PQSoft Case Study

Ferroresonance in an Underground Distribution System

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Solution	Proper Protection	Load	Three-Phase Switching
Problem Cause	Unbalanced Switching	Fuse Blowing	Single-Phase Reclosers
Load Type	Distribution System		
Customer Type	Utility		
Miscellaneous1	Ferroresonance	Transient	Dynamic Overvoltage
Miscellaneous2			
References			

Abstract:

The term ferroresonance refers to a special kind of resonance that involves capacitor and iron-core inductance. The most common condition in which it causes disturbances is when the magnetizing impedance of a transformer is placed in series with a system capacitor. There are several modes of ferroresonance with varying physical and electrical characteristics. Some have very high voltages and currents, while others have voltages close to normal. There may or may not be equipment failures or other evidence of ferroresonance in the electrical equipment. In many cases it may be may be difficult to tell if ferroresonance has occurred, unless there are witnesses or power quality monitoring instruments installed.

This case study presents a ferroresonance evaluation for a 34.5kV underground distribution system.

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RELATED STANDARDS

IEEE C57.105-1978, IEEE Std. 1036

GLOSSARY AND ACRONYMS

MOV	Metal Oxide Varistor Arrester
MSSPL	Maximum Switching Surge Protective Level
SiC	Silicon Carbide Arrester

INTRODUCTION

An underground distribution system ferroresonance evaluation was completed for the system shown in Figure 1.

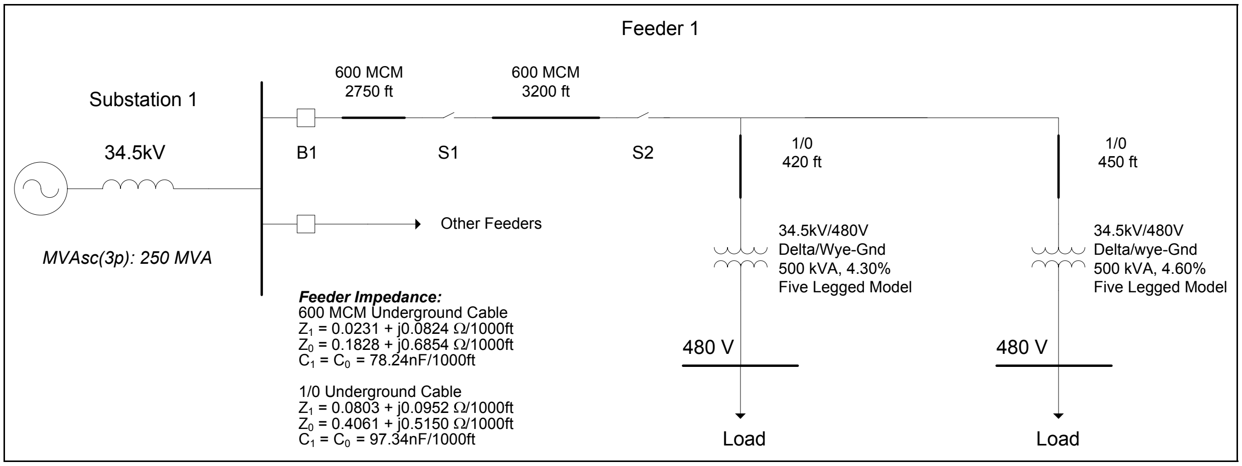

Figure 1 - Oneline Diagram for Underground Distribution Ferroresonance

BACKGROUND

Ferroresonance is a term generally applied to a wide variety of interactions between capacitors and iron-core inductors that result in unusual voltages and/or currents. In linear circuits, resonance occurs when the capacitive reactance equals the inductive reactance at the frequency at which the circuit is excited. Iron-core inductors have a nonlinear characteristic and therefore a range of inductance values. This relationship may lead to a number of operating conditions where the inductive reactance does not equal the capacitive reactance, but very high and damaging overvoltages occur.

