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Distribution Neutral Point Treatment in North America and Europe and Grounding System in Distribution Stations

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SUMMARY

Distribution Neutral Point Treatment/Grounding and Distribution Station Grounding System are topics which are intercorrelated and usually together represented in utilities design guides and Distribution Network books.[1,2] Scientific papers usually do not present these two topics together although they are correlated. This article will deal with radial networks and those facts can be applied to the radial distribution networks with added distribution generation. The distribution station supplying transformer neutral point treatment could determine the level of the ground fault currents and considering that the GPR (Ground Potential Rise), touch voltage, step voltage and transferred voltage/potential depend on the ground fault magnitude, the transformer neutral treatment has direct impact on the distribution station grounding system design. In Europe the transformer neutral treatment can be isolated, directly grounded, through small resistance grounded, through small reactance grounded and compensated/resonant (through Petersen coil grounded). In North America there are all above mentioned transformer neutral treatment, but two dominant methods are small impedance neutral grounding and solid neutral grounded system (also effective grounded neutral system) and additionally a multigrounded neutral system i.e. four wire system. [1]

Distribution system protection device manufacturers (ABB, GE, SEL and Siemens) published protection schemes for different distribution neutral treatment, they also published papers which analyzed impact of the supplying transformer neutral treatment on high impedance fault detection, equipment thermal stress, insulation level needed etc., some of these topics will not be analyzed in this paper. Some manufacturers suggested some different IED (intelligent electronic device) protection relays for different supplying neutral treatment.[3]

Some of the above mention solutions have been used for arc flash control in LV networks (480V and above).[4]

KEYWORDS

Transformer neutral treatment, transformer neutral grounding, Distribution System, Station Grounding System, small reactance grounding, small resistance grounding, resonant grounding, compensated grounding, ground fault current, GPR (Ground Potential Rise), touch voltage, EPR (Earth Potential Rise) step voltage, transferred voltage/potential.

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1. Introduction

The distribution ground fault currents magnitude depends of the type of distribution network neutral point treatment i.e. grounding. The first distribution networks were overhead, the capacitive currents were low and decision in Europe and North America was to start with the networks with isolated supplying transformer neutral. First time change in neutral ground treatment was done by the end of 19th century single phase 3kV cable network in Frankfurt am Main was grounded by a 3Ohm water cooled resistor. Single phase network was later transformed in a 5.2kV four wire system three phase network, but the neutral was grounded through a grounding transformer with a reactance of 4Ohm. Because of the higher GPRs caused by higher fault currents this solution was not accepted in Germany[1,5,6]. Although Prof Petersen advised transfer the single-phase systems into three phase system with small resistors, he wanted to get self-extinguishing ground faults as it was known for isolated networks and in 1917 he suggested resonant (compensated) neutral grounding. The idea was to compensate capacitive currents and reduce radically the current magnitude in the fault point.
In France first compensated neutral was applied in 1893 by George Claude. [1,7] EDF (Electricite de France), but in 20th century and now EDF applied usually small impedance supplying transformer neutral grounding. It is a paradox that Germany and France were pioneers for some kind of distribution neutral grounding and they left this kind of solution.
In USA the distribution network development went in the other direction. Dominant solution was directly grounded transformer neutral or through the small impedance (neutral grounding resistor or neutral grounding reactor.
In UK direct or small impedance neutral grounding were common while the compensated grounding was avoided because of very often double ground faults. The main idea was also to avoid the network supply during the fault condition.
The distribution system neutral grounding has impact on public and personal safety, on voltage and thermal stress on the equipment, on interference on communication system, on the detection and on the elimination of ground faults and on the price of the distribution station grounding.

2. MV Distribution Neutral Treatment

Distribution network neutral treatment can be installed in the following ways:

- Isolated (ungrounded)
- Solid grounded (single point grounding)
- Solid grounded (multi grounded neutral)
- Low impedance grounding
- Combination low resistance and reactor grounding
- Low reactance grounding
- High impedance grounding
- Resonant-compensated grounding

Criteria for the selection of MV Distribution Neutral Treatment are usually:

- - Public and personnel safety
- - Capacitive component of the ground fault current
- - Insulation level of the equipment
- - Interference with communication lines
- - Limitation of transient overvoltages

Operating system with distribution neutral treatment isolated, high-impedance grounded or compensated (resonant) grounded restricts ground fault current magnitudes and matches most of the goals mentioned above, but these neutral treatment methods create fault detection sensitivity problems. [3]

A brief description of MV neutral treatment-grounding is described below..

2.1. Isolated or Ungrounded neutral system

A simplified single core cable distribution network isolated neutral system with a ground fault is presented in Figure 2.1. Parallel to all capacitances are conductance which represent losses in cables. The phasor voltage and current diagrams are presented in Figure 2.2. The capacitive current in the fault is given by equation 1. [1] Figure 2.3 shows the currents in healthy phases and in the phase with the ground fault. The currents in healthy phases flow towards the neutral, in the neutral those currents are transferred to the ground fault phase and then they are building up the ground fault current. The same scenario would happen if the distribution network consisted of many different lines.

