

FERRORESONANCE

SECTION

SUBJECT

SHEET

- Case Study #1.: 3Ø transformer in ferroresonance with secondary side cable.
 Case Study #2.: Delta primary wound transformer in ferroresonance with primary underground cable.
 Case Study #3.: Cable in ferroresonance with transformer that has a delta secondary winding
 Case Study #4.: Overhead capacitor in resonance with improperly grounded overhead transformer bank (3-1Ø transformers) with a delta secondary connection
 Case Study #5.: Primary side circuit in ferroresonance with primary flux leakage of grounded y-grounded y 5 legged core & coil transformers
 Case Study #6.: 3Ø overhead transformer bank of 3-1Ø amorphous core transformers in ferroresonance with itself
 Case Study #7.: 1Ø secondary ferroresonance with customer step up transformer - cable - step down transformer
 Case Study #8.: Cable Ferroresonance feeding a Scott T connected 3Ø pad mount transformer.

Case Study #1. 3Ø transformer in ferroresonance with secondary side cable.

Situation:

A 13200Y/7620 V circuit is feeding a 2500 KVA 3Ø grounded Y-grounded Y 5 legged core & coil padmount transformer that is the source for a 3Ø portion of a distribution circuit operating at 4160Y/2400 V through a 60 foot length of 750 KCMIL AL 15KV EPR underground cable to an overhead line. This transformer had previously been installed to replace an obsolete 13.2KV to 4KV substation which had a little remaining load that could not readily be converted to 13.2KV operation.

A road improvement project has forced the rebuild of the first block of the overhead line to underground construction. The consequence is that this transformer will now feed an 835 foot length of 750 KCMIL AL 15KV EPR underground cable instead of the 60 feet of this cable it formerly fed. At the end of this section of 865 feet is a pad mounted switch that connects to the load. The crew plans to energize the transformer into the 750 AL and then pick up the load with the pad mount switch. When energized, the crew hears the transformer make a lot of noise and fail.

Analysis:

The reactance of the transformer is in series with the shunt capacitance of the cable, creating a resonant circuit which overvoltages and fails the transformer.

APPROVALS	FERRORESONANCE	Article	Revision
Sponsor Engineer:		TS-60	
Engineering Best Practices Chairman:	 Ameren Electrical Distribution Design	Sheet	
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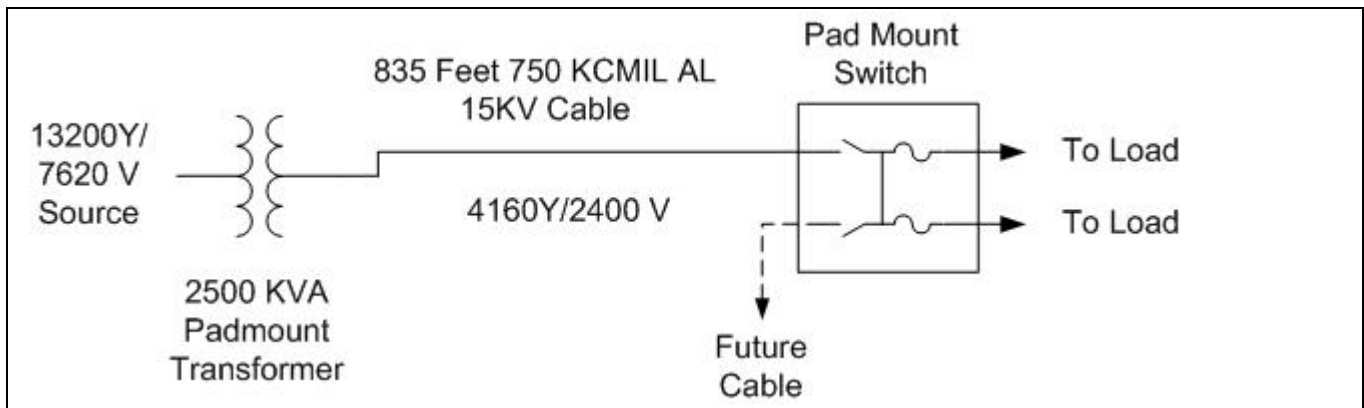


Figure 1. Physical Representation of Case Study #1

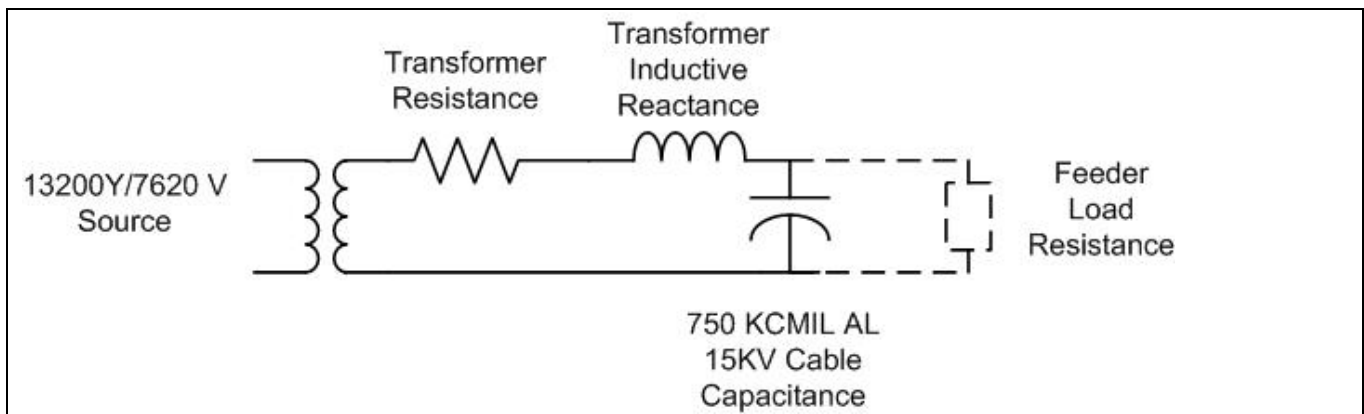


Figure 2. Single Line Representation of 3Ø Circuit in Case Study #1

Solution:

Close the padmount switch prior to energizing the replacement transformer, thus connecting the load to the circuit to be energized.

Why this solution works:

The impedance of the load is lower than the impedance of the cable's shunt capacitance, thereby effectively shorting out the capacitive reactance that goes into resonance with the transformer's inductive reactance.

Case Study #2 Delta primary wound transformer in ferroresonance with primary underground cable.

Situation:

A line crew is going to energize, for the first time, a 112 KVA 3Ø pad mount transformer from a 12470Y/7200 V overhead circuit. The transformer is connected to the overhead line via an underground lateral of 785 feet of #2 AL 15KV EPR in conduit.

The crew first closed the BØ fused cutout at the riser. The crew then closed the CØ fused cutout. The BØ and CØ cutouts are on opposite sides of the pole. The crew was preparing to close the AØ fused cutout when the CØ surge arrester, installed adjacent to the CØ termination, failed violently and the CØ 15T fuse link opened. The crew estimated the time between closing the BØ cutout and the CØ cutout to be about 10 seconds.

Supplementary Data:

The 3Ø pad mount transformer is a live front unit. The high side winding is rated 12470 V and is a delta winding. The low side winding is a grounded wye 208Y/120 V winding. The transformer is a 5 legged core and coil design. The riser arresters are believed to have been 10 KV MOV arresters. The #2 AL 15 KV EPR cable is a concentric neutral design.

Analysis:

In this scenario, the transformer is energized from BØ and goes into ferroresonance with the un-energized cable capacitance on CØ via the direct electrical connection of the high side winding. The CØ arrester is overvoltaged by the ferroresonance and begins to heat up. When the CØ fuse is closed, energizing the CØ arrester from the line, the impedance of the ferroresonant circuit is bypassed, letting the degraded arrester draw current from the line unrestricted by the ferroresonant circuit impedance. This adds more energy to the already failing arrester, which fails in about 10 seconds, blowing the CØ fuse.

