RESONANT GROUNDING APPLIED IN BRAZIL

Carlos FIGUEIREDO
RGE Sul – Brazil
carlos.figueiredo@rgesul.com.br

Gabriel MELLO
RGE Sul – Brazil
gabriel.mello@rgesul.com.br

Mauro SILVEIRA
RGE Sul – Brazil
mauro.silveira@rgesul.com.br

ABSTRACT

Protection is about Safety. The IEC 60479 defines safety by its opposite concept, the Risk, that is proportional to the energy released. The earth fault is one of the most unsafe situations in overhead lines because it involves current to ground close to the people. But this kind of fault can be treated by the transformer neutral connection. The resonant grounding, based on Petersen Coil theory, provides the safer protection available for earth faults because it greatly decreases the energy released and consequently the Risk. RGE Sul is the first Brazilian utility that has experienced the benefits of this technique by replacing the traditional solid grounded system for the resonant grounding. This article describes the main learning got from this project that showed to be feasible its expansion around the country.

INTRODUCTION

RGE Sul is a southern Brazilian utility with more than 1.3 million customers located in 118 cities in the Midwest of the Rio Grande do Sul state. Its medium voltage grids are mainly overhead lines suspended by concrete and wooden poles, operating on 13.8 and 23.1 kV supplied for 82 substations.

The actual neutral scheme applied in high/medium voltage transformers in the company is the solid grounded system, which is the same as in all other Brazilian utilities and many others worldwide, like in Australia, Mexico and United States [1]. Furthermore, the grid protection in this system is made by overcurrent devices like relays, reclosers and cutout fuses. When an earth fault occurs, the overcurrent elements must be sensitive enough to operate and disconnect the affected part of the network.

In the solid grounded system the earth fault current can vary from a few milliamps – high impedance faults – until more than 10 kilo amps. In terms of safety both extremes are dangerous for people in this neutral treatment concept. The massive 10 kA involves the maximum risk according the IEC 60479 standard, because this current is enough to destroy a medium voltage (MV) busbar as RGE Sul had recorded in its system [2]. On the other hand, as the protection scheme for the solid grounded system is based on overcurrent protection, too small currents sometimes cannot be enough to sensitize relays or fuses and turn off the system during a high impedance fault. As result, if the MV live wires touch a tree during a dry day or if a wire broke and fall on the asphalt, the current can be so small that the system do not recognize it as an earth fault and keep the power on under the full voltage. It will be just switched off after some people from the community call to the utility informing about the situation and the operator manually disconnect.

It is necessary just to take a quick glance on *youtube* to find lots of videos showing the danger around a system that is not sensitive to detect and turn off earth faults.

In March, 2012, during a Saturday sunny day, one team arrived at a certain street in the São Leopoldo city, where a truck had just hit one pole and broke a medium voltage wire. The phase line was smoking and burning in the asphalt because the overcurrent protection was not sensitive for the tiny current. After parking the car in the middle of the street to avoid traffic during their job, one of the RGE Sul linemen started to open the fuses while the other, safety responsible, followed the task close to their vehicle. During the opening of the second fuse, accidentally the electrician caused an earth fault with the hot stick, breaking the energized wire on their car that was below the line. As his colleague was in contact with the truck, he suffered a fatal medium voltage discharge. Unfortunately this is just an example of how poor is the overcurrent protection in a solid grounded system.

According Brazilian Utilities Association (ABRADEE) just in 2012 it was recorded 818 electrical accidents in the Brazilian medium voltage distribution system, resulting in 292 deaths around the country. As it is possible to notice in the figure 1, the main cause of deaths was building construction. As it is not strictly observed the safety requirements for many Brazilian constructors and the overhead grids are accessible (even complying with standards), it is possible the involuntary contact with the power lines (movement of metal bar, for example), creating a path for an earth fault.

In the same year RGE Sul had 4 fatalities, all of them involving direct contact with live wires in its solid grounded systems.