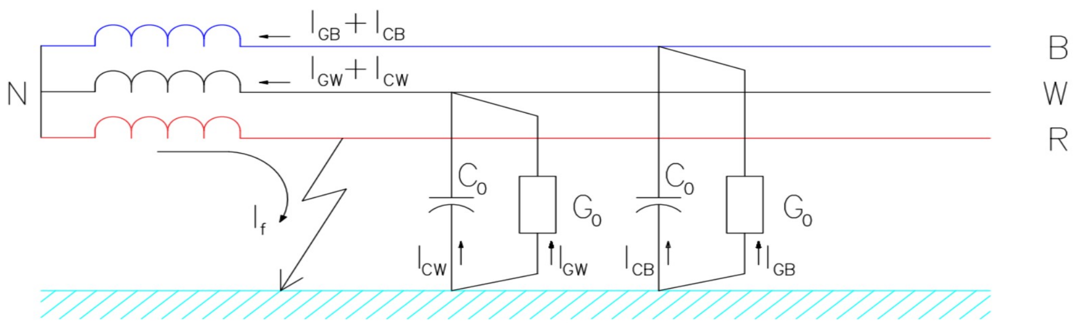

Figure 2.1: Schematic presentation of an isolated supplying transformer neutral and a ground fault.

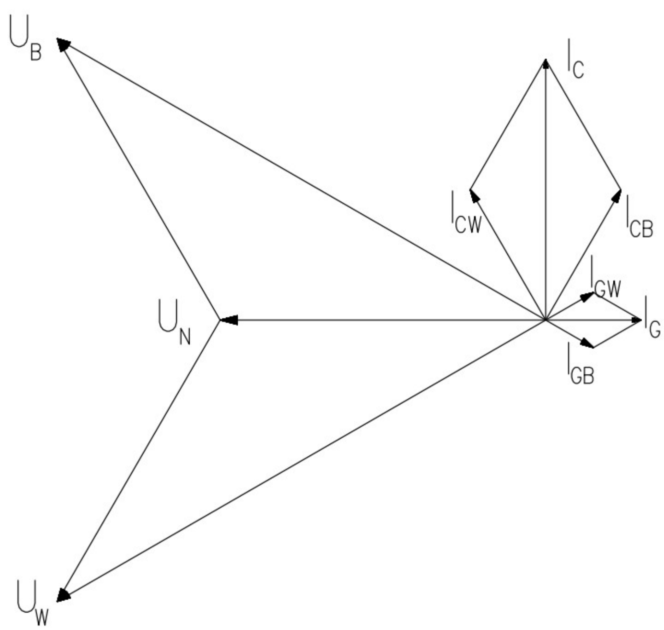

Figure 2.2: Phasor current and voltage diagram for isolated supplying transformer neutral and a ground fault.

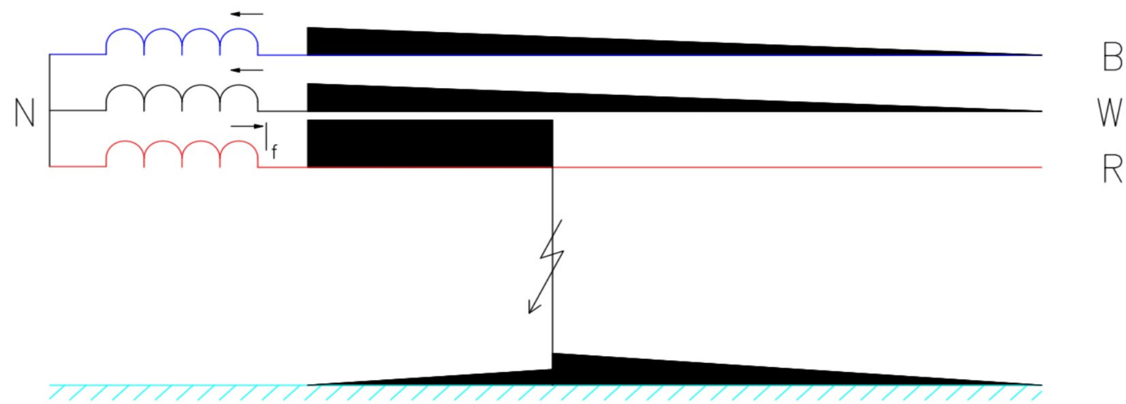

Figure 2.3 Current flow in a circuit with an isolating supplying transformer neutral and ground fault

For this solution is phase to phase insulation needed. The most positive effect of this neutral treatment is that the network could work with a ground fault (small fault currents) and that the load transfer i.e. outage could be done later. This approach allowed self-extinguishing of the temporary ground faults. VDE standards presented diagrams which showed dependance of allowed self-extinguishing currents and nominal network voltage [1,8,9]. The development of the network increase the capacitive currents. Those currents could exceed the self-quenching criteria (e.g. 40A) and because of that utility companies have their own current level when they plan to transfer isolated neutral to other distribution neutral treatment (e.g. 20A) [10]. The self-extinguishing and restriking of small currents could produce high transient overvoltages on healthy phases and on ground fault phase as well.
This isolated neutral system is dominant in Italy, Japan, Ireland, Russia, Peru, Spain and also exists in Germany, and some other European countries.
Advantages:

- during ground faults, which statistically represent over 90%[12], in the case of a very low capacitive currents the self-extinguishing of the ground fault happens.
- relatively small fault currents, the distribution system grounding is inexpensive and simple

Disadvantages

- Intermittent voltages could be high and cause double ground fault
- High impedance faults cannot be easily detected.

