Examples of Ferroresonance in Distribution Systems

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***Abstract*—This is a summary of three different classes of ferroresonance problems commonly encountered on distribution systems.**

***Index Terms*—Ferroresonance, Power distribution systems.**

I. Introduction

I have been asked to describe some case examples of ferroresonance I have encountered in practice. I have selected three that I recall most clearly that are quite typical of problems encountered on distribution systems.

II. Shopping Mall Incident

Many utilities first encountered instances of ferroresonance when they began to build 34.5 kV underground distribution systems. They had built 15 kV underground systems for years without having a known problem. When the same designs were attempted at the higher voltage levels, problems were soon encountered. One incident containing several interesting elements involved a shopping mall that suffered some damage as a result.

Utility personnel were called to the scene in response to a complaint about a "power surge" and a noisy transformer. They were immediately drawn to a padmounted service transformer that was making loud, irregular growling noises. They also observed a spot on the top of the tank where the paint had bubbled and charred. This was presumably caused by the magnetic flux heating the tank as the core alternately saturated during ferroresonance. However, the transformer was tested and found not harmed internally. It was eventually returned to service.

The root cause was an automobile accident that had resulted in an open conductor fault on the overhead line tap just upline from the cable drop to the shopping mall (refer to Figure 1). The line had separated and fallen in such a way that there was not a short circuit fault. This yielded the traditional circuit configuration for ferroresonance, which continued for at least 30 minutes before crews arrived. Most of the 3-phase load in the mall tripped off line due to the low or fluctuating voltage. This only made matters worse for the loads that remained connected because there was insufficient load to damp out the ferroresonance. The weakest link in the chain then were the surge suppressors (usually simple MOV arresters) on the low voltage system in the mall. Failures were reported in cash registers and computer equipment.

The fused cutouts on the UD cable drop were opened, removing the transformer from service. Then the overhead line was repaired and the transformer tested. It was subsequently placed back into service. The disposition of the failed load equipment is not known.

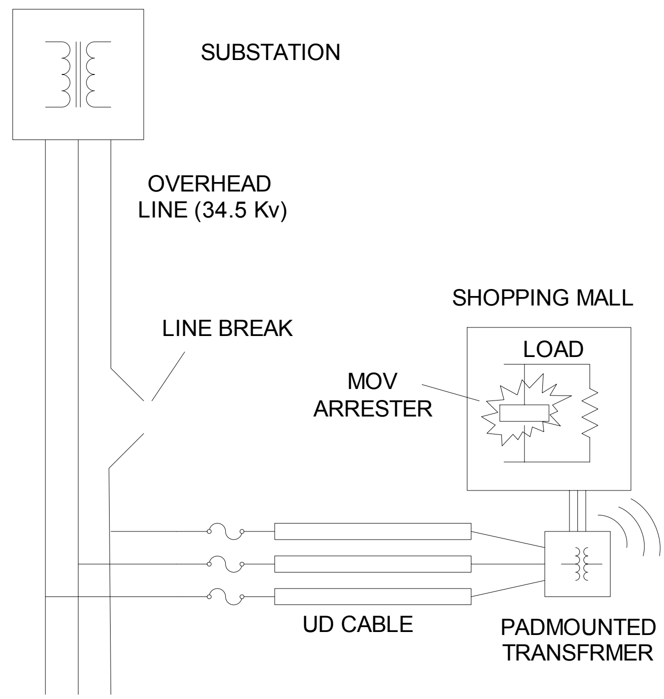

Fig. 1. Situation for shopping mall incident.

III. Single-Phasing Distributed Generation

Distribution generation (DG) protection requirements are creating some interesting protection conflicts. Most utilities require DG above a certain size to have a separate service transformer and these are frequently served underground as shown in Figure 2. Many commercial buildings are served with a similar arrangement. The stage is thus set for a serious case of ferroresonance should one of the fuses blow when there is no permanent fault in the cable. This can occur due to an animal climbing the pole or simply a fuse element failure.

DG is required to disconnect immediately after detecting a problem with the utility system. If the problem is an open riser pole fuse, the transformer could very well go into