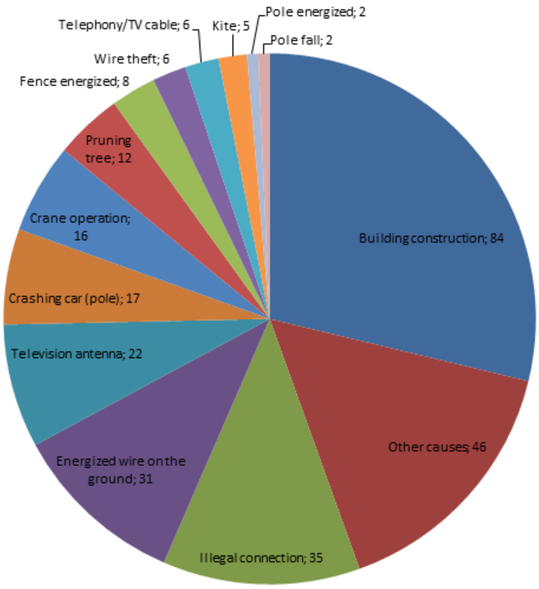

Fig. 1 – Cause of deaths in the Brazilian distribution electrical system – 2012

Another important issue regarding to the solid grounded concept is the protection selectivity, based on the switching off the grids under fault. Both permanent and transient causes have the same treatment: disconnection the line. Some devices like circuit breakers and reclosers have the possibility to keep the system off for some time (usually seconds) and automatically try to reclose. This procedure has the purpose to wait transient causes extinguish (like lightning or touching of trees) before trying to switch on again. But this procedure is not always successful and it also causes disturbances to the whole circuit if the fault is permanent.

Both problems – unsafe grounding system and poor reliability – were technically discussed in the RGE Sul. The company was deeply engaged to do something to avoid electrical accidents with people and improve the technical performance indicators. After evaluate the causes, it was found an opportunity to act in these two aspects by modifying the neutral treatment, based on benchmarking, bringing overseas experiences.

The resonant grounding is increasing its use in Europe representing a step forward in terms of quality supply [3]. While the earth fault can reach more than 10 kA in a solid grounded system, in the resonant grounding this current is below than 10 Amps for the same fault, in a system that's much more sensitive even for high impedance faults.

A Swedish system called Ground Fault Neutralizer (GFN) goes further, because this system handles the earth fault current to practically zero in less than three cycles, keeping the normal power supply for all the customers [4]. This system associates a residual current compensator to the Pertersen Coil providing a complete compensation for the earth fault current.

RGE Sul has installed both resonant and GFN systems in three of its substations and all these experiences are described below.

HISTORICAL SAFETY PROBLEMS WITH SOLID GROUNDING SYSTEM IN THE RGE SUL

The electrical line protection in a solid grounded system is made by overcurrent elements [2]. So, the protection devices are set to leave the load current flow during the normal situation and when a current is higher than the pickup it trips because the system is under fault.

Faults involving the ground can have currents lower than the load depending on the impedance involved. For such cases there is a neutral relay that is more sensitive than the phase ones. But in some cases the impedance involved in the fault is so high that the resulting current can be not enough to sensitize the protection. In these cases, the system keeps working with the full voltage applied in the whole grid, including the ground contact point.

Figure 2 shows the number of electrical accidents in the latest years recorded in the RGE Sul grids. Most of them involved the population. These figures were one more reason that took the company look for new concepts of protection.

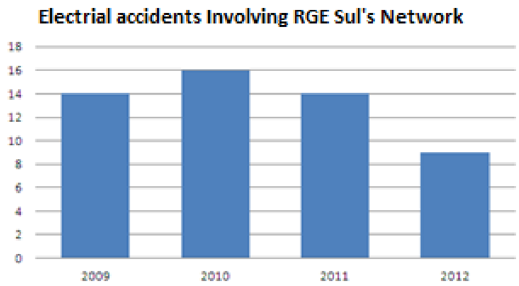

Fig. 2. Number of electrical accidents recorded in the RGE Sul Network.