In a typical power system, ferroresonance occurs when a transformer becomes isolated on a cable section in such a manner that the cable capacitance appears to be in series with the magnetizing characteristic of the transformer. An unbalanced switching operation is required to initiate the condition. Several of the more common causes include:

- Single-phase cutouts
- Fuse blowing or opening (transformer/line fuse, or a lineman pulls an elbow connector)
- Single-phase reclosers
- Cable connector of splice opening
- Manual cable switching to reconfigure a cable circuit during an emergency condition
- Open conductor fault in overhead line feeding cable
- Three-phase switch with large pole closing span

Two additional conditions must be satisfied for ferroresonance to occur:

- The length of cable between the transformer and open conductor location must have sufficient capacitance to produce excessive ferroresonant voltages.
- The losses in the circuit and the resistive load on the transformer must be low.

SIMULATION RESULTS

The accuracy of the system model was verified using three-phase and single-line-to-ground fault currents and other steady-state quantities, such as transformer and customer load rated currents.

A ferroresonance condition developed on a roughly 7,000-foot underground cable supplying a medical facility. Severe voltage fluctuations occurred at the customer load when one of the riser pole fuses blew. As a temporary solution, the utility replaced the fuses with a three-phase recloser. A study was completed to determine under what conditions the three-phase recloser might be removed and the fuses reinstalled.

The ferroresonance condition did not damage the two 500 kVA transformers or the customer loads at the medical facility. However, it was reported that a sudden overvoltage did occur and lights flickered between bright and dim.

The lengths of the cable from the first pole to the first switch (S1), and from the first switch (S1) to the second switch (S2) were approximately 2,750 feet and 3,200 feet long. The cable size was 600 MCM with the following characteristics:

Insulation: .... 0.1406 outside diameter in feet
Jacket: .... 0.1412 outside diameter in feet
Neutral: .... 0.1409 outside diameter in feet

A line constant program was used to compute the positive and zero-sequence impedances of the cable, yielding the following results:

$Z_1 = 0.0231 + j\ 0.0824$ ohms/1000 ft
$Z_0 = 0.1828 + j\ 0.6854$ ohms/1000 ft
$C_1 = C_0 = 78.24$ ηF/1000 ft

The lengths of the underground cable from the second switch (S2) to the first transformer, and from the first transformer to the second transformer were 420 and 450 feet long, respectively. The type of the cable was 1/0 with the following characteristics:

Insulation: .... 0.0629 outside diameter in feet
Jacket: .... 0.0688 outside diameter in feet
Neutral: .... 0.0794 outside diameter in feet

The computed positive and zero-sequence impedances were:

$Z_1 = 0.0803 + j\ 0.0952$ ohms/1000 ft
$Z_0 = 0.4061 + j\ 0.5150$ ohms/1000 ft
$C_1 = C_0 = 97.34$ ηF/1000 ft

The two 500 kVA transformers were modeled using a five-legged core transformer design. In order to investigate overvoltage due to ferroresonance, one phase of the cable was intentionally opened to simulate the circumstances leading to the ferroresonance (e.g., fuse blows, cable connector or splice opening, etc.) event. In the transient simulation, Phase B at the first pole was open-circuited, while the switches S1 and S2 (refer to Figure 1) were closed at all times. Figure 2 shows the three-phase voltage waveform at the secondary winding of one of the 500 kVA transformers with both of the 500 kVA transformers unloaded (Case 2a). Industry analysts have historically assumed that when the voltage exceeds 1.25 per-unit, the system is said to be in ferroresonance. Figure 2 clearly illustrates that the system is in a ferroresonance condition because Phase A exhibits sustained overvoltages greater than 2.0 per-unit.

