ADEQUATE NEUTRAL TREATMENT FOR 25KV POWER SUPPLY SYSTEMS OF A NEW HUGE OPEN CAST LIGNITE MINE

Stefan Höne
Siemens AG Germany
Stefan.Hoene@siemens.com

Walter Krudewig
RWE Power Germany
Walter.Krudewig@rwe.com

INTRODUCTION

RWE Power is the biggest power producer in Germany with an installed capacity of 33.7 GW and produced 183 billion kWh in the year 2005. The contribution of lignite fired power plants is 41%.
There are three open cast lignite mine areas operated by RWE Power:

- *Garzweiler with 35.7 mega t lignite per year,*
- *Hambach with 39.1 mega t lignite per year,*
- *Inden with 22.6 mega t lignite per year.*

RWE Power started the exploitation of the new open cast mining area Garzweiler II in 2006. The mine area is located in the West of Germany about 30km North West of Cologne adjacent to the existing mining area Garzweiler I. The output in the final stage will be 40 mega t lignite per year.

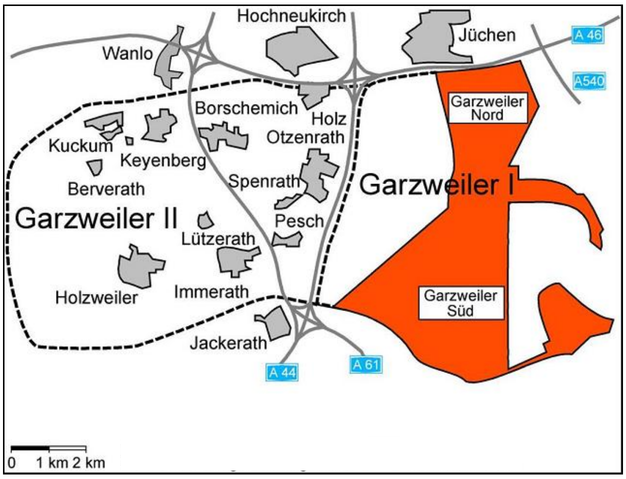

FIGURE 1: Area of open cast mine area Garzweiler

The 25kV systems of existing open cast mine power supplies are operated with arc suppression coils. As the operation with arc suppression coils with regard to fast earth fault localization and following short circuits was not very satisfying the neutral treatment of the 25kV systems for the new mine areas was discussed.
Based on experience and measurements carried out in the existing mining areas different solutions were investigated and compared considering technical, operational and economical criteria.
Considering the results of this investigation, RWE Power decided to introduce the low impedance neutral earthing in the 25kV systems of new open cast mining Garzweiler II.
Earth fault trials, earthing measurements and up to now more than one year of operation verifies the successful introduction of a new neutral treatment scheme for Garzweiler II.
The paper shows the measurement methods and the results of investigation as well as the conclusions regarding design of required neutral treatment equipment and operation. Additionally, results of earth fault trials, results of earthing test carried out at the first new portable equipment and the experience of the first year of operation including practice during first earth fault will be reported.

DESCRIPTION OF THE 25KV NETWORK GARZWEILER II

The following points describe some of the basic characteristics of a power supply system of open cast lignite mines:

- Movement of equipment like stations, transformers, conveyer belts and excavators (figure 2) following the work progress
- Heavy duty conditions due to large mechanical stress, dust, rock, rain, heavy vehicles
- Movement of ground due to soil instability in excavation or fill up areas
- Not all areas are accessible at all time due to work progress
- Reliability requirements regarding permanent output of coal mines due to nearby power stations and maintaining ground water level
- Fault detection selectivity and speed of fault clearing due to reliability requirements

The power supply system of Garzweiler II is characterized by the following electrical data:

- Nine 110kV bays, single bus bar, located at 110/25kV main substation Jackerath
- Six 110/25kV transformers with together 390 MVA, located at 110/25kV substation Jackerath
- Eighty 25kV bays, double bus bar, located in the main substation Jackerath
- 165 km of 25kV lines and cables feeding 45 medium voltage transformers (25/6kV) with together 438MVA.
- The network is operated as radial system equipped with over current protection

FIGURE 2: Equipment of Garzweiler

MEASUREMENTS

Most of the data decisive for the effects of earth fault depend on the condition at site and network. They have to be measured. Particularly with regard to the very difficult earthing conditions in the open cast mine areas the check of the effectiveness of earthing systems were essential.
The following measurements were carried out:

- Determination of zero sequence impedances of cables and lines
- Measurement of earth electrode potentials and touch voltages of different portable equipment located at the open cast mine area at adverse locations
- Measurement of interference on telecommunication lines

Heavy Current Injection Tests

As the current distribution in the ground beneath medium voltage stations is fairly unpredictable the actual touch and step voltages can only be obtained from measurements in a reliable way.
The suitable method for large ground grids is the current injection method according to HD 637 [1]. By this method the ground potential rise, the touch and step voltages under fault conditions can be obtained as well as the impedance to earth of the ground grid. The test circuit can also be used for measuring zero sequence impedances and inductive interference of communication lines running in parallel to medium voltage lines.
The zero sequence impedance of cables depends on the surrounding of the cable route. In case of steel armoured cable it depends additionally on the current level. Therefore the measurement of zero sequence impedance is required to get a reliable data base for single phase short circuit calculation. The test circuit is shown in figure 3.

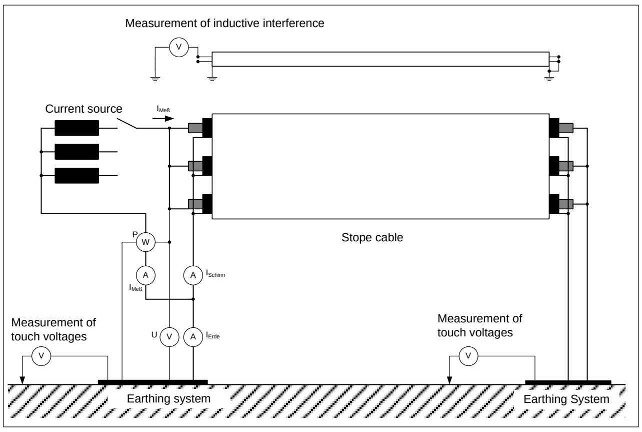

FIGURE 3: Test circuit, heavy current injection test

As current source a diesel generator set with 400 kVA and a welding transformer were used. The earthing conditions of 10 stations and portable cable connectors were checked to cover main types and location. The inductive interference at one test line and zero sequence impedances of typical medium voltage stope cables were measured.

Earthing conditions in an open cast mine area

Due to the fact that the portable equipment like the transformers and cable connectors shown in figure 4 are not equipped with an earthing system buried in earth additional requirements have to be considered to keep tolerable touch voltages. These additional requirements are given in the DIN VDE 0168, January 1992 "Erection of electrical installation in open cast mines, quarries and similar works". Two of the essential requirements given in the above mentioned standard are:

- All equipment has to be connected to the earthing system of the source via a protective earthing conductor similar to the TN-system defined in the IEC 60364 standard.
- The maximum earth potential rise has to be smaller than the tolerable touch voltage

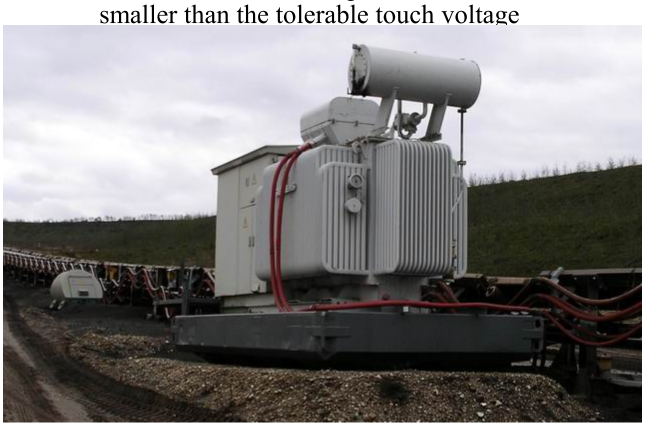

FIGURE 4: Portable transformer

The results of the heavy current injection test regarding protective earthing are summarized for the 10 measured locations in figure 5.
According to HD 637 [1] in systems operated with current limiting neutral earthing the decisive current regarding touch voltages is the maximum single phase short circuit current. Therefore the measured earth potential rise and touch voltage values listed in figure 5 are referred to the

maximum earth fault current of 1kA.
The figure 5 reflects soil conditions, size of substation and size of current flowing through resistance to earth. Adverse soil conditions and small size are not a problem as fault current returns via protective earth and additional local equipotential bonding. This underlines the fact that safe conditions can be achieved even in case of high station earth impedances.

