Technologies for Transient Voltage Control During Switching of Transmission and Distribution Capacitor Banks

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Introduction

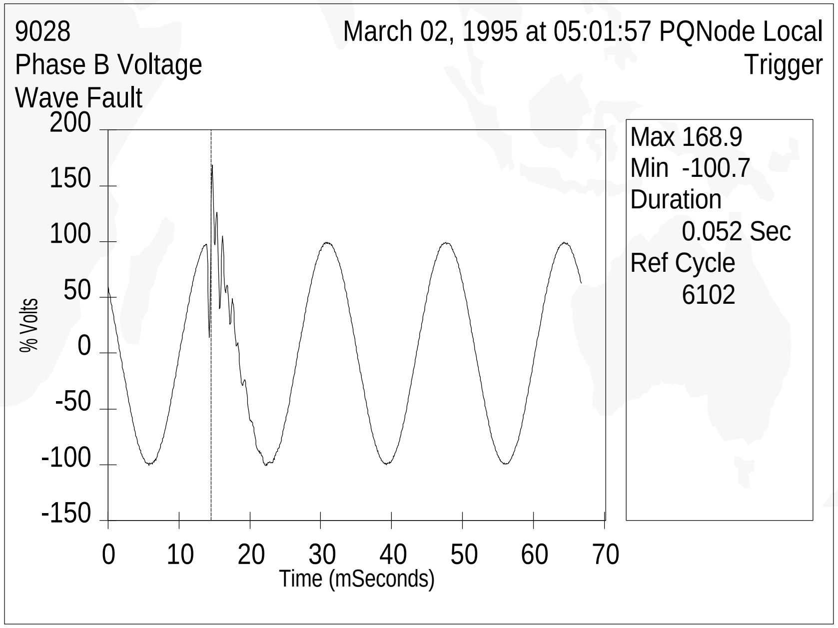
- Application Concerns
  - Voltage magnification & nuisance tripping
- Capacitor Energizing Transient
- Design Criteria
- Mitigation Techniques
- System Considerations
  - Application Experience
  - System Studies
- Conclusions

Application Concerns

- Overvoltages associated with normal energizing
- Open line/cable end transients
- Phase-to-phase transformer transients
- Magnification / impact on customer systems
- Arrester duty (restrike conditions)
- Back-to-back switching / outrush into nearby faults
- Frequency response / harmonic injection
- Ferroresonance

