Impulse Test concepts

by Philip J Hopkinson, PE

A. Impulse Tests need to be upgraded

1. Factory tests not achieving as much winding stress as field conditions
2. Factory tests are on transformer without load and without cables
3. Series resonances are occurring between leakage reactance of transformer and capacitance to ground.
4. Part winding resonance often results in internal winding voltages > BIL
5. Failed windings in the field may even still pass impulse test back at factory!

B. No basis for reduced BIL's for Dry Types

C. Liquid Filled Transformers may need faster waves and special termination for impulse testing

Impulse Test Concepts

2007 IEEE Seminar in Minneapolis on Data Center

PJ Hopkinson, PE, R Degeneff, N McQuin

Data Center

- **Breaker**
- **Cable**
- **Transformer**
- **Inductive Load**
- **Low Power Factor**

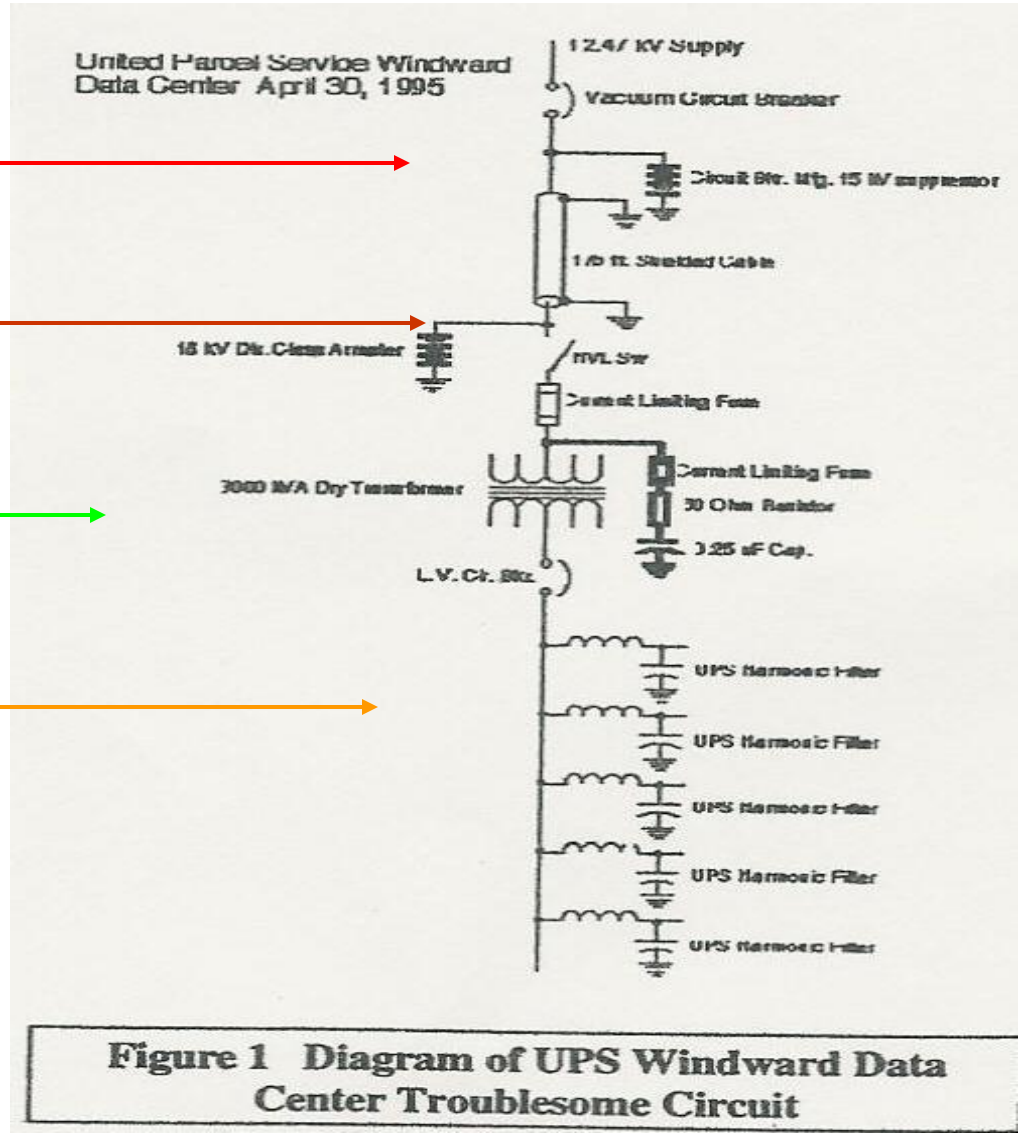

Figure 1 Diagram of UPS Windward Data Center Troublesome Circuit

Current Chops & Breaker reignitions

Impulse Test concepts

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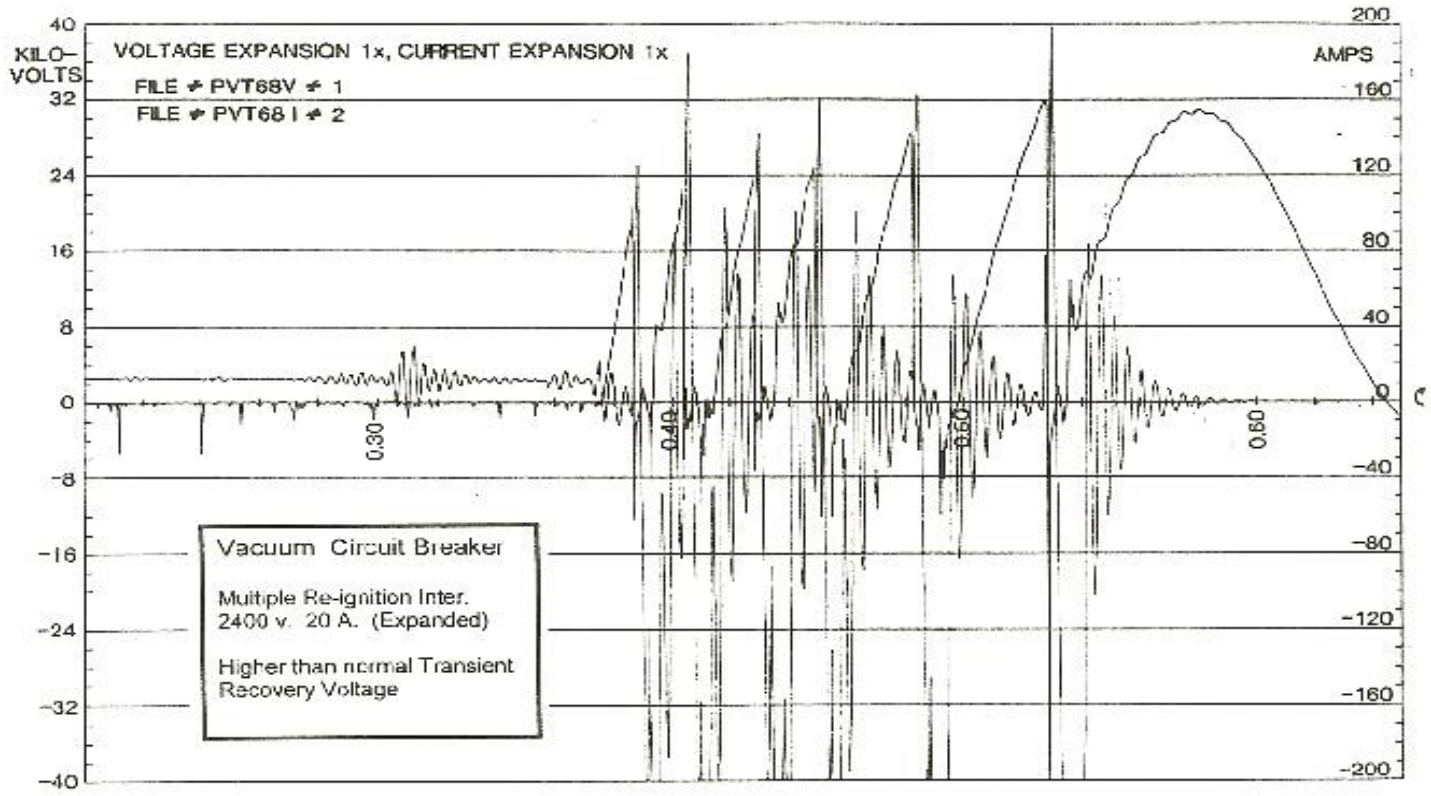
Data Center Line to ground voltage measurement with 15 kV switching-opening on ac system