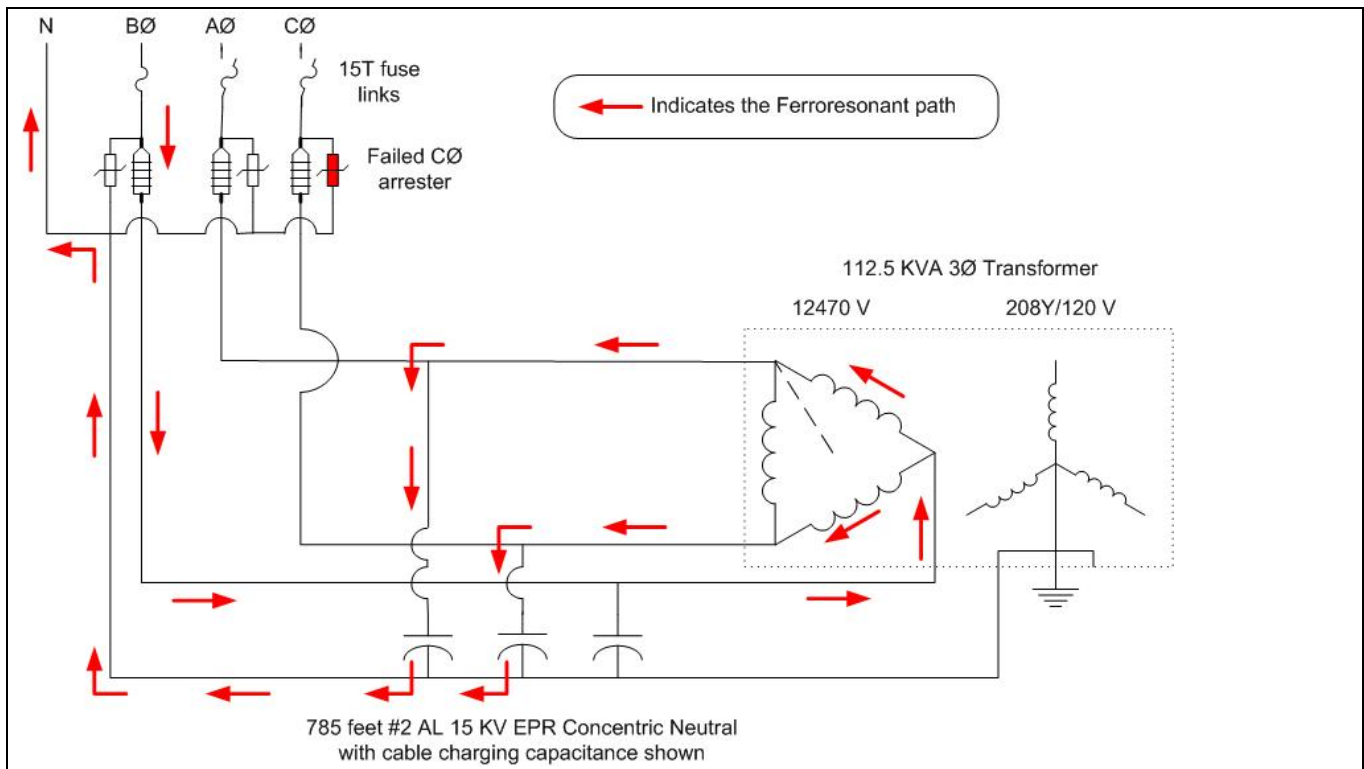


Figure 3. Physical Representation of Case Study #2 with Ferroresonant path shown.

No mention is made of the AØ arrester. If it failed, or didn't fail, after the problem was diagnosed, solved, and the transformer successfully energized is unknown.

Solution:

After verifying that the transformer and cable were not damaged the line crew obtained 3 space heaters and clip lead connected the space heaters to the secondary of the pad mount transformer. The transformer then was successfully energized by closing in the fused cutouts in the same BØ, CØ AØ order.

Why this solution works:

As shown in Figure № 4, the resistance of the space heaters parallels the inductance of the phase to phase windings and effectively shorts out the transformer magnetizing inductance removing the inductance from the resonant circuit.

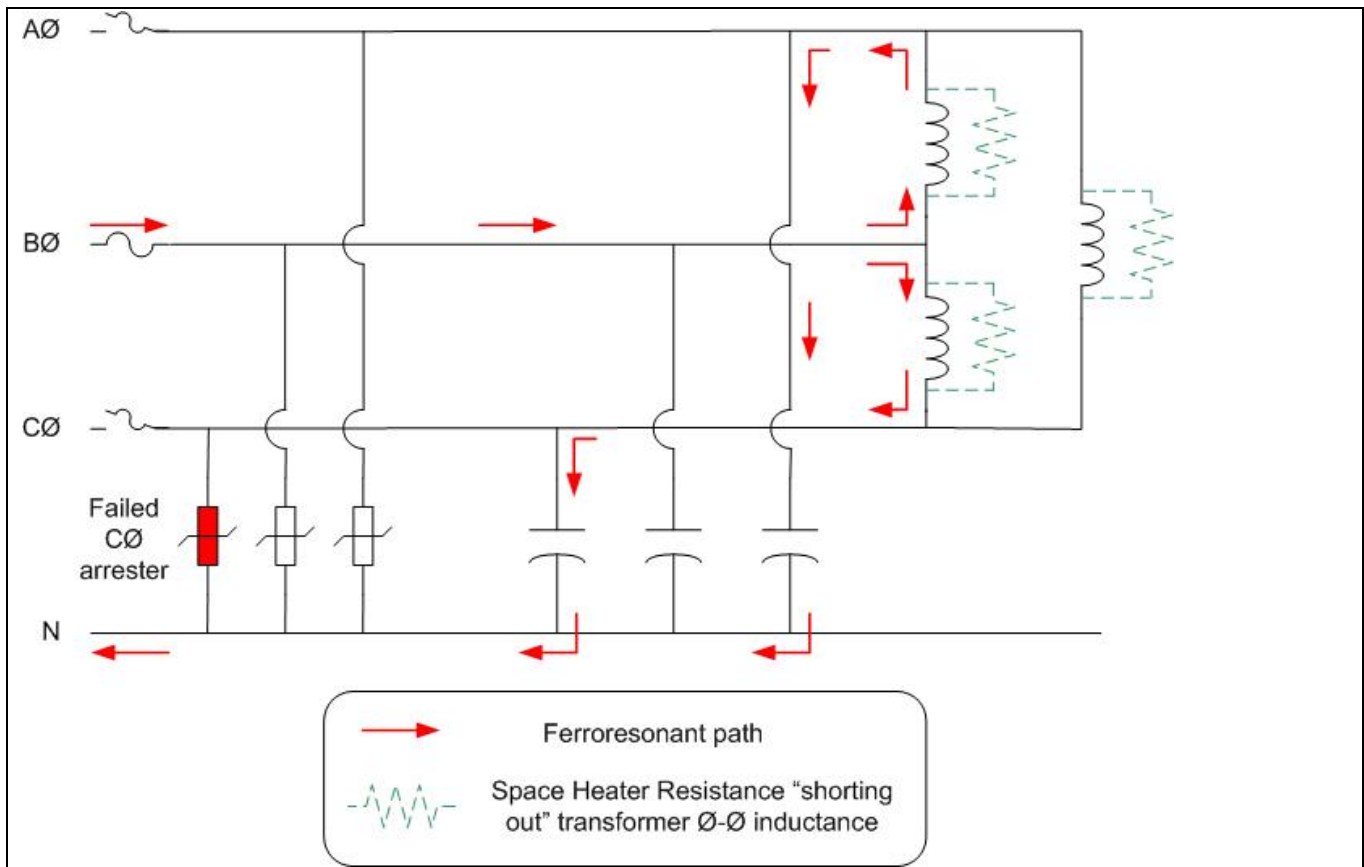


Figure 4. Electrical Line Drawing Showing Space Heater Resistance Reflected to Primary

Case Study #3 Cable in ferroresonance with transformer that has a delta secondary winding.

Situation:

A crew is initially energizing a 150 KVA dead front pad mounted transformer from an underground lateral off of an overhead 13.2Y/7.62 KV feeder. The crew first connects the cable to the transformer. Second, they start to energize the transformer from the cable riser to the overhead line with the single phase cutouts. After the crew closes the first and second cutouts, and the cutout fuses blow.

Supplementary Data:

The pad mount transformer is a 3Ø, 5 legged core and coil design with an ungrounded wye high side winding and a 240/120V delta low side winding. The underground cable is 1/0 AL concentric neutral 15KV direct buried EPR and is 440 feet long.

Analysis:

When the first two cutouts are closed, 2 windings of the high side winding become energized at one half line to line voltage each. These windings then energize the remaining “unenergized” high side winding at about 3.81 KV through the ungrounded neutral into the “unenergized” cable. The result is a series LC circuit. This circuit consists of the transformer inductance and the cable charging capacitance, which goes into ferroresonance.

Solution:

After verifying that the cable and transformer are good, the crew first parks the cable elbows on insulated stand off bushings at the transformer. Next, the crew energizes the cable. Lastly, the crew energizes the transformer at the transformer using the elbows.

Why this solution works:

By separating the connection between the transformer and the cable, the charging capacitance of the cable is no longer in series with the transformer during the energization process. This removes the capacitance from the series LC circuit.

Case Study #4 Overhead capacitor in resonance with improperly grounded overhead transformer bank (3-1Ø) transformers) with a delta secondary connection.

Situation:

While responding to investigate a high voltage complaint, a troubleman passed a set of 3 single phase line reclosers and he noticed that one of the line reclosers had tripped open. Since there was a voltage complaint (customer measured voltage of about 135V on 120V circuits) and there were no outage complaints, yet, the troubleman proceeded to the voltage complaint location. Upon arriving, he verified the high voltage condition (the accuracy of customer voltmeters should usually be questioned as they are seldom calibrated or verified accurate). Since this was a light load time of the year, and this is a lightly loaded portion of a rural feeder, and there was a capacitor located nearby for voltage support, the troubleman, knowing that excess capacitors can sometimes raise voltage to high voltage levels under these conditions, went to the capacitor location and de-energized the capacitor. Upon returning to the complaint location, the complainant now had extremely low voltage, about 40 to 60 volts on his 120V circuits. The troubleman now thought of the tripped open single phase recloser. The 3 single phase reclosers fed this area where the complaint was. Since this event took place more years ago than the author can remember, the author can no longer remember if the troubleman patrolled beyond the reclosers for a problem or not. But upon closing the tripped open recloser, power was restored to normal voltage levels. The capacitor, however, was left offline and the author was contacted to figure out what had happened.

