Voltage Backfeed on Distribution Lines

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Background

A thunderstorm with high winds, lightning and rain caused two phases of a three-phase distribution primary lateral to blow together at a slack span location causing the A or B (unknown phase) and C phase lateral fuses to open leaving the lateral energized by only one phase.

A residential subdivision customer served by C phase on this lateral called in and reported “dimly glowing” lights.

Outage restoration personnel went to the residence and measured approximately 27V (23% of nominal voltage) at the meter base.

The voltage was high enough to cause the filaments in the incandescent light bulbs in a ceiling fan to dimly glow. The ceiling fan motor was attempting to turn.

The customer was concerned about potential damage to appliances from low voltage.

This prompted an investigation into the source of the voltage backfeed condition.

Potential Sources of Voltage Backfeed On A Distribution Circuit

Emergency generators – residential or commercial customers

Distributed generation – photovoltaic systems or wind turbines

Inadvertent interconnections with street light circuits

Transformer banks connected in delta configuration

Padmount transformers – delta and wye winding configurations

Distribution Circuit Configuration

This is a typical distribution circuit in an urban setting where both a commercial strip center and a residential subdivision are served from the same three-phase lateral.

The distribution primary voltage is 14,400V phase-to-neutral and 24,940V phase-to-phase.

The lateral circuit is protected by 3 – 100 A fuses.

Google Earth View with Primary Map

Electrical load

The commercial customers are served using 4 three-phase padmount transformers and 3 banks of single-phase transformers connected to the lateral circuit. All the transformations are wye-wye. The transformer sizes are shown below:

4 padmount wye-wye transformers

1000 kVA, 500 kVA, 225 kVA, 150 kVA

3 single-phase overhead transformers banked in wye-wye configuration

3 - 75 kVA, 3 - 37 kVA, 3 - 25 kVA

The customer served by the 1000 kVA transformer has 300 kVAR of power factor correction capacitors that are connected phase-to-phase. This customer also has 922 kVA of delta connected dry type transformers. Other commercial customers also have delta connected dry type transformers.

The residential subdivision customers are served by three single-phase underground loops that were all on C phase. The load has since been balanced across all three phases. This load is connected phase-to-neutral.

Wye-Wye Transformer Bank using 3 Single-Phase Transformers – B & C Phases Open

$V_{A\text{-}G}$ = 100% of Nominal Voltage

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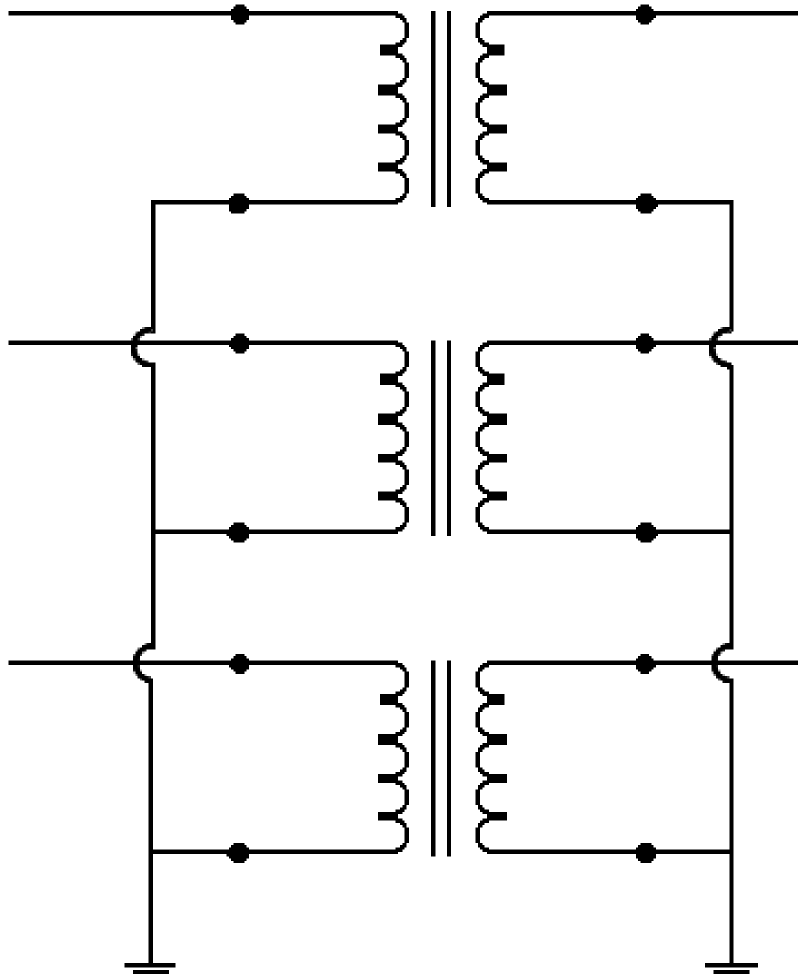