Current Chops & Breaker reignitions make 700 kHZ

Two dominant frequencies: 45 kHz and 700 kHz

Impulse Test concepts

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Winding had 16 disk-disk flashovers but passed 150 kV BIL impulse back at factory!

Impulse Test Concepts

Transformer Switching-A Current Update:Part 1

PJ Hopkinson, PE, R Degeneff, N McQuin

Data Center Line-Gnd Voltage during Breaker opening with snubbers in place- - note absence of high frequency transients

Current Chops & Breaker reignitions make 700 kHZ

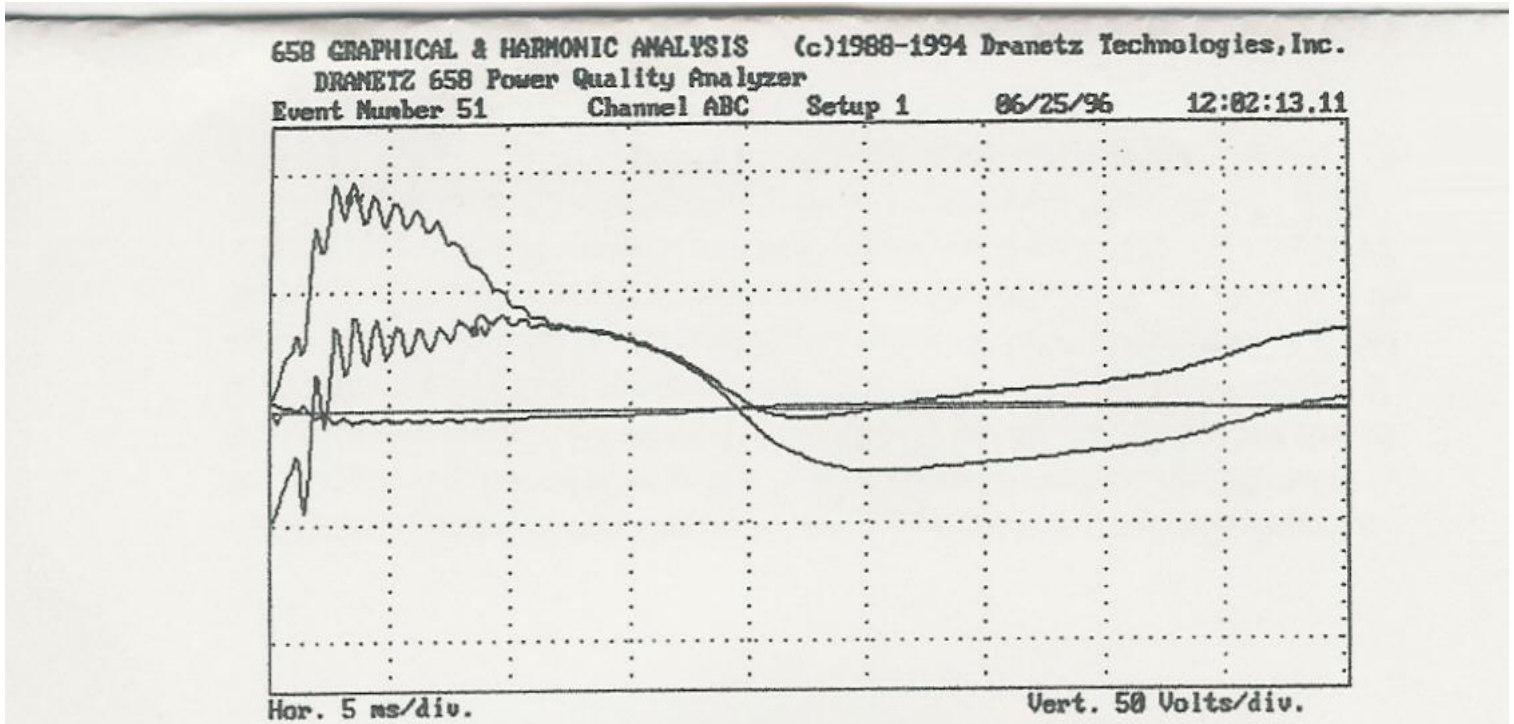

Figure 22 Test Duty #3c Opening Operation with Five Loaded UPS Units

Figure 22 represents an opening operation and as was typical there were no re-ignitions

AEP experience at 765 kV

1. Early experience had 25 field failures out of 100 transformers in 1980's.
2. Test levels too low
3. BIL raised from 1800 kV BIL to 2050 kV BIL
4. Switching Surge increased to 1700 kV
5. Induce increased to 2.0 XN Enhanced and 1.8 XN for 1 hour.
6. Chop wave at 2255 kV more severe than FFSI.
7. No failures after new tests.

Two Tests especially important:

1. Fast Front Switching Impulse
2. Special Termination Lightning Impulse

Impulse Test concepts

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Apparent upgrades that have worked in the field

1. Extensive inter-shielding of disk type windings.
2. Add line shields to layer windings.
3. R-C snubbers to provide over-damping.
4. Add multiple groups of part-winding arresters
5. Likely improvement would add series resistors to Multiple arrestors to absorb and dissipate energy.

Robustness achieved either by:

1. Improving ratio of (winding series capacitance divided by capacitance to ground)
2. Adding damping to the circuit
3. Finding ways to clip internal voltages

