HIGH RESISTANCE GROUNDING OF LOW VOLTAGE SYSTEMS: A STANDARD FOR THE PETROLEUM AND CHEMICAL INDUSTRY

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***Abstract* - A debate has existed in the petroleum and chemical industry for years concerning grounding of low voltage (480-600 Volt) power systems. Since reliability and continuity of service are important in the petro-chemical industry, some engineers in the past preferred using an ungrounded system. The practicality of such ungrounded systems becomes questionable as the size and extent of coverage increases. Many of these systems are still in existence, but few ungrounded low voltage systems are presently being designed and constructed due to the possible destructive nature of transient overvoltages resulting from an arcing ground fault, especially in a large configured facility. Most systems now utilize either a solidly grounded or high resistance grounded source.**

This paper will begin with a brief history of low voltage grounding which includes ungrounded, solidly grounded and resistance grounded systems. As part this discussion, benefits and limitations of each system will be covered. Reliability, continuity of service and personnel safety are important issues and will be discussed. It will be shown that the use of high resistance grounded low voltage systems makes good sense in the petro-chemical industry. Design, construction, operation and maintenance factors for high resistance grounded systems will be discussed and analyzed. The use of a high resistance grounded system when three phase, four wire loads are present will be discussed. Finally, operational problems and solutions will be discussed where significant variable speed drive loads are utilized. The use of the high resistance grounded system provides so many benefits that it should become a standard of the industry, and the solidly grounded system should be used only in applications where the high resistance grounded system becomes impractical.

I. INTRODUCTION

Reliability has always been an important aspect in the design and operation of a low voltage power utilization system, and especially in the petro-chemical industry. (In this paper, the term low voltage will typically reference the use of voltages in the 440-600 Volt range.) Loss of low voltage power can cause a complete upset to a plant, create personnel and equipment safety problems, have an adverse environmental impact, and can result in substantial economic losses. As such, the need for a safe, reliable low voltage power source is essential.

In the past, an ungrounded system was extensively used with the assumption that the system was more reliable. However, experiences with multiple failures due to arcing ground faults on an ungrounded system have resulted in a change in philosophy about the use of the ungrounded system. Solidly grounded and high resistance grounded systems have become the standard for large industrial complexes. Solidly grounded systems may have their place where redundant equipment is installed and are the norm for 3 phase, 4 wire systems.

The solidly grounded system provides some interesting problems. First of all, as the source transformer becomes larger, the available fault current increases substantially. Since the vast majority of faults are ground faults, the resulting damage can be great. Secondly, arcing faults can present a serious problem in that the arc voltage may become sufficiently high to limit ground fault currents to such low values that the fault current magnitude may fall within the load current range. Prior to the introduction of ground fault protection, there were many cases where an arcing fault occurred on a circuit and went undetected until the fault propagated into a multiple phase fault, cleared itself or was manually disconnected by an operator. Faults lasting many minutes and doing extensive damage occurred.

With the NEC 230-95 requirement for ground fault protection on service entrances 1000 Amps and larger, and the utilization of ground fault protection on many other circuits, the number of sustained ground faults has been reduced. However, the number of cases of miscoordination of protective devices has drastically increased. There have been numerous cases of ground faults occurring on downstream protective devices and tripping the main breaker. The result is that an entire plant may be shut down due to miscoordination caused by the ground fault protective device.

The solidly grounded system can present problems with reliability and coordination. As a result, the high resistance grounded system, if properly installed, can be superior to any other type of system. The use of the high resistance grounded system can provide a safe, reliable and economic system with many benefits to the user.

II. HISTORY OF LOW VOLTAGE GROUNDING

There are several methods of grounding which have been used on low voltage systems. In the past, the ungrounded, the corner grounded and the mid-point grounded systems were used with varying degrees of success. See Figure 1. Today, the solidly grounded and high resistance grounded systems are the two most commonly used methods of grounding. See Figure 2.

