EARTHING SYSTEMS CONNECTED VIA METALLIC SCREENS OF THE 20 KV UNDERGROUND CABLES IN NON-URBAN AREAS

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ABSTRACT

Secondary substations' earthing systems are connected to each other via metallic screens of the 20 kV underground cables also in suburban and rural areas nowadays. Topology is different from the earthing systems in city centers, where earthings are connected via multiple mesh connections forming a solid ground level. The standards EN 61936-1, EN 50522 and the Finnish SFS 6001 (High voltage installations) do not clearly consider the case of connected earthings. In 2015 studies were launched to investigate this issue. According to results of the studies, the connected earthings should be evaluated as a whole, and not separately as in the overhead networks. There is a need for renewing earthing network design principles because at the moment, the connections between the secondary substations are not systematically taken into account in the non-urban areas' earthing design. Results show that the resulting impedance was typically 50-80% lower than the secondary substations' individual earthing resistances. It means that there is great potential for savings in the earthing network without risking the safety. Furthermore, there is a need to develop earthing impedance measuring methods. Methods that are used for overhead network earthing measurements are not often suitable for cable network, where the earthings are connected. This paper brings out recommendations how the design and measurement principles could be developed and which possible changes in the relevant standards should be considered.

INTRODUCTION

Underground cables in medium voltage networks have become common also in non-urban areas. Customers are increasingly dependent on the reliability of electricity supply and in addition, distributed generation such as solar and wind units, must have reliable connections to the grid. In the near future, electric vehicles' recharging infrastructure and energy storages will put even more pressure on the distribution networks reliability.

Traditionally in Finland, in 20 kV overhead networks there has been a local earthing system for each secondary substation in non-urban areas. But nowadays, in many cases secondary substations' earthing systems are connected to each other via metallic screens of the 20 kV underground cables.

The standards EN 61936-1, EN 50522 and the Finnish SFS 6001 do not clearly consider the case of connected earthings in non-urban areas. Finnish distribution system operators brought out a question, how to handle connected earthing systems in the sense of network design. In 2015 new studies were launched to analyse the issue. The main question was to study, if it is possible to take all the connected earthings into account as a whole in network design, or should earthings be considered separately as in the overhead network. Furthermore, if it is possible to take the connections into account, what is technical framework.

Final target of the studies was to describe, what would be a possible solution to handle connected earthings in the standards and network design and what is the correct way to confirm the functionality of the earthings in terms of safety. As soon as the final conclusions are done, proposals for possible standard changes will be presented to Finnish Electrotechnical Standardization Organization (SESKO).

The study consists of practical considerations, theoretical calculations, simulations and on-site measurements. In theoretical part the research issue was approached by calculating the resulting impedance in different network topologies by varying relevant parameters.

On-site measurements were carried out in September 2016. Heavy-current-injection method was used to verify the theoretical calculations and alongside that, also other measurement methods were evaluated.

THEORETICAL STUDY

Aim of the theoretical study *[1]* was to model and simulate interconnected medium voltage network earthing constructions to observe the effects of local earthings on the resulting impedance. Resulting impedance is a key component in the earthing voltage calculations which confirms the safety of the network. Other key components are earth fault current and trigger times of the network protection relays.

Background

Theoretical study began by selecting relevant network topologies and parameters to be varied. Network topologies were chosen so that typical Finnish network constructions are covered:

1. Rural area, 10 secondary substations' chain with long distances between the substations
2. Sub-urban area, 5 secondary substations' chain with typical distances between the substations
3. Urban area, 4 to 16 secondary substations' in a mesh, short distances between the substations

Parameters to be varied in the calculations were based on a survey for the distribution system operators (DSO). Parameters were selected so that difficult but realistic circumstances are covered. Varied parameters were:

1. Earthing resistances of the secondary substations
    a. Based on real measured network data
    b. Variation 2 to 50Ω
2. Distances between the secondary substations
    a. Based on typical network topologies
    b. Variation from 0.5 to 10 km
3. Cable types
    a. Typical Finnish medium voltage cable types were selected (AXAL-TT 20 kV 3x50 mm^2 to AHXAMK-W 20 kV 3x240 mm^2)
4. Soil resistivity
    a. Values were selected so that typical circumstances and extremely difficult circumstances were covered
    b. Variation from 2300 to 15 000 Ωm

Research methods

The network models were implemented applying PSCAD™ simulation software and MS Excel software. Modelling included the topologies of connected earthing systems. Mutual resistances of earthings were modelled in simulation so that to each earthing was added a voltage source whose voltage was dependent of the currents and distances of all other earthings. In Excel application some heuristics and approximations were needed.

