

# The Ping Test and Circuit Resonance

by Philip J Hopkinson, PE HVOLT Inc.

Low Energy dc test circuit to determine system switching resonance

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The Circuit

The Test

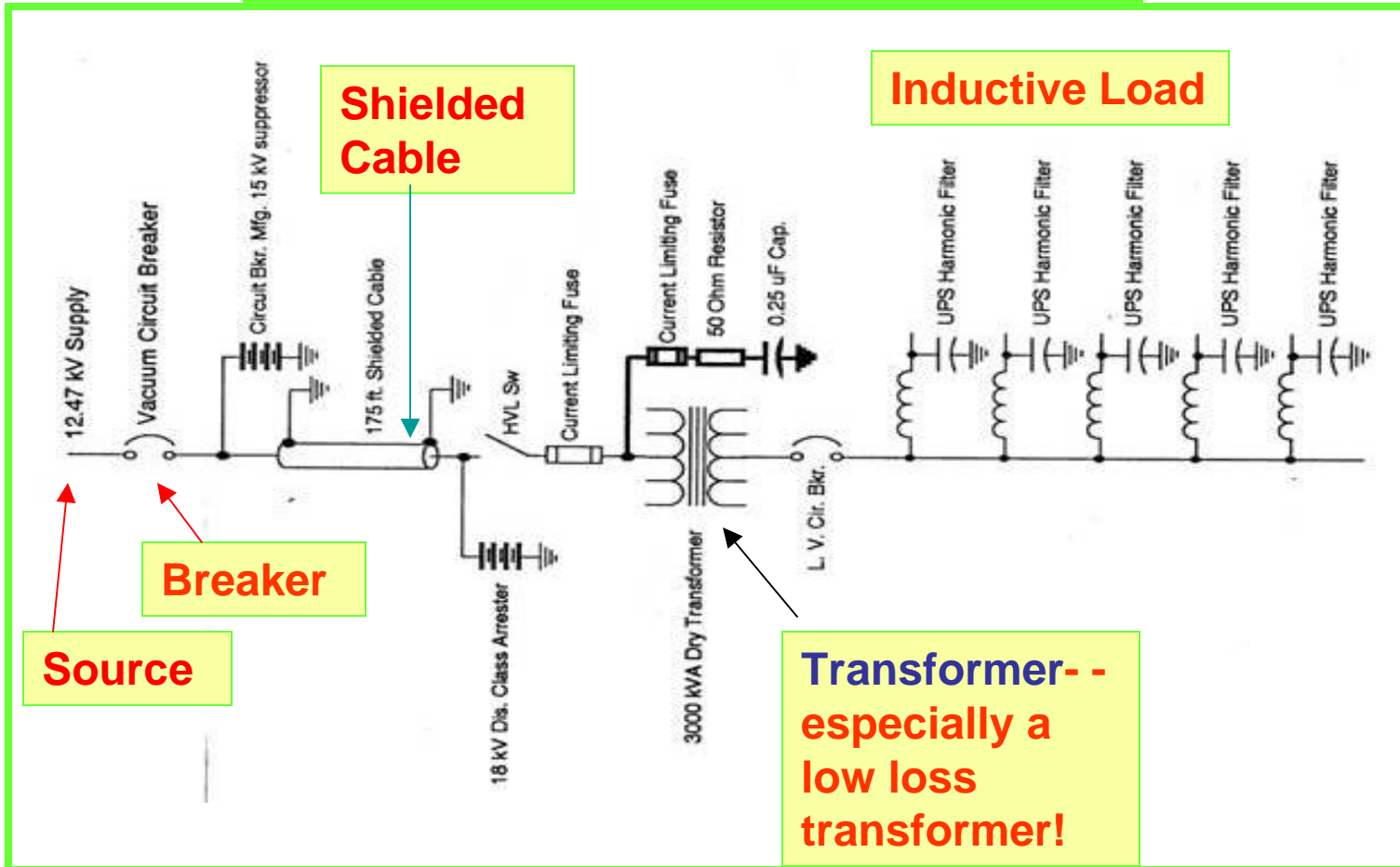
The waveforms

Conclusions and Discussion

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## Typical Circuit at a Data Center



