THE IMPACT OF NEUTRAL TREATMENT AND EARTH FAULT PROTECTION ON RESILIANCE AND RELIABILITY OF HIGH VOLTAGE GRID

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ABSTRACT

Since EdF in France and Enel in Italy changed the neutral treatment in their power distribution grids to resonance grounding in the late nineties, this kind of grounding has become popular again in Europe. Both companies reported large improvements of their SAIDI and SAIFI figures short after the switch to resonance grounding.

Resonance grounding has been used in Swedish and German power grids right after Waldemar Petersen's invention of the arc suppression coil in 1917. More recent safety regulations in Sweden stipulate mandatory fault detection up to 20kOhm. This led to the development of a new protection algorithm at the Royal Institute of Technology in Stockholm in the late eighties.

Figure 1 Modern Neutral treatment with Ground Fault Neutralizer, German Railway 110kV transmission system (courtesy Deutsche Bahn)

The new protection scheme – zero sequence admittance differential – provides not only safe detection of high impedance earth faults, but also the tools to improve the fault current compensation of the Petersen coil. With practically no voltage injection and fault current left at the fault site in less than three cycles, the new "GFN Ground Fault Neutralizer" finally brings a substantial improvement for public safety and fire prevention.

The latter problem is of particular interest in countries like Australia and California with considerable bushfire problems cause by undetected line fracture faults. A recent press release of the government in Victoria/Australia (7) claims a forty percent reduction on bushfires after installation of "Rapid Earth Fault Current Limiters". Facing similar climate conditions in the Mediterranean parts of Europe the new GFN now offers a way to reduce the increasing risk for devastating bush- and forest fires.

A second field of application for the new Ground Fault Neutralizer is for cable grids. For the first time arcing cable faults are quickly stopped without power interruption. But cable faults are generally not transient. Sooner or later the faulty cable must be disconnected for repair. Therefor a more important aspect on cable protection is the possibility to detect faulty cables long before they develop a full insulation breakdown. Here the GFN offers a new powerful tool for the early detection of cable PD.

KEYWORDS

Neutral treatment, Earth fault protection, GFN-Ground Fault Neutralizer, ASC-Arc Suppression Coil, RCC-Residual Current Compensator, Sensitive Earth fault detection, Transient Earth fault detection, Advanced PD-monitoring

THE EARLY NEUTRAL TREATMENTS

The word's first long distance power transfer from Lauffen power station to Frankfurt in 1891 decided the battle between AC and DC in favour for AC. While Edison's DC grids could transfer electrical power a couple of hundred meters, Dolivo-Dobrowolski's new 3-phase AC system could transfer electrical power over hundreds of kilometres. Both producers and consumers could easily connect to this revolutionary grid. Today, large interconnected AC power systems cover all continents.

The idea to arrange three single phase AC voltages into a cyclo-symmetrical 3-phase system by connecting them in one common point – the neutral – was brilliant. It not only reduced power transfer losses immediately to half, but also created a possibility to arrange rotating magnetic fields by phase shifted AC voltages at virtually any point of the grid. This opened for a very robust design of electrical motors.

The story of the neutral could have ended here if it wasn't for the leakage currents. All AC systems have inherent leakage currents to earth. These mainly capacitive currents are determined by voltage level, grid frequency, physical distance and medium between phase and earth. In case of an earth fault all leakage current close up through the fault and can cause considerable damage at the fault site.

The original diagram of the Lauffen - Frankfurt installation shows two YY-connected transformers - one on each end of the three high voltage transfer wires (9). All four transformer neutrals are connected to earth - but with dotted lines only! Dolivo-Dobrowolski probably discovered during the cause of commissioning the system that these ground connections were not very efficient. To balance single phase currents on a three-phase transformer (both fault- or load currents), one of the transformer windings need to be delta connected.

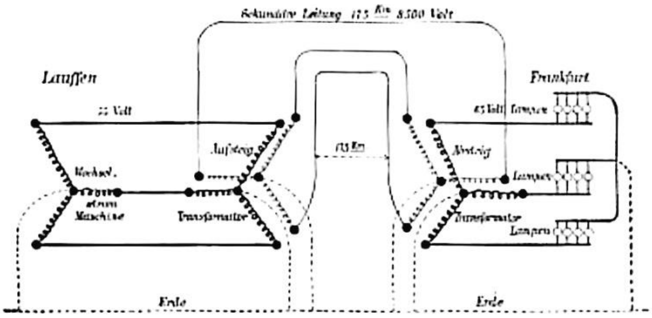

Figure 2 Diagram of the first long distance power transfer system, Lauffen power station to Frankfurt International Electrotechnical Exhibition 1891

Dolivo-Dobrowolski's patent application for the DY vector group also dates 1891 but it was probably too late to change the transformers in time for the exhibition show in Frankfurt. Most probably the transformer neutrals were never connected to ground in this first power transfer system. As the common grounding of both upside and downside also implements some overvoltage risk on the low voltage side, they needed to avoid that connection anyway.