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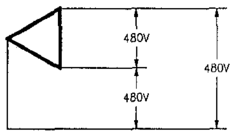
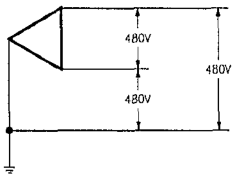
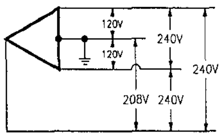


a) UNGROUNDED 480 VOLT SYSTEM



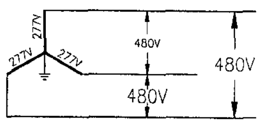
b) CORNER GROUNDED 480 VOLT SYSTEM



c) MID-POINT GROUNDED 120/240 VOLT SYSTEM

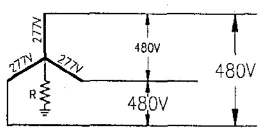
FIGURE 1

a)



SOLIDLY GROUNDED

b)

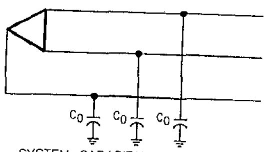


RESISTANCE GROUNDED

COMMON GROUNDING OF THE PRESENT

FIGURE 2

The **ungrounded system** is really a misnomer in that the system is actually capacitively grounded through the capacitance of the equipment. See Figure 3. As a result of this capacitance, a certain amount of capacitive current will flow during a line-to-ground fault. In addition, it has been found that arcing ground faults on the large "ungrounded" system can cause transient overvoltages several times normal voltage. [10] As a result, multiple motor failures have been caused by an arcing ground fault on an "ungrounded system.



SYSTEM CAPACITANCE TO GROUND

FIGURE 3

The **corner grounded system** was one attempt to provide a grounded system. Although a simple system, there are several distinct disadvantages with this system:

- Normal line-to-ground voltages on the two ungrounded legs are at line-to-line voltage which is 73% greater than normal line-to-ground voltage on a grounded wye system.

- A ground fault on the grounded leg can go undetected.

- A ground fault on one of the two ungrounded legs will in actuality be a phase-to-phase fault with a ground path.

The **mid-point grounded system**, commonly referred to as a 3 phase, 4 wire delta, was a system which allowed both three phase and single phase loads. (Electric utilities commonly used this connection in providing a 3 phase, 4 wire, 240 volt system and center tapping one 240 volt leg for 120 Volt lighting service. The center tapped transformer allowed the use of 120/240 Volt, single phase lighting and power loads in conjunction with 3 phase power loads.) Electric utilities, while still utilizing this design, have largely done away with the 3 phase, 4 wire delta 240 and 480 volt systems and replaced them with 208 Y/120 Volt and 480 Y/277 Volt systems, respectively. Likewise, large power utilization customers prefer the 480Y/277 Volt transformers at this time.

III. COORDINATION PROBLEMS

NEC Article 230-95 requires ground fault protection of equipment rated 150 Volts or greater to ground, but not exceeding 600 Volts phase-to-phase for each service disconnect rated 1000 Amps and above. In reviewing this code requirement, two observations can be made:

- Ground fault protection on systems with line-to-ground voltages of less than 150 Volts do not require ground fault protection. Part of this reason is due to the fact that the arc-voltage on a low voltage system is in the range of 140-150 Volts. [02,06] For a system voltage of approximately 150 Volts or less, there is normally insufficient voltage to sustain an arcing fault. The fault either welds itself to another conductor causing sufficient fault current to clear the protective device, or the fault is self clearing by tripping a breaker and/or extinguishing the arc.

- With arc voltages in the range of 150 Volts, ground fault currents on 440-600 Volt system are often-times limited to relatively low values. In the past, phase-sensitive protective devices with high current ratings have failed to clear arcing ground faults. The 1000 Amp rating appears to be the code accepted lower limit where sustained arcing ground faults may occur and ground fault protection is necessary. The actual value may be somewhat lower.

One of the fine print notes (FPN No. 2) of Article 230-95 states:

> "The added *(ground fault)* protective equipment at the service equipment may make it necessary to review the overall wiring system for proper selective overcurrent protection coordination. Additional installations of ground-fault protective equipment may be needed on feeders and branch circuits where maximum continuity of service is necessary."