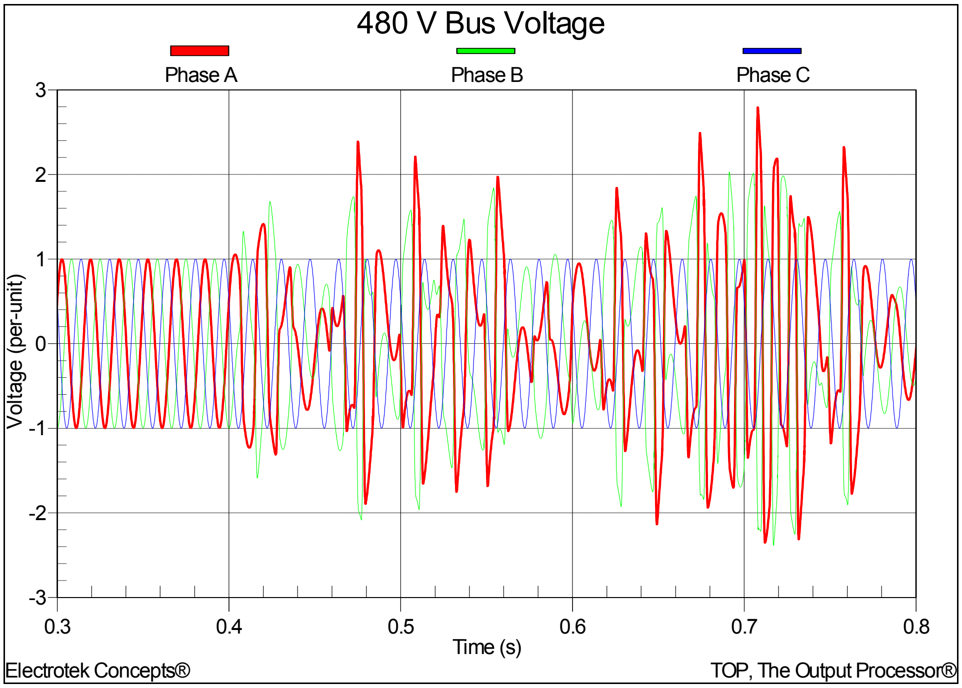

Figure 2 - Customer Transformer Secondary Voltage with no Secondary Load

A series of cases were completed to determine the relationship between the amount of customer secondary load and the resulting ferroresonant overvoltages. As the load is increased, the transient overvoltage drops very quickly. Figure 3 shows the three-phase voltage waveform at the secondary winding of one of the 500 kVA transformers with both of the 500 kVA transformers having a resistive load equal to 5% (25 kW) of the transformer rating (Case 2b).

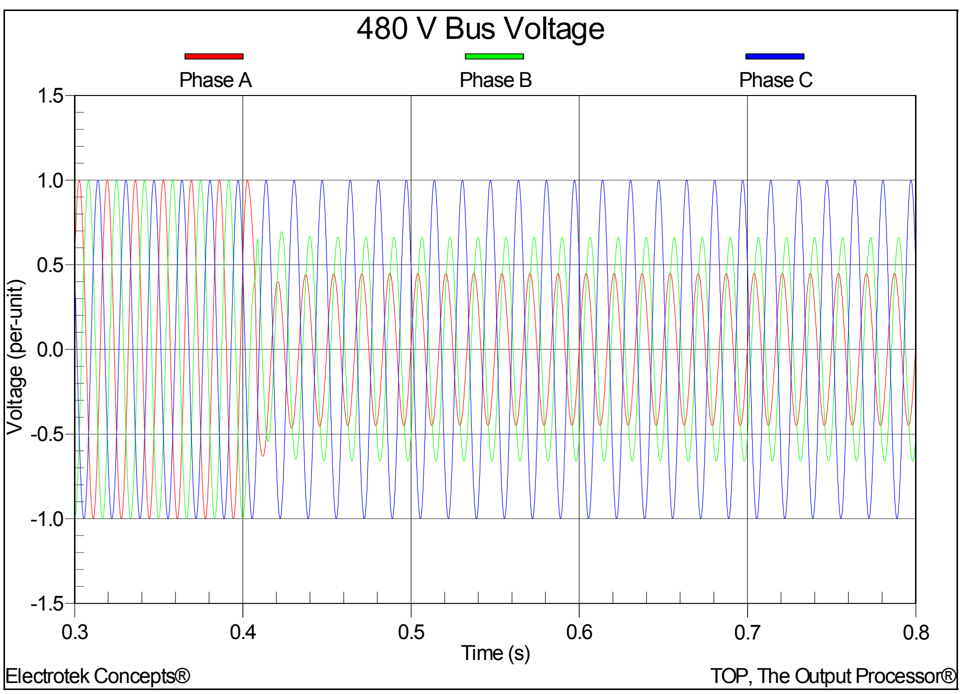

Figure 3 - Customer Transformer Secondary Voltage with 5% Secondary Load

The final case investigates the use of a three-phase recloser rather than three single-phase fuses. Figure 4 shows the three-phase voltage waveform at the secondary winding of one of the 500 kVA transformers with both of the 500 kVA transformers unloaded and with a three-phase switch opening on the primary distribution feeder (Case 2c). No ferroresonance occurs during the three-phase switching.

