PRACTICAL PROBLEMS WITH SUBSTATION EARTHING

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This paper considers the issues around substation sites where the soil resistivity is of particularly poor quality and makes it particularly difficult to achieve a safe installation. The issues will be examined around Eskom's planned Wonderkop substation which sits on the Bushveld Igneous Complex where the earth resistivity is very high.

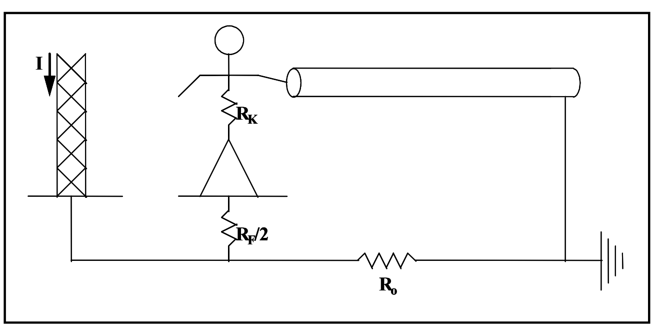
Objectives of substation earth electrode design

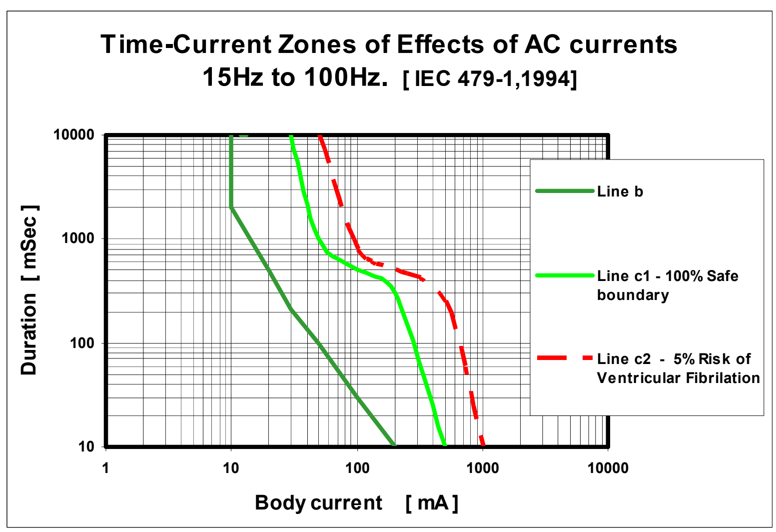
Safety of utility staff and workers of incidentally connected plant

Substation earthing play a vital role in the safety of the environment when a phase to ground faults occurs in or close to the substation. This impact on the safety of staff inside the substation as well as the safety of staff of substations and the factories of customers connected to the faulting substation. In addition it affects the safety of the public that are in the vicinity of the substation and may even have an effect on the safety of public services in the vicinity of the substation where incidental connections exist between the substation earth and the public service.

In order to ensure a safe installation the step and touch potentials around a substation are designed according to the IEC and IEEE standards (Ref 1,2,3). This design broadly aim to limit the current that would go through the body of a person exposed to such a Ground Potential Rise to within the limits of the IEC criteria that is given in Figure 1B.

Figure 1A and 1B. The basic approach to modelling transferred potential from IEEE 80 and the safe current criteria from IEC 479-1 which has to used to determine safe conditions for staff and public exposure to Ground Potential Rise caused by faults in the power network.





In addition to ensuring safe step, touch and transferred potential to persons, the Eskom standard (Ref 1) required that the ground potential rise is limited to 5000V. This is related to the protection of services such as telephone lines that run external to the substation to be adequately protected. (Ref 4).

To achieve these design objectives it is normally required to achieve a very low earth electrode resistance at a substation (less than 1ohm). For example in a substation with a phase to ground fault level an earth electrode resistance of 0.5 ohm is required.

Lightning protection

The lightning protection of a substation does not depend on reaching a magical (low) earth resistance value. In-fact very low earth resistance values in the networks is known to cause the failure of surge arresters due to the majority of lightning current passing to ground at that point and eventually exceeding the energy rating of the arrester. When an arrester has failed it leaves the plant it was protecting vulnerable till it is replaced.

Successful lightning protection require that surge arresters are placed in the correct positions in the substation, which include all points where lines exit or enter the substation and in addition to ensure that the travelling wave phenomena and effects of inductance of earth tails of arresters are taken into consideration. This may required for example that arresters are installed on the bushings of transformers as well etc. It requires that the bonding of arresters and equipment to the earth grid is designed and done with care.