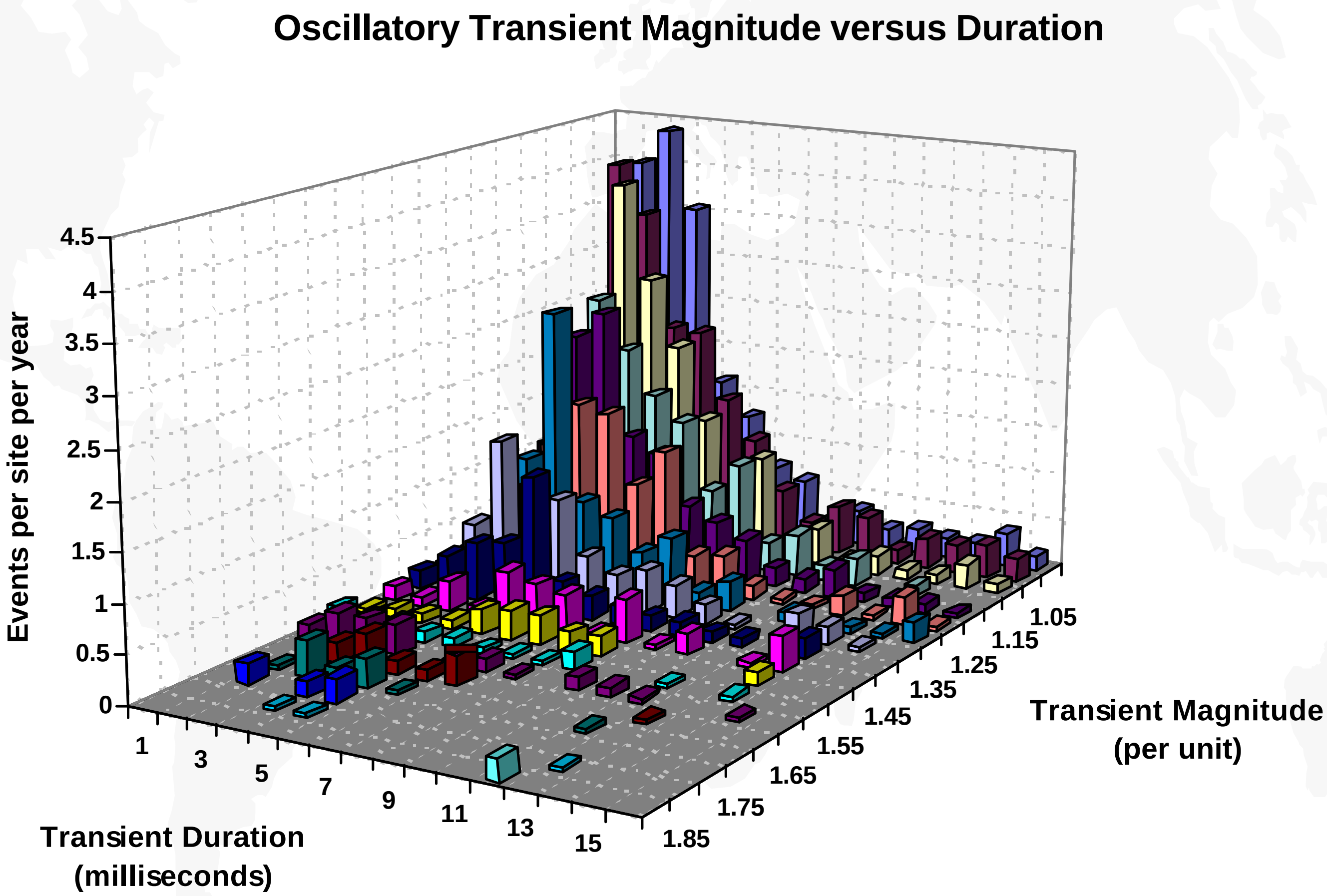
Capacitor Energizing Transient

- The voltage across a capacitor cannot change instantaneously:
  - The step change in voltage when a capacitor is energized results in an oscillation between the capacitor and the system inductance.