Supplementary Data:

The capacitor is a 600 KVAR fixed (i.e., non-switched) 7620V bank. The voltage rise from the capacitor bank is designed so as to not cause a high voltage condition at light load, for normal circuit configuration.

Analysis:

The low voltage is indicative of an improper backfeed on the tripped phase from either an incorrectly grounded transformer bank or a Scott Tee wound 3Ø transformer. The capacitor was either in resonance with the back feed or working against the inductance of the transformer to boost the voltage to the unacceptably high level. There were few 3Ø pad mount transformers and there were no overhead 3Ø transformers (these are commonly wound Scott Tee) in the area fed by the reclosers, but there were a number of 3Ø transformer banks on the overhead system constructed of 3 single phase overhead transformers.

Solution:

A recommendation was made to patrol the area to look at the overhead 3Ø transformer banks. Two transformer banks were found which had the transformer primary neutrals connected to the system neutral and had the secondaries connected to provide 120/240V 3Ø 4 wire service. With the transformer primary neutral connected to the feeder neutral, this transformer configuration will attempt to backfeed the primary through the delta connected secondaries should a single phase become deenergized for some reason. The transformer primary neutral to system neutral connection was removed at these locations.

Removing the improper connection was only a partial solution to ferroresonance. It still leaves open the possibility of ferroresonance through the ungrounded wye connection of the transformer primary windings. See Case Study #3. In the ensuing years, the customers with the 120/240V 3Ø 4 wire service either have added load or had some other reason for upgrading and converted to 480Y/277 V 3Ø 4 wire service.

Why this solution works:

The short term solution did not pose a permanent fix. The long term solution was to eliminate the ungrounded wye connected transformers, which was possible with the customers' cooperation and desire to modify their facilities.

Removing the direct backfeed energization to the capacitor did alter the inductance in the circuit. Although there still is a potential for an inductive feed to an open phase through the ungrounded wye connected transformer primaries, the connection has a substantially different inductance thus reducing the likelihood of ferroresonance with an unchanged capacitance.

Incidentally, this type of direct back feed has been known to be strong enough to energize customers on the opened phase at anywhere from low to almost normal voltage.

Case Study #5 Primary side circuit in ferroresonance with primary flux leakage of grounded Y – grounded Y 5 legged core & coil transformers.

Situation:

In a rural area, on an overhead 13.2Y/7.62 KV 3Ø fused tap, there are 9 transformer installations serving 9 customers. Five transformers are single phase units feeding residential farms at 120/240 1Ø 3 wire. Another transformer is a 3Ø overhead bank constructed of 3 single phase 50 KVA conventional transformers. The last three transformers are pad mount 75 KVA 13.2Y/7.62 KV design units. All 4 3Ø transformer banks feed irrigation. Each of the 75 KVA pad mount transformers is connected to the overhead 3Ø line with its own dedicated underground tap line. Occasionally there are momentary faults on the overhead line, which blows one of the fuses where this line taps off the 3Ø line feeding it. When a momentary fault occurs, a tap fuse blows, and single phase customers experience 130+ volts on the “faulted” phase.

Supplementary Data:

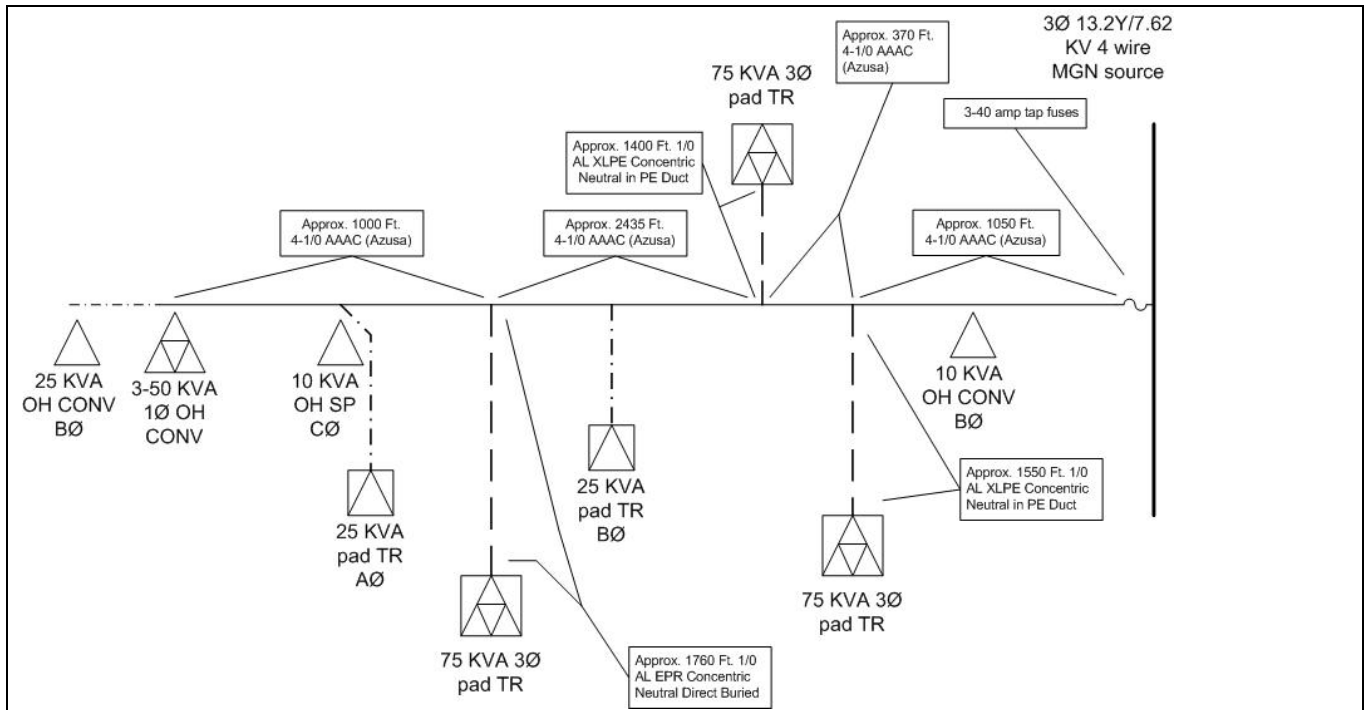


Figure № 5 Case Study #5 Physical Layout with Dimensions

The 3-50 KVA 1Ø OH conventional transformers are 7620 – 277 V units and are connected grounded wye – grounded wye. The 1Ø overhead transformers are 7620 – 120/240 V units and the 1Ø pad transformers are 7620 – 240/120 V units. The single phase transformers are connected phase to neutral on the indicated phase.

The 75 KVA 3Ø pad transformers are all 13200Y/7620 V to 480Y/277 V, 5 legged core & coil design and are connected grounded wye – grounded wye.

Some extensive testing was performed. After disconnecting all customers' loads when irrigation was not needed, with 1, 2, or all 3, 75 KVA pad transformers and their respective cable feeds energized in different combinations, one of the tap fuses was opened. In all cases, the voltage on the opened fuse phase, on the 120V winding of the 1Ø transformers, was in excess of 130V.

Analysis:

Stray flux leakage between the primary windings of the 3Ø pad mount transformers was energizing the “faulted” phase which in turn was going into ferroresonance with the cable charging capacitance of the cables feeding each transformer.

Figure № 6 shows a 5 legged core and coil transformer, ignoring the magnetic flux paths. It is difficult to see the mechanism by which the inductance of the “faulted” phase is going into ferroresonance with the capacitance of the cable.