Ground fault protection on solidly grounded systems provides a more sensitive means of detecting and isolating ground faults than fuses and circuit breakers without ground fault protection. The major benefit of ground fault protection is the relatively quick and sensitive detection and isolation of circuits having a ground fault. However, along with the quick and sensitive detection of ground faults comes the problem of miscoordination as mentioned in FPN No. 2 associated with NEC Article 230-95. Numerous cases have been reported and observed where a main breaker trips for a fault on an insignificant downstream feeder or branch circuit. In fact, the most common coordination problems at 440-600 Volts is caused by having a downstream phase device which miscoordinates with an upstream ground fault protection. See Figure 4.

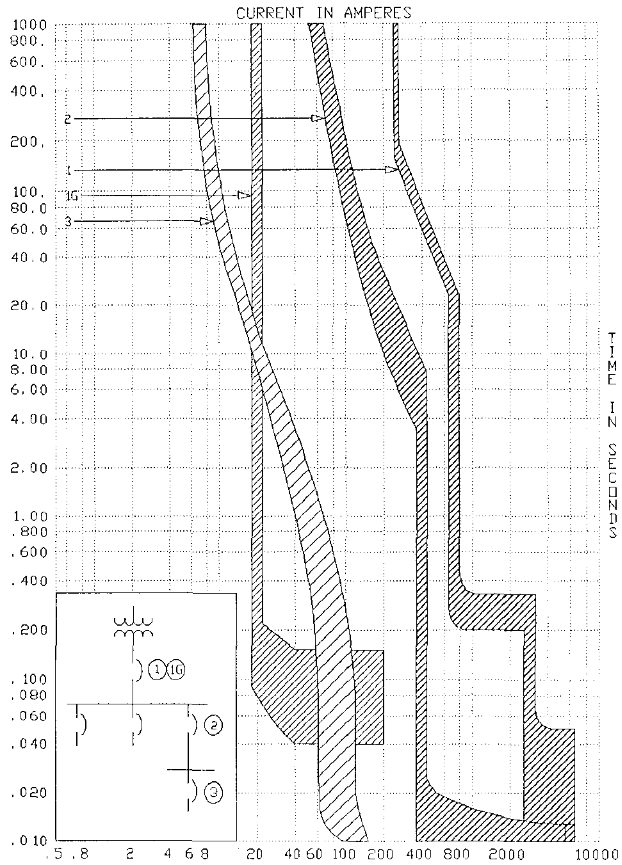


Figure 4: Device 1 - Main Breaker Phase Protection
Device 1G - Main Breaker Ground Protection
Device 2 - Feeder Breaker Protection
Device 3 - Remote Breaker Protection

In Figure 4, the main breaker, device #1, has a combination of both phase and ground fault protection as shown by phase time current curve #1 and ground fault time current curve #1G. The feeder breaker, device No. 2, has no separate ground fault protection and its time current curve is #2. A downstream branch breaker, device No. 3, also has no separate ground fault protection and its time current curve is #3, (This breaker could easily be a minor, insignificant circuit breaker in the circuit). As can be seen, the phase protection curve of circuit breaker No. 2 does not coordinate with the ground fault protection curve 1G of the main breaker. Furthermore, the time current curve for circuit breaker No. 3 does not totally coordinate with the main breaker ground fault curve. The result is that the main breaker will open for most ground faults downstream of the feeder breaker before the feeder breaker can open. Furthermore, circuit breaker No. 3 also does not properly coordinate with the ground fault protection on the main and the main breaker can trip for a ground fault associated with breaker No. 3. This type of miscoordination is quite common when a service disconnect is installed without a coordination study. False tripping can occur on downstream breakers rated as low as 20 Amps, and is almost always a problem with downstream breakers rated 75 Amps and above. Better coordination can be obtained by performing a detailed short circuit and coordination study in conjunction with installing downstream ground fault protective devices. However, in most cases, compromises must be made and maximum reliability is not attained using a solidly grounded system at 440-600 Volts.