2.2. Compensated (Resonant) supplying neutral grounding

When the magnitude of the ground fault exceeds the critical self-extinguishing limit, the probability of self-extinguishing becomes low. The critical values are written in 0228 and are based on trials done in 1963 by M. Erich and H. Heinze. When the ground fault currents are higher than the critical values, the work with an isolated neutral is not reliable and self-extinguishing characteristic vanishes.
In order to get this self-extinguishing effect in urban network with many cables with higher ground fault current, the currents can be reduced if an inductive current is added. This inductive current will be produced by installation of a reactor between supplying transformer neutral and the ground. This compensation could be done by automatic regulated coils called Petersen cols. The purpose of the installation of those coils is to provide an increased quality of power supply.
The application can be done in two different manners:

- Continuous automatic compensation coil
- Stepped automatic compensation coil

Schematic phasor diagram and current flow in an urban network is shown below.

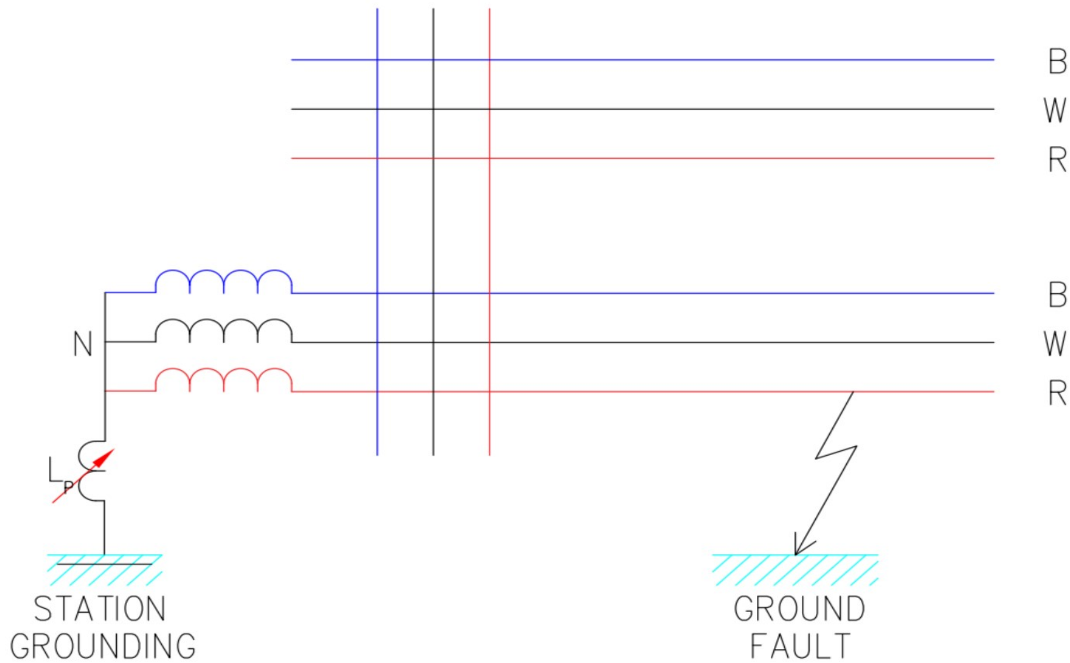

Figure 2.4: A ground fault in a distribution network with a compensated neutral.

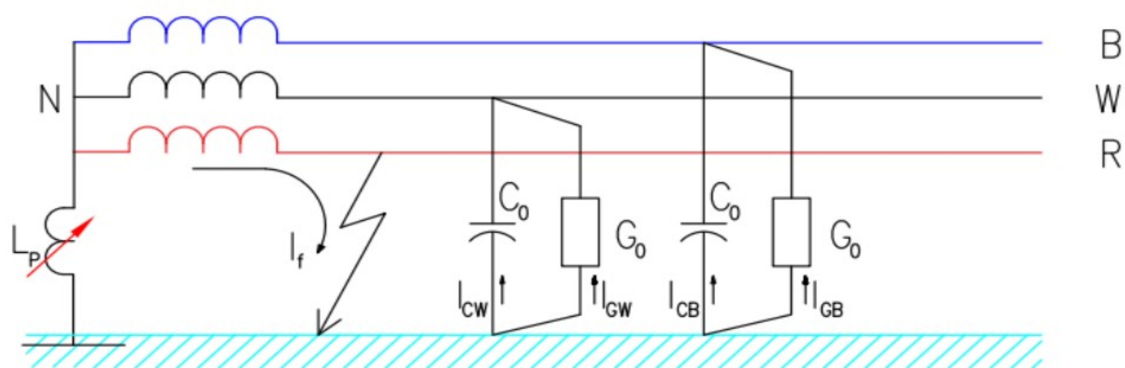

Figure 2.5: Schematic presentation of a compensated supplying transformer neutral and a ground fault.