Typical Magnitude: 1.2 - 1.7 pu
Frequency: 300 - 1000 Hz

Distribution System Events



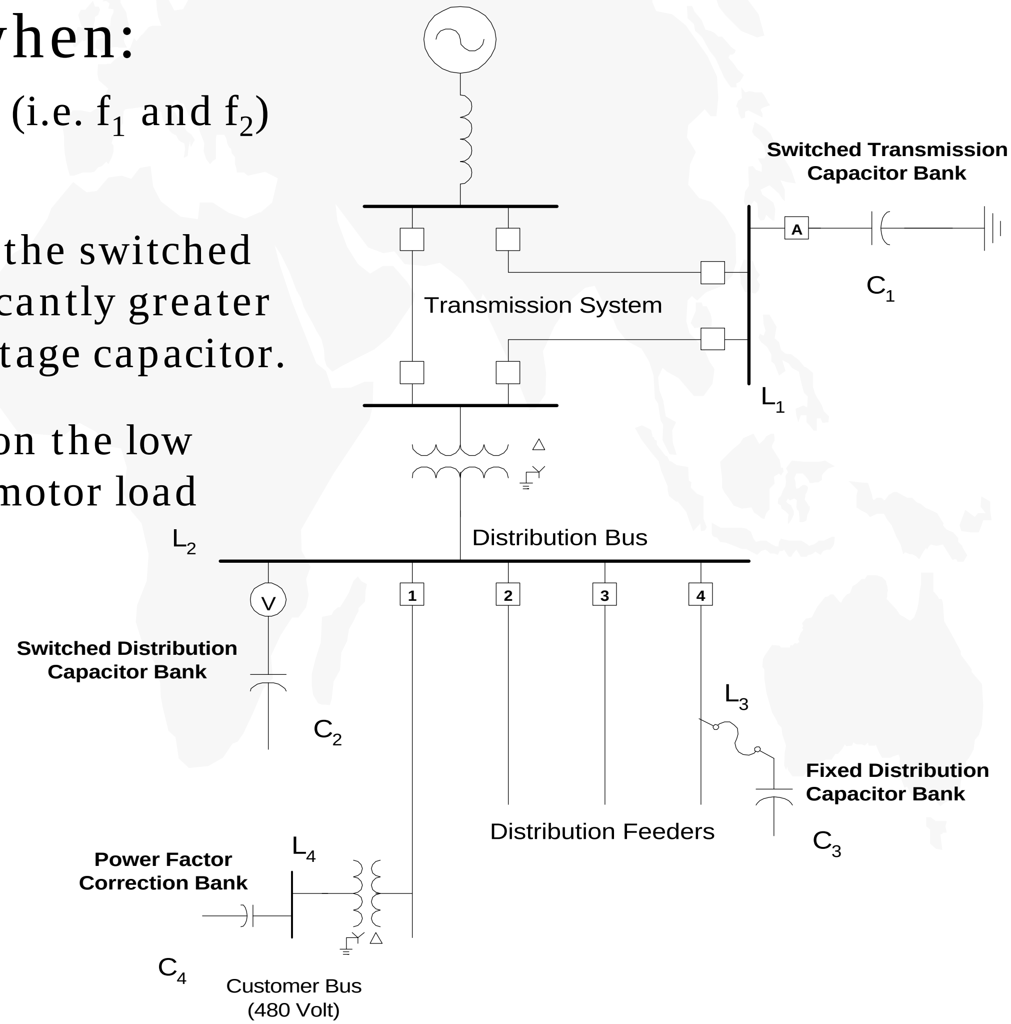
Only one transient per 5 minute period counted - measurement and phase with largest absolute magnitude used