Current is injected to the examined earthing, and resulting earthing impedance is solved based on the current and the risen potential.

Results of the theoretical studies

Wide amount of different earthing topologies were studied. Some key results of the study are presented in the examples 1-5:

Example 1: typical rural network with difficult earthing conditions:

Input data:

- 10 secondary substations in a chain
- Earthing resistance of each single substation 50 Ω
- Distance between the secondary substations 1 km
- Cable type AXAL-TT 20 kV 3x50 mm^2

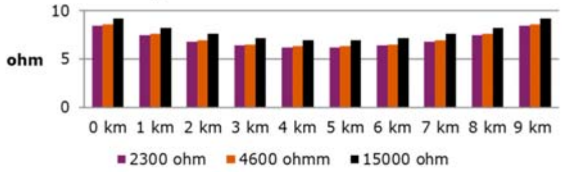


Figure 1. Simulation results in a typical rural network.

Simulation results of the figure 1 show that the resulting impedance is less than 10 Ω at every secondary substation. Difference is significant compared to each secondary substation's own earthing resistance (50 Ω). It is notable that the highest values of the resulting impedance were calculated in the first and last secondary substations. Best (lowest) values were calculated in the middle of the chain.

Example 2: typical sub-urban network with difficult earthing conditions:

Input data:

- 5 secondary substations in a chain
- Earthing resistance of each single substation 15 Ω
- Distance between the secondary substations 1 km
- Cable type AXAL-TT 20 kV 3x50 mm^2

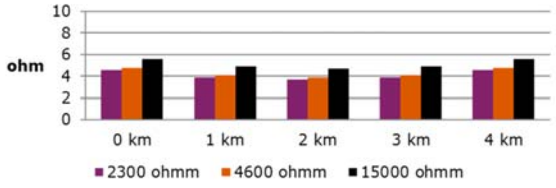
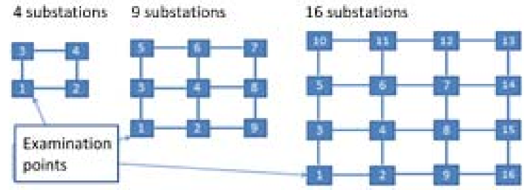


Figure 2. Simulation results in a typical sub-urban network.

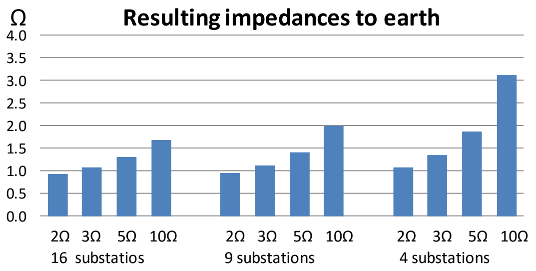
Simulation results of the figure 2 show that the resulting impedance is less than 6 Ω at every secondary substation. Difference is significant compared to each secondary substation's own earthing resistance (15 Ω).

Example 3: typical urban network with difficult earthing conditions:



Input data:

- Soil resistivity 2300 Ω
- Earthing resistance of each single substation varies from 2 to 10 Ω
- Distance between the secondary substations 1 km
- Cable type AXAL-TT 20 kV 3x50 mm^2
- 2x2 to 4x4 secondary substations in a mesh



Cable AXAL-TT 3x50, distances 1.0 km and the resistivity of soil 2300 Ωm
4 ... 16 kpl 2 ... 10 Ω connected earthings

Figure 3. Simulation results in a typical urban network.

Simulation results of the figure 3 show that the resulting impedance is less than 3.5 Ω at every scenario. Resulting impedance is over 50% lower than the secondary substation's own earthing resistance in every case. In the 2x2 mesh the significance of each secondary substation to the resulting impedance is higher than in 4x4 mesh.