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The Switching event:

Opening or closing the Vacuum or  
SF6 Breaker

Shielded Cable

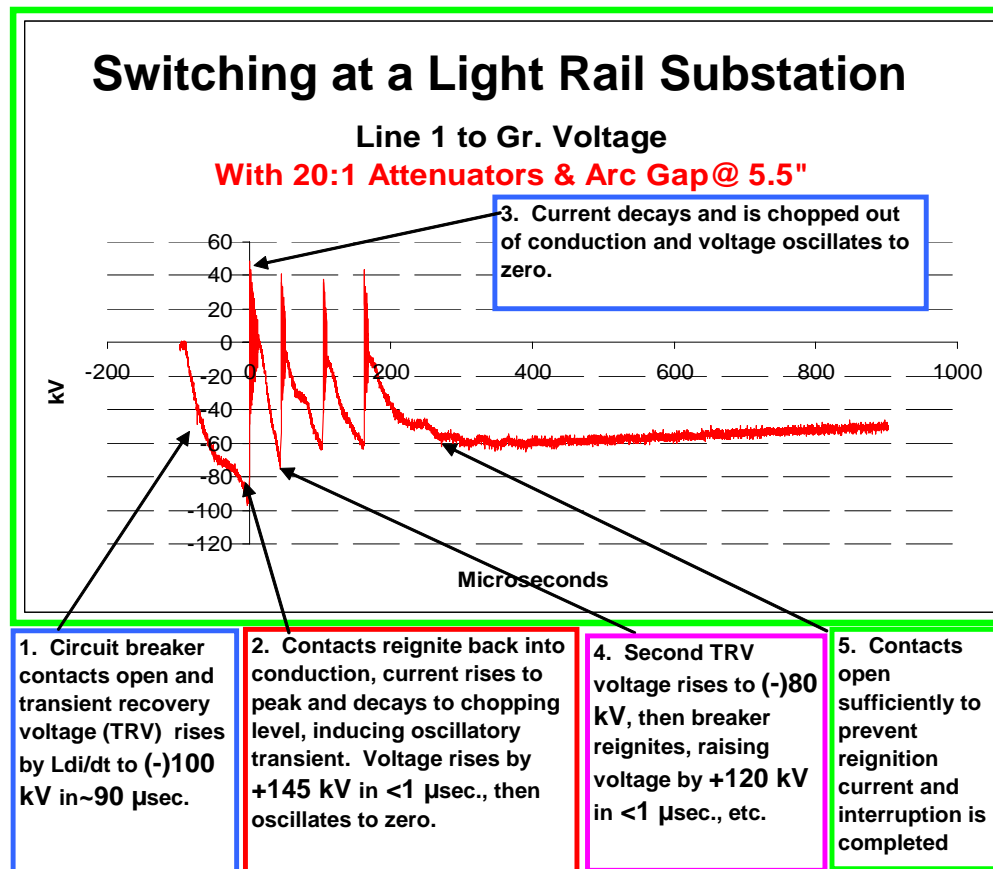
Low Loss Transformer

Inductive Load

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## The Switching event:



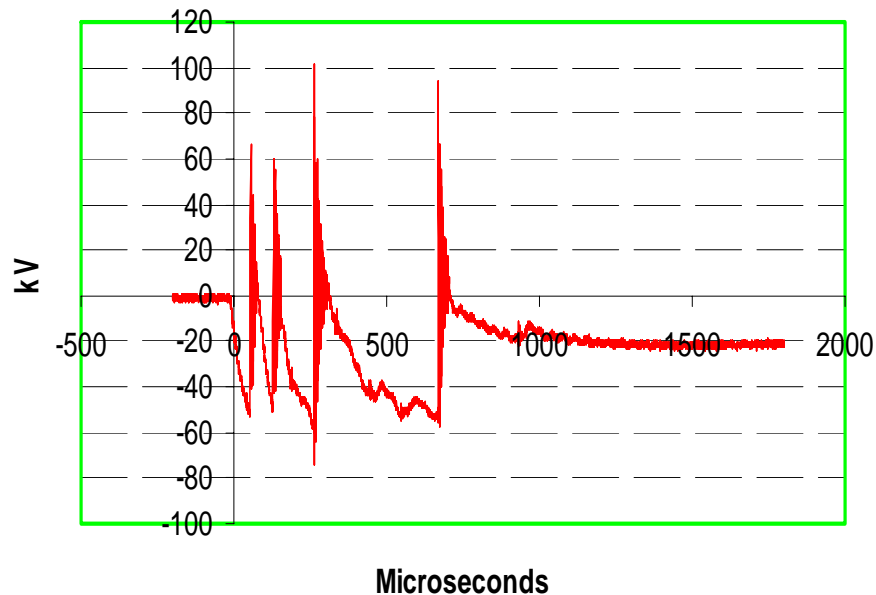
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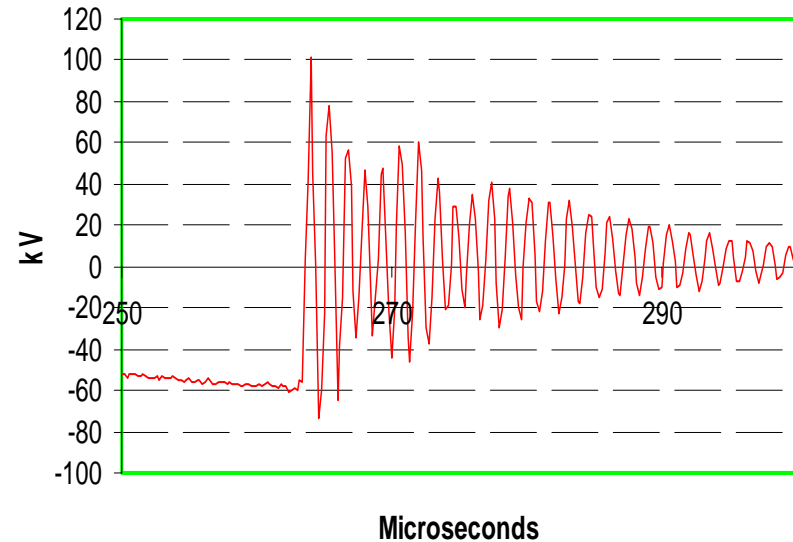
## The High Frequencies from Current Chops:

Right view is expansion from 263-300 microseconds.

Ping Test on 34.5 kV Light Rail Transformer with  
3.9 amps/pole: Line 1 to ground on 2/2/06, tap  
position 4,5  
(2:1 attenuators and 4" gaps)



Ping Test #2 at 3.9 amp/pole on 34.5 kV Light  
Rail Transformer Line 1 to ground  
(2:1 attenuators and 4" gaps),  
Reignition/Current chop starting at 263.4  
microsec. 1st rise 0.6 microsec., 714 kHz



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## The Switching event:

### Two dominant frequencies observed

- **20 kHz Transient Recovery Voltage associated with total system impedance**
- **700+ kHz Circuit Breaker chops/reignitions, driven mostly by cable impedance**