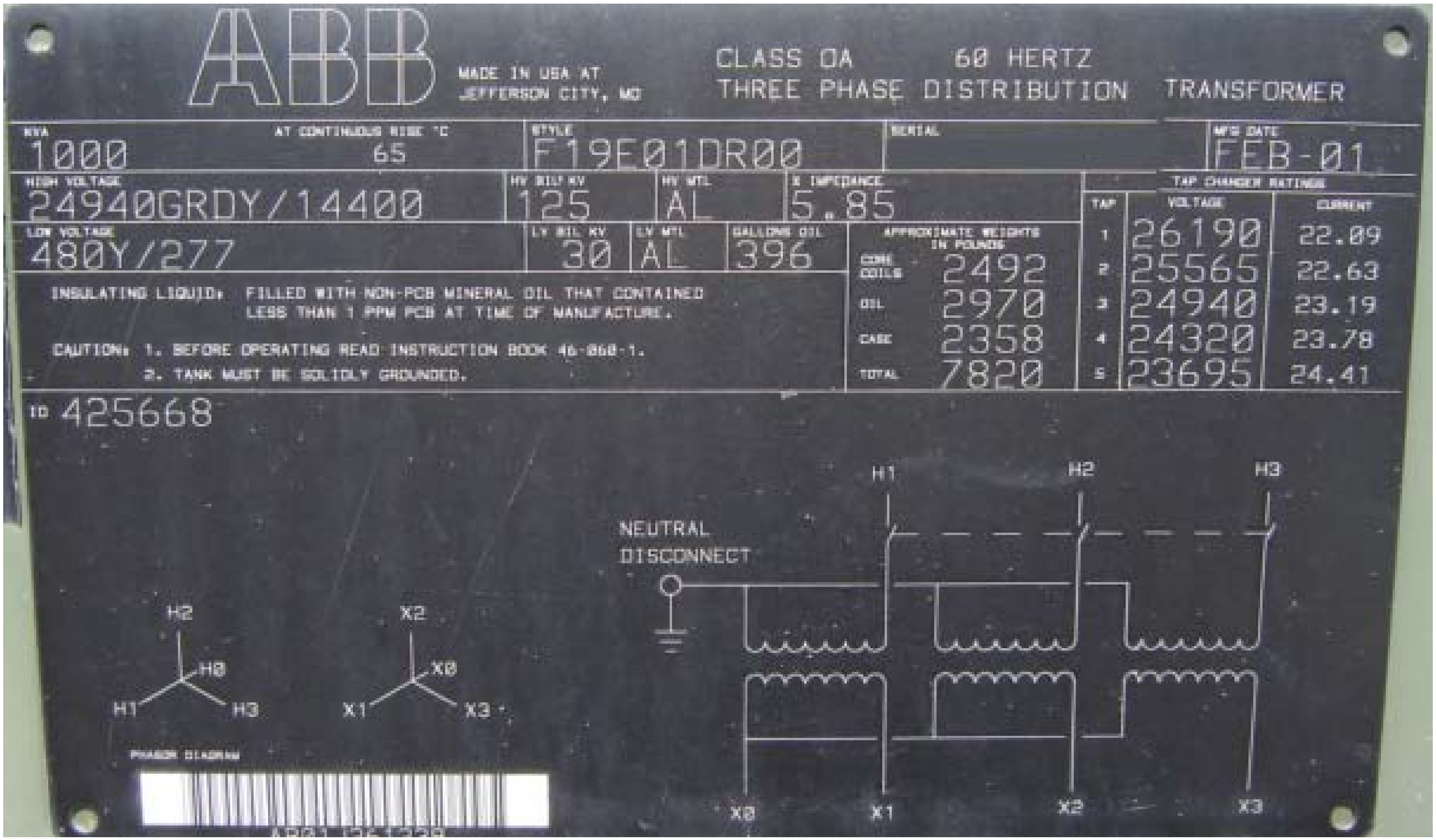
$V_{B\text{-}G}$ = OPEN

$V_{b\text{-}g}$ = 0

$V_{C\text{-}G}$ = OPEN

$V_{c\text{-}g}$ = 0

Transformer Nameplate



The connection diagram on the nameplate is similar to the diagram for three single-phase transformers connected in a wye-wye bank. Similar voltage characteristics would be anticipated based on the diagram.

Padmount Transformer Design

Oncor's three-phase padmount transformer purchasing specification requires 4 or 5 legged core design in order to reduce the probability of tank heating when zero-sequence voltage is applied.

All the padmount transformers involved in this case study were 5 legged core construction.

The result of a phase loss is not intuitive. The results of a phase loss depend on which phase is lost.