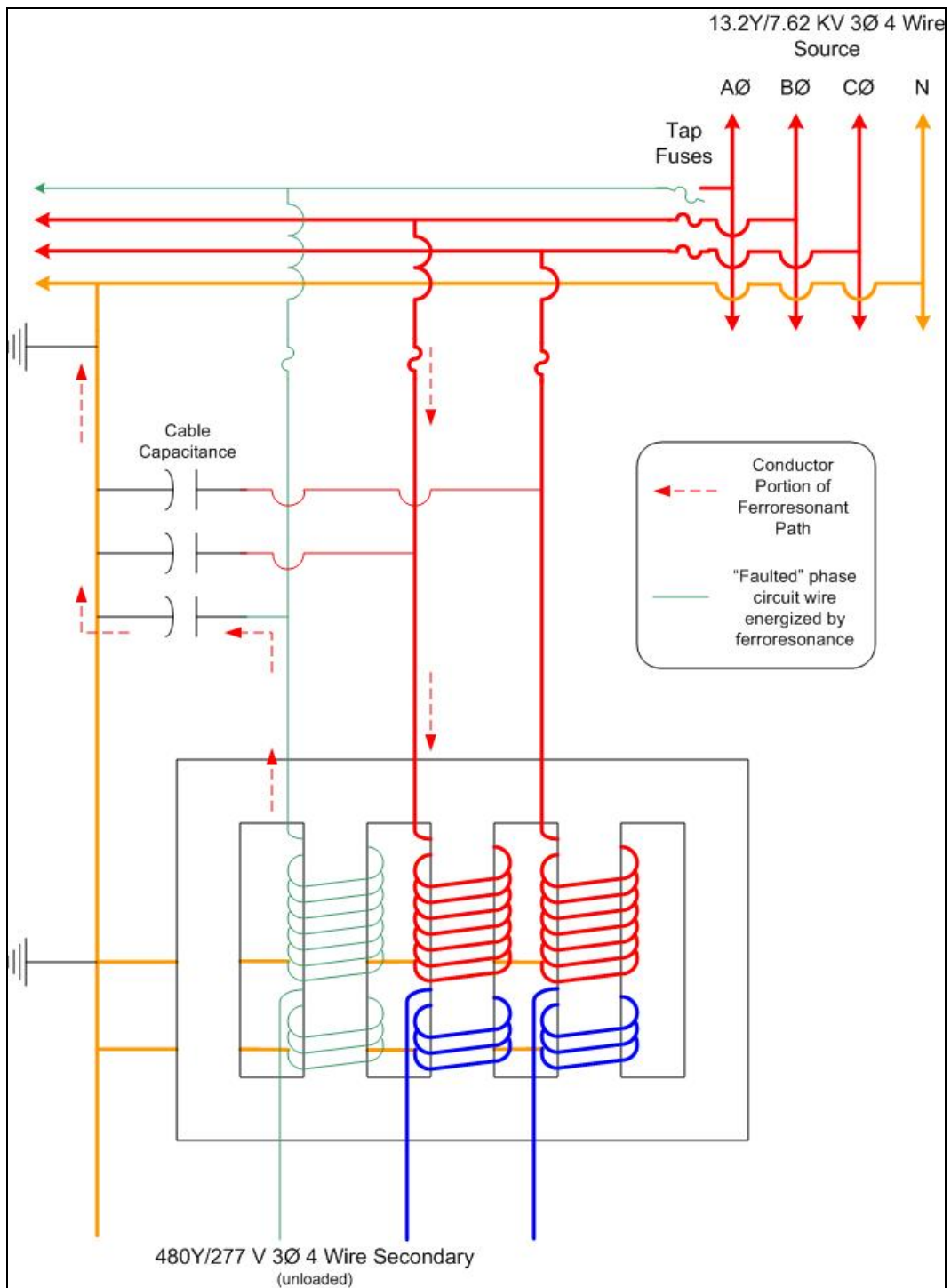


Figure № 6 Wye-Wye 5 Legged Core & Coil Transformer, Ignoring Magnetic Flux Paths

Figure № 7 shows a wye-wye 5 legged core & coil transformer and the magnetic flux leakage paths, with one phase not energized from the source. This figure shows how magnetic flux, also known as

leakage flux, that flows through the “faulted” phase’s part of the core from the energized phases. It is this leakage flux that attempts to energize the faulted phase’s coil. This is a weak circuit which does not support much load. So if there were many customers connected, or if there was a lot of single phase load on the secondary of this transformer, the voltage would collapse from the load resistance shorting out the inductance of the “faulted” phase of the transformer. In this particular case, there is no secondary load and there is extremely light other customer load, so in the absence of load to short out the “faulted” phase, the faulted phase goes into ferroresonance via the magnetic connection of the leakage flux with the primary cable capacitance as shown in Figure № 8.

Engineering and Operations should also remember that 3Ø customers should have single phasing protection on their 3Ø motors. Consequently, should a momentary fault on a phase could trip the customer’s single phasing protection, if the situation is conducive to ferroresonance, ferroresonance can occur should power not be restored to the faulted “phase”.

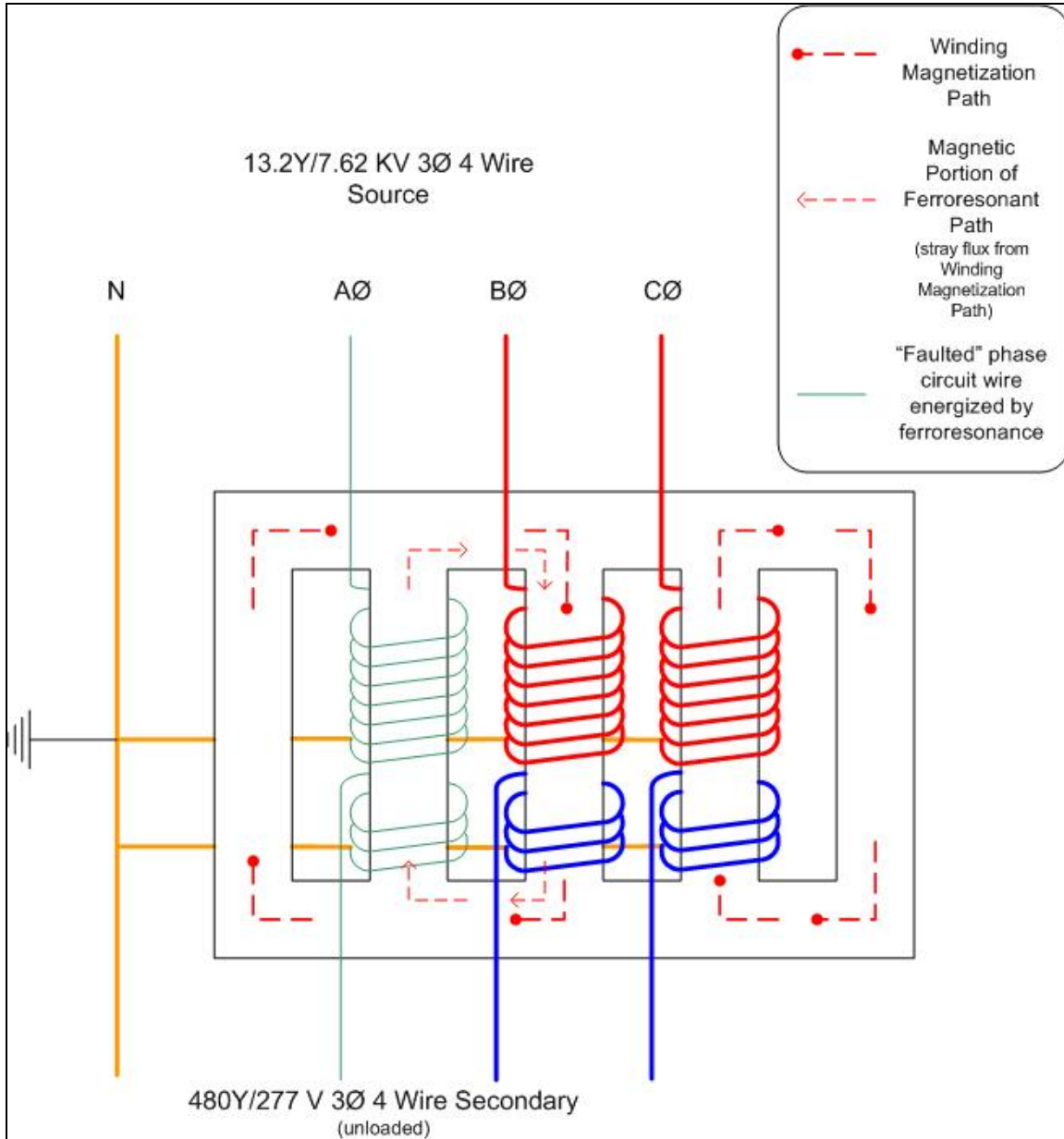


Figure № 7 Flux path details of a 5 legged Core & Coil Transformer with 1 "Faulted" Phase