It's quite common to see trees planted under the lines, even with all campaigns that every year RGE Sul do in the media, asking for people avoid to plant in such place. The company spends more than US$ 3.3 million in tree pruning every year.

There are so many trees under the grids that it is one of the main causes of outage in the distribution system, especially during storms, when the branches and leaves touch the lines by the wind action and the ground is wet creating an easy path for the current.

On the other hand, during dry days the trees can hide a danger behind the leaves. Some trees grow up and start to touch continuously the line creating a high impedance fault circuit. This creates step and touch voltages close the tree.

One example of this danger happened in June, 2010 in a primary school in the Novo Hamburgo city. A 10 years old boy during the break time climbed a tree and suffered an electrical discharge caused by the touch of the leaves with a 23 kV power line.

Fortunately the boy didn't have serious injuries. This case was broadly publicized in the local media.

Fig. 3. Accident place - Escola Estadual Kurt Walzer – Novo Hamburgo city

This is a continuous problem not just in RGE Sul but all Brazilian electrical system. Accidents like the reported above unfortunately happen quite often in the country.

Cases like the reported moved RGE Sul to look for solutions to avoid accidents. The reliability and the safety were the frontline for RGE Sul to better think about earth fault protection and neutral treatment.

GENERAL APPROACH TO EARTH FAULT PROTECTION

Protection is about safety. To get some guidance in this question we can have a look at the IEC standards.

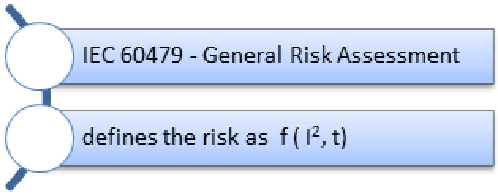

Fig. 4. Function that defines Risk according IEC 60479

IEC 60479 defines the general risk for damages when there is an electrical fault in the network. This risk is determined by the energy released in the fault site. The energy release in turn is determined by the speed of protection and the square of the fault current.

Both speed of protection and fault current can be affected by neutral treatment [5]. To illustrate this, let us have a look at the most commonly used grounding concepts with respect to speed of protection and fault current levels.

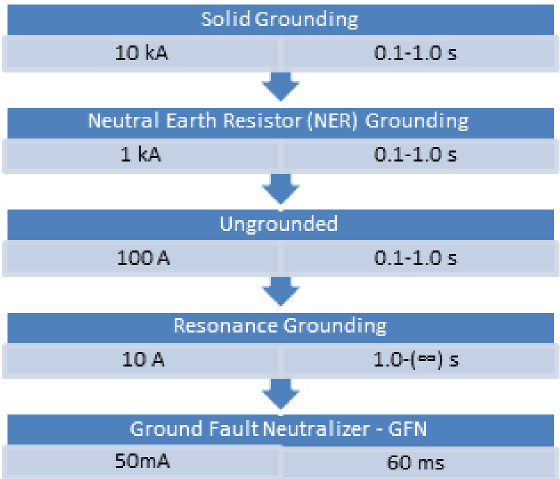

Fig. 5. Earth fault currents and protection time for different neutral grounding concepts

Solid Grounding

The solid (also called direct) grounding is the one where the neutral of transformer is bridged to ground by a solid copper bare, as it can be seen on the figure below.

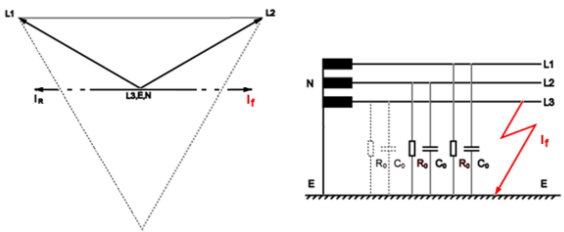

Fig. 6. Solid grounding diagram and phase vector

With this grounding system it is possible to have fault currents in the order of tens kA [2]. With regard to protection time, this concept enables relatively fast tripping, down to around 100 ms. However, if downstream breakers are introduced to improve selectivity this will slow down protection, as upstream breakers will have to wait for downstream breakers to operate. It will be a tradeoff to improve selectivity.