This transformer design will allow voltage to backfeed from the energized phase to the open phases.

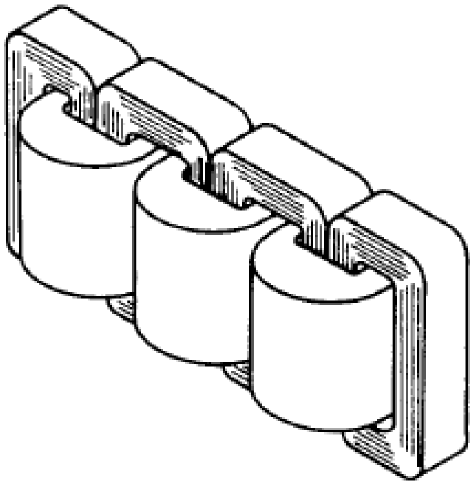


Figure 9— 3-Phase 5-Legged Core [4]

ABB Transformer Voltage Measurements

ABB agreed to assist with transformer voltage measurements under various loss of phase scenarios.

ABB Jefferson City performed voltage measurements on the transformer secondary terminals while simulating the range of open primary phase conditions in their local test booth. These tests were performed on serial 10J434104 (JC507460001) (Style F73E0179F) on March 4th 2010.

Transformer Information

The transformer under test was a 7200/12470GRDY/7200 (HV) and was a 480 Y/277 (LV). The transformer has a delta-wye switch.

The design and construction of this transformer is similar to transformers used in the Oncor system.