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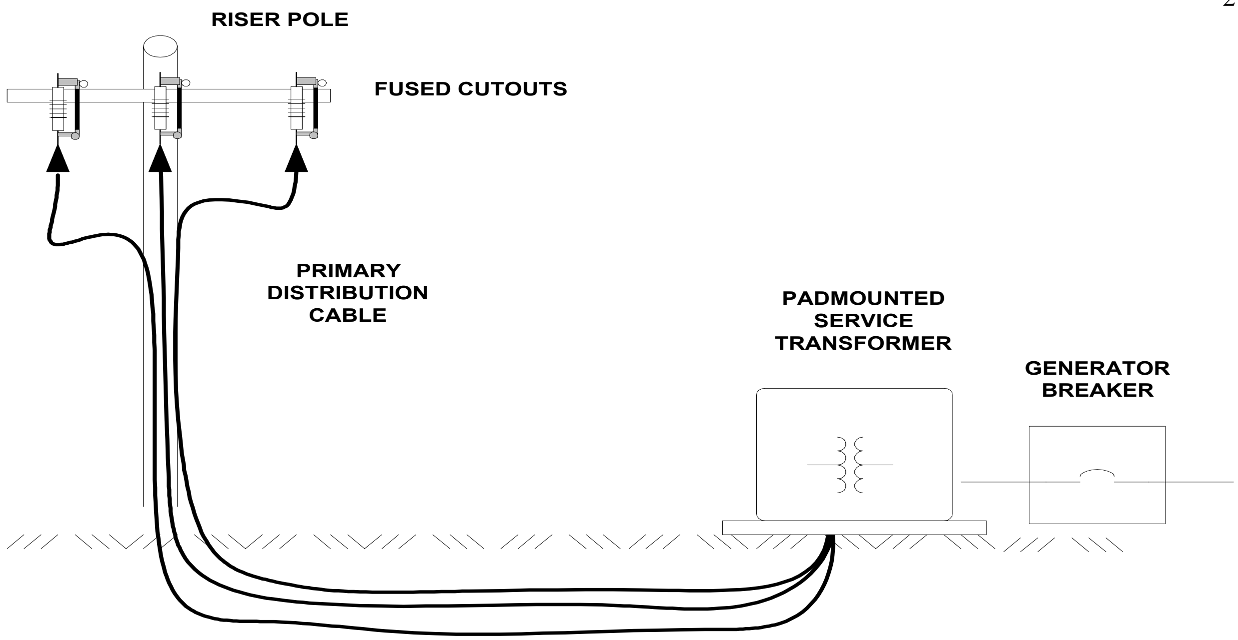

Fig 2. Common DG (and commercial building) installation with cable-fed service transformer.

ferroresonance since there is no load to damp it out. Only the generator is connected and its breaker is open. It could remain in ferroresonance for quite some time before it is reported depending on how closely the site is monitored. The transformer itself can be damaged.

The solution is to have three-phase switchgear on the primary side of the transformer. This is not a problem for larger DG installations. However, it is prohibitively expensive for small generators.

In general, I advise against line fuses in series with DG. This is not economically avoidable in some cases. How the rules for this evolve with DG advocates increasing the pressure to apply DG to distribution systems will be interesting.

There have been a number of incidents nearly identical to this with large commercial building. It is common for hospitals, banks, and other commercial buildings to have backup power installed. It is also common for such installations to be fed underground with a cable drop of 1000 feet, or so. The standard protection is a set of three fused cutouts on the riser pole. Sometimes the implementation is such that as soon as a problem with the utility service is detected, nearly all the load is transferred to backup power. This leaves the service transformer energized and isolated without load to damp ferroresonance. Thus, any loads that remain connected are subject to excessive duty. Low-voltage surge suppressors commonly succumb to this duty. Also, UPS systems that monitor the fluctuating voltage may cycle on an off repeatedly. This is not necessarily damaging, but can disrupt IT operations.

Again, the solution is to use three-phase switchgear such as reclosers or sectionalizers at the riser pole. Alternatively, the fused cutouts may be replaced with solid blades, which will cause the feeder breaker or recloser to operate to clear faults. This will be an inconvenience to other customers.

IV. Delta-Connected Padmounts on 15 kV Class Underground Distribution Systems

The potential for ferroresonance has caused nearly all utilities in the U.S. to apply grounded wye-wye transformers at 25 and 35 kV classes. However, many utilities continue to use delta-connected primaries on underground transformers at 12.47 kV for decades with no known difficulties. There may be a perception that ferroresonance cannot happen in 15 kV class systems. While it is less likely, it is still possible. One factor is the proportion of losses. Newer, low-loss transformer designs are making it more likely than previously.

In one case, a utility that was constructing a new 12.47 kV underground service for a multi-building complex. As each cable run and padmount transformer was connected, the system was energized from the riser pole cutouts to test it. At some point, the number of transformers and cable capacitance was sufficient to support strong ferroresonance.

The problem in this case was first noticed when the unloaded system was being de-energized after testing. When the second cutout was pulled, leaving one, the transformers started making an unusual loud noises. When the final cutout was pulled, a large arc was drawn that could not be extinguished simply by pulling the cutout open with a hot stick. This would suggest that a large current was flowing, much the surprise of the line personnel, who believed the system to be unloaded.

Subsequent measurements with a power quality monitor showed very unusual voltage waveforms. These were easily duplicated by simulation and found to be the expected line-to-line voltages during delta winding ferroresonance with two cutouts open. This demonstrates that ferroresonance is not just a 25 kV or 35 kV system phenomenon, but can occur at any voltage with the appropriate combination of cable capacitance, transformer connection, and losses.