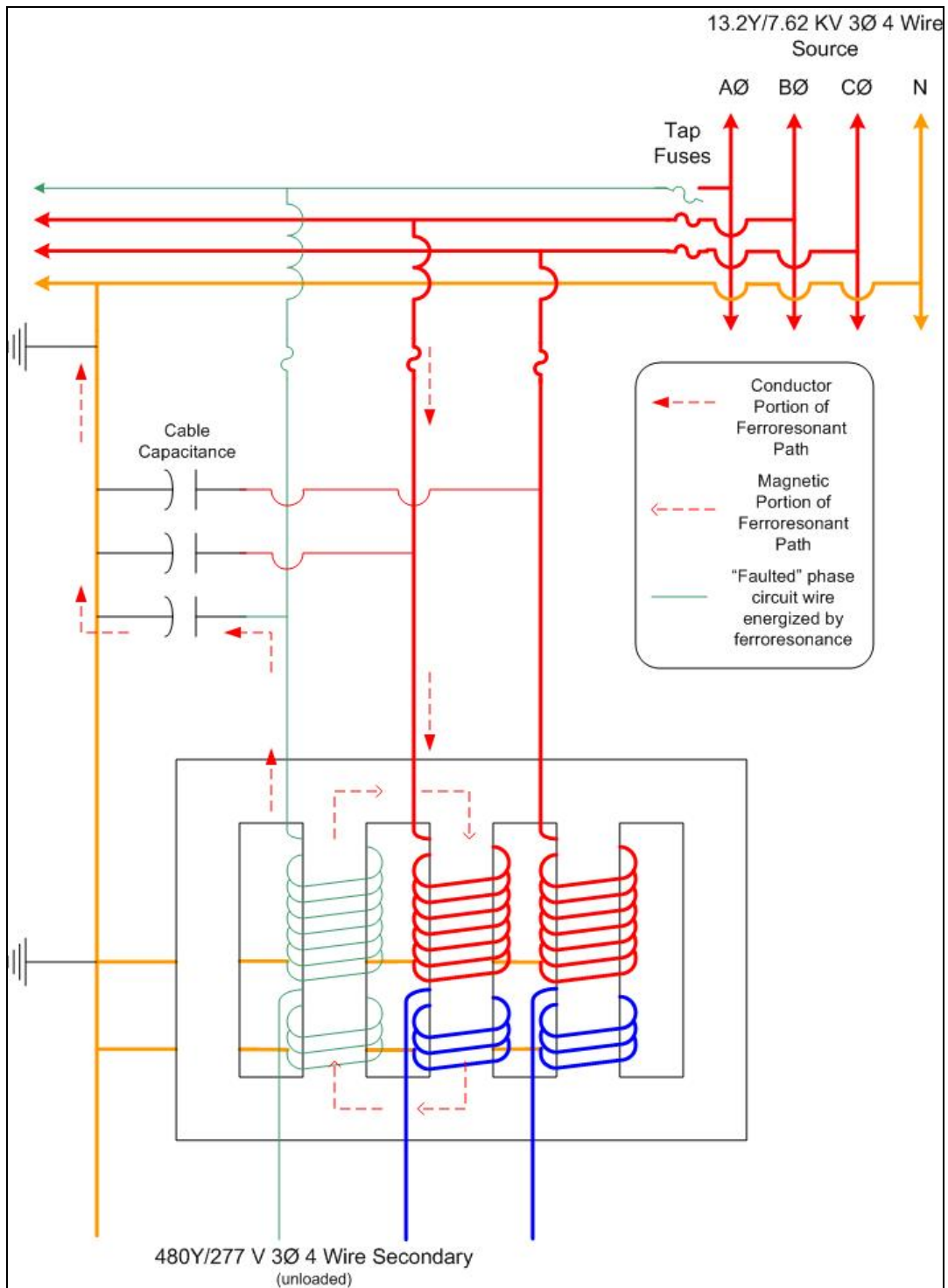


Figure № 8 Primary Side Ferroresonance Between Cable Capacitance and Stray Flux in a Grounded Wye – Grounded Wye Transformer

Solution:

Replace the 3Ø 5 legged core and coil transformers with the less ferroresonant susceptible triplex core and coil design.

Why this solution works:

The triplex core and coil design transformer utilizes 3 single phase transformer core and coils in a pad mount transformer tank. The single phase core and coils are magnetically insulated from each other, so there is no direct magnetic path for stray flux to flow between the energized windings and the “faulted” phase’s winding. This is illustrated in Figure № 9.

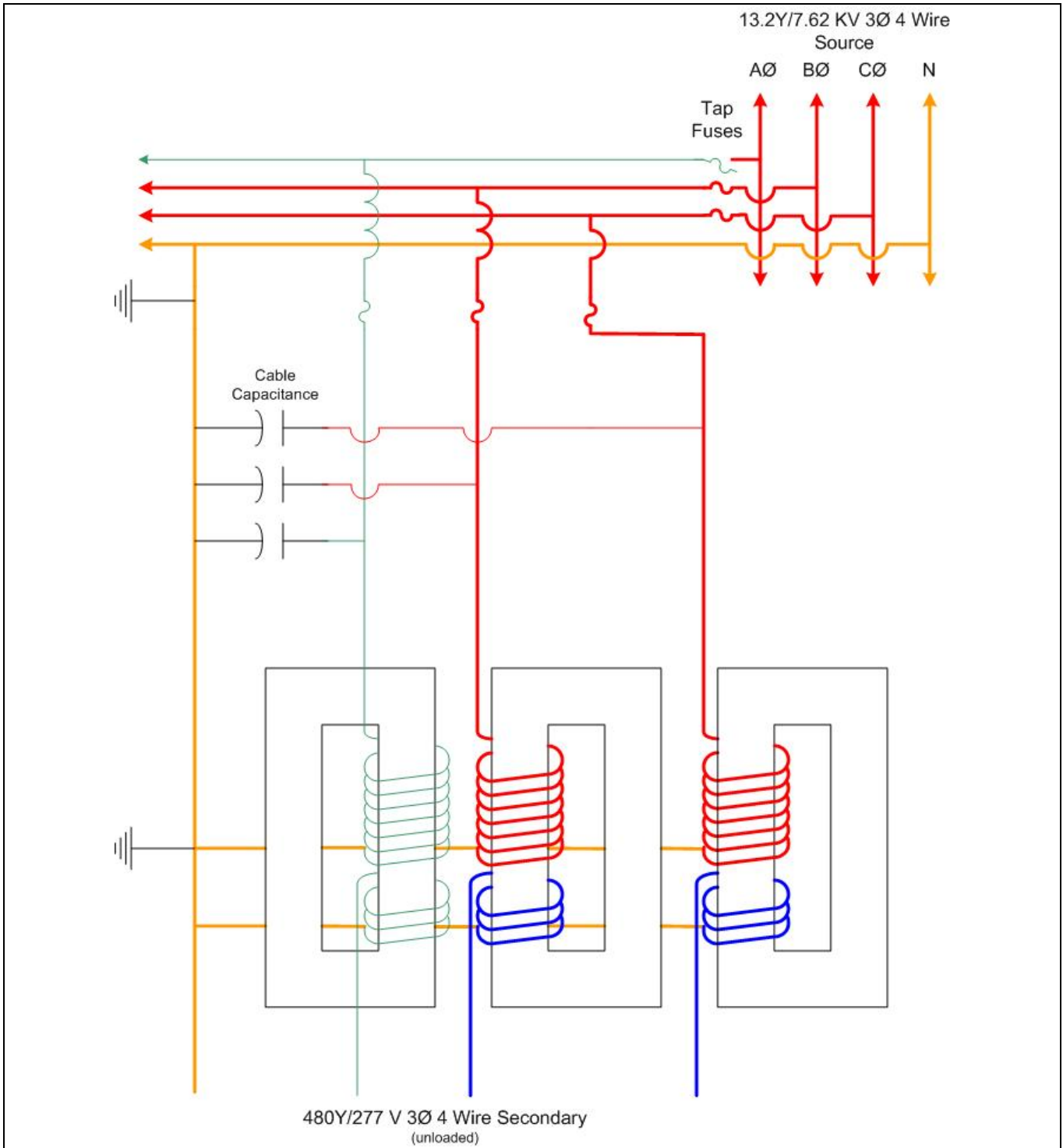


Figure № 9 Triplex Core and Coil 3Ø Transformer

Situation:

A field crew is completing the installation of an overhead 3Ø transformer bank built from 3 single phase 25 KVA transformers. This is a 12.47KV to 120/240 V 3Ø 4 wire secondary transformer bank. There is no load on this bank yet as there is no service installed to the customer. The crew starts to energize the bank for the first time. After closing the first fuse, the transformers make noise and the fuse blows.

Supplementary Data:

The transformers are amorphous core transformers. Amorphous core transformers have extremely low no-load losses. A typical 25 KVA overhead transformer at the time, had a no load loss of about 78 Watts, whereas a typical amorphous core 25 KVA transformer had no load losses of about 17 Watts.

