Transient in bus voltage following back-to-back switching.

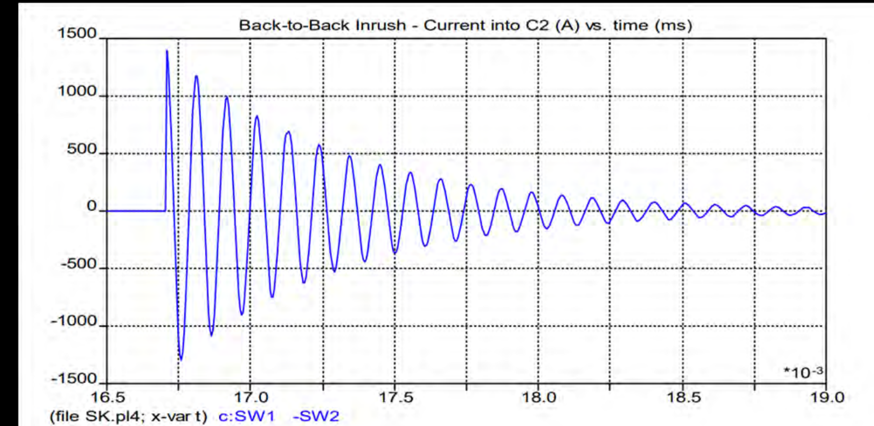
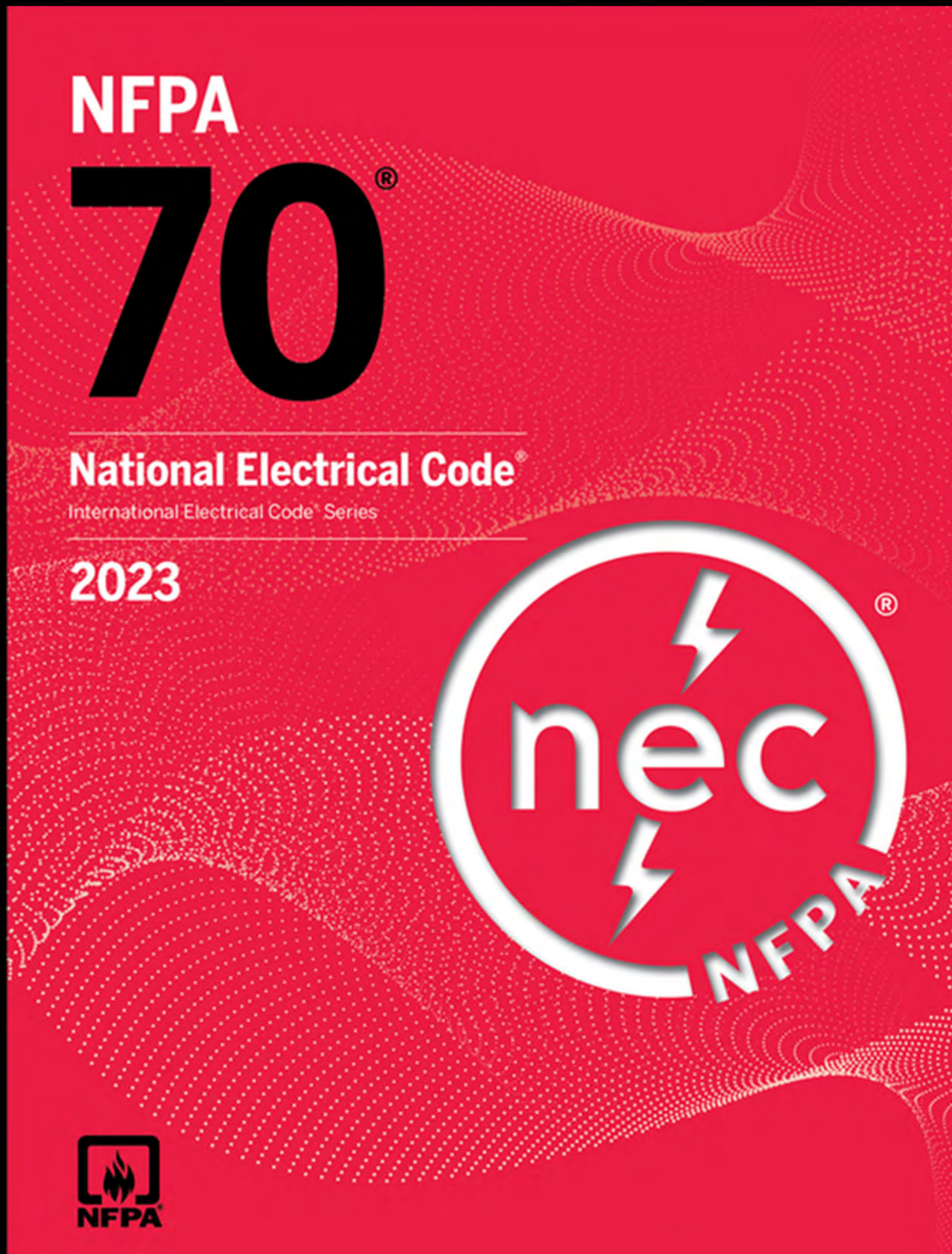