ref: EPRI DPQ Project RP3098-01

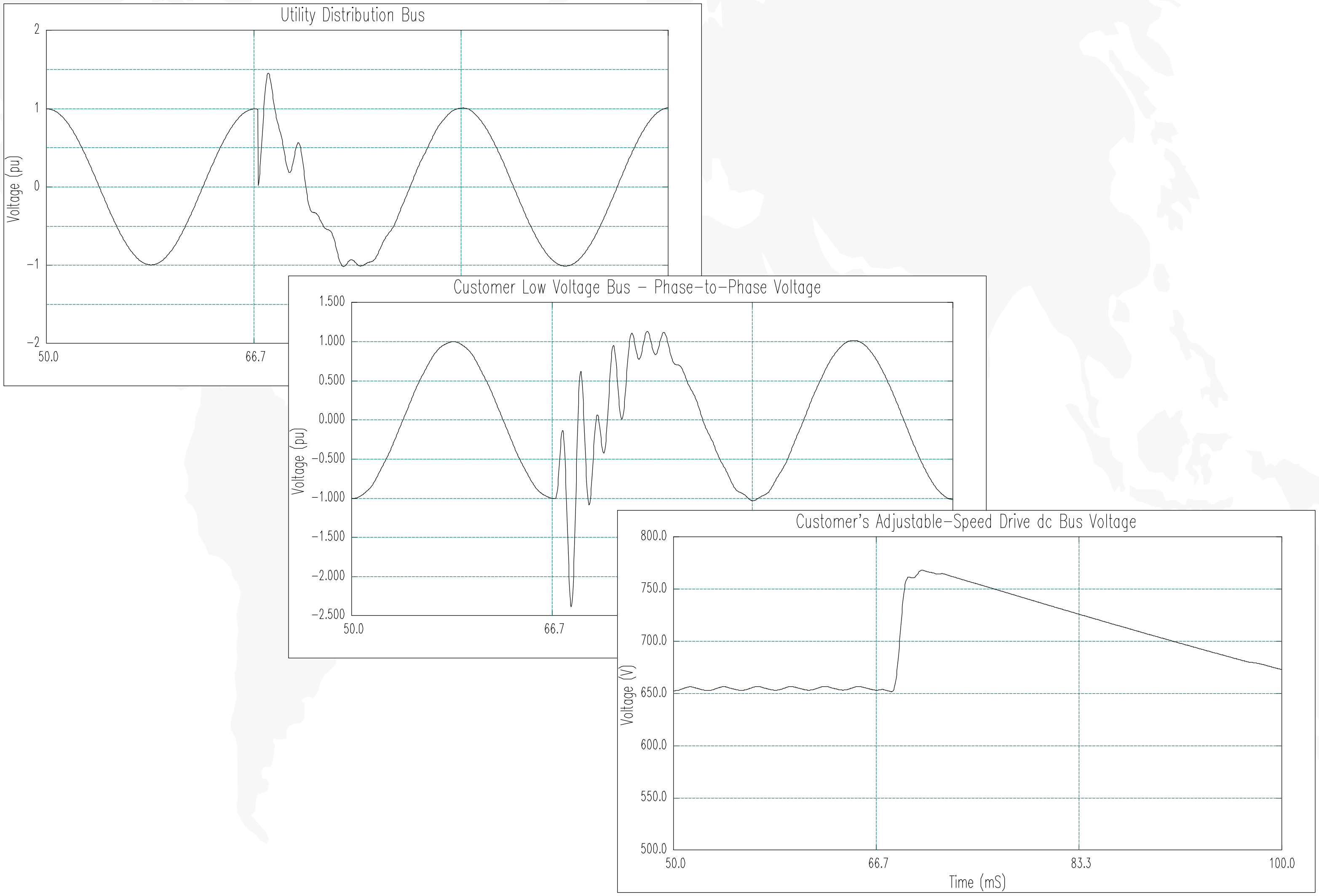
Magnification / Nuisance Tripping

- Worst case event when:
  - The natural frequencies (i.e. f_1 and f_2) are nearly equal.
  - The capacitive MVAr of the switched capacitor bank is significantly greater (>10) than the lower voltage capacitor.
  - There is little damping on the low voltage system (mostly motor load for customer systems).

$$f_n \approx \frac{1}{2\pi\sqrt{(L_n \cdot C_n)}}$$



Magnification / Nuisance Tripping



Design Criteria

- Previous factors geared toward limiting impact on the power system:
  - overvoltages
  - overcurrents
  - equipment failure
  - arrester coordination
- Today's requirements often include:
  - all of the above
  - minimizing (or eliminating) potential for mis-operation of customer PE-based equipment:
    - ***TRANSIENT-FREE OPERATION***