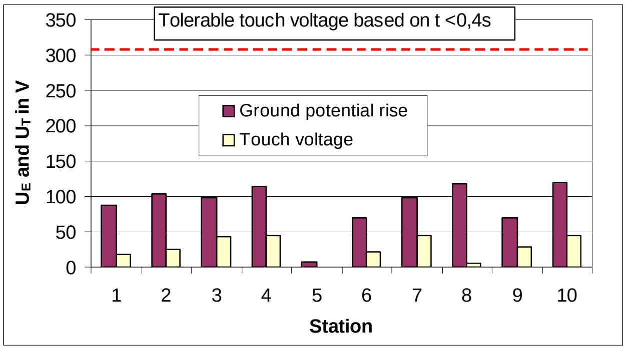

FIGURE 5: Measured ground potential rise and touch voltage

Inductive Interference

The maximum inductive interference measured at a telecommunication line running in parallel to a 25kV stope cable gave a value of induced voltage of U_i = 115 V/(kA km).

Zero Sequence Impedances

The results of zero sequence impedance measurement indicate values comparable with measurements carried out for similar stope cables. A typical value was (0.4 + j0.15)Ω.

COMPARISON OF DIFFERENT NEUTRAL EARTHING SCHEMES

Basically there are two different methods available [3]: Resonant earthing with operation under permanent earth fault condition and neutral earthing with automatic fault detection and disconnection.

Resonant Earthing

The capacitive earth fault current at the fault location is compensated by an inductive current fed in by Peterson coils.
Due to the small residual current at the fault location this method allows operation under earth fault conditions to detect and disconnect faulty section without supply interruptions. Considering conditions of over head line systems most of arcs extinguish in a very short time automatically without any action. The self extinction of arcs depends on different parameters. One decisive parameter is magnitude of residual current. According to DIN VDE 0228 part2 [2] the flashover in a 25 kV systems may extinguish up to 60 A residual current. Considering conditions of a cable system each earth fault is a permanent fault and the fault detection and disconnection of faulty section requires switching of several circuit breakers and load breakers before clearing the fault. Typically the operation under earth fault conditions takes between half an hour and two hours. The protection device has to detect and to indicate the faulty feeder. For this purpose transient earth fault relays or sensitive directional earth fault relays are installed.
The main risk regarding operation during the time the staff is trying to locate the fault is the fact that the permanent earth fault may extent to a double earth fault before the faulty section can be located.
At the fault location the residual current leads to damages and touch voltages. Additional to the effects at the fault location all parts of interconnected network will be affected during earth fault conditions. The medium voltage equipment will be stressed by transient overvoltages characterized by the factor up to k_t = 2.7 and by power frequency overvoltages characterized by the factor of c_f = 1.73.
In medium voltage overhead line systems resonant earthing has the advantage of self extinguishing arcs and option of fault clearing without supply interruption. Depending on the size of capacitive earth fault current and the structure of the network the problems for operation and equipment increase.

Current limiting neutral earthing

Current limiting impedance reduces the single phase fault current to a level that the protection devices are able to clear the faulty feeder in the same way as a three phase fault.
The earth fault current level should be as high as necessary to pick up the protection devices but as low as possible to reduce damages and touch voltages at fault location as well as inductive interference to a minimum.
In case of a neutral resistor limiting the earth fault current transient overvoltages will be reduced up to about factor k_t = 1.8. The power frequency overvoltages are in the same size as given for resonant earthing but limited to fault clearing time.
One target is to clear earth fault currents fast and selective as far as possible with the same protection devices as two and three phase short circuit currents. Precondition is that the protection devices work in all three phases and the minimum single phase fault currents based on actual zero sequence impedances are known for the settings.
All customers of the faulty feeder and switched off by circuit breakers are affected. In distribution networks with radial feeders the faulty section can be detected by fault current indicators. The use of fault current indicators can minimize the outage time.
At the fault location the earth fault current leads to damages and touch voltages. Due to the short fault clearing time (typically some 100 ms) the thermal affects at fault location are limited.

