Ferroresonance in the High Voltage Powerline Industry

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Abstract

Ferroresonance is an issue often overlooked in the high voltage powerline industry. Ferroresonance is a complex nonlinear electrical phenomenon that can cause dielectric and thermal problems to transformers. It is a very complex topic that is not completely understood and requires a large amount of work in order to comprehend. It can cause injury to Lineman that work around it and damage equipment. The proper training and a safety device could make the industry safer and save money. Through interviews and research I have studied the need for a safety device that applies load to a transformer during installation in order to eliminate the risk of Ferroresonance. I have also developed a prototype that can be used to apply 20 amps of load at 120V to the secondary side of a transformer. A product like this could be very valuable to have in the industry.

Introduction

What is Ferroresonance

Ferroresonance: is a nonlinear phenomenon. It creates a resonance in a transformer where energy is being fed to the circuit but since it is nonlinear there is nowhere for the energy to go. The way a transformer usually operates the resonance creates a parallel reaction that allows infinite voltage and current. This reaction is demonstrated with the equation $V_L = j w L I = j X_L I = V - (- j X_c) I$, when the reaction is not parallel it causes the problem of ferroresonance. Another definition is a complex nonlinear electrical phenomenon that can cause dielectric and thermal problems to components power systems.

Where Ferroresonance takes place

There are two conditions that allow Ferroresonance to take place.

1. The Fuse operates (Correctly or inadvertently) or a Lineman pulls an elbow connector for switching purposes.
2. Three Phase transformers is energized by manually switching cables intentionally or inadvertently some distance upstream from the transformer. This leaves the transformer isolated.

(Power Quality and Utilisation Guide)

The situations that cause Ferroresonance are unique and only show up in a few situations during linework. They include three phase pad-mount delta-connected Transformers, WYE transformers, and aerial three-pot bank served by long-dedicated aerial circuits.

I have decided to narrow my study into the most common situations where Ferroresonance takes place during Linework in the United States. This includes three phase underground pad mount transformers. The common voltages that will be studied are 480 bank, 120/208, 120/240, and 240/480. For three phase pad mount transformer the problem of ferroresonance occurs when two phases are energized and one is open. The voltage back feeds the distribution line, the distribution line is highly capacitive,

system involves the nonlinear magnetizing reactance of the transformer open phase this results in a shunt and series capacitance of the distribution line.

What is caused by Ferroresonance

Ferroresonance is characterized by a sudden jump of voltage or current from one stable operating state to another. Voltages that are 3-5 times the rated primary can appear on the primary in the core and on the secondary. The oil in the transformer heats to a very hot temperature. The vents can blow and the paint on top of the transformer can bubble. Surge arresters, since the transformer is not designed to sustain over voltages. The transformer will cook to destruction, sometimes fragmenting during failure.

Below is a list of situations that make ferroresonance possible

- Capacitance in series with the cores magnetizing inductance clook for the series L-C
- Unloaded or lightly loaded transformer (roughly below 10-20% rated load)
- Single pole switching procedure or interrupting devices in a three-phase system

Dangers of Ferroresonance

Ferroresonance can be dangerous for the Lineman working on the transformer and anyone around the area. The overload of energy can also cause damage to the system as well. Jim Vaughn in his article Ferroresonance explained says that the rise in primary causes a rise in secondary which makes meters sometimes blow up like bombs.

Why Ferroresonance is not predictable

Ferroresonance can be hard to study and predict. Electrical systems exhibiting ferroresonance behavior are categorized as nonlinear dynamical systems. Therefor conventional linear solutions cannot be applied to study Ferroresonance. Bruce Mork in his study Understanding and dealing with ferroresonance says “In general we engineers can often work around nonlinearities by using a simplified linear approximation to calculate or predict performance within the “normal” range of operation. This is not possible in the case of ferroresonance since our linearized calculations will not predict it. Luckily we can more directly and successfully deal with it today thanks to computer simulation tools such as EMTP (the Electromagnetic Transients Program)”.

Possible solutions to the problem

- Use 3 way switchgear instead of fuses
- Close all three cutouts at once
- Ensure a transfer of load while being switched
- Rely on feeder breaker fault interruption
- Various Measures to prevent inadvertent fuse operation
- Opening loads by elbows to isolate cable capacitance
- AB switch to isolate the coil before switching potheads

History of Ferroresonance

1907 Resonance involving transformers was reported
1914 It was first described in literature
1920 word Ferroresonance was coined
1930 It was a noted problem

1960 Transient network analysis were used to carry out research
1970 Important breakthrough in nonlinear dynamics and chaos theory were made
1980 Useful engineering references that could be applied to ferroresonance began to be published. The significance of the history of Ferroresonance is to show that it is a relatively new idea and not a well-studied topic.