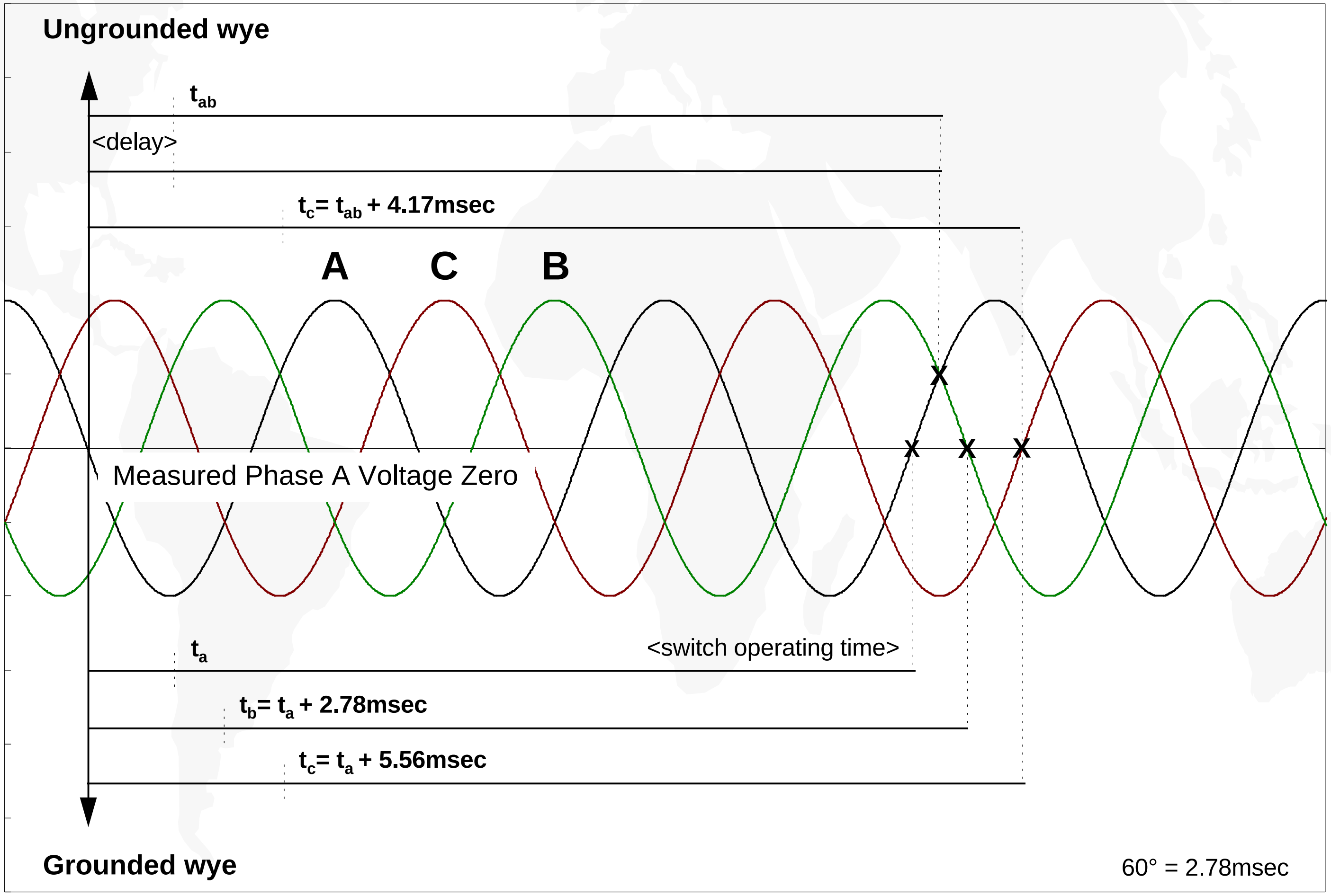
Mitigation Techniques

- Uncontrolled
  - No preventative means applied (always simulation basecase for comparison of effectiveness of other methods).
- Synchronous closing control
  - Method for controlling overvoltage by switching when the voltage across the switch at the closing instant is equal to zero.
- Preinsertion device
  - Method for controlling overvoltage by temporarily inserting an impedance (usually inductance or resistance in series with the bank).
- Arresters
  - Method for controlling overvoltage by “clipping” at a specified protective level.

Synchronous Closing Control

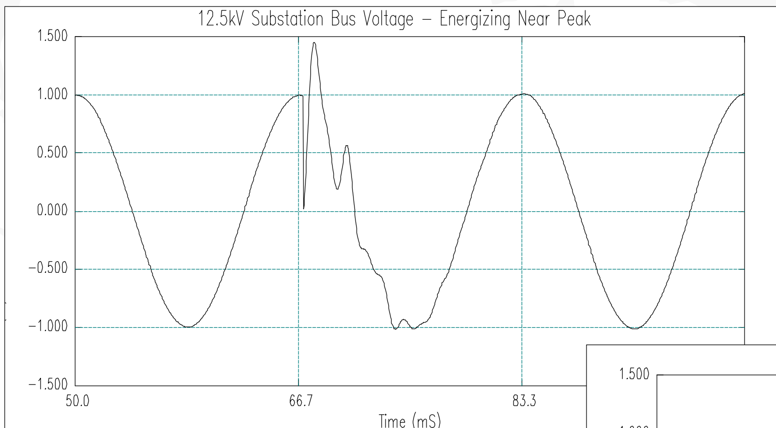
- Several manufacturers now have synchronous closing available at transmission and distribution voltage levels.
- Methods include analog and microprocessor controls.
- Can be used in combination with preinsertion device for added protection.
- Does not provide protection during restrike event.
- May be a cost effective method when considering overvoltages at lower voltages (including customers).
- Power electronics (switches) will make concept very successful as switch voltage ratings increase.