Earth resistivity and electrode resistance of the Wonderkop substation

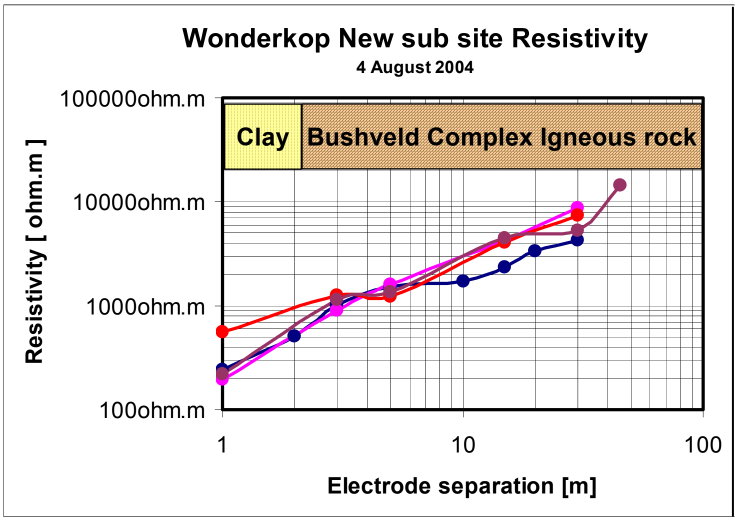


Figure 2. The resistivity measured at Wonderkop planned substation site.

Figure 2 shows the earth resistivity measurement at Wonderkop substation. Geologically it is known that the site has a surface clay layer of around 1 to 2m thick. This sit on top of the Bushveld Ingenious Complex strata which are 100's of m thick in the area. If the resistivity measurement is converted to a two layer resistivity model with CDACS the results does not converge nicely. The results gives quite large variations in layer thickness and resistivity, especially that of the deep layer. This is due to the large difference in resistivity between the two layers. It is believed to be an underestimate of the actual resistance if a top layer of 3m with a resistivity of 300 ohm.m and a deep layer resistivity of 10 000 ohm.m are assumed.

The substation design footprint is 80m by 60 m with 10 trench conductors parallel to the length and 15 parallel to the width buried at a depth of 1m. The resultant electrode resistance calculated with CDACS is 22.3 ohm. The resultant Ground potential rise profile result from CEDACS is shown in figure 3.

The result raises the question how such a high value of resistance could be lowered. One option would be to enlarge the substation and to bury much more copper in the substation: For example by increasing the footprint of the sub to 160m by 120m and installing 19 by 29 conductors in the ground. This improves the resistance only to 15 ohm. It is well known that under these conditions little can be done to improve the resistance of the station and other options has to be exposed.

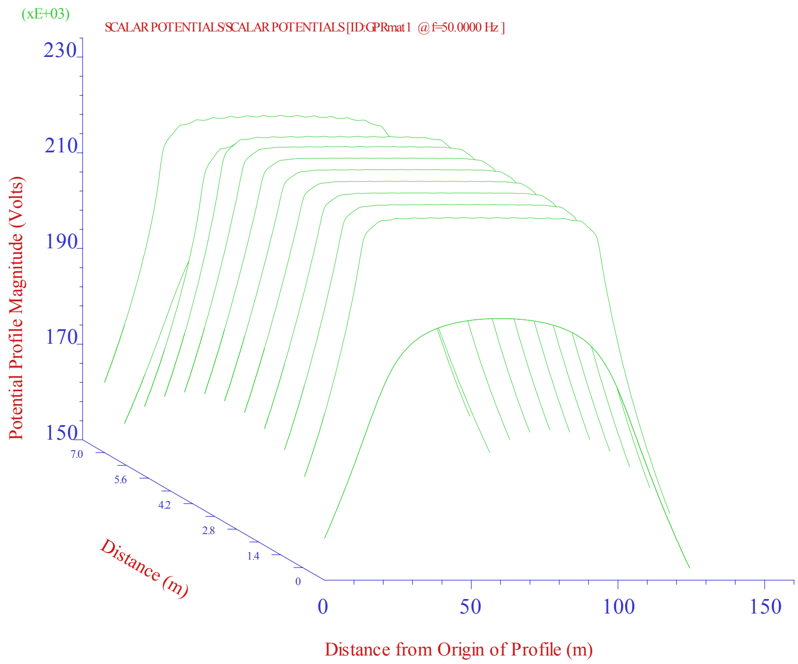


Figure 3. The GPR calculated with CDACS injecting a fault current of 10kA into the substation grid electrode

An alternative possible solution is to treat the soil around the electrode by means of a salt such as gypsum or inbed the electrode into bentonite. The effect of the salt or bentonite is only around the electode itself, very localised. It may improve seasonal variation of resistivity close to the electrode, however it does not change the resistivity of the deeper strata and thus leaves the electode resistance just marginally better than without the treatment. The value of the resistance has to be better than one ohm which will not be achieved.

