RESONANT GROUNDED GRIDS – QUO VADIS?!

Lothar Fickert  
IFEA, TU Graz  
Graz, Austria  
lothar.fickert@tugraz.at

Georg Achleitner  
IFEA, TU Graz  
Graz, Austria  
georg.achleitner@tugraz.at

Ernst Schmautzer  
IFEA, TU Graz  
Graz, Austria  
Schmautzer@tugraz.at

Clemens Obkircher  
ÖBB Infrastruktur Bau AG  
Innsbruck, Austria  
Clemens.obkircher@bau.oebb.at

Christian Raunig  
IFEA, TU Graz  
Graz, Austria  
Christian.raunig@tugraz.at

ABSTRACT:
In earth fault compensated networks the basically capacitive earth fault current is counterbalanced by the injection of an inductive current through the arc suppression coils in such a way, that for most overhead line faults these arcs extinguish without the necessity of disconnecting the faulty grid section. Therefore these grids can be classified as self healing grids which have good power quality.

Due to the fact of sometime prolonged earth fault current flow special safety precautions must be met.

When present-day grids are extended by the installation of additional cables, their operation is subjected to limitations concerning the effects of the earth fault current. The current can exceed the admissible limits and an innovative neutral point treatment is necessary.

This effect leads to costly modifications of either the grounding systems or modifications in the protection schemes or both. As far as standardization is concerned, the present standards in central Europe may undergo changes which will lead to modifying the design and operation mode of these networks. This network operation implicates problems in localization of earth faults, especially concerning the in-depth localization.

Under these aspects the operation mode of principally continuing the regime of resonance grounded networks with a change to transient middle ohmic earth fault compensated networks in case of a persisting earth fault appears to be in many cases an attractive solution.

INTRODUCTION
Under the aspect of the continuous growing electric energy consumption the goal of the electricity supply is to provide electricity in high quality.

In order to meet the rising current consumption, besides establishing adequate power station reserves above all the networks must be strengthened. In order to allow further extensions of these networks without endangering both humans and animals in case of ground faults, considerations regarding the neutral point treatment of these networks in the sense of precaution are absolutely necessary.

In the event of a fault the admissible voltages are described in standards [1].

Figure 1: Permissible touch voltages $U_{TP}$ depending on the duration of current flow

Because modern grids are extended by inserting overhead power lines, cables or changing overhead lines to cables, the phase-to-ground capacitances and consequently the earth fault currents increase considerably and enforce the re-consideration of the network operation as it is used up to now.

One major advantage of resonant grounded grids is the high power quality because most common insulation fault, the single line-to-ground fault, is in most cases self extinguishing in a short time and does not require any switching activities on the operation side or leads to automatic protection tripping. Because of this outstanding feature resonant grounded grids can be classified as self healing grids.

Since in Central-Europe a majority of the medium voltage and high-voltage transmission systems are operated as resonant grounded grids, the extension measures must be carried out with adherence to the given standards.

LIMITING PARAMETERS OF RESONANT GROUNDED GRIDS
It can be seen from Figure 1 that the touch voltage $U_{TP}$ is the only and real limiting factor in dependency from the actual fault current duration $t$. Due to the ohmic law the touch voltage $U_{TP}$ is proportional to the current to earth $I_E$ and the impedance to earth $Z_E$ at the fault point in the worst case.

$$U_{TP} \sim I_E \cdot Z_E$$ (1)
The current to ground $I_E$ depends on the
- Phase-to-ground current $I_C$ of the resonant grounded system. This component is capacitive.
- Current $I_L$ from the arc-suppression coils (inductive current).
- Harmonic current $I_{H}$. This component is mainly capacitive and depends on the pre-fault harmonic content of the phase-to-ground voltages and can reach considerable amplitudes due to resonances between the line-to-ground capacitances and the – where applicable – line inductances [2].
- Leakage current $I_R$, which is a resistive component.
- Auxiliary location current $I_{LOC}$, which is mostly resistive.

Figure 2: Voltage potential of a grounding system

The impedance to earth $Z_E$ at the fault point is determined by the
- specific soil resistance ($\Omega m$)
- grounding system at the fault point consisting of
  - natural or artificial earth electrodes
  - relation to any multiple-earthed system, e.g. low voltage neutral conductor (if present), either by direct galvanic coupling or influence from the electric flow field

The fault clearing time ($t$) depends on the operation of the electrical system under fault conditions:
It can be either
- manually operated if the resulting clearing times are tolerated
or
- automatically switched off by protective devices such as phase or zero sequence overcurrent relays with or without directional fault detection, or any other advanced and sensitive protection equipment.