IV. ARCING FAULTS AND ARC RESISTANCE

Short circuit and coordination studies are commonly performed considering only bolted three-phase or phase-to-ground faults. However, real life equipment failures rarely are bolted faults. Instead, the faults are normally arcing type faults which have arc resistance and this resistance must be taken into consideration. It has been shown that on low voltage equipment, an arc voltage in the range of 150 Volts is developed [02] [06]. The arc voltage is relatively insensitive to current which means the arc resistance is variable. Two observations can be made from this information:

1. A sustained arcing fault is unlikely for systems with line-to-ground voltages of less than 150 Volts. In other words, a 208Y/120 Volt system will not likely sustain an arcing fault. Conversely, low voltage systems with line to neutral voltages in excess of 150 Volts are much more likely to sustain an arcing fault. For example, a 480Y/277 Volt system has sufficient voltage to maintain the arc.

2. The arc resistance will tend to vary in order to maintain the arc voltage of 150 Volts. As such, the current magnitude may be limited to a value below the phase current sensing protective device. (With a sustained arcing fault and limited ground fault currents, the explanation for sustained arcing faults at 480 Volts is clear.)

Sustained arcing 480 Volt ground faults were a major problem prior to the extensive use of ground fault protection. The use of ground fault protection has minimized the damage caused by arcing faults which could not be cleared by insensitive phase protective devices which were sized for large continuous currents of 1000 Amps and more.

In addition to equipment damage, the flash and heat from an arcing fault can cause severe injuries or death. Temperatures greatly in excess of 10,000°C can be created almost instantaneously from the plasma of the fault [11]. The ionization gases expand at an extremely high rate which will engulf any person or thing in its path.

The use of a high resistance grounded system minimizes the amount of damage created from the fault by:

- Reducing the fault current to some small value, typically 1-5 Amps. The I^2T for a 1 Amp fault is one millionth (1/1,000,000!) of a 1000 Amp fault, assuming an equal amount of time (T). Therefore, the energy normally dissipated in a ground fault is drastically reduced by using high resistance grounding.

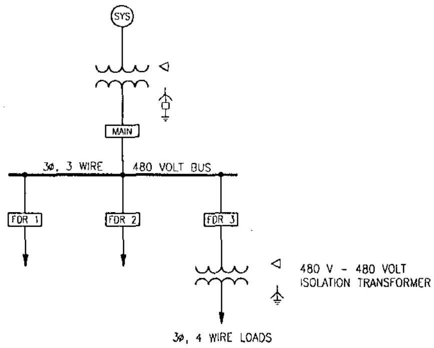
- By creating a voltage drop across the neutral grounding resistor, the remaining voltage at the point of the ground fault is much less than 150 Volts. Therefore, a sustained arcing fault is not likely.

V. HIGH RESISTANCE GROUNDING AND 3 PHASE, 4 WIRE LOAD APPLICATIONS

One of the most common reasons for not using a high resistance grounded system is that single phase or 3 phase, 4 wire loads are required. If the majority of the loads are 3 phase, 4 wire loads, high resistance grounding is most likely not practical. However, if most of the loads are 3 phase, three wire type loads, high resistance grounding may still be an option.

With proper planning, many single phase, line-to-neutral loads can be replaced with line-to-line equipment. All step-down transformers such as the 480 Volt - 208Y/120 Volt transformer should utilize a delta primary which equates to a 3 phase, 3 wire, load.

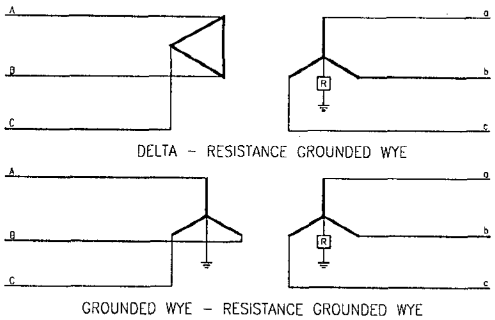
If 3 phase, 4 wire loads are essential, a delta-wye isolation transformer may be installed to isolate the 3 phase, 4 wire loads (Example: 480 Volt Delta - 480 Y/277 Volt transformer) See Figure 5 . The delta winding provides the 3 phase, 3 wire load required for the high resistance grounded system while the secondary 480Y/277 Volt winding provides the ground source for 3 phase, 4 wire loads. The wye on the secondary of the isolation transformer would be solidly grounded. Also, normally the size of the transformer secondary breaker will be sufficiently small that ground fault protection is inherent with the phase-current sensitive breakers.