ABB Test Transformer Nameplate

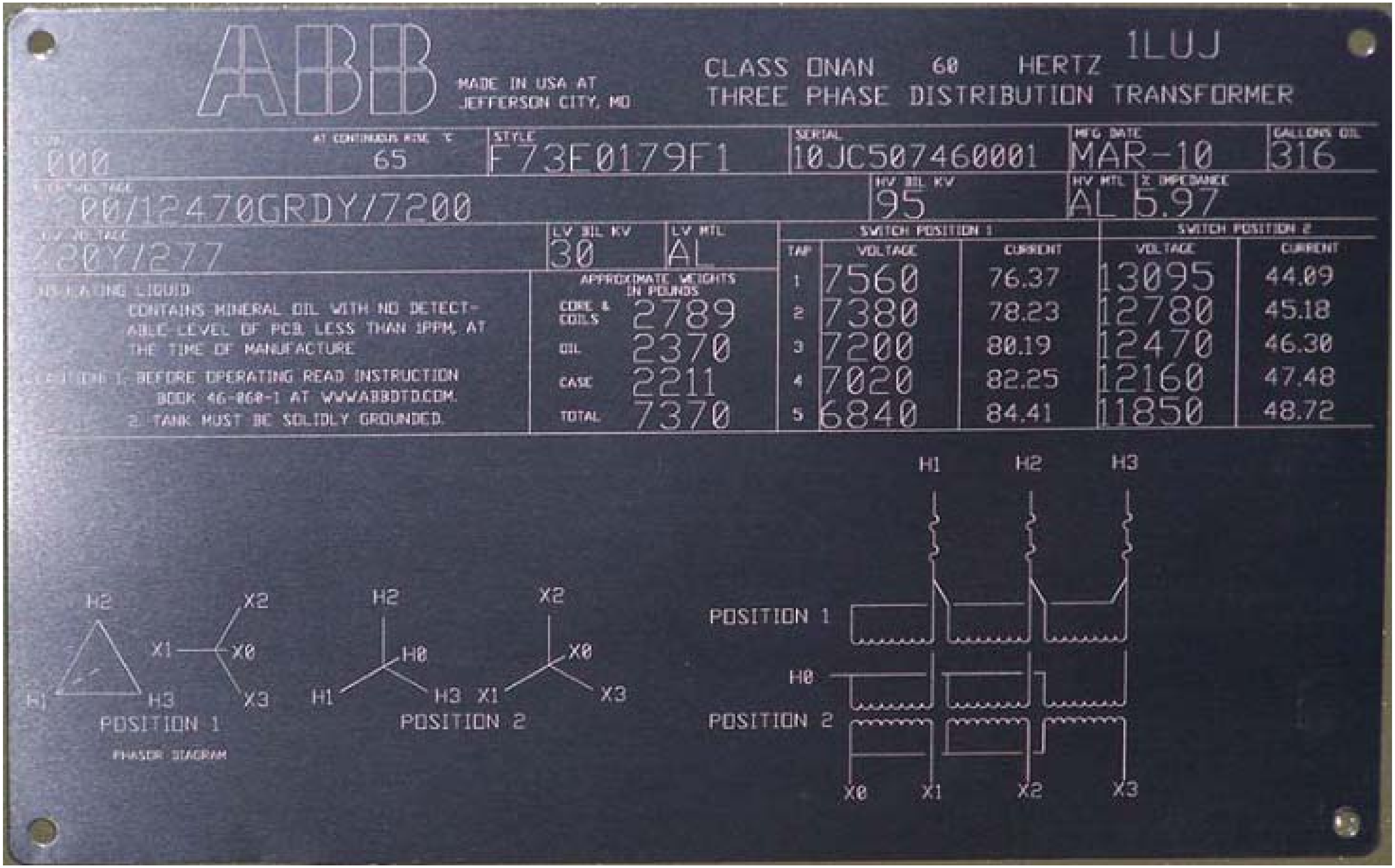


ABB Transformer Voltage Measurement Setup

ABB Voltage Measurement Testing Procedure

The testing was performed by energizing the transformer from the high side with full rated voltage and the voltage was measured on the low side.

Different scenarios of voltage loss on the the high side was tested.

The test was performed on Wye HV position and was repeated on Delta HV position.

The test was performed on nominal tap (Tap Position 3).

Transformer Voltage Measurements (Delta-Wye) ABB Test Results – All Cases with Open Phases For Reference

Phase Designation	A	B	C	a	b	c	a	b	c
Measurement points	H1	H2	H3	X1-X0	X2-X0	X3-X0	X1-X0	X2-X0	X3-X0
Units V = Volts % = % of Rated Voltage	V	V	V	V	V	V	%	%	%
1	7200	7200	7200	277	277	277	100%	100%	100%
2	0	7200	7200	149	164	276	54%	59%	100%
3	7200	0	7200	276	163	149	100%	59%	54%
4	7200	7200	0	138	276	138	50%	100%	50%
5	7200	0	0	4	4	1	1%	1%	0%
6	0	7200	0	1	5	4	0%	2%	1%
7	0	0	7200	3	0	3	1%	0%	1%

Transformer Voltage Measurements (Wye-Wye)
ABB Test Results – Open Primary Phases
No Load Connected On Secondary