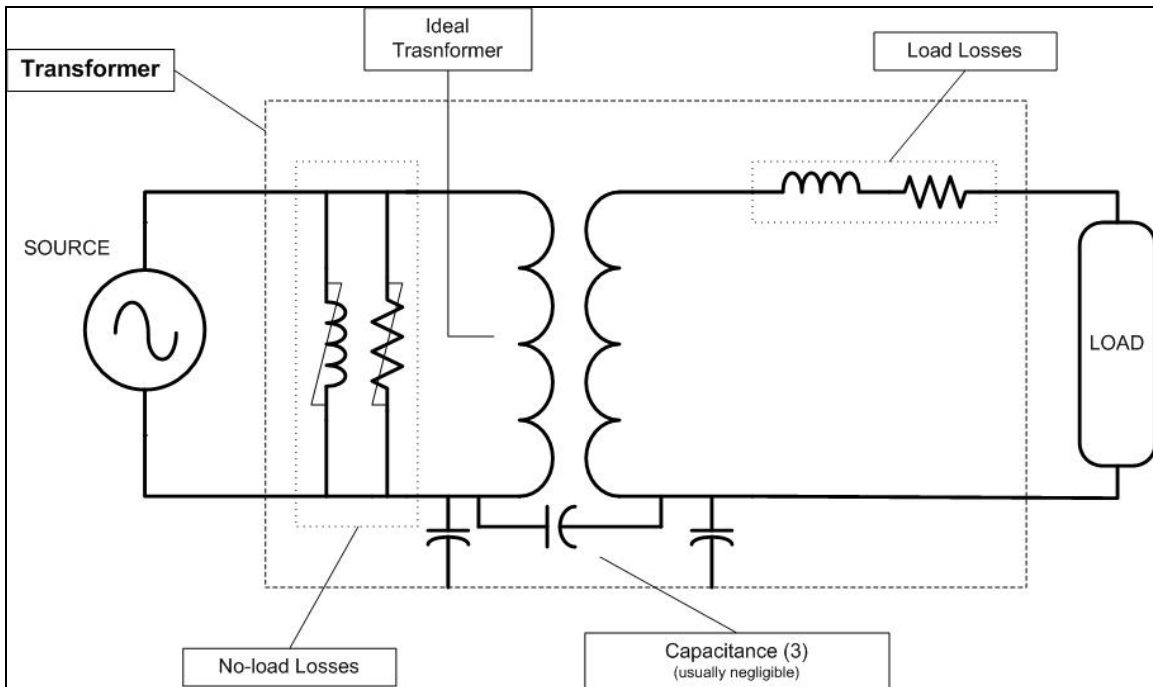


Figure № 10 Typical Transformer Model with Capacitance Shown

Figure № 10 illustrates the typically used transformer model. This figure, however, adds the capacitance. The capacitance is usually negligible but has been added because the no-load loss watts are so low with amorphous core transformers, that the capacitance is no longer negligible.

This utility does not temporarily ground the neutral point of the transformer primary wye before attempting to energize the transformer bank. This reduces the risk of leaving the primary neutral grounded permanently, which can backfeed faulted phases and also cause transformer overloading and failure from uneven primary phase to neutral voltages.

Analysis:

According to Hopkinson – Ferroresonance During Single-Phase Switching, the capacitances in a 3Ø transformer bank, made of 3 single phase transformers, can be re-arranged as shown in Figure № 11 to simplify the analysis. The no-load losses are omitted from Figure № 11 to simplify the drawing.

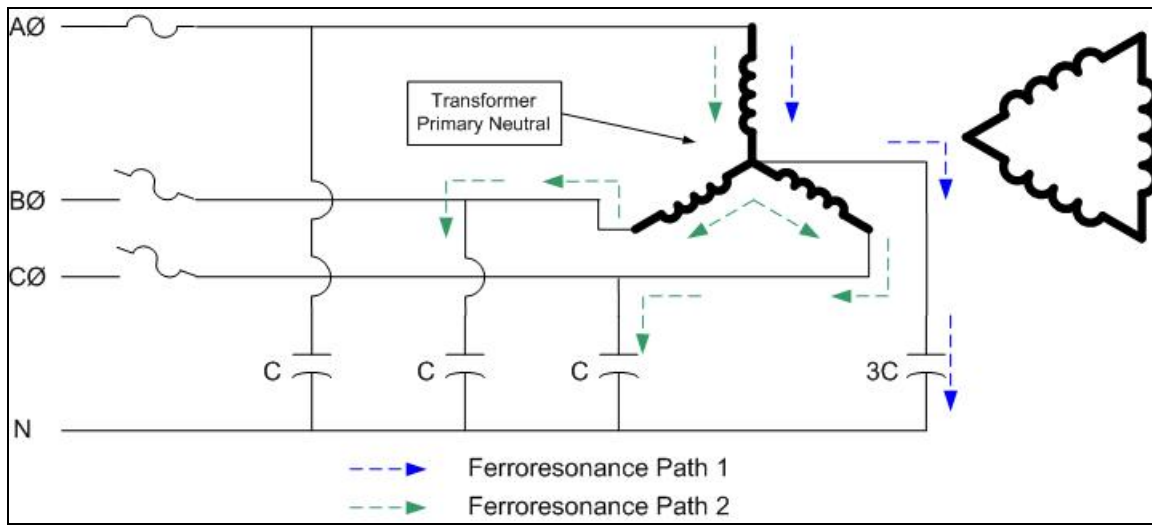


Figure № 11 Possible Ferroresonant Paths of an Ungrounded Wye – Delta Transformer Bank

Rearranging Figure № 11 and adding the transformer losses, Figure № 12 is developed. Figure № 12 shows how the no-load losses can dampen the ferroresonance possibility. The lower no-load losses are, the higher resistance component of the no load losses will be. With higher no load resistance, the no load losses become more inductive. The no load inductances become in series with the capacitances present in the transformer bank. These series circuits then just have to be energized single phase, as shown in Figures № 11 and № 12, for ferroresonance to occur. Conversely, the higher the no load losses are, the lower the no load resistance is, the more resistive the no load impedance becomes and the series circuit becomes more resistance in series with capacitance, eliminating the ferroresonance between inductance and capacitance.

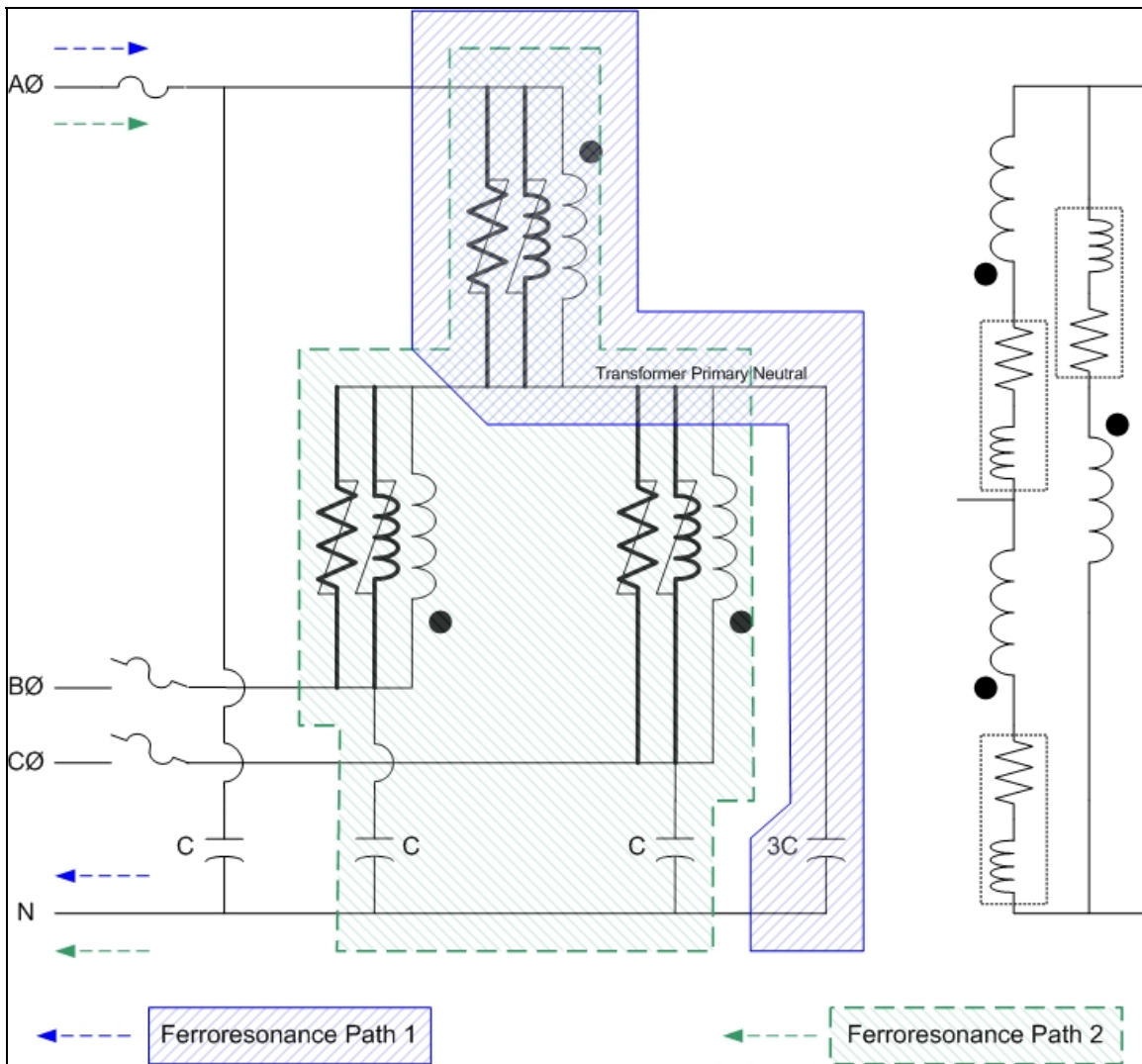


Figure № 12 Possible Ferroresonant Paths of an Ungrounded Wye – Delta Transformer Bank with Losses

Solution:

Replace the amorphous core transformers with standard transformers. In the future, don't use amorphous core transformers in 3Ø transformer banks.

While it may be possible to temporarily ground the transformer primary neutral to the circuit neutral, since it is not this utility's work practice to routinely do so, it's better to replace the transformers and avoid the possibility of a future incident.

Why this solution works:

The higher losses of the standard transformers dampen out the resonances created by the series LC circuits that occur.