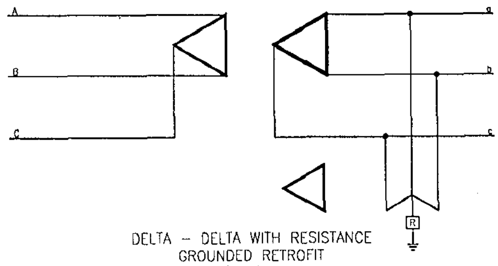


HIGH RESISTANCE GROUNDED MAIN SYSTEM WITH
3φ, 4 WIRE LIGHTING LOADS
FIGURE 5

VI. DESIGN CONSIDERATIONS

The design of a high resistance grounded system is relatively simple for a delta primary - wye secondary transformer. Similar concepts can be used with a wye-wye transformer provided the primary neutral bushing, Ho, and the secondary neutral bushing, Xo, are separate. The Ho bushing should be solidly grounded and the Xo bushing can be high resistance grounded. The delta secondary connected transformer requires additional design calculations and equipment since an auxiliary high resistance grounded wye-delta transformer is required. See Figure 6.





DELTA – DELTA WITH RESISTANCE
GROUNDED RETROFIT
FIGURE 6c

The first step in the design is to calculate the system capacitance Xc. Reference [17] provides many typical capacitance values for low and medium voltage equipment. Although the accuracy is not critical on this calculation, the conservative approach would be to err on the high side for the system capacitance. During the testing phase, the actual charging (capacitive) current will be measured to verify the adequacy of the grounding resistor.

After determining the system capacitance, a tapped ground resistor may be adjusted for proper size . In order to minimize the probability of transient overvoltages [09], the resistive current I_{RO} during a ground fault should be equal to or greater than Ico.

$$I_{RO} > I_{CO} \qquad (1)$$

The zero sequence circuit of the resistor and equivalent capacitance are in parallel. See Figure 7. Since the resistor is placed in the neutral of the transformer, 3Io will flow through it. As a result, that current makes the apparent resistance of the grounding resistor appear to be three times as large. Therefore, 3R is used in the zero sequence circuit. Based on the circuit in Figure 7 and the fact that the positive and negative sequence impedance values are negligible, a good approximation for the resistance and current flows are as follows:

$$R = \frac{Xco}{3} \quad \textbf{Ohms} \qquad (2)$$

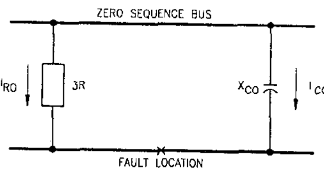
$$I_R = \frac{V_N}{R} \quad \textbf{Amps} \qquad (3)$$

$$Ic = \frac{V_N}{Xco/3} \quad \textbf{Amps} \qquad (4)$$

[Note that $I_R = 3*I_{RO}$ and $Ic = 3*Ico$ from symmetrical component calculations.]

The resistor size (wattage) may be determined by the following equation:

$$\textbf{Watts} = I_R^2 * R \quad \textbf{Watts} \qquad (5)$$



ZERO SEQUENCE CIRCUIT
OF HIGH RESISTANCE GROUNDED SYSTEM
FIGURE 7

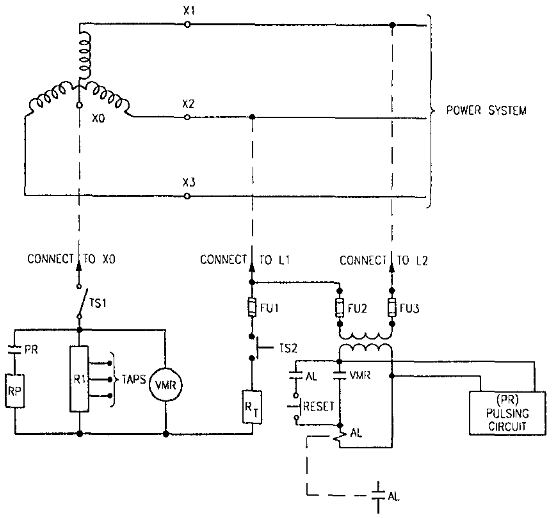
Typical resistance and wattage range for 480 Volts grounding resistors are as follows:

Resistor Range: 60 - 300 Ohms

Wattage Range: 260 - 1300 Watts

The grounding resistor is normally provided with taps which allow for fine tuning of the resistance during the time of installation and testing. The author's experience has been that the capacitive test current is usually somewhat lower than the calculated value. This is based on the conservative nature of the calculations and allowances made for future expansion and addition of equipment.

Once the capacitance of the system and the size of the grounding resistor have been determined, the specific detailed design and options for the system can be made. Figure 8 shows a typical design with some installation, testing and operational features.



HIGH RESISTANCE GROUNDED SYSTEM

AL - ALARMING/TRIPPING RELAY
R1 - TAPPED GROUDING RESISTOR
RT - TEST RESISTOR
RP - PULSING RESISTOR
PR - PULSING RELAY
TS1 - RESISTOR DISCONNECT SWITCH
TS2 - GROUND TEST SWITCH
VMR - VOLTAGE METER RELAY
FU1, FU2, FU3 - FUSES

FIGURE 8

The basic design will include the tapped grounding resistor and a voltmeter relay, VMR. The voltmeter relay provides for a voltage reading across the resistor and an adjustable voltage relay with one or more contacts. The VMR contact can be used for either tripping or alarming.

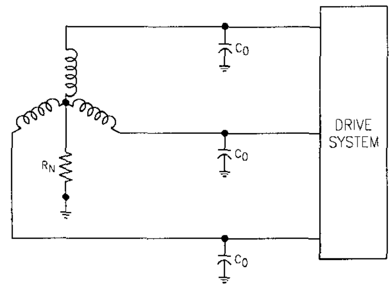
The first optional feature should include a second fused switch and resistor for providing a ground fault test. The second option could include an isolating transformer and an alarm or tripping seal-in control circuit. Finally, a pulsing relay circuit could be installed to aid in locating the ground-fault. The pulsing circuit places another resistor in the circuit to allow more current to flow so that a clamp-on ammeter could be used to locate the fault.

VII. APPLICATIONS HIGHER HARMONIC CURRENTS

Many low voltage systems have loads which produce harmonic current and voltage distortions. These distortions are created by rectifiers, dc drives, variable speed ac drives and other electronic switching devices which are connected to the power system. Without the drives, the capacitive current at 60 Hz is normally a positive sequence value under steady state conditions (non-fault conditions) and the currents cancel. However, many drives create a zero sequence voltage and, when coupled with the earth, will create a high frequency zero sequence current to flow in the neutral grounding resistor. The result is that the high frequency zero sequence current will flow through the resistor creating a high frequency voltage of significant value. This voltage can result in the following:

- Nuisance alarms and/or trips due to the RMS voltage across the resistor.
- Resistor sizing problems due to the harmonic current flow. The resistor sizing must include the heating effects caused by the harmonic current flow.

The cause of the problems can best be shown in Figure 9. The system capacitive reactance is inversely proportional to the frequency. With higher order harmonic voltages present due to the electronic switching of the loads, currents can and do circulate through the neutral grounding resistor. When applying such loads to the system, the harmonic voltage across the resistor should be measured and an oscilloscope should be used to view the voltage waveform where both magnitude and frequency can be recorded.