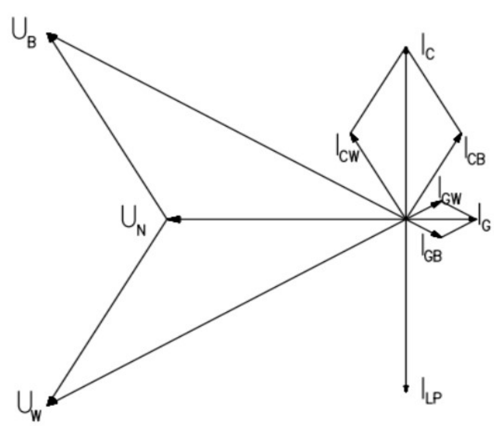

Figure 2.6: Phasor current and voltage diagram for a compensated supplying transformer neutral and a ground fault.

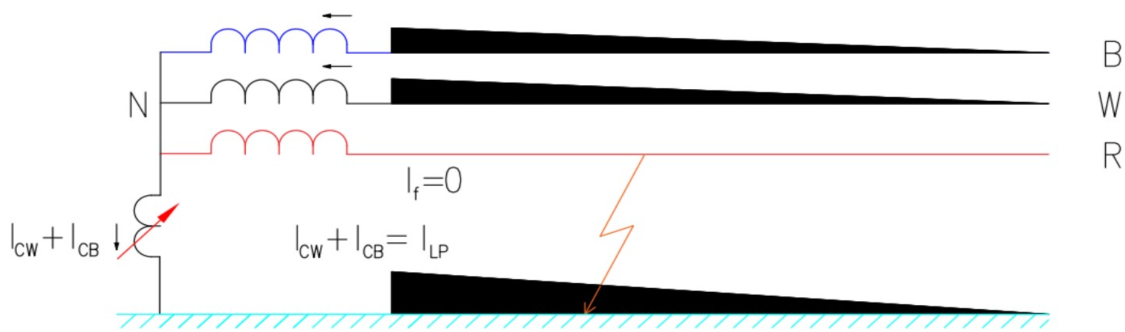

Figure 2.7 Current flow in a circuit with a resonant supplying transformer neutral and ground fault

Phase to phase insulation level is needed for this kind of the supplying transformer neutral grounding.

Advantages:

- Small ground fault currents provide self-extinguishing, the ground faults do not cause supply interruption and the temporary ground faults (more than 80% of all ground faults) will be removed with self-extinguishing
- Suggested to be used where the grounding (soil, bedrock etc.) is an issue.

Disadvantages

- High impedance faults cannot be easily detected.

2.3. Solid grounded neutral system (single point and multigrounded neutral)

The solid supplying transformer neutral grounded system was also popular in Great Britain where the transformer neutral is directly connected to the ground. The ground fault magnitude is similar to three phase fault magnitude. The ground fault protection sensitivity is good. The solid neutral grounding and solid multigrounded neutral are presented in Figures 2.8 - 2.11. The fault current magnitude depends on the fault location. The phase angle between current I_f and voltage Ur depends on the type of network (overhead or cable), fault location and neutral grounding impedance.