Modelling the Ground Potential Rise on the Wonderkop earth electrode

A model for the Wonderkop single phase to ground fault was established, this is shown in figure 4.

The distance between the Main Transmission Substation and the Wonderkop substation is only 900 m. With the poor earthing conditions in the area the footing resistance of tower in the area is estimated to be at best around 100 ohm and most likely worse. For this reason the tower footing resistances was ignored in the modelling.

The impedances of the conductors, shield wires and the transformers had to be established. This presented its own problems as classical calculation of some of these parameters; especially the earth return part and impedance do not follow classic assumptions, which is a good connection between the substation earth and the body of the earth. Some assumptions had to be made to compensate for this.

The phase conductors on the line are Kingbird and two 132kV lines run between the two substations. It should be noted that the return current in the case of a phase to ground fault may not necessarily return equally via both interconnecting lines. This can only happen if the coupling breaker between the bus bars of both lines is closed. The fault current can then be fed into the substation via both lines and the impedance of the fault in this case would see the zero sequence impedance of both lines in parallel. In the case where the breaker coupling the lines is open, fault current will only be fed via one of the lines. The shield wires of the not faulting line will be in the circuit but the inductance in that circuit will be that of the faulting line phase conductor relative to the non faulting line's shield wire. Clearly this inductance/ impedance is relatively very high.

The calculation of the GPR of a single phase to ground fault at the substation using standard 19/2.64 steel wire shielding wires is a voltage rise of 12.2 kV. This is clearly way above the design targets.

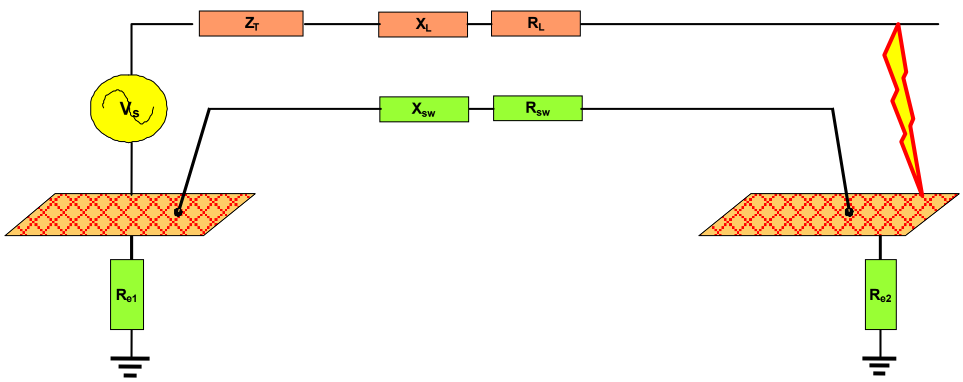


Figure 4. Simplified Model of a single phase to ground fault in the Wonderkop substation.

One possible solution for this particular problem is to use a much more conductive shield wire. Instead of using a steel shield wire a conductor such as hare can be used.

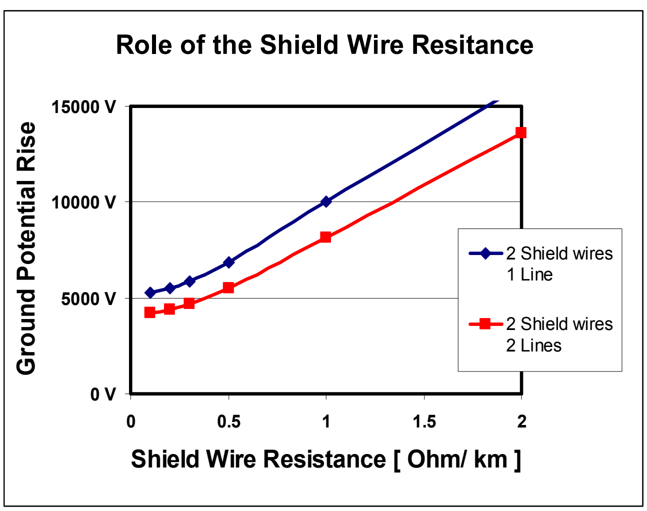


Figure 5. The ground potential rise due to a single phase to ground fault versus the shield wire resistance for different line configurations

The result of such an approach is shown in figure 5.