Example 4: saturation of the resulting impedance in a secondary substation chain:

Input data:

- 10 secondary substations in a chain
- Earthing resistance of each single substation 20 Ω
- Distance between the secondary substations 1 km
- Cable type AXAL-TT 20 kV 3x50 mm^2

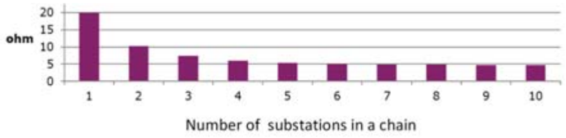


Figure 4. Saturation of the resulting impedance.

Simulation results of the figure 4 show that the resulting impedance is significantly saturated when a few secondary substations are in the chain. As the length of the chain increases, the effect of the single secondary substation's earthing on the resulting impedance decreases.

Case 5: effect of the cable type and soil resistivity on the resulting impedance:

Input data:

- 10 secondary substations in a chain
- Earthing resistance of each single substation 20 Ω
- Distance between the secondary substations 1 km
- Cable types AXAL-TT 20 kV 3x50 mm^2, AHXAMK-WP 20 kV 3x95 mm^2 and AHXAMK-W 20 kV 3x240 mm^2)

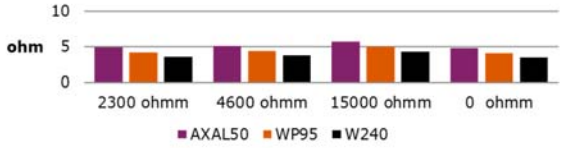


Figure 5. The effect of cable type and soil resistivity on resulting impedance.

Simulation results of the figure 5 show that the cable type and soil resistivity have relatively small effect on the resulting impedance. Secondary substations' earthing resistances have more significant impact on the resulting impedance.

Calculation tool

A calculation tool was developed for helping the DSOs to calculate resulting impedances in their networks. The tool is based on Excel and the user can model his own secondary substations' earthings to the tool. The tool calculates the resulting impedance at the selected point. The earthing resistance of each secondary substation, soil resistivity, cable types and sizes and network topology are fed as input data. In addition to the earthings of the secondary substations, any other earthings can be included in the topology. In reality, there is also other connections such as connections to low voltage network's earthings, water pipes, railways and telecommunication cables. If those are not included to the calculations the value of resulting impedance in the calculation tool is always higher than the measured value. It means that the calculated results in this study are on the safe side.

Calculation tool is in its early development stage and further development is needed to be able to effectively use the tool. To make the calculation tool practical, it could be integrated to network information systems.

ON-SITE MEASUREMENTS

On-site measurements were carried out after the theoretical study. Purpose of the measurements was to

1. confirm the methods of the theoretical study in reality, and
2. evaluate the practicality and reliability of earthing impedance measurement methods.

The resulting impedance of the measured network was calculated before the measurements and it was used as a reference value. Input data were fed in to the calculation tool and the result was 2.5 Ω at the selected point.

All the input data were collected from the network information system, except the soil resistivity which was measured next to each secondary substation. Earthing resistance of each secondary substation was calculated according to the structure of the earthing and the measured soil resistivity.

Measurement scheme

Heavy-current-injection method was used in the measurements. This method requires challenging arrangements, but then again, it is reliable and accurate. Suitable place for the measurements was found from Eastern Finland at Savon Voima Verkko's network, where it was possible to use 45 kV overhead line to get the reference point of current measurements far enough. Topology of the substations in the observed network is shown in figure 6.

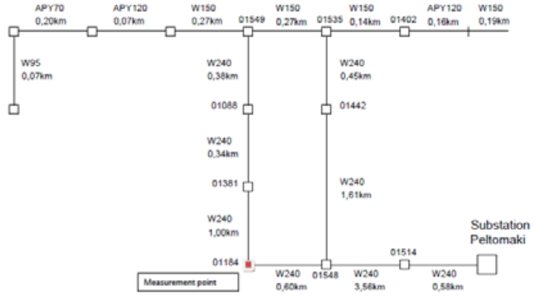


Figure 6. Topology of the measured network.