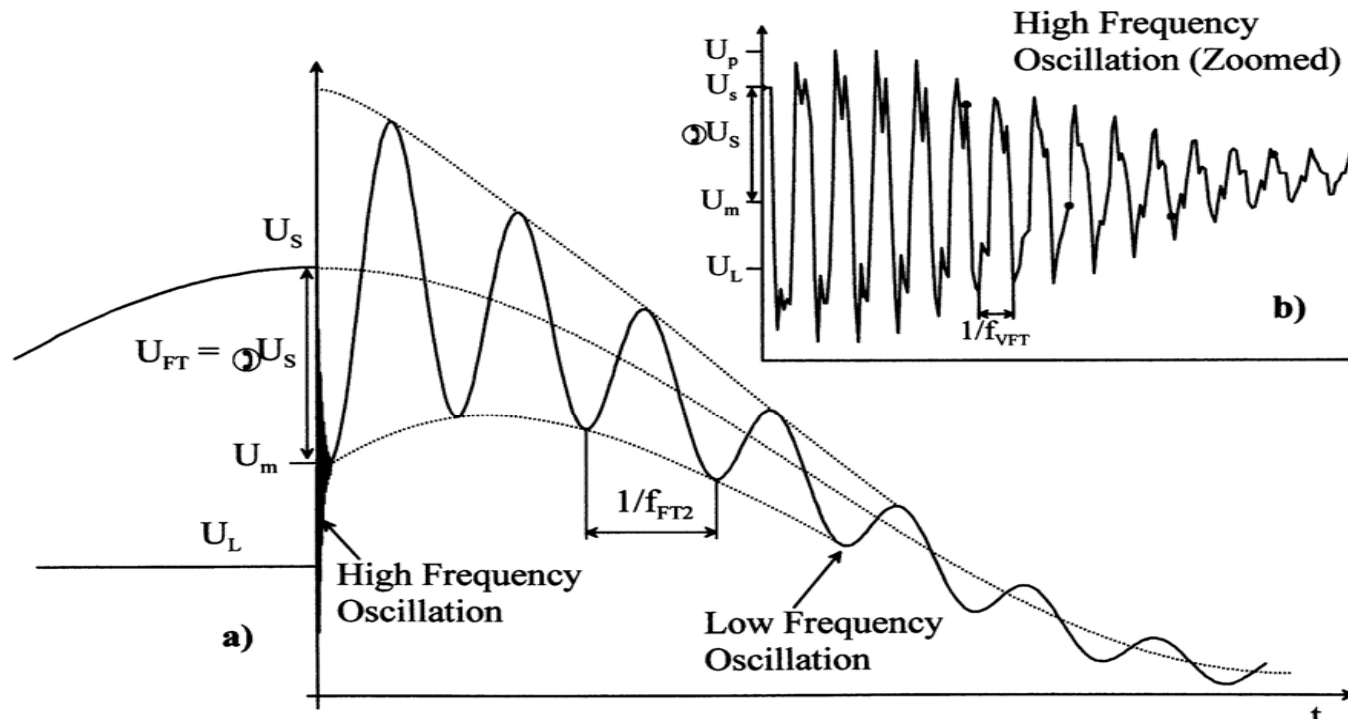
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## The Switching event:



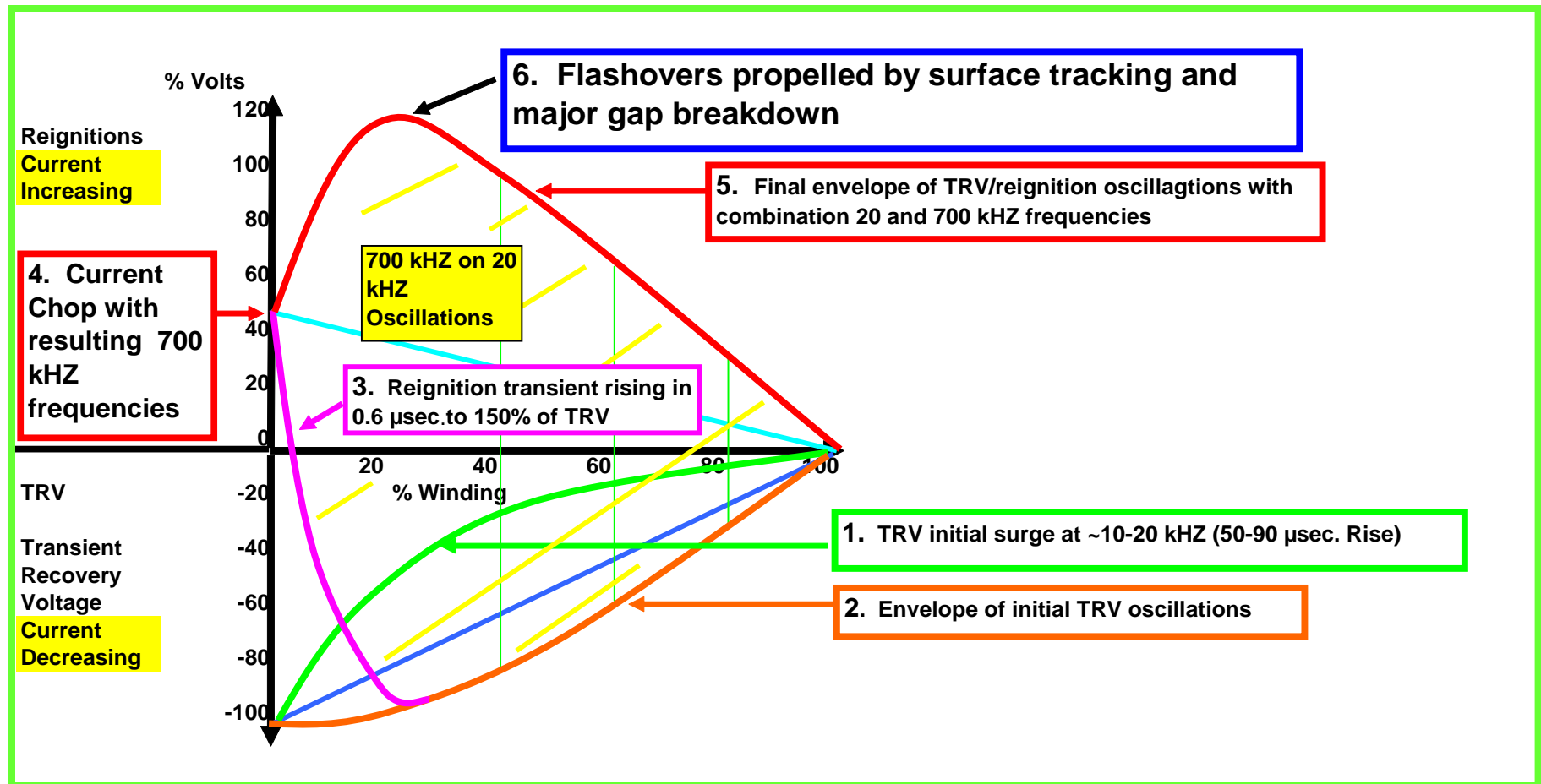
### HV SF6-insulated metal-enclosed switchgear (GIS)



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## The Switching event:

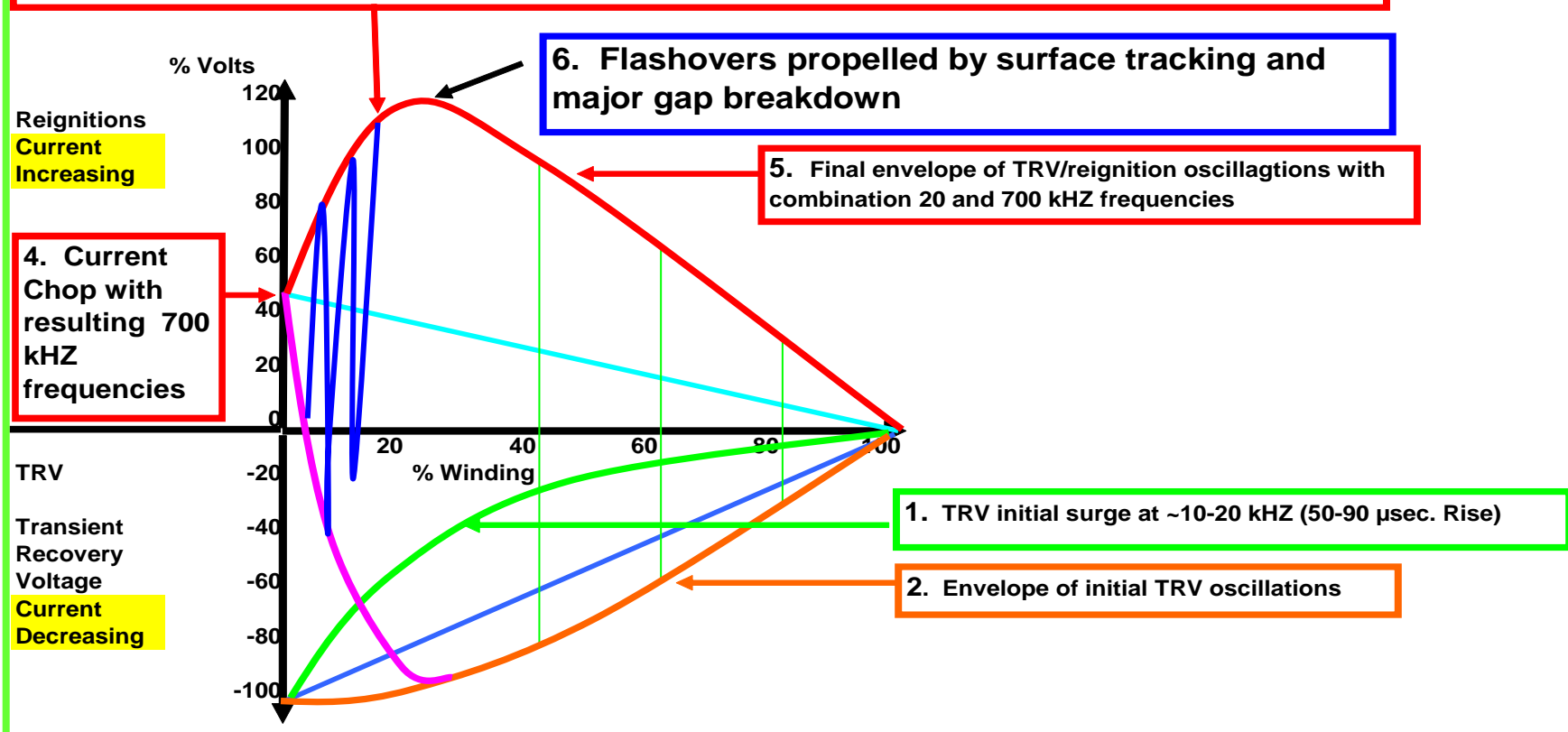


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## The Effect Of Cable Resonance:

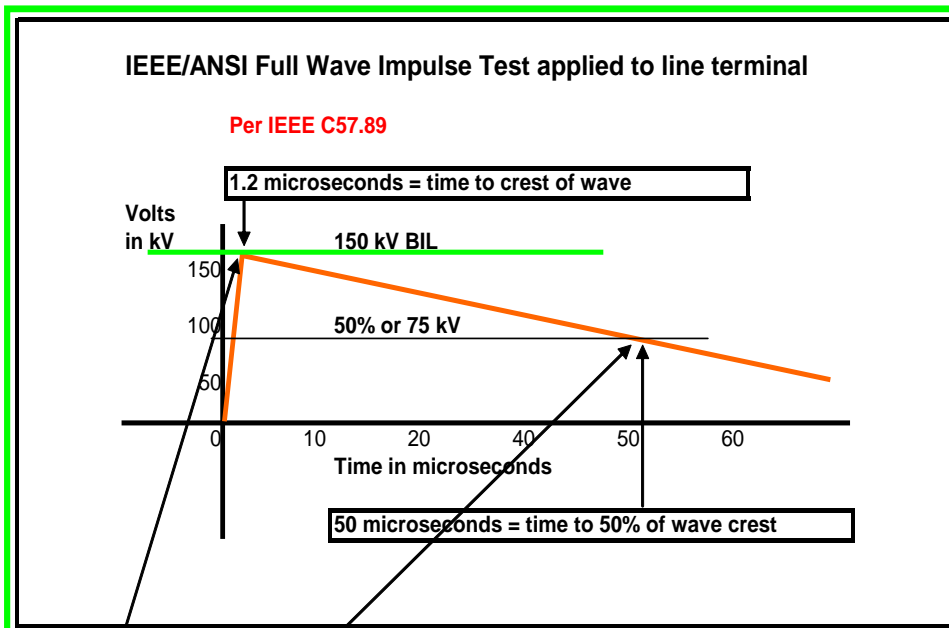
Effect Of Cable Resonance Is Large Voltage Gradients Across High Voltage Coil Surface Produced by Multiple Voltage Swings (>30) per TRV Voltage Period!