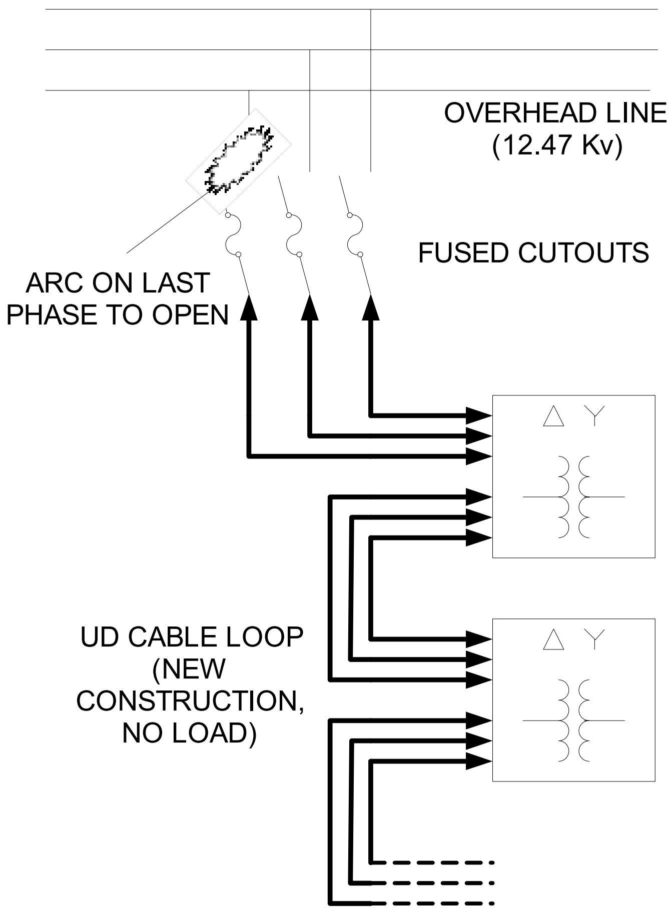

Fig. 3. Ferroresonance occurring on last phase to open on new construction UD cable system.

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The transformers were not damaged despite the impressive display of audible noise and arcing. However, some surge protectors on the low voltage side were blown off the wall. It is not known if this happened during the ferroresonant activity or after. It may have occurred when the cutouts were pushed back in after the third one failed to clear. This type of failure often occurs when the surge protectors have become overheated. Re-establishing full power makes available enough fault current to cause catastrophic failure.

Normally, ferroresonance is no longer a problem once the system is loaded. However, ferroresonance from the two-phase open condition on a delta transformer often requires more load to damp it out than the one-phase open case.

V. Observations

Some points common to all three of these cases include:

- The event was caused by opening one or two phases, either intentionally or accidentally
- The basic situation is established by the commonplace UD cable service drop from an overhead line.
- The cable system had either light load or no load.
- The transformers were not permanently damaged (to my knowledge).
- Damage did occur to load side equipment.

VI. Corrective Measures

Corrective measures include:

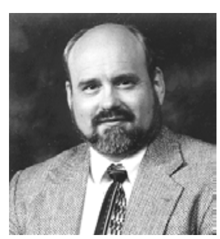
- Use three-phase switchgear instead of fuses. This is not economical in many cases.
- Open or close all three cutouts as simultaneously as possible.
- Ensure the transformer is loaded while being switched.
- Eliminate fuses. Rely on feeder breaker for fault interruption.
- Various measures to prevent inadvertent fuse operation.

Obviously, each of these measures have certain costs associated with them. Distribution engineers may simply choose to accept the risk or adapt operating procedures to minimize it. There may be no economical way of dealing with certain accidental occurrences.

VII. Acknowledgment

This panel summary was prepared at the request of the Practical Aspects of Ferroresonance Working Group of the Transmission & Distribution Committee. The examples are derived from the actual work experience of the author.

VIII. Biographies



Roger C. Dugan (F '00) has been Sr. Consultant with Electrotek Concepts, Knoxville, TN, since 1992. He holds the BSEE degree from Ohio University and the MEEPE degree from Rensselaer Polytechnic Institute, Troy, NY. He was previously employed in the Systems Engineering department of McGraw-Edison Power Systems, now Cooper Power Systems, for 19 years. Roger has worked on many diverse aspects of power engineering over his career because of his interests in applying computer methods to power system simulation. Beginning with a student internship with Columbus and Southern Ohio Electric Co, his work has been heavily in distribution engineering. He was elected a Fellow for his contributions in harmonics and transients analysis. Recently, he has been very active in distributed generation, particularly as it applies to utility distribution systems. Ferroresonance has been a long-time hobby. He is coauthor of *Electrical Power Systems Quality* published by McGraw-Hill, now in its 2nd edition. He serves as Secretary of the Power Systems Analysis, Computing, and Economics Committee.