CONSEQUENCES

Because of the necessity that an electrical system provides the energy in a safe way, especially in the above mentioned self-healing resonant grounded grids, the limitations of the effects of earth faults is important.

The demands for the continuity of supply on one side and for the safety of the population on the other side can be contradictory due to fact, that the self healing process of the self extinguishing arc requires a certain time. In this time span no automatic tripping or even reclosing should occur. The obvious danger of a voltage build up due to the line-to-earth current $I_E$ over the dominating impedance to earth $Z_E$ is addressed by national standards and can be minimized by heavily investing into the reduction of the impedances to earth, e.g. by means of certain buried earth electrodes, or other means, which will be discussed in this paper.

It can be seen that economic aspects are not negligible because they involve both costs related to power quality parameters such as ENS (Energy Not Supplied) and costs of increasing personal safety levels by means of additional grounding measures. The following example may demonstrate this point:

If the cross country or double earth fault is taken as the dimensioning parameter for the impedance to ground $Z_E$, in a typical medium voltage system with a short circuit level $S_{k,n}=500$ MVA and a nominal voltage $U_N=20$ kV a cross country or double earth fault current can be expected in the order of magnitude of 85% of the symmetrical short-circuit current ($14$ kA) may be used as a maximum [9]. In this example the resulting double earth fault current is approximately 12 kA. In this case a technically feasible minimum tripping time $t = 100$ ms is assumed, which in turn according to Figure 1 leads to a maximum admissible touch voltage is 700 V. Using the formula

$$U_E \leq 2 \cdot U_{TP}$$

from HD 637 / Figure 9.2, the resulting maximum impedance to earth $Z_E$ is:

$$Z_E \leq \frac{2 \cdot 700V}{0.85 \cdot 14kA} = 120m\Omega$$

It must be assumed that for grids that were originally designed to be operated as resonant grounded grids, this is a possibly unrealistic target value.

APPLICABLE STANDARDS AND THEIR PRACTICAL IMPLICATIONS

In Austria and Germany the safety standards concerning the resonant grounded grids in case of an earth fault distinguish between two regimes:

- $I_E$ is below the self extinction current limit: No further investigations are required.
• $I_E$ is above the self extinction current limit:

In this case two possible paths can be chosen:

1. If it can be proven that the faults are self extinguishing, no further measures are necessary.

2. If point 1. cannot be verified, and the actual operation regime (earth fault compensation) is kept, then the double earth fault current $I_{KEE}$ is to be taken into consideration concerning the touch voltage in accordance with HD 637 [1]. Additionally it has to be proven that in case of a cross country fault or double earth fault the inductive and ohmic interferences with telecommunication lines and pipelines are below certain limits.

In recent times the operation of the self healing resonant grounded grids for unspecified time spans is under reconsiderations:

It is suggested in prEN 50522:2008 that an earth fault has to be disconnected (switched off) within 5 seconds regardless the self healing capacity of the grid and the residual current magnitude [3]. Since it will not be possible to localize and consequently disconnect (switch off) manually an earth fault in such a short time span, automatic tripping must take place, e.g. by protective devices such as phase or zero sequence overcurrent relays with or without directional fault detection, or any other advanced protection equipment.

Up to now automatic localization within a protection operating time span of a few seconds is not state of the art. In most resonant grounded grids the localization of the faulty section is carried out by reclosing and sectionalizing the existing network feeders. By this means the steady state feeder earth fault indication in a substation will give an indication to where the earth fault is. Usually there are no in-depth localization means in ring main units.