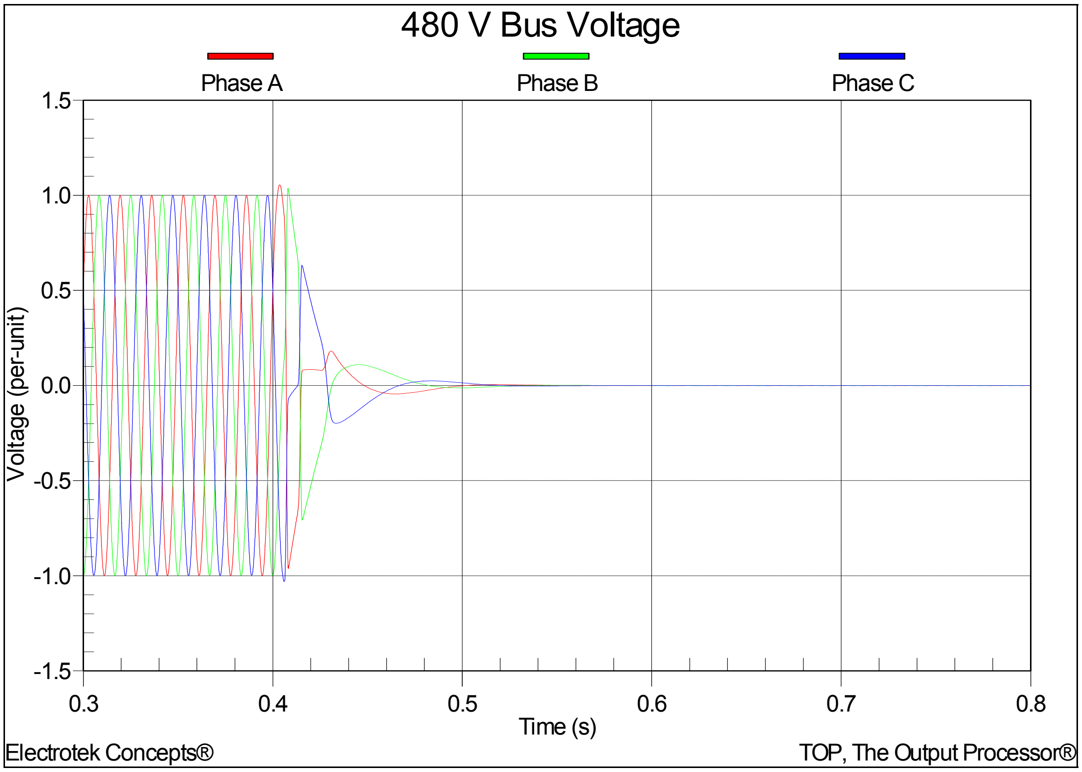

Figure 4 - Customer Transformer Secondary Voltage with a Three-Phase Switch

CONCLUSIONS

Observations and conclusions for this case study include:

- The term ferroresonance refers to a special kind of resonance that involves a capacitance and a variable iron-core inductance. A 34.5kV underground distribution feeder ferroresonance event occurred when a single-phase riser fuse blows.
- Transient computer simulations of the underground distribution feeder circuit indicated that the ferroresonant overvoltages were very dependent on the circuit configuration (e.g., cable length and capacitance, transformer ratings, etc.) and on the rating of the load on the customer secondary circuits.
- Solutions to the ferroresonance problem generally include adding resistive load to the secondary of each customer transformer. For this circuit configuration, a resistive load representing 5% of the transformer rating significantly reduced the secondary transient overvoltages. In addition, the potential for ferroresonance may be eliminated by using three-phase switches in place of single-phase fuses.