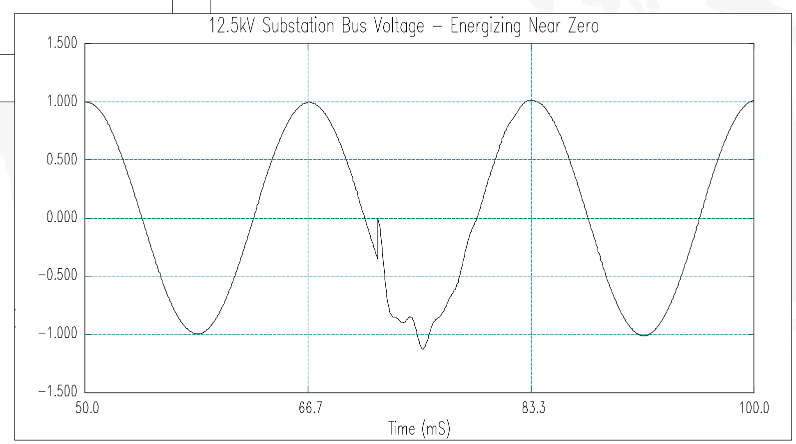
Synchronous Closing Control



Example Simulation Result

- Impact of +1.0mSecond error on energizing transient:



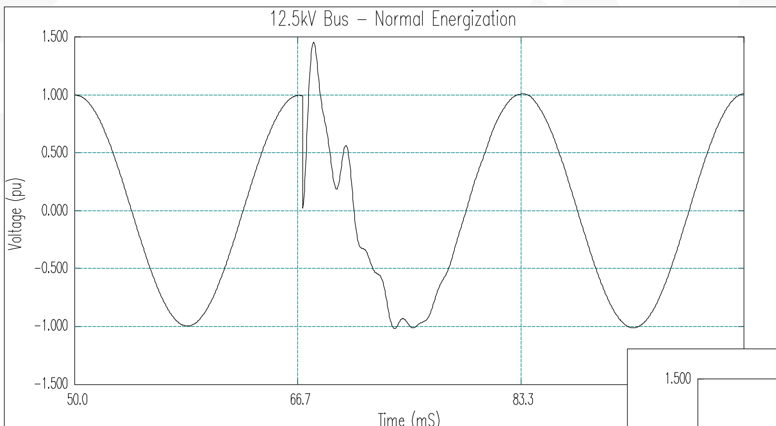


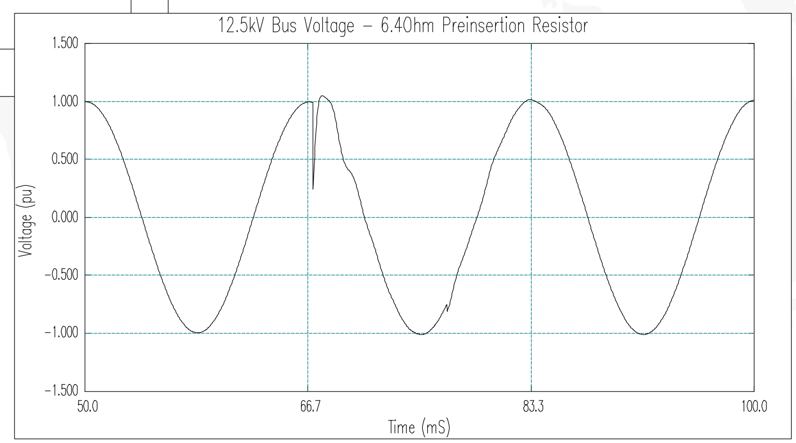
Preinsertion Device

- Many options available at transmission and distribution voltage levels.
- Devices typically include resistors and/or inductors.
- ***In general***, resistors provide better overvoltage control and inductors provide better overcurrent control.
- Can be used in combination with synchronous closing control for added protection.
- Does not provide protection during restrike event.
- May be a cost effective method when considering overvoltages at lower voltages (including customers).

Example Simulation Result

- Impact of 6.4Ω preinsertion resistor on energizing transient:





3.0 MVAr, 12.5kV
Distribution Capacitor Bank

Application Experience

Technologies have been applied with varying degrees of success.