In this system it is possible to use single phase loads, such as single phase lines with single phase transformers. It is quite common in Brazil mainly after the government program "*Luz Para Todos*" (Energy for All) that extended electrical lines for all Brazilian rural communities that didn't have electricity so far. It's a very low cost network, but it also brings protection problems for the system. As the load current flows through the ground, the neutral relay must be set with a value higher than the load. It makes the protection to earth fault less sensitive.

NER (Neutral Earth Resistor) Grounding

A first step to minimize the risk would be to introduce a Neutral Earthing Resistor connected to the transformer neutral or a separate grounding transformer, as it is show on the next figure.

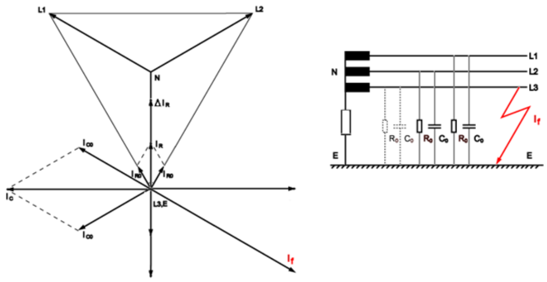

Fig. 7. NER grounding diagram and phase vector

This will bring the fault current down to the order of 1 kA. This current level is still high enough to allow simple overcurrent protection to detect an earth fault.

The speed of protection is the same as for solid grounding with the same problem when down-stream breakers are introduced to improve selectivity.

Under earth faults this system shifts the neutral voltage but without modifying the phase-to-phase voltage.

Isolated (Ungrounded) Neutral

With nothing connected to the neutral, this would create an isolated (also called ungrounded) network.

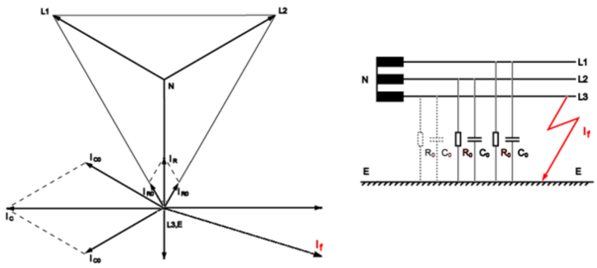

Fig. 8. Ungrounded neutral diagram and phase vector

Earth fault currents will be dependent on grid leakage currents to ground which would mean fault currents in the order of a 100 A. This significantly lower fault current introduces a complication.

With fault currents in the order of 100 A, a separate earth fault protection scheme is needed as the fault current will be below the load currents, which means that simple overcurrent protection cannot operate.

The speed of the separate earth fault protection scheme is generally the same as for overcurrent protection, with the same problem of slowing down the fault interception when using down-stream breakers to improve selectivity.

Resonance Grounding

The superior traditional device to reduce earth fault currents in medium and high voltage networks is the Petersen Coil, or as it also is called, the Arc Suppression Coil.

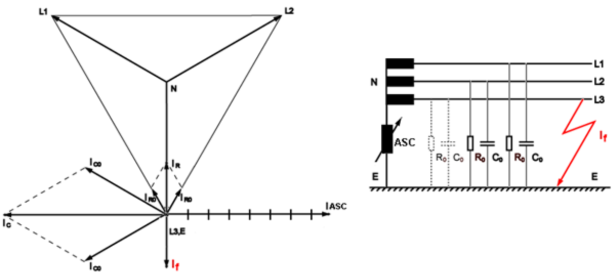

Fig. 9. Resonant grounding diagram and phase vector

The Petersen Coil was invented in 1917 by Waldemar Petersen. This system has been the dominating grounding concept in large parts of Europe for a long time.