HIGH RESISTANCE NEUTRAL GROUNDING WITH HIGH FREQUENCY FILTERING CAPACITOR

R_N = NEUTRAL GROUNDING RESISTOR

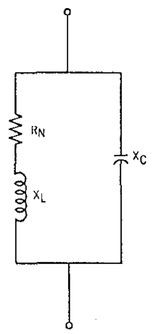
C_0 = SYSTEM CAPACITANCE

FIGURE 9

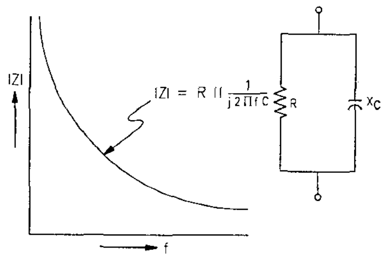
When applying a high resistance grounded system where there is a significant amount variable speed drives, the resultant zero sequence currents caused by the switching of the drives and the capacitance of the system must be taken into consideration. Due to the relatively high amount of neutral resistance, typically in the 60-300 Ohm range, a small amount of high frequency current can result in a significant voltage across the resistor.

As an example of this problem, a 575 Volt, 870 KVA drive supplying a 945 hp motor was inspected and found to have a significant voltage across the grounding resistor on the transformer. The transformer was rated 1000 KVA, 4.16 kV delta primary - 575 Y/332 Volt secondary with a 670 Volt, 4.5 Amp, 150 Ohm grounding resistor. A high frequency (800+ Hz) current was found to be flowing through the resistor. The resultant voltage across the resistor was measured at 100-110 Volts RMS from a 0.66 Amp current. As can be easily seen, such a high voltage across the resistor creates a problem when that voltage is used for alarming or tripping.

There are most likely a number of solutions to this problem. One is to place a reactor in series with the resistor and a capacitor in parallel with the series combination of the resistor and reactor. See Figure 10. This solution would provide blocking of high frequency currents through the resistor and by-passing the high frequency currents. However, further inspection of the circuit will reveal that the parallel capacitor will provide a low impedance path for the high frequency currents and act as a high impedance for the low frequency, 50 or 60 Hz, ground fault currents. See Figure 11. In other words, the capacitor acts as a high-pass filter to eliminate the nuisance current, but will allow the fault current to flow through the resistor for alarming and/or tripping.



NEUTRAL R-L-C IMPEDANCE
FIGURE 10



NEUTRAL R-C IMPEDANCE CHARACTERISTICS
FIGURE 11

In the above example, a 10 micro-Farad, 600 Volt capacitor was inserted in parallel with the resistor. The voltage across the resistor was reduced from approximately 100-110 Volts to 12.5-15 Volts. The voltage reduction results were quite significant. With the high frequency nuisance voltage being reduced to a relatively low value, a reasonable voltage setting can be made for alarming and/or tripping when a ground fault occurs.

A secondary benefit which was observed on the above test was a reduction in the high frequency noise on the phase voltages. The original phase-to-ground voltage waveform was quite distorted resulting in a varying RMS voltage of 345-355. Upon insertion of the capacitor into the circuit, the voltage waveform was much less distorted and the voltage was a solid 335 Volts RMS.

VIII. APPLICATION FOR EMERGENCY SYSTEMS

Another use of the high resistance grounded system is for emergency systems as described in NEC Article 700. According to NEC 700-26, ground fault protection is not required. However, the article further states that ground fault indication should be provided. Again, the use of the high resistance grounded system can provide the reliability required for the emergency system as will as the indication.

IX. INSTALLATION AND TESTING

The installation and testing of the high resistance grounding system is important. The installation of the system should be performed in accordance with the engineer's and/or manufacturer's specific instructions. Those instructions should include these basic steps:

1. With the system de-energized, install the high resistance grounding system. On a wye connected transformer or generator, the resistor is connected between the ground bus and the neutral. On a delta system, the auxiliary transformers need to be properly connected to the 480 Volt system bus. Proper installation and safety procedures need to be strictly followed.

2. The capacitive charging current should be measured using proper testing procedures. (An independent testing company may be used.) *The entire system should be energized during* this test to assure that the maximum charging (capacitive) current is measured. The following steps will be required:

   A. The tapped grounding resistor with a conservative resistance value should be connected to the system.

   B. The system should be energized initially with the resistor in place to test for ground faults. Little or no voltage should be present across the resistor. For a solid ground fault on a 480 Volt system, a voltage of approximately 277 volts would be present. For a motor winding or high resistance ground fault, voltages lower than 277 Volts may be measured. If a ground fault is found, it must be removed prior to the next step.