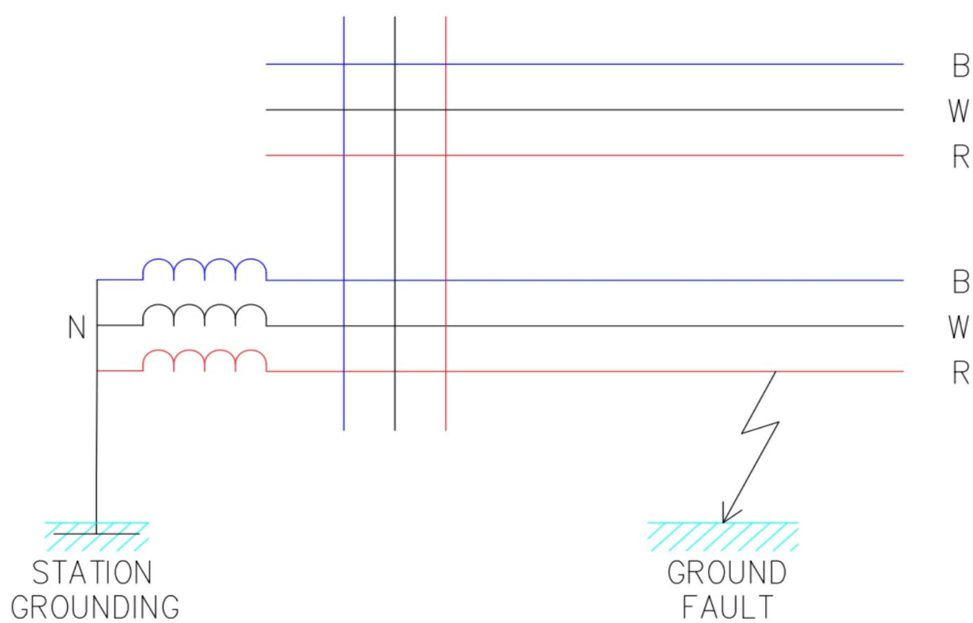

Fig 2.8 Solid grounded supplying transformer neutral

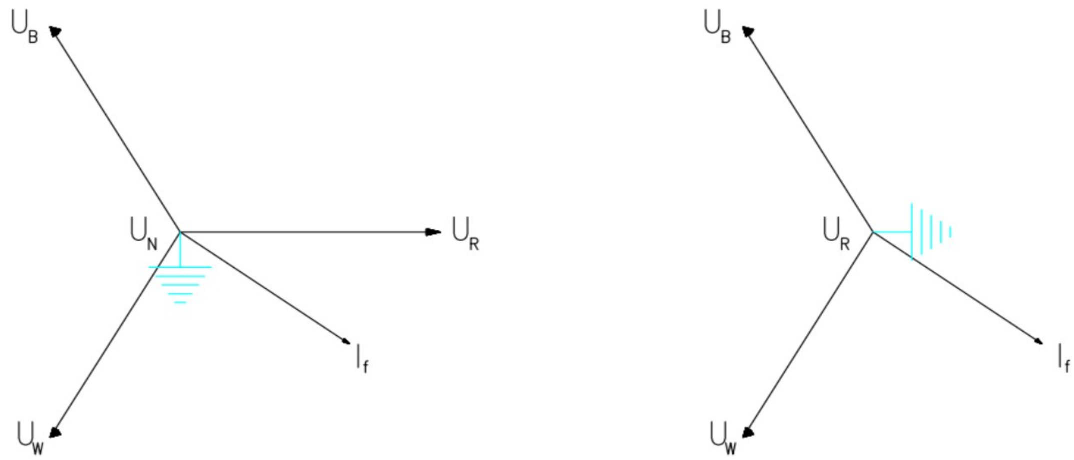

Fig 2.9 Phasor voltage and current diagram for a solid grounded supplying transformer neutral