Figure 3. Back-to-back energization. Current inrush into C_2. Frequency = 9.4 kHz.

Problems are made worst when residual voltage is out of phase with the grid on energization.

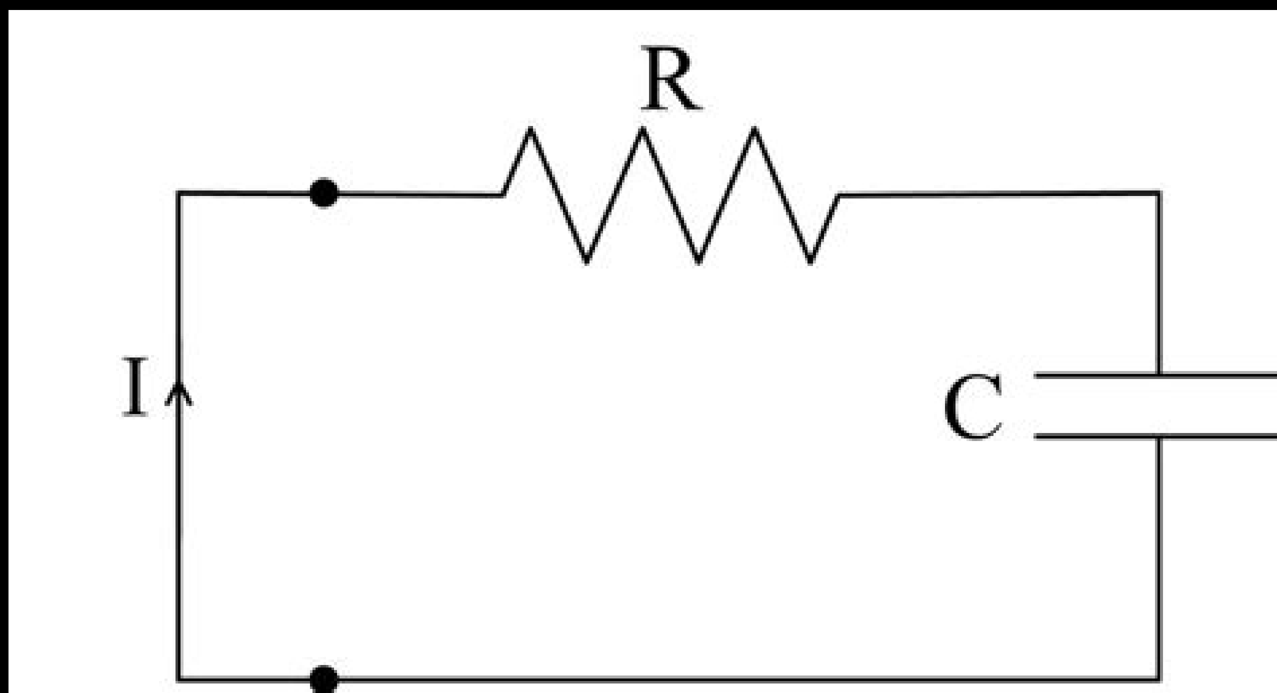
Why not close in each phase to whatever voltages were left on the capacitor bank to avoid inrush?

Congratulations, you just re-invented point on wave switching 40+ years late.