"Degree of success" may be moving target:

- ❖ fast approaching transient-free energization

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- ❖

- ❖ Pre-insertion inductors (on transmission banks) may not

Application Experience

- Number of factors that have delayed the widespread application of mitigation technology:
  - transients generally not a major concern for utility equipment.
  - cost (may not be cost effective for smaller distribution [pole-mounted] banks)
  - reliability:
    - pre-insertion resistor failures
    - drift in the synchronous closing control signal (usually climate related)
  - No effect during restrike event

Application Experience

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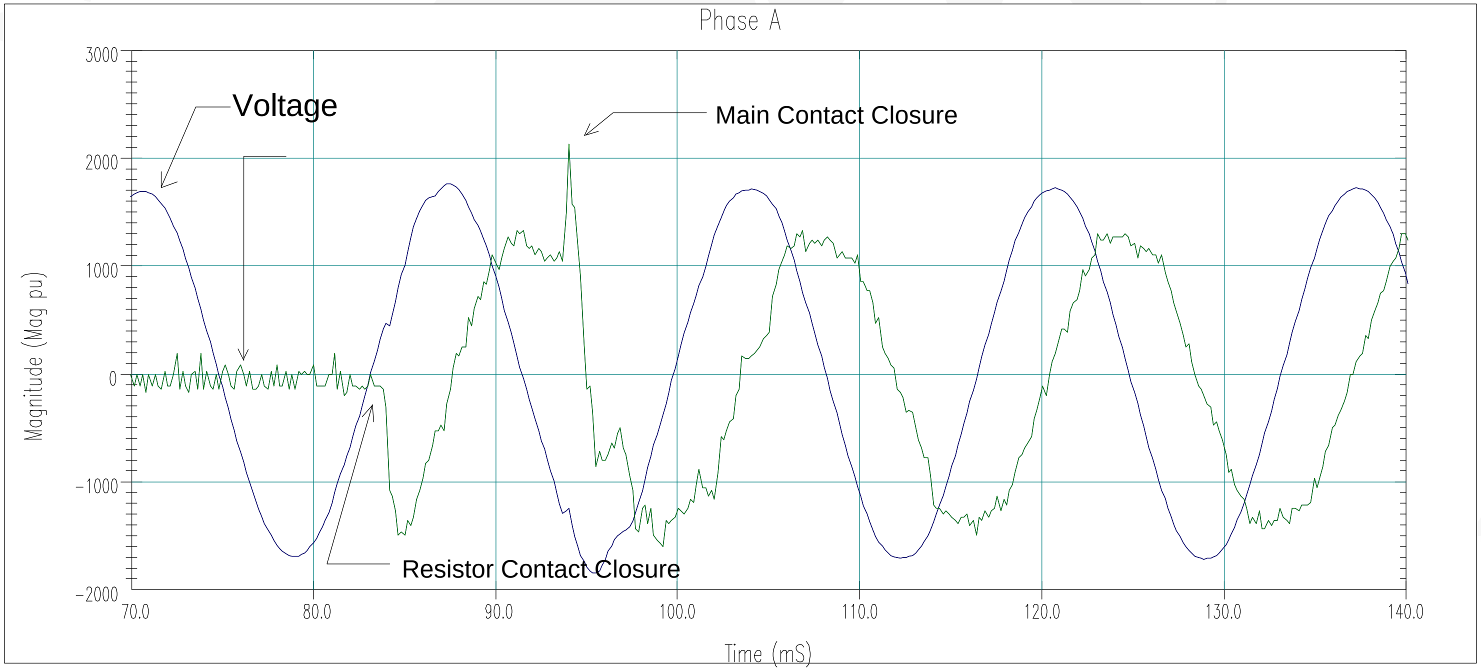
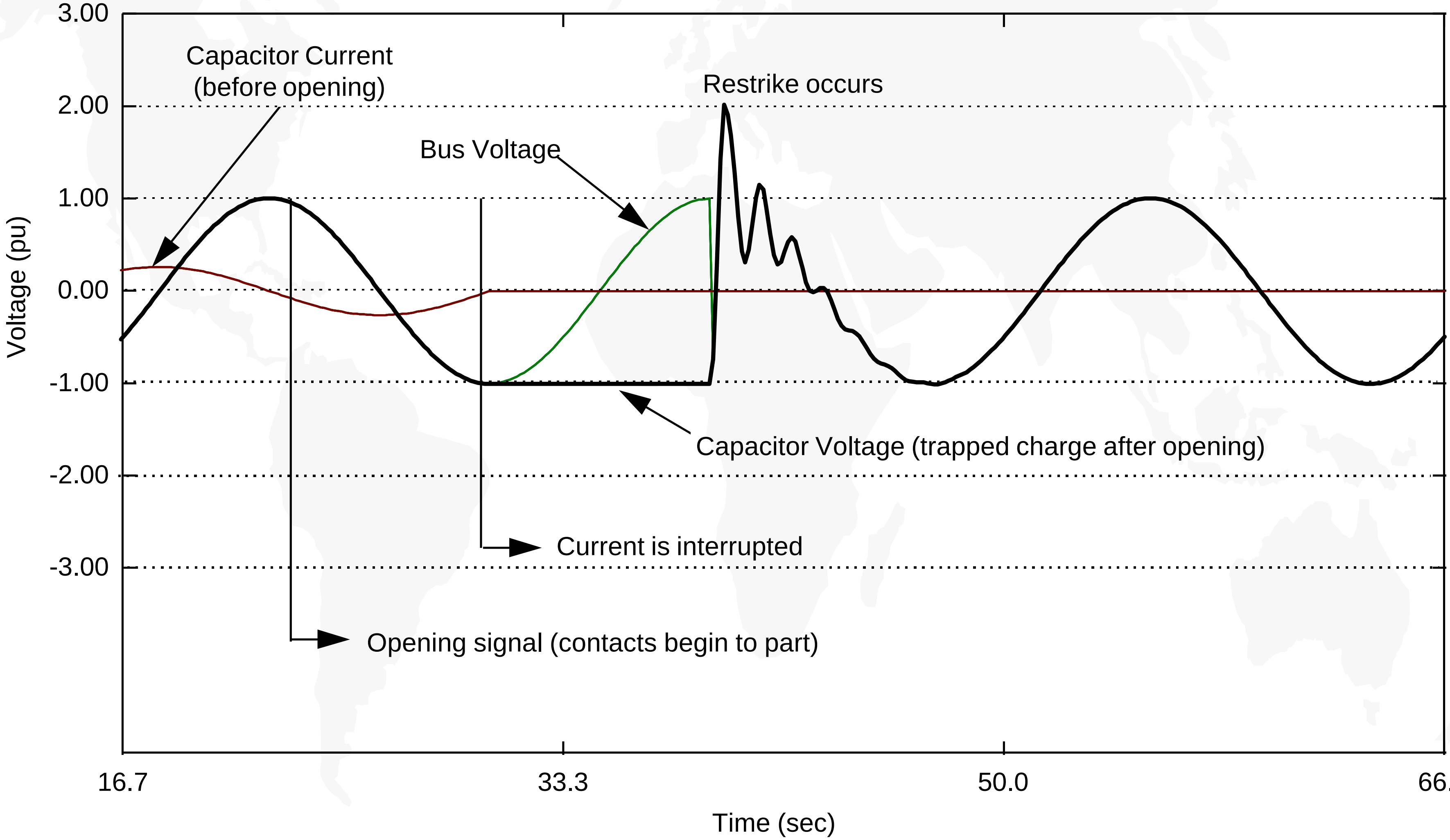
- 500kV, 367.5 MVAr
- Pre-insertion resistors and synchronous closing



Problem: Restrike Event



Future Enhancements

- Adaptive synchronous closing control:
  - microprocessor-based
  - able to learn from previous events
  - paired with three-phase breaker
- Enhanced-duty pre-insertion inductor:
  - resistive value is significantly higher (30-40 times)
  - Overcurrent and overvoltage control
- Pole top option for synchronous closing (vacuum switch)

Conclusions

- Proliferation of sensitive customer equipment has produced a new assortment of concerns.
- Typical transient levels between 1.2-1.7 pu & 300-1000Hz.
- Mitigation techniques are available for transmission and distribution capacitor applications.
- System studies may be required to evaluate effectiveness of various schemes.
- Common sense / “reasonable” design goal required.