In a way Dolivo-Dobrowolski's "mistake" was lucky. With no grounding of the neutrals, the earth fault current in the Lauffen – Frankfurt transmission was limited to its inherent leakage currents. The line had a total length of 175km and was from the beginning operated at 8500V, roughly seven meters above ground. From this one can calculate the total of the leakage current to around 15A. The limit for self-extinction at this voltage level is around 60A. Most of the line faults were single-phase flash over faults, simply handled by self-extinction.

The "mistake" was lucky also because a single phase fuse action cannot clear the fault. Instead the fault side stays powered from the other two phases through downstream transformers. This problem is still latent in today's low impedance grounded distribution grids with fuse protection on the many lateral branch off's. Instead of replacing all these fuses by expensive three phase reclosers, the switch to high impedance GFN grounding offers a very cost-efficient solution to ensure public safety and fire prevention.

A special group among the low impedance grounded distribution grids are the Anglo-American multi-grounded 4-wire systems. Before the grounding in these grids can be changed, Load currents must be separate from earth fault (leakage) currents. Single-phase connected loads must be changed to two- or three phase connection. This is the only way to improve today's poor performance on earth faults, especially high impedance line fracture faults.

The need for improved earth fault compensation

The identification of the leakage currents or, to be more precise, the imbalance of these currents, is a clear indicator of an earth fault in the grid. From the beginning the leakage currents were relatively small and did not cause any direct problem to the transfer of power. But with the rapidly growing grids also the leakage was growing, causing sustained arcing on overhead lines, which in turn resulted in many power outages due to line fractures.

The Swedish engineer Thorsten Holmgren, who worked for Siemens&Halske in Germany in the mid 1890ties, suggested a summation of all three phase currents to separate leakage currents from the fluctuating load currents. This fundamental CT arrangement (Holmgren Schaltung) made sensitive earth fault detection and subsequently automated localisation possible and is still the basis of all earth fault protection in high voltage systems.

But the fundamental problem with the growing leakage currents, causing line fracture faults, was not solve until 1917, when Waldemar Petersen suggested his arc suppression coil. With the "Petersen Coil" connected between transformer neutral and ground it was possible to reduce the capacitive leakage currents at the fault site. Petersen's invention paved the way for the further expansion of high voltage AC systems into transnational grids. Central and Northern Europe became already in the early 1930ties covered with 220kV resonance grounded transmission grids (1).

The demand for sensitive earth fault detection

After a series of devastating accidents with undetected line fracture faults, the authorities in Sweden introduced mandatory fault detection for earth faults up to 20kOhm in the mid-eighties. A 20kOhm earth fault in an 11kV distribution network produces roughly 0.3A fault current.

This fault current level is in the range of normal imbalance currents, especially in grids with many two-wire spurs or long parallel run with un-transposed voltage systems. The first thing to do is to balance the leakage currents to allow a safe discrimination of fault currents on this level.

Traditional protection relays are considered to be fit for earth fault detection down to 1A. The search for a more sensitive and selective protection scheme started in the mid-eighties at the Royal Institute of Technology in Stockholm. With the new tools, microprocessor and power electronics the underwriter developed a novel admittance differential scheme, capable of separating the actual fault current from other leakage currents in the zero-sequence system.

Residual current compensation

Once the actual fault current could be determined with high accuracy, the next step was to also eliminate the uncompensated residuals of the arc suppression coil by injecting an equal but opposite current in the neutral. With practically no fault current left and voltage injections at the fault site below touch voltage levels, there is no need for immediate tripping. Valuable time for fault localization prior to fault clearance was gained.