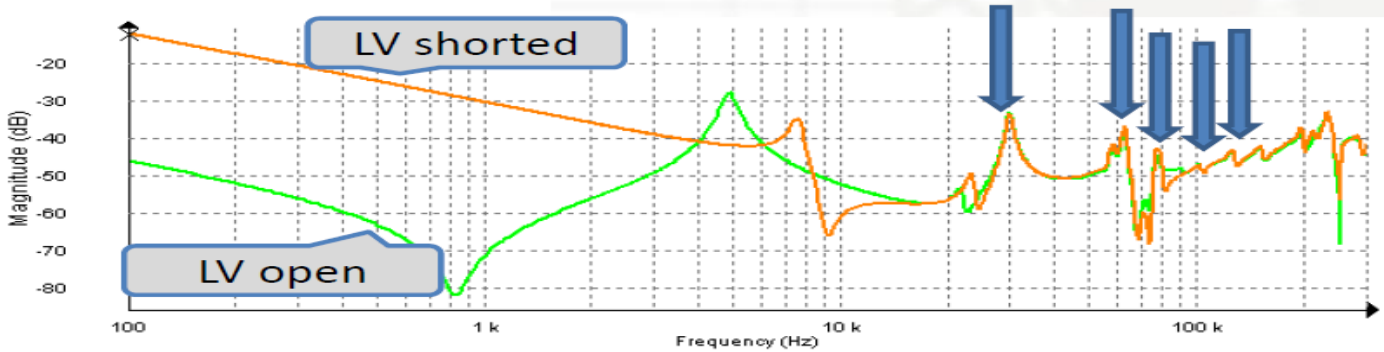
SC A2 2016 CIGRE SESSION

Identification of natural frequencies from FRA

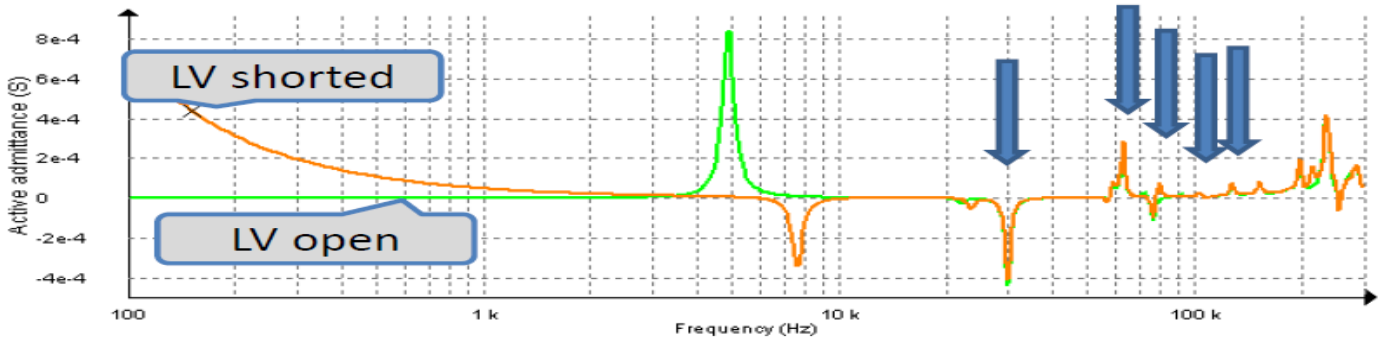
Comparison of "LV open" and "LV shorted"

- In general the frequency response of individual winding (end-to-end measurement) contains set of "resonant" frequencies, a lot of them are not winding natural frequencies.
- The natural frequencies of individual winding can be distinguished by comparison of frequency responses with open and shorted secondary winding.

Frequency response of HV winding



Active admittance of HV winding



PS1/Q1.8 V. LARIN (Russia)

SC A2 Discussion Group Meeting – 26.08.2016

Natural frequencies show resonance for LV Shorted and Open

Impulse Test concepts

by Philip J Hopkinson, PE

SFRA determination of transformer Natural Frequencies are clues but not directly relatable to field performance

1. Circuits in the field are more complex than in the factory
2. Field circuits may enhance certain natural frequencies.
   a. Cable lengths may further reinforce natural frequency response
   b. Harmonic filters and other devices may also be in tune
4. Current chops and restrikes of breakers may excite resonances.
5. Lack of any real load makes for a dangerous combination.

Strong clues to Field Problems:

1. Highly oscillatory windings to impulse and chop wave tests
2. Low power factor circuits at the point of switching
3. Lack of damping in the circuit

Impulse Test concepts

by Philip J Hopkinson, PE

Ideal Impulse Test

1. Fast rising wave.
2. Significant hold time
2. Severe chop wave.
3. Includes test with shorted terminals of untested windings