Phase Designation	A	B	C	a	b	c	a	b	c
Measurement points	H1-H0	H2-H0	H3-H0	X1-X0	X2-X0	X3-X0	X1-X0	X2-X0	X3-X0
Units V = Volts % = % of Rated Voltage	V	V	V	V	V	V	%	%	%
1	7200	7200	7200	277	274	279	100%	99%	101%
2	0	7200	7200	183	275	277	66%	99%	100%
3	7200	0	7200	276	147	277	100%	53%	100%
4	7200	7200	0	277	275	183	100%	99%	66%
5	7200	0	0	275	131	68	99%	47%	25%
6	0	7200	0	141	274	141	51%	99%	51%
7	0	0	7200	56	132	275	20%	48%	99%

Transformer Core Flux Paths - Example
Phase A Energized, Phase B & C Open

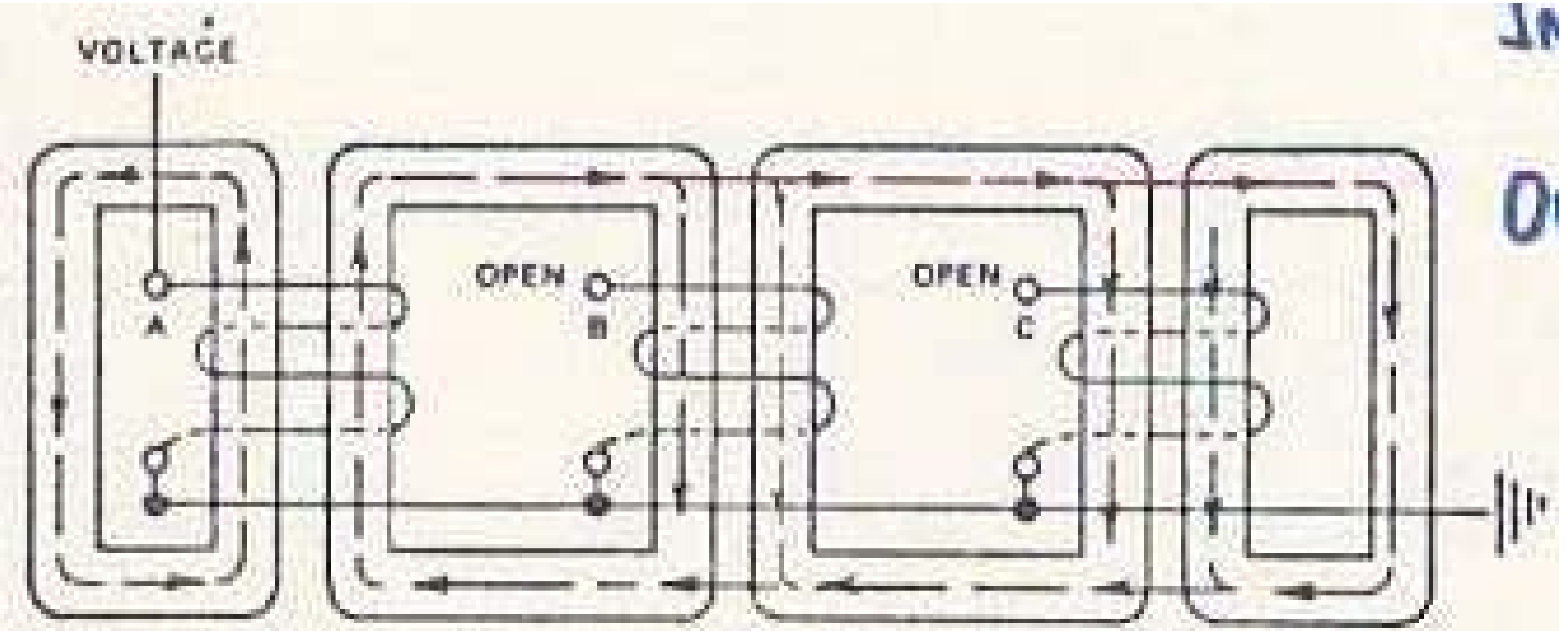


Figure 2 – WESCORE FLUX PATTERN - PHASE A ENERGIZED
PHASE B & C OPEN

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Voltage Comparisons (Wye-Wye) – With Phases B & C Open at Lateral Fuse Location