Information for a device that applies load to the transformer

Baitch Ferroresonance critical cable length formula: used to determine a maximum cable length that can be safely switched in conjunction with a lightly loaded distribution transformer. I have also found some formulas for the amount of load needed on the transformer although none of them are consistent.

Interview 1- Armando Flores

Armando is a Journeyman Lineman with over twenty years of experience in the trade. He is the Forman on an underground crew in southern California. He said that he has encountered it in multiple situations and that it is something to be mindful of. Edison property has a lot of situations where Ferroresonance takes place. One situation where he came close was a few years ago they connected the first two phases and the third one caused an ARC. Ways to prevent it include having load on the transformer so you can drop the fuses. Another is to have load and pull the elbows simultaneously. SDG&E have the boxes that apply load to the transformer in order to eliminate the risk of Ferroresonance.
Using a hang switch is also an option. They also have transformers that have switches, cabs, they separate the secondary from the primary coils. This switch can eliminate the risk of ferroresonance.
The places Ferroresonance occurs is if the cable length is greater than the CVA of the transformer. This does not always result in a Ferroresonance situation but it's a strong possibility. Cable length x 1.73= a number (if the number is more than CVA of the transformer) then a ferroresonance situation is possible.

Interview 2- Steven Granger

Steven is a journeyman lineman with 21 years of experience in the trade. He said the main situations he has seen where ferroresonance is a problem is where the front of the transformer was a live feed with no elbow to operate. It was not safe to pull the 3 off at once so they energized the cable and transformer at the same time. He said having a load box in this situation would have made things a lot safer.

Interview 2-Tony Williams

He is a journeyman lineman with 21 years in the trade. He has a lot of experience with underground and is currently on an underground crew. He said that it is not completely understood or explained through science but it happens on two or three phase wire. It has to do with the amount of winding, if length of the windings is somewhat equal to the wire in the ground ferroresonance is a risk. To prevent it you can energize the cable to stand off at the transformer, then energize the transformer using your already energized cables, rather than energizing the cable and transformer at the same time. If you have the transformer plugged in and you energize from the handhole it will come through the

transformer and into the other phase. Another option is to try to close all three phases at once but it is risky because sometimes one guy is slow.

The situation is also common when companies use live front transformers, because it is hard to energize and deenergize.

A situation where it is really hard to prevent is when transformers are all tied together, so when you do it you have to pick up the wire and energize the transformer.

Sometimes when Edison encounters situations where they have a ferroresonance that is hard to prevent they will use a gang switch. This is not always an option and many companies do not offer this type of transformer.

Load needed for it to not be Ferrol is 15% but 5% might be good enough. If you had a device that applied load it would definitely help.

He has been around underground a lot in his 21 years in the trade. He said they encounter it about once a week and once a month they are faced with a situation where they cannot take the necessary preventive measures.

When it starts to take place the transformer will start to vibrate and come off the pad in some situations. It can then cause an ARC or kick the circuit.

It is common for Lineman that are not very familiar with underground to overlook the risk of ferroresonance. They teach you in school but it is very different in the field and there are a lot of different situation where it needs to be prevented.

He said that having a box that applied load to the transformer would be a very useful device in the trade.

<u>Interview 3- Dan Haggard</u>

Dan Haggard is a Journeyman Lineman that has worked his way from Forman, General Forman, super intendent, and is now the vice president of International Line Builders. I asked him if Ferroresonance was a problem that varied based on the region they were working in. He said it is not more common in different places geographically but it values based on systems. The systems depend on the utility and what they use. In the last 30-40 years some utilities have started to use transformers with a phase switch. They cost more so this practice is relative to the utility. The utilities are aware of the problem but trying to fix it with equipment such as a gang switch.

Haggard estimated that in the field less than 50% of Lineman have encountered ferroresonance. The reason for this is that some work primarily on overhead not underground where ferroresonance is most common. Most have probably worked around ferroresonance but not realized it.

When I asked about whether companies should provide a device that applies load to the secondary side of a transformer to prevent ferroresonance. He said a load box might not be feasible for a company to get because they might not use it enough. There should be a device available for lineman to use so a reasonable solution would be for the utility to have a box and loan it out to the contractor when needed. If a transformer blows up because of Ferroresonance then it is the utilities equipment so they would want to prevent damage to the equipment and workers wherever possible. If it was an OSHA requirement the cost would be so high that it would not be feasible.