Parameters For Comparison

For the comparison the following parameters were investigated.

Voltage dependent aspects
- Transient overvoltages
- Power frequency overvoltages

Current dependent
- Damages at fault location
- Inductive interference (whole network)
- Thermal stress of equipment (whole network)
- Stress of load breakers (whole network)

Operational
- Fault detection
- Fault location

- Amount of switching for re-supply required
- Possibility for automation of operation

Investment

- Cost for neutral treatment equipment
- Cost for protection

COMPARISON AND PROPOSAL

The examination and evaluation of the network of Garzweiler I indicates that there are no problems at all with regard to protective earthing and interference.
Main advantage of the current limiting neutral earthing are:

- The risk of earth fault developing into cross-country faults is eliminated
- Fast and selective tripping of faulty feeder by protection devices
- Fast fault location
- Possibility of automation of network operation is given
- Lowest Costs

It was recommended to introduce a current limiting neutral earthing with single phase fault current limit of 1kA.
RWE Power decided to introduce a current limiting neutral earthing for the power supply of the conveyer and excavator systems of Garzweiler II.

CHECK OF PROPOSED SYSTEM AND PRACTICE WITH REALIZED SYSTEM

Due to the heavy duty conditions of operation a cable fault without metallic connection to earthed structures can not be excluded. The fast and selective tripping even in case of an internal cable fault is essential with respect to safety of staff. The new stope cables shown in figure 6 are equipped with three separate protective earth conductors but without metallic screen surrounding each phase. In case of the mentioned internal cable fault the semi conducting layer surrounding the phase conductor insulation has to ensure a minimum earth fault current that earth fault protection is able to clear the fault as required.

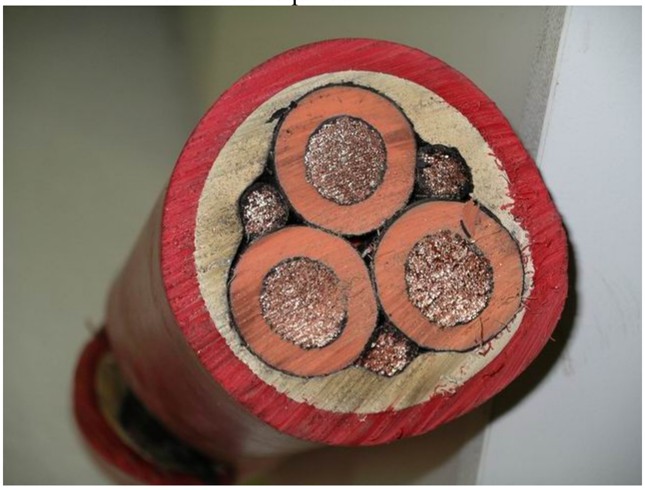

FIGURE 6: Stope cable

To show the effectiveness of proposed neutral earthing scheme earth fault trials were carried out.

Check of realized System

Earth Fault Trials

Figure 7 shows the test circuit for the earth fault trials.

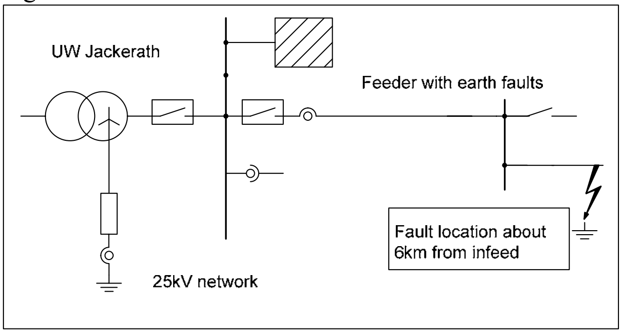

FIGURE 7: Earth fault test circuit

The earth fault at a stope cable remote to infeed was triggered by a nail. For the shown tests the three phase voltages, zero sequence voltage and the current of faulty phase are recorded at the substation Jackerath.