Phase Designation	A	B	C	a	b	c	a	b	c
Measurement points	H1-H0	H2-H0	H3-H0	X1-X0	X2-X0	X3-X0	X1-X0	X2-X0	X3-X0
Units	V	V	V	V	V	V	%	%	%
ABB Factory Measurements - With no load	7200	0	0	275	131	68	99%	47%	25%
Field Measurements with some load									
Measurements at 1000 kVA Padmount									
300 kVAR Capacitors ON	14400	0	0	285	57	94	100%	20%	33%
300 kVAR Capacitors OFF	14400	0	0	282	44	70	100%	16%	25%
Measurements at the 500 kVA Padmount	14400	0	0	284	70	52	100%	25%	18%
Measurements on A Phase in Subdivision	14400	0	0	123			103%		
Measurements on B Phase in Subdivision	14400	0	0		27			23%	
Measurements on C Phase in Subdivision	14400	0	0			32			27%

Effect of Phase-To-Neutral Load on Excitation Voltage on Open Phases

The amount of phase-to-neutral load present on the phases influences the voltage levels on the corresponding open phases of the transformer.

The comparison of voltage measurements in the ABB results to the field measurements indicate that more phase-to-neutral load will further reduce the open phase voltage levels.

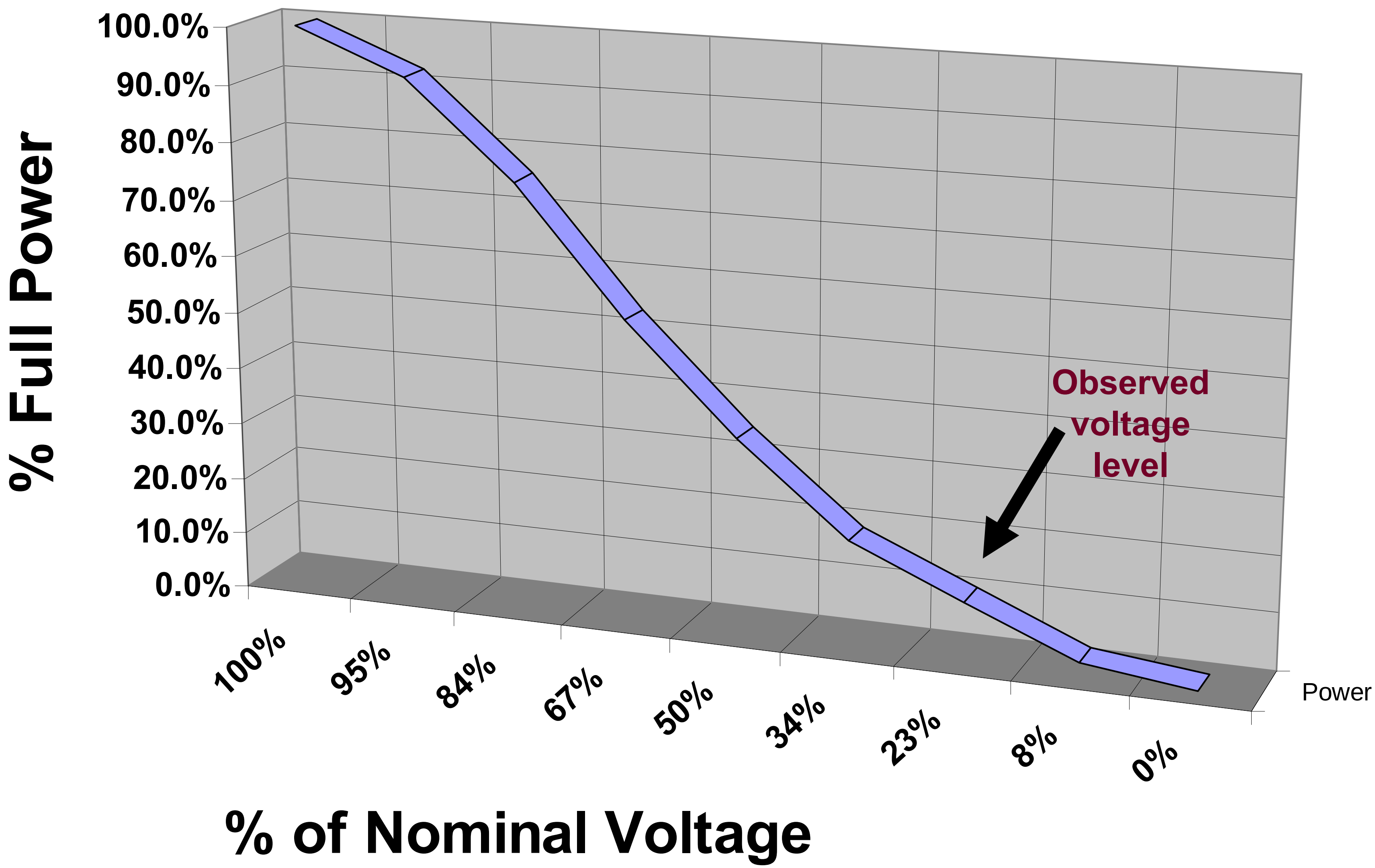
Voltage and Current Measurements During Extended Low Voltage Conditions