NEC code requirements for discharge resistors

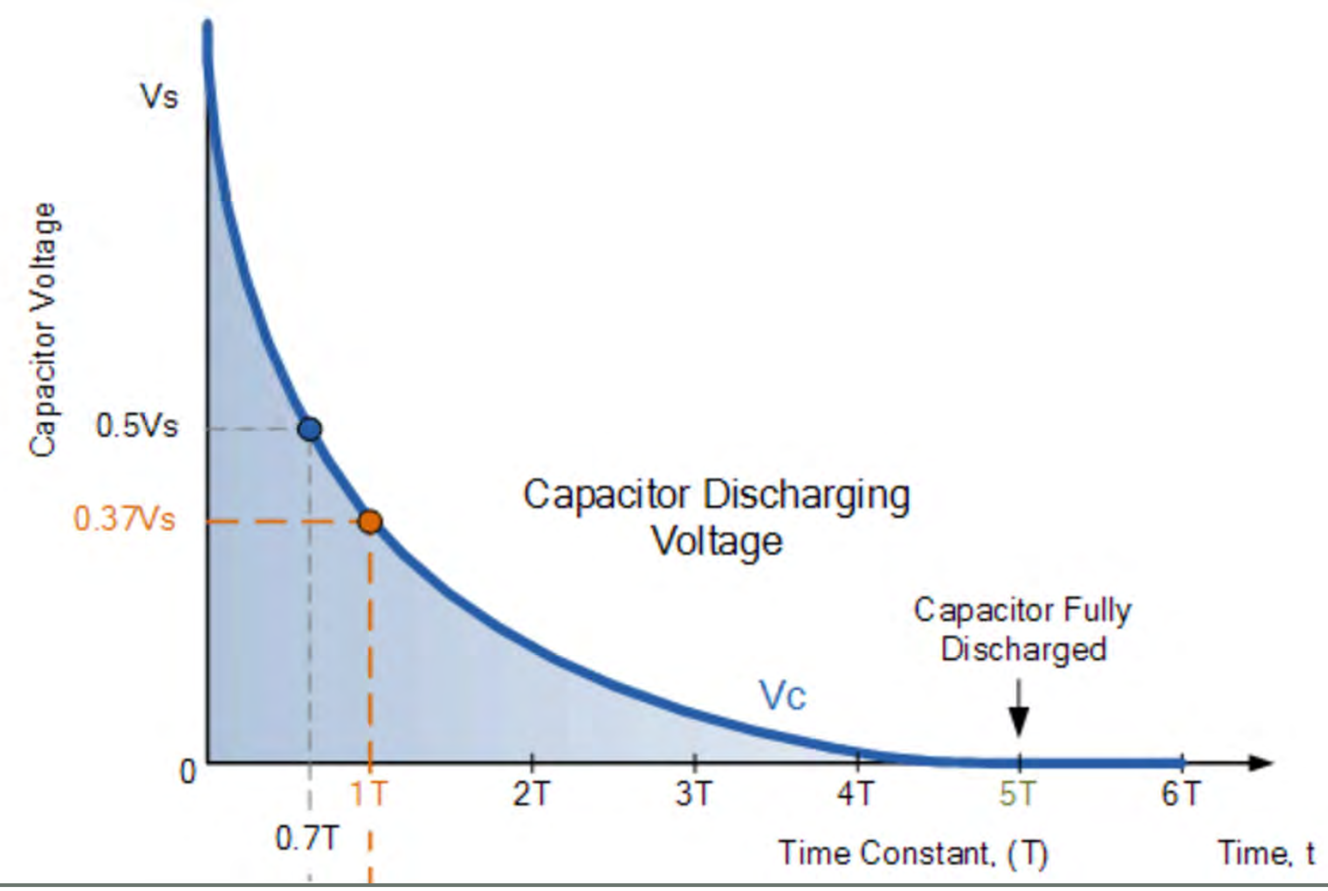
1. 460.6 - 1000 V or less - One minute or less to discharge to under 50 volts. No manual discharging
2. 460. 28 – Over 1000 V – Five minutes or less to discharge to 50 V. No manual discharging but motors, transformer windings or other equipment can be used to drain the capacitors.



How do you go about sizing a discharge resistor?

1. This is a simple RC circuit.
2. The time constant is RC
3. According to the NEC, the voltage needs to drop below 50 V in 1 minute for arrangements under 1000 V and 5 minutes for 1000 V+.

How do you go about sizing a discharge resistor?



$$V_C(t) = V\left(1 - e^{-\frac{t}{RC}}\right)$$

1. This is a simple RC circuit.
2. According to the NEC, the voltage needs to drop below 50 V in 1 minute for arrangments under 1000 V and 5 minutes for 1000 V+.
3. Final voltage is <50 V. T is 1 or 5 minutes. C is the cap banks capacitance. Solve for R. Take into account if your resistor is discharging a row or the whole thing.

Conclusions

Before discharge resistor

After discharge resistor

1. Discharging the residual charge on a capacitor bank is necessary for safety and is mandated by the NEC.

2. Discharging a capacitor bank helps reduce issues related to inrush and back to back bank switching.

3. Look at how much happier the substation tech is knowing the capacitor bank is safe to work on.