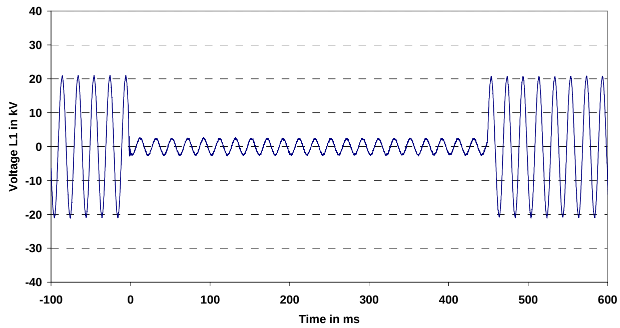

FIGURE 8a: Voltage of faulty phase L1 at substation

Figure 8a shows the line to earth voltage of faulty phase L1 at substation. The voltage in the faulty line at feeding substation decreases to about 2.3kV.

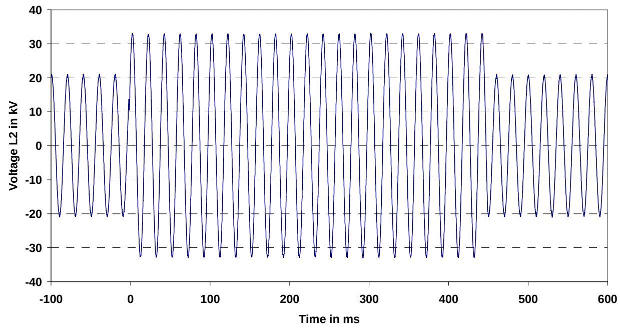

FIGURE 8b: Voltage of healthy phase L2

Figure 8b and 8c give the recorded line to earth voltages of healthy phases L2 and L3. After beginning of earth fault the voltages rise up to the factor 1.73. Figure 8d shows the fault current in the faulty phase. The measured earth fault current comes to 840A (r.m.s. value).
Figure 9 shows the faulty cable after earth fault test triggered by a nail. The faulty feeder was switched off as required in a fault clearing time of 440ms.

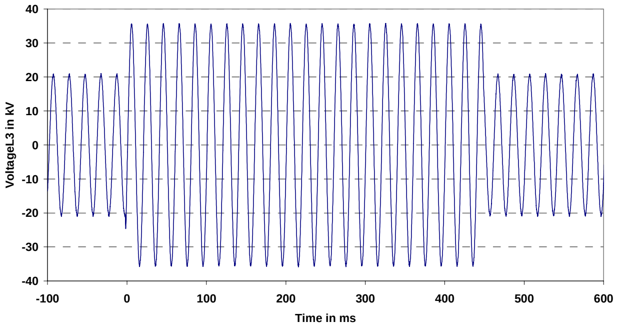

FIGURE 8c: Voltage of healthy phase L3

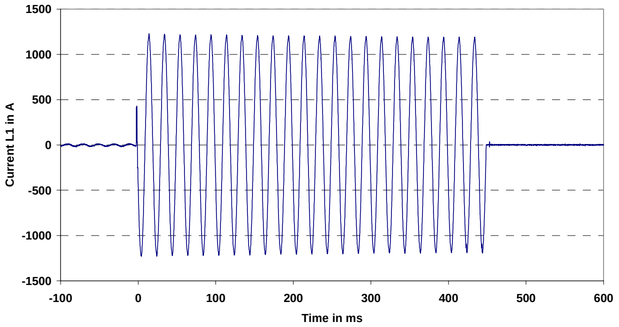

FIGURE 8d: Current of faulty phase L1

FIGURE 9: Stope cable after earth fault triggered by nail

Heavy Current Injection Tests

The heavy current injection tests carried out at different locations of new open cast mine Garzweiler II underlines the measurements carried out at the existing area of Garzweiler I. At all location the tolerable limits are kept.

SUMMARY

During the first year of operation one earth fault had occurred. The protection has cleared that fault fast and selectively.

Earth fault trials, earthing measurements and up to now more than one year of operation documents the successful introduction of a new neutral treatment scheme for Garzweiler II.

REFERENCES

[1] HD 637, Power installations exceeding 1 kV a.c., European Committee for Electrotechnical Standardization (CENELEC), Harmonization document HD 637 S1, May 1999

[2] DIN VDE 0228, Proceedings in case of interference on telecommunication installations by electric power installations, Deutsche elektrotechnische Kommission (DKE), December 1987

[3] Stefan Höne, Dr. Alexander Montebaur, Hans Joachim Nehrkorn, 2005, "Earth fault trials and measurements in rural 20kV networks of avacon AG as basis for improving the performance of the 20kV networks" Cired2005_Session2 paper 420