Measurements were taken on an incandescent light bulb in the lab in an effort to determine the voltage sensitivity of light bulbs and to estimate the amount of load that might be present at each home during reduced voltage conditions.

Field measurements of voltage and current using power quality recorders were taken at three selected single-phase padmount transformers during an outage to balance the subdivision load across all three phases. Measurements were also taken at the 1000 kVA and 500 kVA three-phase transformers. The voltage and current levels that occurred during the open phase conditions were recorded.

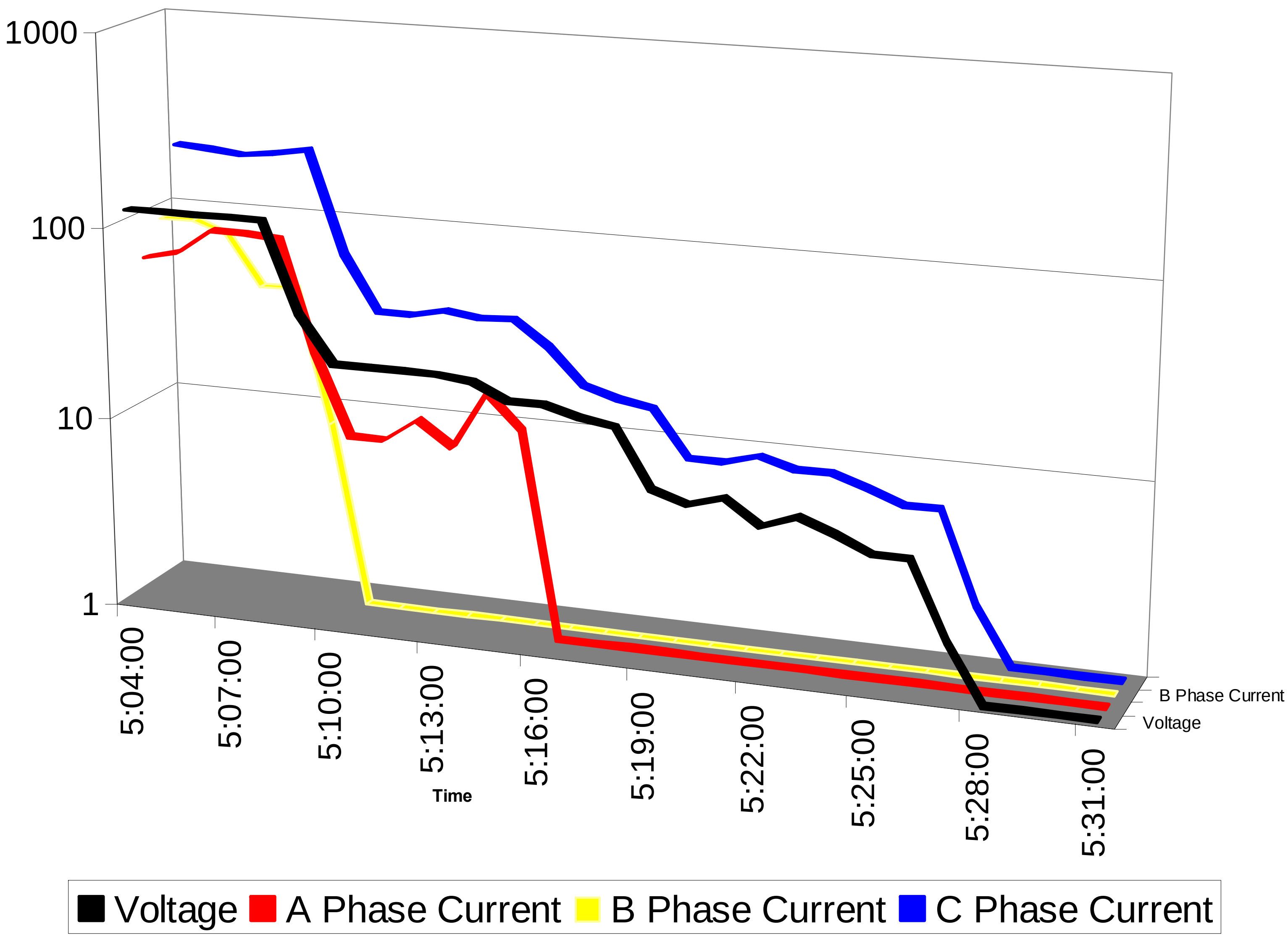
The load measurement results are shown on the following slides.