# The Ping Test and Circuit Resonance

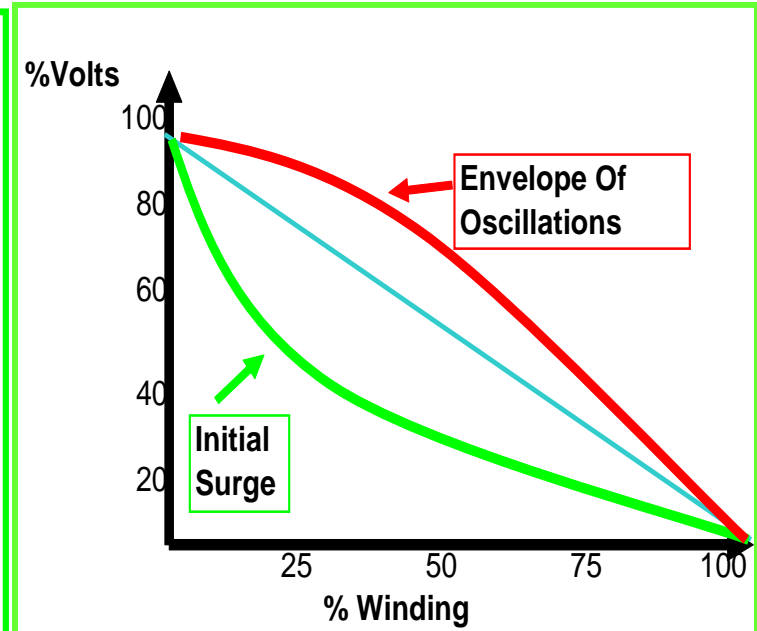
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## Relationship to Full-Wave Impulse:



Voltage rises from zero reference to crest BIL level in 1.2  $\mu$  sec.

Voltage decays slowly from crest BIL level to 50% of crest level in 50  $\mu$ sec.



Full Wave Impulse a single-event test with adjacent sections of windings oscillating together

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## Circuit Protection Objectives:

1. Minimize TRV Voltage excursion
2. Prevent Breaker reignitions

**High Frequency switching energy must be dissipated**

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## Circuit Protection Options:

- 1. Use much slower Breakers**
  - Oil
  - Air
- 2. Increase transformer Losses**
  - Magnetic Circuit
  - Windings
  - Dielectric System
- 3. Add Resistor-Capacitor Snubbers**

**Lightning Arresters alone generally not effective for Delta-Connected Windings**

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## Circuit Protection Options:

- 1. Slower Breakers is contrary to 40-year Industry evolution**
  - Oil generally considered objectionable due to maintenance, environment and safety**
  - Air-breakers used for low current switching only**

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## Circuit Protection Options:

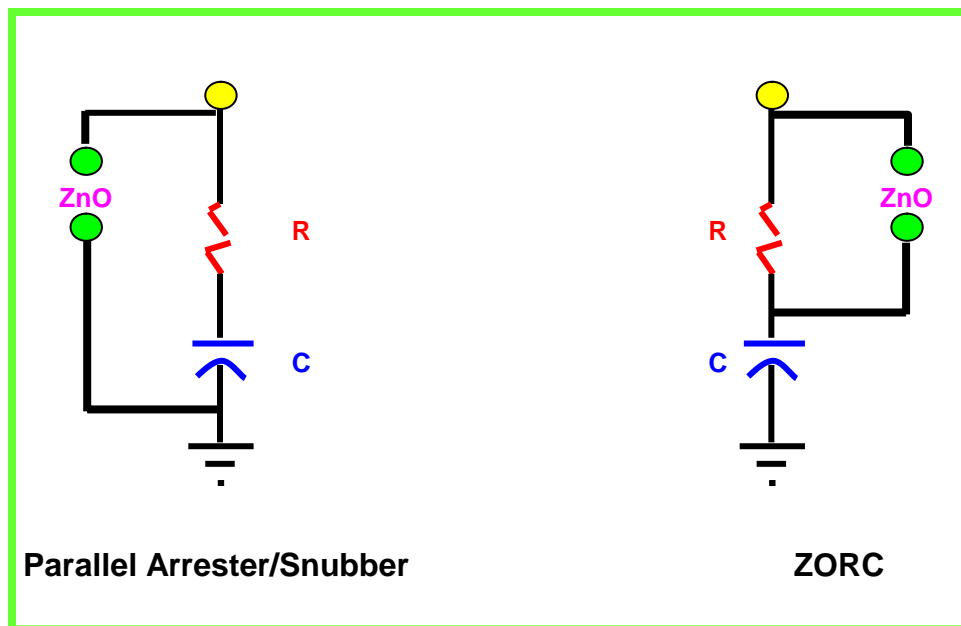
- 2. Lossy Transformers contrary to National and International push for higher Energy Efficiency**
  - **Modern magnetic circuits use high grade grain-oriented steels and wound or mitered cores.**
  - **Winding resistances kept low for efficiency, temperature rise and life**
  - **Dielectric loss normally associated with poor dielectric strength**

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## Circuit Protection Options:

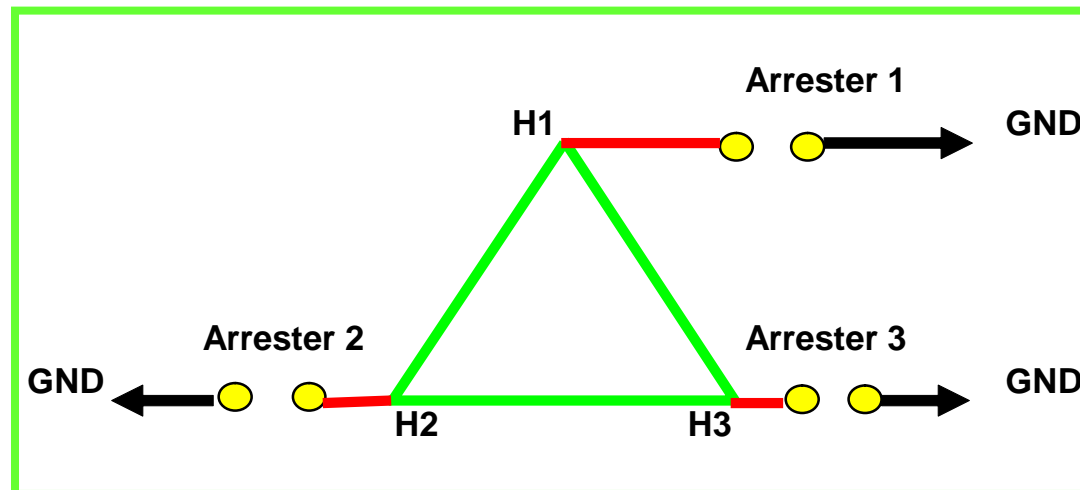
### 2. Resistor-Capacitor Snubbers Including ZORCS Costly but effective



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## Arrester Limitations For Delta-Connected Windings:



### 2 Basic Limitations Of Arresters

1. Arresters clip but do not damp
2. Arresters ground 1 corner only- protection requires 2 or more arresters to fire

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## Conclusions:

- 1. Switching Transients may produce a combination of 2 frequencies (20 and 700 kHz).**
- 2. Delta-connected high efficiency transformers with Very Low Power factor inductive loads are most susceptible, esp. Light Rail, Welders, Drives, Data Centers, and other Rectifier loads.**
- 3. Switching Voltages can easily exceed BIL Levels.**
- 4. R-C Snubbers or ZORCS are best system protectors.**