4. Includes test with open terminals of untested windings but protected with arresters.

Good impulse Test :

1. Higher line terminal voltage than can occur in the field
2. Able to excite all natural frequencies of the windings

Impulse Test concepts

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AEP success at 765 kV attributed to:

1. Raising BIL from 1800 kV to 2050 kV, or +14%.
2. Raising cop wave to 2255 kV from 1980 kV. or +14%
3. Switching impulse rise time decreased from 100 µ sec. to 1.2 µ sec.
4. Switching Impulse time to first 0 increased from 1000 µ sec. to 4200 µ sec.
5. Includes test with shorted terminals of untested windings
6. Includes test with open terminals of untested windings or protected with arresters.

Table 2. Termination Requirements for Special Termination Lightning Impulse Tests on Wye/Wye/Delta Transformers

(Only Phase 1 Tests Given to Illustrate Method)

Case	H1	H2,H3	X1	X2,X3	Ho, Xo	Y1	Y2,Y3
1	I	O	SA	O	G	SA	--
2	I	O	SA	O	G	G*	--
3	SA	O	I	O	G	SA	--
4	SA	O	I	O	G	G*	--

I = Input SA = Surge Arrester O = Open G = Grounded

*One terminal brought out and grounded

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Conclusions: Transformer design to withstand switching must add strength

1. Greater linearity of impulse wave distribution.
2. Greater attenuation of high frequency energy
3. Less susceptibility to internal series resonances

Conclusions: Impulse Testing must add stress

1. Higher BIL levels
2. Faster front waves
3. Higher chop waves
4. Longer switching waves
5. Open as well as shorted terminals of non-tested windings