Case Study #7 1Ø secondary ferroresonance with customer step up transformer cable – step down transformer.

Situation:

An agricultural customer is expanding his hog farm. The additional facility has to be located 1200 feet from his service. He hires an electrician to do the work. The electrician and farmer come to the decision that the best solution is to install a step up transformer and a step down transformer and high voltage cable to connect the latter to the former. They decide to purchase two 25 KVA single phase pad mount transformers, of the type commonly used by the local utility, from the local utility (thinking that if there is a future transformer problem, that the local utility will have spares handy). They also purchase 1200 feet of 1/0 AL 15KV EPR cable and elbows from a local electrical supply house. The electrician feeds the step up transformer from a 200 amp 240V breaker in the farmer’s main panel. The day comes to energize the feed to the new hog building. The electrician throws the breaker, and it immediately trips. After checking everything he can check, the electrician thinks the local utility sold him a bad transformer. So he and the farmer call the local utility and have the local utility check the transformers. The local utility finds that the transformers are good, and also verifies that the cable and elbows are good. The utility crew, however, can’t figure out what’s wrong either. The farmer, in frustration, calls the utility rep. The rep, thinks it might be ferroresonance, but he’s never heard of ferroresonance on anything but a 3Ø system, so he calls engineering.

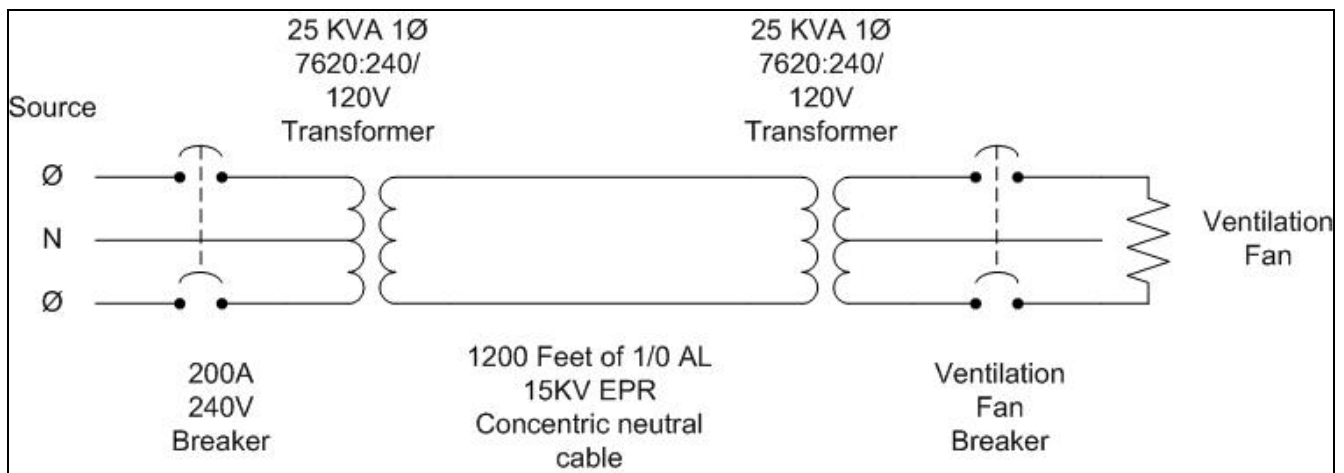


Figure № 13 Physical Description

Supplementary Data:

The transformers are standard 25 KVA 7620 V to 240/120Vpad mount 1Ø transformers.

Analysis:

The step up transformer is in series resonance with the cable capacitance. This is the same circuit as in Figure № 2, but on a single phase circuit, instead of a 3Ø circuit. This is shown in Figure № 14.

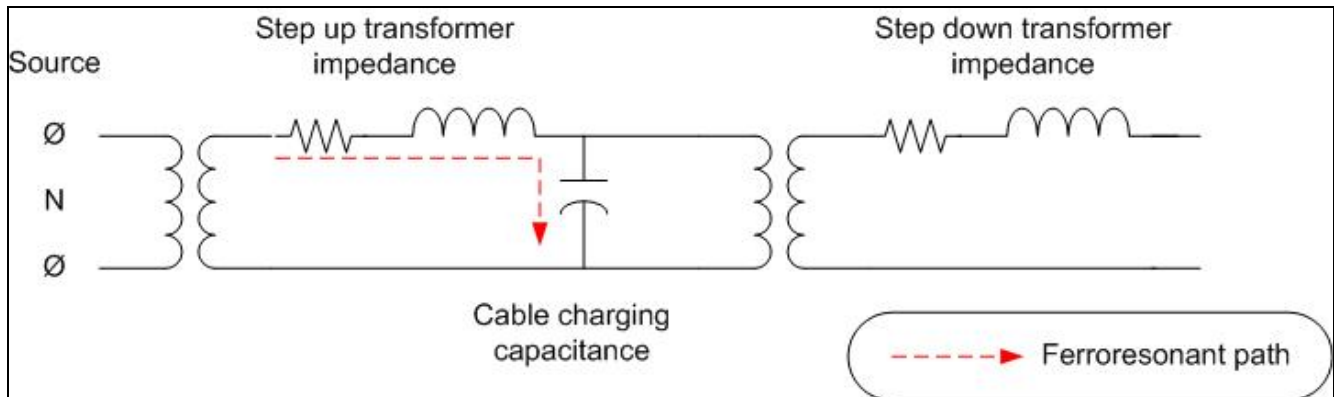


Figure № 14 Illustration of Ferroresonant Circuit in Case Study № 7

Solution:

Engineering thinks that it is ferroresonance and asks if the farmer has anything wired up in the hog building. The electrician has wired up the ventilation fan. Following Engineering's instructions, the electrician turns on the breaker to the ventilation fan before closing the 200 amp breaker to the step up transformer. When the 200 amp breaker is closed, the breaker holds closed and the fan starts working.

Why this solution works:

Switching the ventilation fan to the on position adds load resistance. This load resistance is equivalent to a primary phase to neutral load which effectively shorts out the cable capacitance, stopping the ferroresonance. This is illustrated in Figure № 15, below.

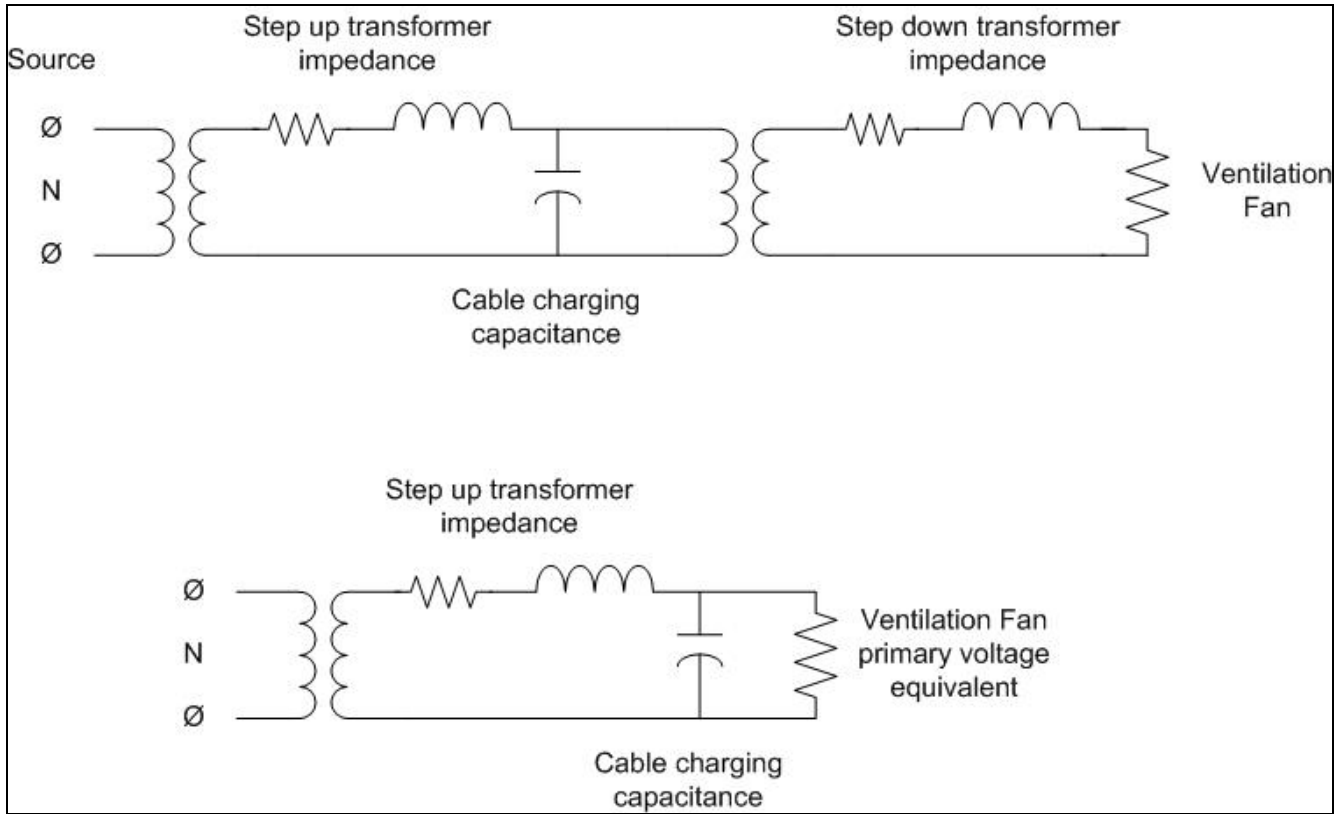


Figure № 15 Electrical circuit of solution to Case Study № 7

Case Study #8 Cable Ferroresonance feeding a Scott T connected 3Ø pad mount transformer

Situation:

A customer owned transformer 1000 KVA pad mount is fed by an underground cable that is about 550 feet long. The underground cable is feed off an underground system from a subsurface vault having 4 way load break stand off bars. The primary cables were first connected to the transformer in preparation for energizing the transformer from the vault. When energizing the transformer from the vault, the cable riser fuses blow.