   C. The system should be de-energized and the grounding resistor disconnected from the system.

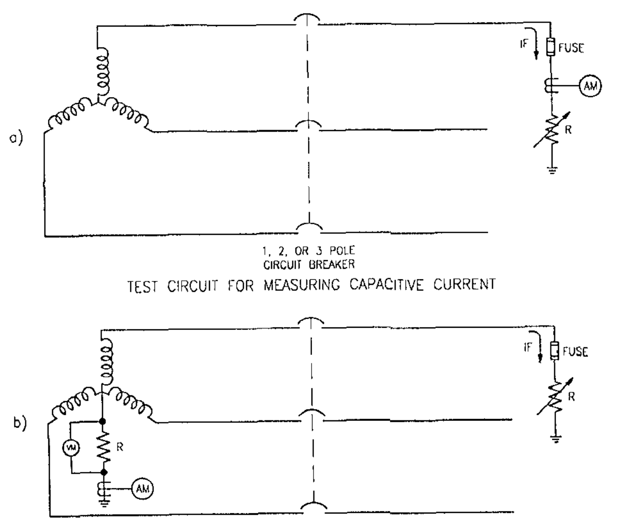
   D. Using an isolated circuit with the circuit breaker open, install the test circuit as shown in Figure 12a

   E. Energize the entire circuit, slowly reduce the resistance to zero and measure the charging (capacitive) current.

   F. Verify that the calculated resistive current, I_R, is greater than Ic measured in the above step. To calculate I_R, divide the voltage by R.

$$I_R = \frac{V_N}{R} \qquad \textbf{Amps} \qquad \textbf{(6)}$$

   G. De-energize the system, properly set the tap, reinstall the grounding resistor, and again place a fault on the system. See Figure 12b.



TEST CIRCUIT FOR MEASURING VOLTAGE & CURRENT
AT GROUNDING RESISTOR
FIGURE 12

   H. Measure and record the ground fault current in the resistor and the voltage across the resistor.

I. Test and place settings on any protective devices.

J. Remove the fault and place the system in service.

X. CONCLUSIONS

High resistance grounding has a good track record in the petro-chemical industry for a number of reasons:

- Capacitive current on low voltage systems (440-600 Volts) is low enough (less than 5 Amperes) that resistive controlled current can be kept low enough to avoid escalating the fault and resultant equipment damage.
- Proper application of the high resistance system will limit the transient overvoltages of arcing faults to a reasonable value.
- The application of high resistance grounding has historically been limited to three phase, three wire systems. However, this paper has shown that three phase, four wire loads and/or single phase loads can be accommodated with the use of an isolation transformer.
- The proper use of grounding and bonding is still important even though the normal ground fault current may be limited to a few amps. In the event of a phase-to-phase fault involving ground, the ground currents could be quite high.
- Although the high resistance grounding is quite simple, a detailed design is still required in order to adequately select and size the equipment. Once the system is installed, it requires testing in order to adequately select the optimum resistance value. Taps on the resistor are beneficial for the final setting of the ground resistance.
- High resistance grounded systems may be used to trip a breaker or initiate an alarm. If used for alarming, the ground fault location needs to be determined and isolated in a reasonable amount of time. While the ground fault persists the voltage on the two ungrounded phases can elevate to 73% greater than normal line-to-ground voltage.
- A high resistance ground system will minimize the chances of serious "burn-down" damage and severe arc flash damage. The result is safer for both the equipment and personnel.
- A high resistance grounded system can be successfully used on systems with rectifiers, dc drives, ac drives and other harmonic current producing circuits. The proper placement of a capacitor across the resistor will help filter the high frequency current.

This paper has shown the benefits of high resistance grounding for continuous process industries. When reliability and limitation of ground fault current is essential, a high resistance grounded system is recommended. With the proper design and testing, a high resistance grounded system provides the safety and reliability necessary for a petro-chemical or other heavy industry. As such, the high resistance grounded system should become a standard of the industry and the solidly grounded system should only be used where the high resistance grounded system cannot be used for three phase, four wire utilization equipment.

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