Voltage Sensitivity of 45W GE Reveal Light Bulb



Variability of Residential Load Currents vs. Voltage Level

(A Φ at 37 kVA, B Φ at 37 kVA, C Φ at 75 kVA transformer)



Load Characteristics under Low Voltage Conditions

"Modern loads typically have a higher power factor, wider voltage range, and more constant power characteristics than their predecessors. In general, modern controlled loads (e.g. office equipment containing switching power supplies; adjustable frequency drives), drop out at a minimum voltage and do not restart until near rated voltage or until manually reset." [1]

"Motors used in small residential air conditioners and refrigerators tend to stall when the voltage is reduced below 60% for 5 cycles or longer.

Under these conditions, the motor will continue to draw very high current, depending on the voltage level, approaching the locked-rotor current at rated voltage. The motor will normally trip on thermal overload after 3 to 30 seconds." [2]

"Larger commercial and industrial air conditioners are typically equipped with an undervoltage protection relay that trips-off the unit for voltages less than 70% in 0.1 seconds." [3]

Conclusions

An open fuse doesn't mean the line is de-energized. In this case, the primary voltage was measured in excess of 3 kV on the open phases at the fuse location!

Utility personnel have been trained to consider any conductor to be energized unless it has been de-energized and grounded.

Customers need to be told the same message.

The low voltage condition caused by an open conductor situation will last as long as it takes utility personnel to respond to the outage.

This low voltage condition should not result in damage to the customer's appliances. The customer can trip the main breaker until the electrical service returns to normal.

Remember, It's not dead unless it is grounded!

Acknowledgements

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We thank the Oncor personnel who initially observed and reported this condition and performed the subsequent field measurements: Joe Loosier and Kenneth Townsend.

References

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2. Williams, B.R.; Schmus, W.R.; Dawson, D.C.; “Transmission Voltage Recovery Delayed by Stalled Air-Conditioner Compressors”, *IEEE Transactions on Power Systems,* Vol. 7, No. 3, pp. 1173-1181, August 1992.
3. J. W. Shaffer, “Air Conditioner Response to Transmission Faults”, *IEEE Transactions on Power Systems*, Vol. 12, No. 2, pp 614-621, May 1997.
4. IEEE C57.105-1978, IEEE guide for application of transformer connections in three-phase distribution systems.