Supplementary Data:

The cable is 1/0 AL direct buried 15KV XLPE with a bare concentric neutral. The underground system has several 850 feet of 4/0 AL 15KV cable back to the overhead riser. The transformer is a 1000 KVA Scott Tee transformer designed for 4160Y/2400 x 13200Y/7620V 3Ø primary to 480Y/277V 3Ø 3 wire secondary. It is believed that this was a live front transformer and therefore had to be energized from the vault. It is also believed that the primary winding of the transformer was an ungrounded winding.

Analysis:

Energizing any phase of the transformer, energizes the other winding that shares the common core with that winding which was energized. The winding that was energized via the common core is energized into the cable capacitance. The cable capacitance is in series with the energized winding, so may experience ferroresonance.

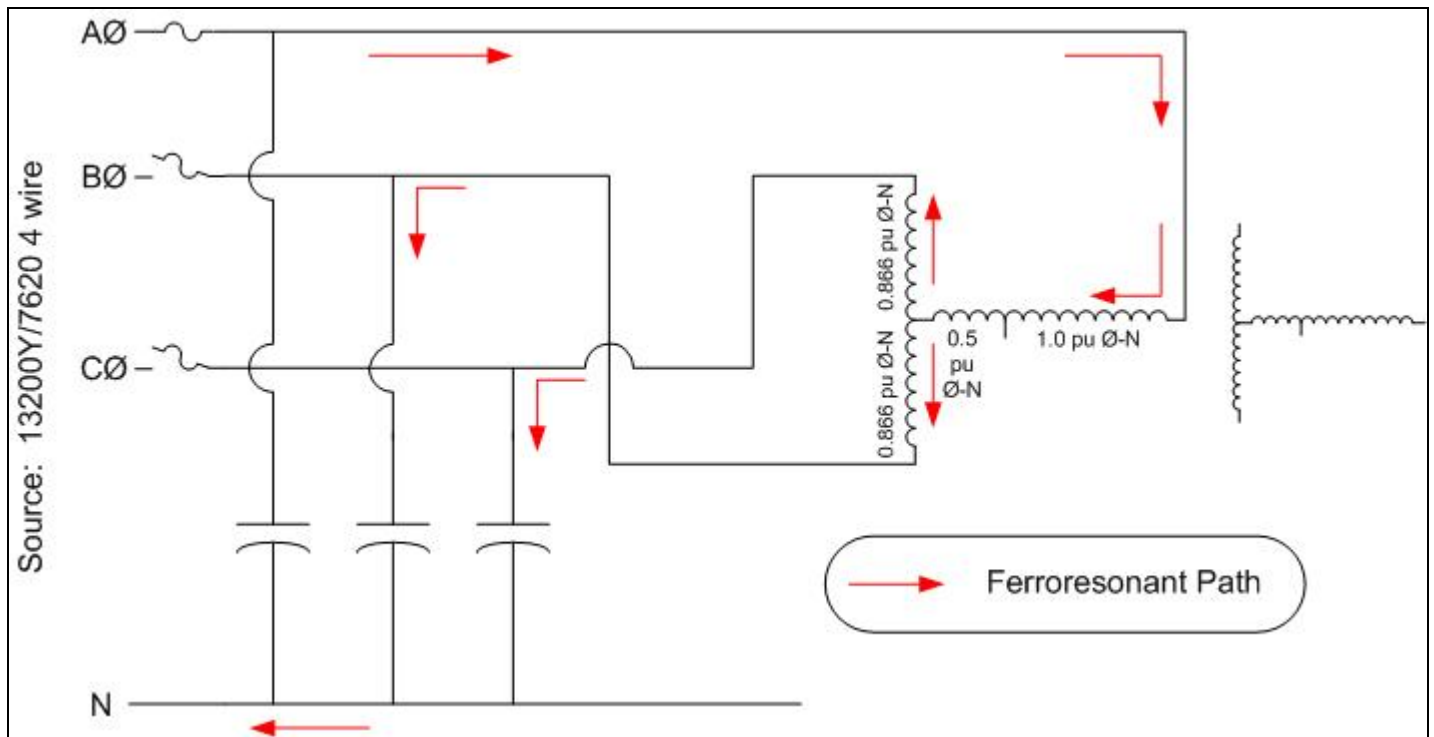


Figure № 16 Ferroresonance path through Scott Tee Wound 3Ø Transformer

Figure № 16 shows the start of the unsuccessful energizing sequence that went into ferroresonance for this particular installation. In this case energizing AØ first caused ferroresonance to occur.

Solution:

A switching routine was developed which was able to energize the transformer by first energizing the transformer's BØ, then CØ, and last the transformer's AØ.

Why this solution works:

By energizing the BØ cable, as shown in Figure № 17 the transformer coil from BØ to CØ was energized into a different LC circuit than the circuit created by first energizing AØ. This different circuit has a different LC ratio that didn't go into ferroresonance.

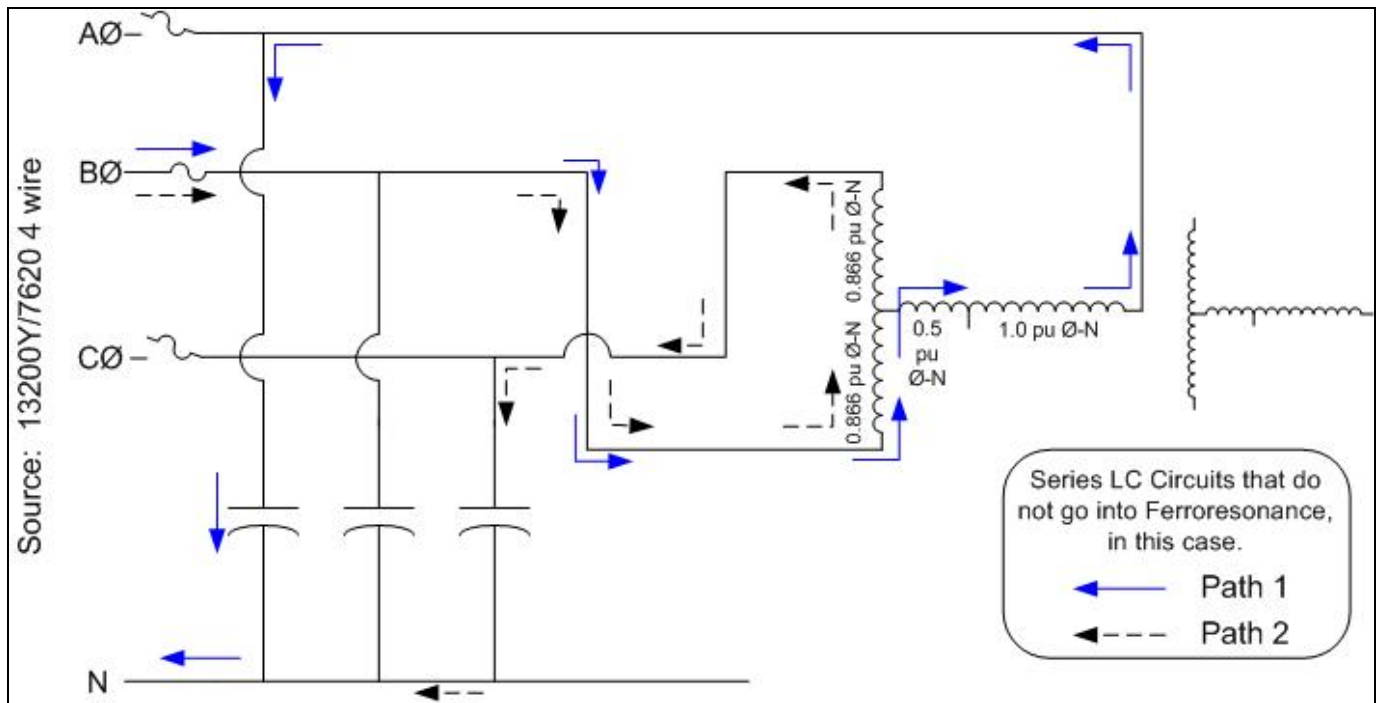


Figure № 14 Illustration of Energizing Scott Tee 3Ø Transformer