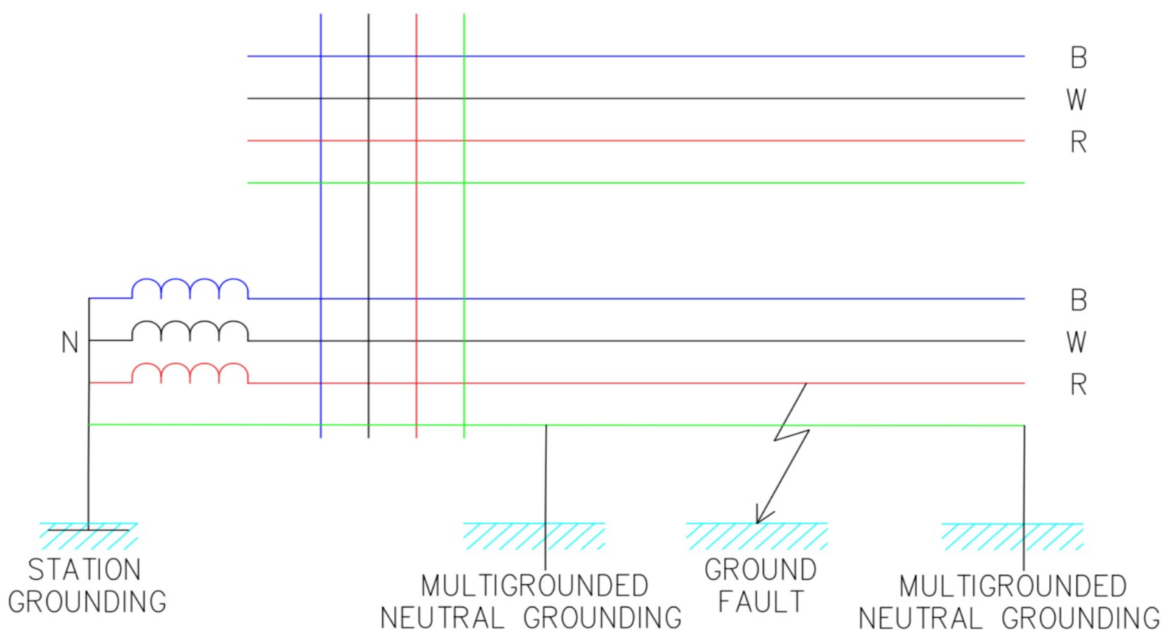

Fig 2.10 Solid grounded multigrounded neutral system

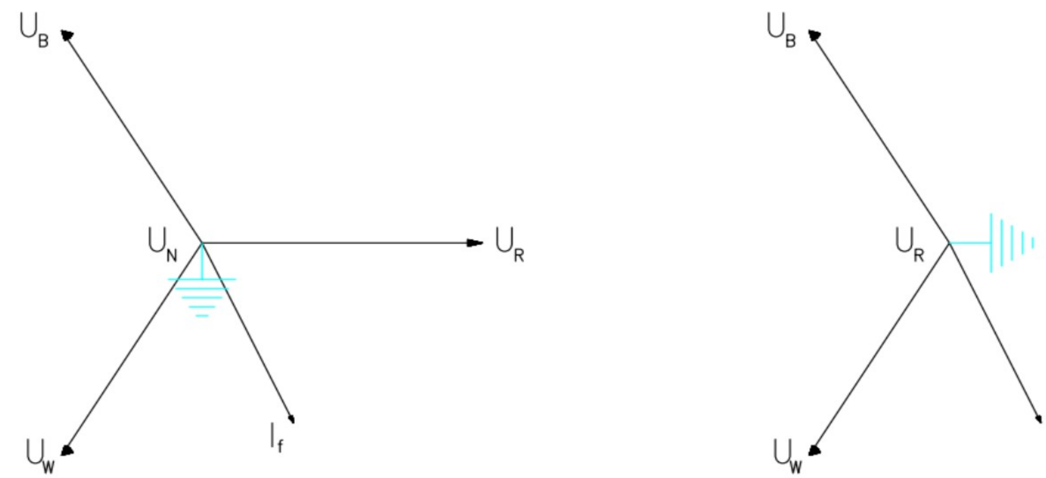

Fig 2.11 Phasor voltage and current diagram for a multigrounded neutral system

The high ground fault currents could cause that the required distribution station grounding system become expensive and provision of required touch and step voltage level[10] and of GPR becomes difficult as well. The required system insulation level is phase to neutral.
In USA and Canada an effectively grounded transformer neutral system is also applied. For that system the following ratios are applied X0/X1 ≤ 3 and R0/X1 <= 1. X0 and R0 are zero sequence reactance and resistance, X1 is the positive-sequence reactance of the power system. In that case the transformer could be grounded through a very small reactance which will meet above mentioned requirements. The same rules are applied for single point grounded neutral system i.e. 3 wire system (34.5kV and 44kV) and for multigrounded neutral systems i.e. wire system. Multigrounded neutral system consists of neutral conductors whicha are grounded at least 4 times per mile Figure 2.10. Unbalanced current is flowing through the ground and the neutral conductor and it is very difficult to distinguish high impedance fault from unbalanced load, a required personnel and public safe grounding system is very difficult to achieve. [3.]
Advantages [3,10]

- easier detection of the fault and simpler relay protection (this is not valid for multigrounded system)
- lower switching overvoltages
- lower insulation level

Disadvantages [3,10]

- The relay protection needs reclosures, considering that each fault needs interruption, the quality of power supply is worse than with isolated neutral system.
- Higher ground fault current cause the distribution station grounding system to be complicated
- For multigrounded neutral the high impedance fault cannot be detected.

2.4. Low impedance (resistance and reactance) transformer neutral grounding

The system with low impedance transformer neutral grounding does not produce intermittent ground faults overvoltages. The transformer neutral is grounded through a low impedance reactor and resistor with the objective limiting ground fault current. The neutral grounding through a small reactance is usually provided through a grounding transformer. [1] The method of the neutral grounding through a small impedance is sometimes applied in USA and Canada on 34.5KV network and some 13.8kV networks.

In Europe the neutral grounding through a small resistance is more often applied than the grounding through a small reactance. This system exists in France, Eastern Europe in distribution networks and in mining industry. This current is selected to be large enough (EDF 150-200A in rural area) that the fault can be detected and located. In order to meet overvoltage criteria the resistor should be selected in that way that the current through the resistance meets the ratio of the fault currents IR:IC ≥ 3:1. In some cases this ratio could be even lower.
In Croatia this type of supplying transformer neutral grounding is used in 35kV networks, but if the distribution station soil is very bad they leave isolated neutral system or install resonant neutral grounding. The vector diagram of small resistance grounding is given below on Figure 6. In urban area where the cable network is dominant, EDF limited ground fault currents are up to 1000A. Those cases where the cable network dominant the ground fault current can be lowered i.e. this issue can be also resolved with an application of combination of neutral grounding resistor and neutral grounding reactor[11] the capacitor current will be reduced and limitation for IR can be kept lower e.g. 200A. This circuit can be overcompensated IL>IC or undercompensated IL<IC. The reduction of ground faults will reduce GPR caused by ground faults.