Under the requirements of a rapid disconnection of the faulty section of the network this practise is no more possible. If $I_E$ is above the self extinction current limit, according to the present state of the art two possible paths can be chosen:

1. “Localization before tripping”: The standard application of the principle is the time grading of phase or zero sequence overcurrent protection devices with or without directional fault detection. The advantage of this procedure is the robust and established principle, but the disadvantage when changing the fault treatment to “localization before tripping” is the necessity of installing area-wide instrument transformers, protection devices and automatic switching equipment. For a successful localization of the fault an adequate localization current is necessary. Other principles such as distance protection (with an at least temporarily solidly grounded neutral) with additional sensitive earth fault protections are well proven, but they can trigger heavy investment in grounding systems. If as a counter measure the current is reduced by inserting current limiting devices (resistors) between the system neutral and the ground, advanced distance relays will be in a position to make good prediction of localization of the position the earth fault [4] [5].

2. “Localization” after tripping: In this case the difficulty for localizing the fault point is caused by the absence of any current or voltage signals. Therefore it is necessary to inject suitable tracing signals at certain points of the de-energized grid and to follow these signals by appropriate fault tracing devices. These devices can be installed in fixed installations or in portable units. [6]

**FUTURE OPERATION OF RESONANT GROUNDED GRIDS**

The motivation to keep on operating the electrical power networks with resonant grounded neutrals is derived from the good experiences with the high continuity supply due to the self extinguishing properties of phase-to-earth arcs in such grids, especially of grids with a large proportion of overhead lines. Apart from this a not negligible restriction lies in the existing grounding systems which were designed for comparably low fault currents and therefore low touch voltages. In the following chapter the concept of short term grounding of a system with resonant as a measure of mitigation (see Figure 3) is presented:

![Figure 3: Transient middle ohmic earth fault compensated network](image)

In this concept the compensation is kept, but it is supplemented by a current limiter in parallel to the arc suppressing coil [7].

The protection scheme operates as follows:

As soon as an earth fault is detected, e.g. by monitoring the displacement voltage, a timer is started. It is expected, that in the first phase of the earth fault and the arc might be self extinguishing, which can also be detected by monitoring the changing quantities of the displacement voltage. Typical arc
extinction times are in the order of 0.05-1.0 seconds. If this monitoring time has elapsed, the current limiting grounding device ZR (Figure 3) is inserted between the system neutral and ground and causes an earth fault locating current to flow, from the grounding device ZR (source) through the afflicted lines to the fault point (sink). If the amplitude of this current is chosen adequately, e.g. in the order of magnitude of the nominal line current, the localization of this additional zero sequence current can be done by means of protection devices according to the state of the art. A line-to-earth-fault will

- be switched off by the protection device and in the case of an overhead line automatic autoreclosure can be accomplished

and

- the pick-up alarms of the protection devices can be stored for further evaluation by the SCADA system.

It is interesting to note, that one can show that during this localization process the resulting touch voltages \( U_{TP} \) will not exceed the values in Figure 1.

If one assumes as a worst case consideration for a given grounding system a design value of the stationary touch voltage of \( U_{TP,\infty} = 75 \text{ V} \) for a nominal earth fault current \( i_{E,\infty} = 60 \text{ A} \), the resulting impedance to ground is according to equation (4)

\[
Z_e \leq \frac{2 \cdot 75 \text{ V}}{60 \text{ A}} = 2.5 \Omega
\]  

(4)

If during the localization process the whole current to earth increases up to e.g. \( i_E = 220 \text{ A} \), the resulting maximal permissible touch voltage is

\[
U_{TP} = \frac{U_e}{2} = \frac{220 \text{ A} \cdot 2.5 \Omega}{2} = 275 \text{ V}
\]  

(5)

According to Figure 1 this voltage can be tolerated for a time span of 0.4 secs.

If the rms-value of the resulting fault current is composed by superposition of the generally reactive residual currents and the ohmic localization component, the latter one can be chosen quite high.

By changing the neutral point treatment to transient middle ohmic earth fault compensated network and designing the protection scheme \( i_{Loc} = 250 \text{ A} / t_{loc} = 0.4 \text{ secs} \) according to the grounding systems, no change in the existing grounding systems is necessary.

**SUMMARY**

The concept of the self healing resonant grounded grids is a well proven and by all experiences up to now very safe system of providing electricity. Especially under the aspect of high power quality and high reliability concerning the continuity of supply this concept should be kept because due to the low and controlled fault currents a very economic design of the grounding system is possible.

In case of raising earth fault currents the authors suggest the change of the neutral point treatment to transient middle ohmic earth fault compensated network and designing the protection scheme according to the existing grounding systems. In this case no change in the existing grounding systems is necessary.

**REFERENCES**