Using a Hare conductor as shield wire compared to a normal 2.65/19 steel wire with a resistance of 1.85 ohm/km reduces the GPR from 12 kV down to around 5 kV, which is within the design limit set by Eskom's standard.

It can be noted that if the bus coupler at the sub is run closed there are a marginal improvement in the GPR because of both lines taking part in returning the current to the feeding substation.

Transferred Ground Potential Rise to customer substation and plant as well as to other services

In substations where customers are fed from overhead MV lines customer earth electrodes are decoupled from the utility substation earth electrode because there is simply not any direct galvanic connection. MV lines normally does not have shield wires and even if there were shield wires the design of the MV-LV transformer installation is specifically done to prevent the transfer of fault GPR to customers. Eskom maintains an insulation level of 5 kV rms from the MV earth electrode to the customer LV earth electrode. This implies that normally substation GPR will not be transferred in the case of LV fed customers.

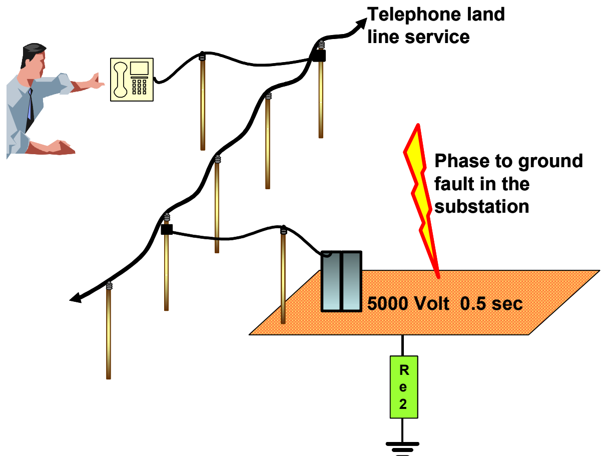


Figure 6. An illustration of transferring GPR via shared telephone services to telephone subscribers.

Figure 6 illustrate one of the potential hazardous situations that substation designers have to avoid. When services such as telephone connections that are shared by other customers are directly connected to a substation it pose a potential thread to the customers on the service.

This situation can be avoided by inserting isolation interfaces between the external connection to the substation and the substation.

In the case of telephone systems both optic fibre as well as radio based systems is available to fulfil such a function. These systems price tags are short of R100 000 and can be used in cases where data transfer on the system are required. Optic fibre units are also available at much lower cost in the case where dedicated data channels are to be connected such as RS 232, 422 and 485.

A much more difficult situation to deal with is the case where customers that receive power directly from the utility substation at MV voltage and have their own substations from where they transform and distribute power directly to their plant. In most of these cases it is not possible to decouple the customer's installation from Eskom's substation earth grid and GPR. It is very difficult or impossible to separate these earth electrodes as cables with armouring interconnect the systems and the substations are often so close to each other that even if it were disconnected by some means the GPR will still be transferred by means of coupling through the ground. One relieving benefit of this situation is that the net earth electrode resistance is lowered in this case by the parallel connection between the earth electrodes of the utility, the customer substation and any incidental electrodes that the customer may have in his plant.

In this case it is imperative to either separate the customer earth or for the customer to maintain similar step and touch potential design principles that are used in designing power substation in his own plant. Separation MV and LV earth electrodes in many cases are not possible for example in the case where MV motors are used in the plant. In this case interconnection of the MV and LV earth is a basic requirement.

Conclusion

The design of substation earthing require attention to detail of plant and services connected to it. In the case where customers take supply at MV or HV from the supply authority careful consideration has to be given to the transfer of GPR under fault conditions to avoid dangerous situations to the public, customer staff and utility staff.

Acknowledgement

The CDACS calculations have been done by Enderani Naicker with the support of Tony Auditore both from Eskom Transmission Technology.

References

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1) Eskom Distribution Standard Part 2: Earthing Section 3: Substation Earthing. SCSASABK2.

2) IEEE Std 80-2000 IEEE Guide for Safety in AC Substations Grounding.

3) IEC 60479-1

4) IEEE Std 487-2000 IEEE Recommended Practice for the Protection of Wire-Line Communication Facilities Serving Electric Supply Locations