With the Arc Suppression Coil the fault current is reduced down to the order of 10 A. One of the major benefits of this further current reduction is the self-extinguishing of flash over faults in overhead networks. To get this effect it is necessary to slow down the protection to enable the Arc Suppression Coil works.

In the Resonant Grounding project – that will be threat in the further topic – RGE Sul moved from solid grounded system to a resonant grounding in the Novo Hamburgo 1 substation. This system supplies the central area of Novo Hamburgo city, located in Porto Alegre Metropolitan region.

Fig. 10. ASC installed in Novo Hamburgo Substation – RGE Sul

As well as in the NER and ungrounded systems, the earth faults in the resonant grounding shift the neutral voltage without modifying the phase-to-phase voltage.

GFN (Ground Fault Neutralizer) Grounding

The first Ground Fault Neutralizer was commissioned in Sweden in 1992 and has since then been implemented in many countries around the world [4].

This system consists of a central processor (NM), the arc suppression coil (ASC) which cancels out capacitive earth fault currents and a RCC Inverter which brings the fault current down to practically zero.

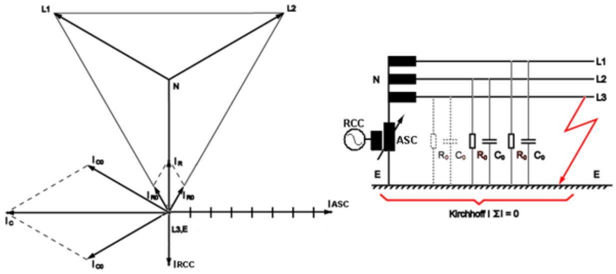

Fig. 11. Ground Fault Neutralizer diagram and phase vector

The arc suppression coil is connected to the neutral of the transformer, the RCC Inverter in turn is connected to the auxiliary winding of the arc suppression coil and both of them are being controlled by the Neutral Manager.

The GFN continuously measures the zero sequence admittance of the feeders when the grid still is in fault free state. This information is stored into the neutral manager (NM) and is constantly updated to always have a fresh picture of the network. Sooner or later an earth fault will occur. Directly when the earth fault comes the GFN takes a new measurement of the zero sequence admittance for each feeder. The zero sequence admittance describes the total leakage to ground for each feeder. What can be seen is that the zero sequence value on the fault free feeders is unchanged, while the faulty feeder has changed.

The GFN is much faster than solid grounding protection based on feeder tripping. It brings the fault current down to practically zero in less than 60ms, without tripping the feeder. This is achieved by using modern microprocessor control and fast power electronics.

RGE Sul started the migration experience from solid to GFN system in 2009 installing this system in two substations (Canudos and Novo Hamburgo 2).

Fig. 12 - Arc Suppression Coil and Grounding Choke – GFN System

RGE SUL PROJECT

The RGE Sul's engineering analysis indicated that the neutral treatment would be the way to improve both reduction of serious population accidents and improve the reliability for transient outages. The earth fault current reduction below the self-extinction (< 35 A) would mean a safer system and a contribution to decrease the outages caused by transient issues in the power grids.

This concept was brought to Brazil by a project started in 2009 in the RGE Sul with the installation of the resonant grounding in Canudos Substation located in Novo Hamburgo city.

During the feasibility studies to implement this new grounding system it was important to have in mind that is forbidden to have single-phase loads along the MV grids and the whole equipment and devices installed in the medium voltage system should be isolated for the phase-phase potential.