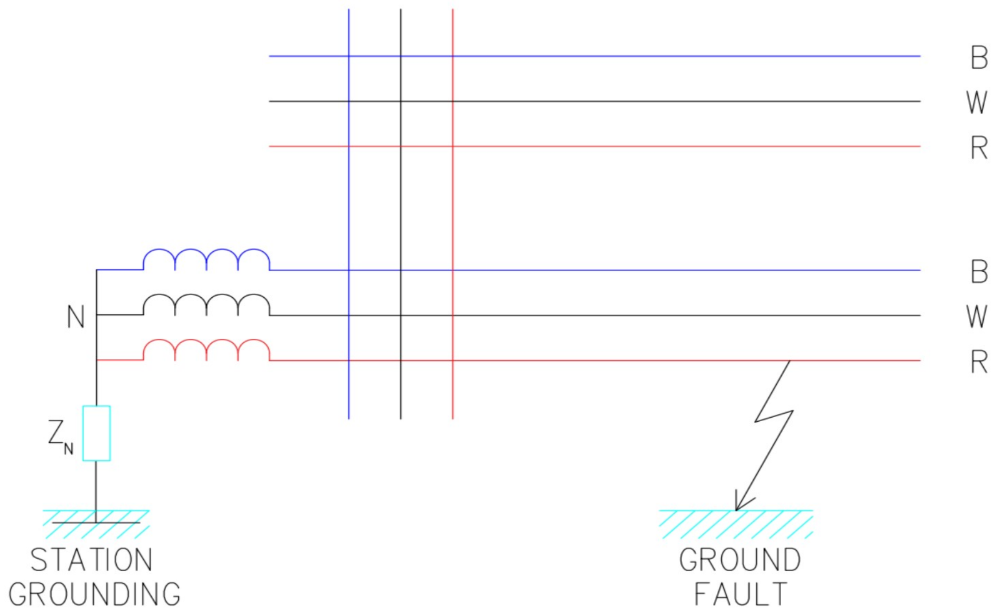

Fig 2.12 Supplying transformer neutral grounded with a small impedance

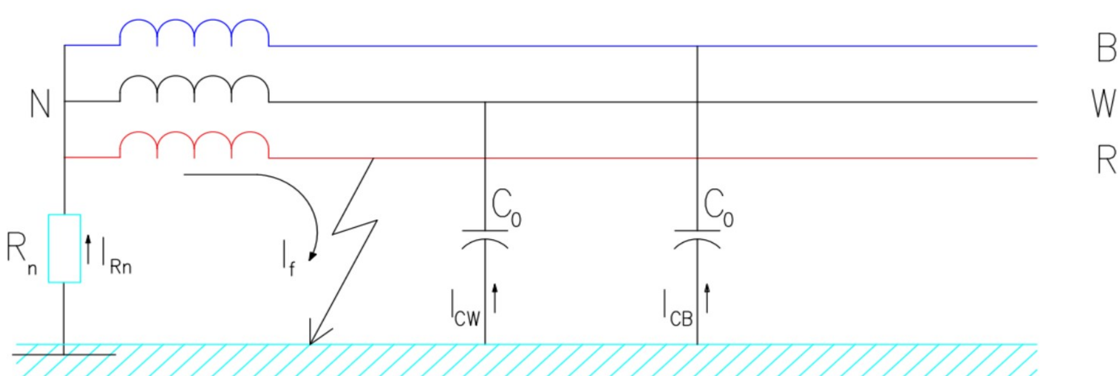

Fig 2.13 Schematic diagram for a supplying transformer neutral grounded with a small resistance