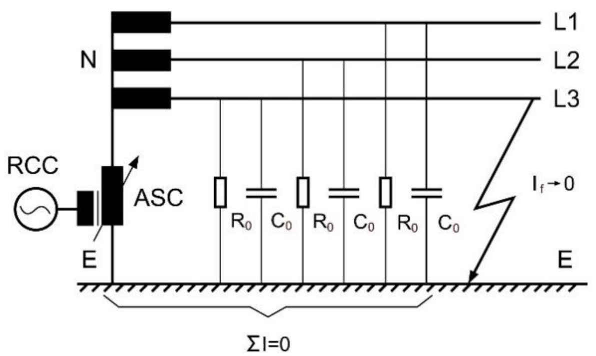

Figure 3 RCC Ground Fault Neutralizer, schematic

The first pilot system of this novel protection was installed in 1992 on the Baltic Island of Gotland (2) (3). Today the "Ground Fault Neutralizer" is a recommended protection standard in the bush fire prone areas of Australia and California (5) (6). A recent press release of the government in Victoria/Australia claims a forty percent reduction of bush fires after installation of "Rapid Earth Fault Current Limiters" (7)

Almost a side effect of the search for a sensitive earth fault detection in overhead systems was the impact of the GFN on cable faults. For the first time re-striking cable faults could efficiently be stopped without supply interruption. This had a dramatic effect on the reliability of cable grids. Many critical industry grids worldwide have now been equipped with Ground Fault Neutralizers.

A second side effect of the GFN is its capability to control phase-to-ground voltages under normal grid operation. This new feature opens for systematic for-checking strategies, combining the GFN voltage control with online partial discharge monitoring.

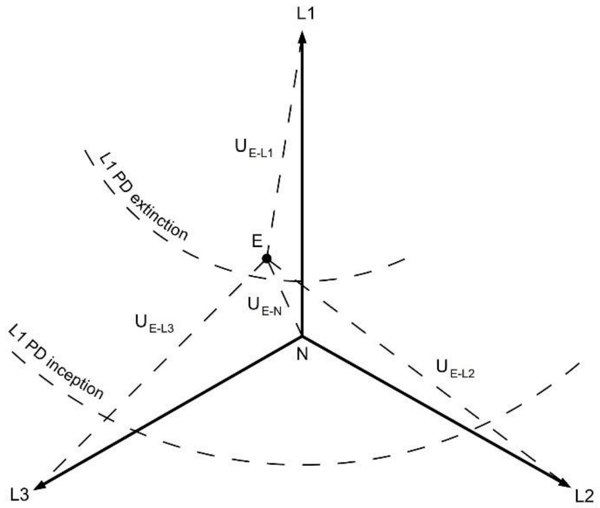

Figure 4 Quenching PD activity in L1 by controlling the neutral (N) towards earth (E) with GFN PD control

One of the main worries for asset management are the aging cables in the large city grids of the world. A reliable condition monitoring system could provide the tool to avoid massive premature cable replacements and base replacement decisions rather on the condition of the cable than age. This could save a lot of money.

A NEW DEVICE FOR RCC PROTECTION

A statistical evaluation of some hundred distribution networks around the world shows residual earth fault currents in the order of 2-5% of the grid's capacitive leakage current. In large urban cable grids, the leakage current can easily exceed 1000A. Correspondingly the residual earth fault current and its compensation device increase. A further study of the records on real earth faults showed the distribution of fundamental and harmonic quantities in the residual earth fault current. In most cases the residual was made up from fundamental quantities. Harmonic values reached only in a few cases levels where their compensation was necessary.

As said, in most cases the compensation of the fundamental quantity is sufficient. An arrangement with two controllable capacitors elements as shown on figure 5 and described in [8] could do this. The arrangement can operate in parallel to an inverter based RCC and offers a cost-efficient and easy scalable solution for ASC upgrades. The device will be commercially available from end 2023.

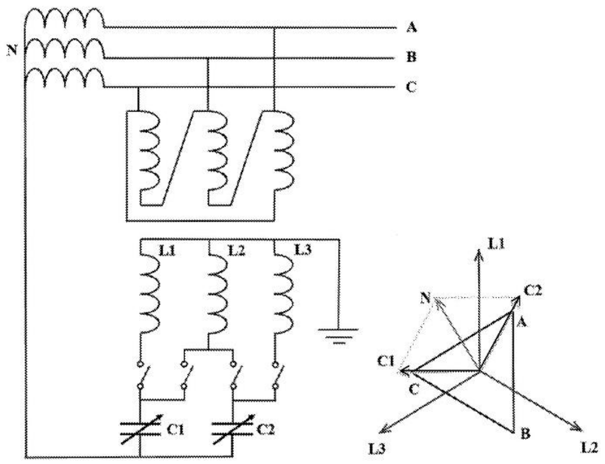

Figure 5 New residual current compensator, schematic

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