The project pointed out the following adjusts in the traditional solid grounded system in the RGE Sul grids:

- Single phase lines and transformers: All of them had to be replaced for three phase ones, as the resonant grounding do not permit such kind of loads;
- Insulators and surge arresters: All insulators and surge arresters were previously inspected. The ones that presented insulation problems or underrated characteristics were immediately replaced;
- Voltage transformers (VT's): Used in metering and to feed distribution equipment relays. The ones underrated for phase-phase voltage were replaced as well as the single phase for phase-phase equipament.
- Voltage regulators (VR): Usually found in rural feeders. There were no VR's in the grids chosed for the project. But like for VT's, it is indicated for new systems to use banks in delta connection.
- Other equipment and elements: As it is possible to see above, the main concern in the feasibility studies to move from solid to resonant grounding is about the loads, insulation and connections. So distribution transformers, capacitor banks, cables and other elements must be fit for phase-phase voltage in the medium voltage system and they should not have Y-ground connection in this sector.
- Customers: As the same as the distribution network equipment, the whole medium voltage customer installation should not have single phase transformers, equipments with Y-ground connection nor underrated equipments for phase-phase voltage in the MV system. In this way RGE Sul checked all their customers installation before to put the resonant grounding in operation.

Generally the Brazilian protection studies set the overcurrent relays considering that the highest impedance in an earth fault will be 40 Ω [6]. This is the parameter used by the engineering area to allow the selectivity between breakers, reclorers, fuses and the other protection devices. If it was used higher impedance reference – what would be safer – it wouldn't be possible to achieve selectivity between protection installed upstream like fuses in the studies and it would cause a very low reliability, increasing the number of customers affected by the same outage.

The resonant grounding system applied in the RGE Sul is sensitive for 3 kΩ impedance faults. It represents a huge improvement of 75 times more sensitive than the current protection, maintaining selectivity in the entire system.

Another goal have respect to the poor sensitivity in reverse earth faults (downstream broke wires), that is the situation where the earth fault is established on the load side of the line, what can be detected by this technique.

So far RGE Sul had no reports about accidents in the networks where the resonant grounding is in operation. Important to point out that the company is just informed for the authorities when occurs accidents with serious injuries, otherwise the utility does not even know. It takes to conclude that or there were no accidents in these grids or severity of accidents is lower than the past.

Also technical reports indicate that the number of transient earth faults dropped down than 50%. This information just highlights the successful implantation the resonant grounding in RGE Sul and the feasibility to expand it in Brazil and Americas.

CONCLUSION

The historical problems of RGE Sul led the company to move from its regular network standard to a new concept of power distribution system. The Resonant Grounding Project represents an important step forward in terms of Safety and Reliability, as presented throughout this article. After the implementation of the system in three substations, there were no serious accidents involving their medium voltage networks. There was also a significant reduction in the outages, since one of the main reasons for these shutdowns were transient faults and flash-overs on the insulators.

So it is perfectly possible to install the resonant grounding in any other utility since checked their grids standard. The RGE Sul experience is quite positive regarding the results that it has been achieved with this project.

REFERENCES

[1] R. Lavorin, D. Hou, H. J. Altuve, N. Fischer, 2007, "Selecting Directional Elements for Impedance-Grounded Distribution Systems", *Southern California Edison and Schweitzer Engineering Laboratories, Inc*. 3-4.

[2] M. S. Silveira, G. A. Gonçalves, E. Barboza, 2012, "Proteção Rápida de Barras com utilização de relés digitais de sobrecorrente", *20th Electrical Brazilian Power Distribution Seminar - SENDI*, Rio de Janeiro, Brazil. 1-2

[3] M. Hand and N. Mc Donagh, 2010, "ESB's adoption of smart neutral treatments on its 20 kV system", *20th International Conference on Electricity Distribution (CIRED)*, Lyon, France.

[4] K. Winter, 1993, "Swedish Distribution networks – A new method for Earth-fault Protection in Cable- and Overhead Systems", *5th International Conference in Power System Protection, IEE conference publication No 368*, York/UK.

[5] R. Wilheim and M. Waters, 1956, "Neutral Grounding in High Voltage Transmission", Elsevier Publishing, New York, USA.

[6] J. Mamede Filho, 2013, *Proteção de sistemas elétricos de potência*, LTC, Rio de Janeiro, Brazil, 406-407.