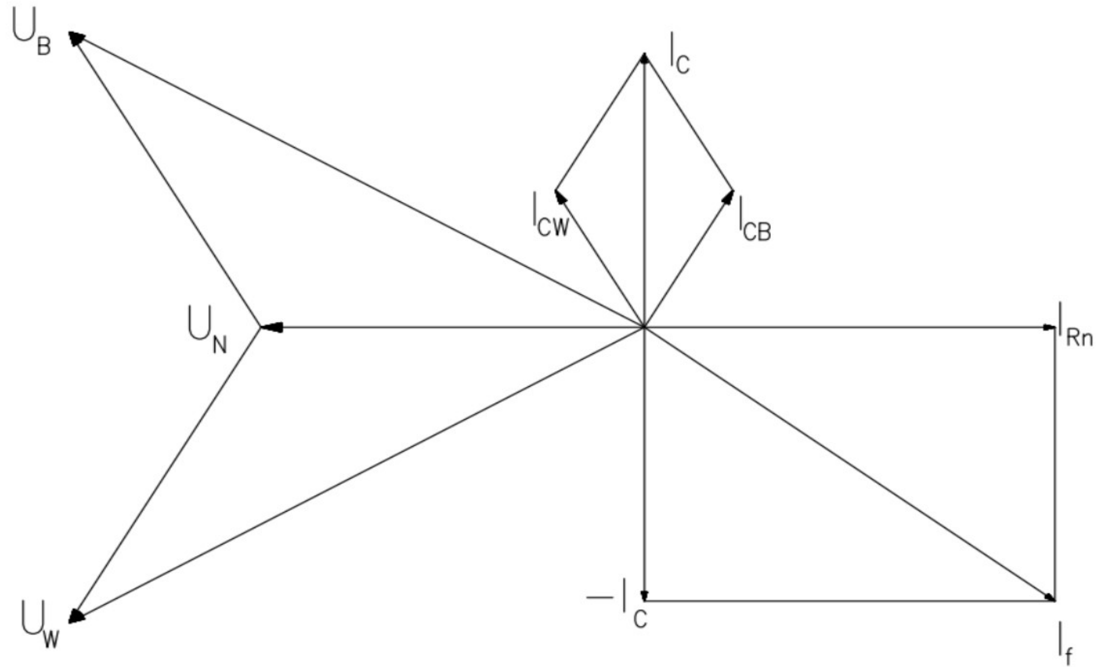

Fig 2.11 Phasor voltage and current diagram for a supplying transformer neutral with a small resistance grounding

Advantages

- Simple and reliable relay protection (in comparison to the isolated neutral system)
- Intermittent overvoltages avoided (reduced possibility of double ground fault formation)
- Required insulation phase to neutral

Disadvantages

- Every single fault should be interrupted and a reclosing operation is needed to remove temporary faults
- The ground fault currents are higher than in isolated or resonant neutral system, but lower than solid grounded neutral system. Distribution station grounding system is more complicated and expensive than for isolated system, but less expensive and complicated than it is for solid grounded neutral system (touch voltages, step voltages and transfer potential-voltages)

2.5 High impedance transformer neutral grounding

In this case the supplying transformer neutral is grounded through a high impedance resistance with a ground fault of 25A or less. This application similar to isolated neutral system allows utility to continue operating during ground faults. The high resistance grounding limits transient overvoltages to a safe level during ground fault operation.[3] Advantages and disadvantages (except issues with overvoltages) same like for isolated neutral system.

3. MV Distribution Station Grounding System

As it is mentioned above the selection of transformer neutral grounding system depends also on possible solution for distribution station grounding system. The main role of the grounding system is

to bring the ground fault current in the ground and that the voltages above grade inside and outside the station shall not endanger life of people, animals and shall not damage the equipment. Those requirements should be fulfilled in all seasons and weather conditions.
The EU standard EN-50522 presents relation between station grounding system and supplying neutral grounding system and methods of measurements and many topics related to grouding.[13] The standard IEC 61936 presented GPR (Ground Potential Rise, EPR) for different types of LV connections and different clearing time.[14]
The general definitions of a distribution grounding system are presented below. [13,15]

3.1 General definitions of a distribution grounding system

3.1.1 Local ground

Part of the ground which is in electric contact with an grounding electrode and the electric potential of which is not necessary to be zero.

3.1.2 Reference ground (remote ground)

Part of the ground of which the electric potential is taken zero

3.1.3 Grounding electrode

Conductive part, which may be embedded in a specific conductive medium, e.g. in concrete or coke, in electric contact with the earth

3.1.4 Grounding conductor

Conductor which provides a conductive path, or path of the conductive part, between a given point in a system or in an installation or in equipment and a grounding electrode.

3.1.5 Ground potential rise (GPR)

Voltage between a grounding system and reference ground under fault conditions.

3.1.6 Touch voltage

Voltage between a touchable object and the soil surface within a horizontal offset of one meter under fault conditions.

3.1.7 Step voltage

The maximum potential difference on the earth's surface between both feet separated by one meter.

3.1.8 Transferred voltage (Prospective touch voltage)

Voltage between two objects grounded at separate points or between a distantly grounded object and surrounding earth.
Although with the different description Figure 1 in EN 50522 and Fig 9.in IEEE Std. 80-1986[16] present the above-mentioned general definitions. The measurements methods are presented in IEEE standards, however the results of the measurements should be carefully analyzed considering that different seasons and weather conditions could show different values.
Equations for simplified single soil grounding system resistance are given in the Nahman's book.[17]
The distribution station grounding system in most of European countries consists of a ring conductor. The lower fault current magnitude provides an easier design which meets personnel and public safety requirements. In North America distribution station grounding is much more complicated, the grounding system consists of a ground grid. In this case it is much more difficult to meet the safety requirements and the grounding system is more expensive.

4. Conclusion

MV (medium voltage) supplying transformer neutral treatment and distribution station grounding design are complex activities. The decision of the MV transformer neutral grounding treatment should be a task for a multidisciplinary team (neutral grounding, distribution station grounding, relay protection design and the planning department). There is no unique solution and it cannot be standardized. [1,11] The different solutions in the supplying transformer neutral grounding design have been presented and analyzed. The decision of the neutral grounding treatment should be based on several network and grounding calculations and measurements (soil, fall of potential etc.). The paper emphasized difference between several grounded neutral treatments and their application. A proper selected neutral grounding system is important for the design of the distribution station grounding systems. Some of the mentioned ideas can be applied in the arc flash control in low voltage 480V and higher systems as well. Public and personnel safety could be improved with a proper selection of the supplying transformer neutral treatment.

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