As a lineman Dan has been around ferrrosonance a number of times. Never causing it to blow up but enough to shake the transformer and cause a scar.

Interview 4-Scott Schlenker

Journeyman Lineman topped out in 2000 and works for Edison as a trouble man. Trouble shooting the distribution circuits in his region.

He has seen Ferroresonance in lots of situations and has worked on how to eliminate it. Some are because a transformer was not mapped and other are because they were not handled properly. He has had one that blow up and burned two guys.

The effects of ferroresonance are that the transformer blows up or it kicks the circuit (relay the circuit). It can cause damage to the equipment and sometimes injury.

He said it is a problem in the industry for field personnel and the design team. Sometime the field engineer comes out and does not point out the situation properly. The field personnel does not notice that it is a ferroresonance situation. He said that some of the planning department got put through some school and now they are a planner but they do not know what is going on. They used to use the older field personnel but the planners are cheaper so they hire them instead. This can create problems because the planners do not think past what makes sense on paper. The errors by the planners or field personnel as well as a gap in communication can often lead to a ferroresonance situation being overlooked.

He said that a tool that would apply load to a transformer would be useful and easy to make. He has one on his truck that is mad from two hair dryers. It consist of two hot legs and a neutral. It applies 20 amps of load at 120V to the secondary side of the transformer. When he uses it he applies it and the customer load at the same time. The hopes are that the customer load will be enough but the hair dryer tool is there for insurance.

I asked about the utility company providing a device that applies load to the secondary side to reduce ferroresonance. He said that something that could apply multiple different voltages would be useful in the industry. He said it would be hard for the utility company to provide this device because it is hard to prove the tool would be 100% successful. In a situation where it does not work it would come down to a liability issue.

Conclusion

I got a lot of good information from my interviews and got a better understanding of ferrorsonance and how it's a problem in the industry. All interviewees said it is common for lineman in the industry to not be aware of ferrorrsonance on the job. Of the lineman that know about ferroresonance few understand it well enough to take the necessary preventative measures. Even with the proper training the problems a lineman will encounter in the field are likely to be very different then what they learned about in school. Better steps need to be taken to identify ferroresonance and take the necessary preventative measures. This can be a difficult goal to accomplish because it is such a complex issue. A better solution to the problem would be applying load to the secondary side of a transformer to make sure the proper safety measures are taken every time.

I do not think it should be required for Lineman to use this device in every situation because it is not always needed. It is also not a feasible thing to do in terms of time and money. Lineman should have access to this device in case they encounter a situation where it is needed. It will make the industry safer for the workers and save money for the utility companies.

I think that it would be a reasonable solution for the utility companies to allow the contractors to borrow this device when it is needed. It is the best solution because a ferroresonance situation where a load box is necessary will not come up often enough for one to be needed on every crew. Situations where it is needed do come up commonly. It will be helpful for there to be a device available.

The contractors themselves could also buy a device that applies load to the transformer. Especially if they do a lot of underground work. It would not make sense for there to be one on every crew but if the company had one in the yard then crews that were expecting to deal with a possible ferroresonance situation could use it for the day. Since ferroresonance situations do not occur often this would be a feasible and probable solution to the problem.

The liability of the device is the main issue because getting someone to test it and prove it works is difficult. The company that provides the device is accountable for any malfunction or if anything goes wrong from using it which is one of the main reasons that it is not provided. I think that this is an issue the industry should work past in order to provide the highest level of safety to the workers and the best quality service to the customers.

The prototype that I made is something that could be used in the industry but was not tested or constructed to the level that it should be. With more resources this device could be adjusted to accommodate all different transformers where ferroresonance takes place. A switch on the side that allowed it to change for 480, 120/208, 120/240, and 240/480 would be ideal. This device would need to be tested on a regular bases in order to ensure it applies the correct amount of load. It could greatly improve the safety of the industry by illuminating the risk of ferroresonance every time. It

would also save time because lineman would not have to take time performing other safety measures that would not work as well. The device would also save money because it would reduce the amount of equipment that gets damaged from ferroresonance.

In construction it is important to listen to the field personnel about problems they encounter and help them find a solution to the problem. Every person I talked to said that this is something that could be used in the industry. Ferroresonance is not a primary concern for contractors in the industry because it is rare and not well understood. I think that it should not a matter of how much sense it makes but rather doing everything you can to make your field personnel as happy and safe as possible. Lineman should have access to a load box to use in situations where they see fit.