Results of the measurements

Measurements were carried out on September 20th 2016. Weather conditions were suitable for the measurements; half cloudy, no rain showers and temperature 9 to 13 °C.

Measurements were carried out first by applying the heavy-current injection method. This method is used particularly for large earthing systems. By applying an alternating voltage of approximately system frequency between the earthing system and a remote earth electrode, a test current is injected into the earthing system, leading to a measurable potential rise of the earthing system. [EN50522, SFS6001]

The distance of the current injection point was 59 km. Reasonable potential rise was measured at 13 – 18 km distances. Final result for the impedance to earth was 1 Ω.

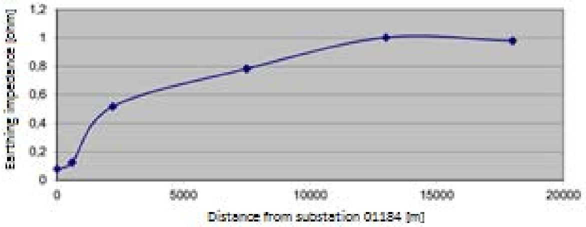


Figure 7. Heavy-current-injection measurement results.

According to measurement report, Heavy-current-injection method was a suitable and obviously reliable method to measure resulting impedance. Difference between measured and calculated value is 1.5 Ω. The difference is mainly due to the other earthing connections, such as connections to low voltage network earthings, which were not taken into account in the calculation tool. Calculated value is higher than the measured value, so according to the results the calculations are not risking the safety.

The resulting impedance was measured also with the fall-of-potential method with the earth tester. This instrument is used for earth electrodes and earthing systems of small or medium extent. Earth electrode under test, probe and auxiliary electrode shall lie on a straight line as far apart as possible. [EN50522, SFS6001]

200 m distance was used for current probe. The distance of the potential probe was varied with 20 m spaces in order to find a turning point. A challenge was to achieve enough spacing between the ground grid and the current probe. Result for the resulting impedance was 1,3 Ω.

CONCLUSIONS AND FURTHER ACTIONS

Connected earthings to be evaluated as a whole

According to the results of theoretical study and on-site measurements, the earthing network should be evaluated as a whole, if there is a connection between the earthings of the secondary substations. There were not any signs that longer distances between the secondary substations would significantly limit this principle. Connecting the first three secondary substations decreases clearly the resulting impedance. After the third secondary substation the effect starts to become saturated. Cable type and soil resistivity have relatively small effect on the overall resulting impedance.

There is a need for separate earthing system design principles in the cable network and in the overhead network. At the moment, the connection between the secondary substation are not systematically taken into account in network design. Resulting impedance was typically 50-80 % lower than the earthing resistances of the single secondary substations. It means that there is great potential for savings in the earthing network design and construction without risking the safety, if the earthing connection were taken into account. When the earthings are connected, it is important that all the connections (such as metallic screens) are mechanically and thermally sufficient according to relevant installation and cable construction standards.

New strategy for earthing impedance measurements in the connected earthing networks

There is also potential for developing the measurements in the case of connected earthings. Nowadays, earthing resistance is periodically measured by the fall-of-potential method. Result of the measurement is not really the earthing resistance of the single secondary substation, which is the target. Instead, the result is the resulting impedance of the connected earthing network, but usually it is not possible to carry out the measurement method according to standard SFS 6001 (e.g. spacing between the ground grid and current probe can be rather difficult). Basically, fall-of-potential method is not suitable for measuring resulting impedance when the earthings are connected.

According to results of this study, practical, safe and reliable enough method for measuring the resulting impedance in case of connected earthings would be the following:

Network construction:

1. Earthing resistance of each secondary substation are evaluated. Measured value (before the secondary substation earthing is connected to others) shall be used if the result is reliable. If there are no measured values available, the soil resistivity next to each secondary substation is measured and the earthing resistance is calculated taking into account the structure of each secondary substations' earthing.
2. Earthing resistance of each single secondary substation is fed into the calculation tool and the resulting impedance is calculated at the selected observation point.

Verification:

1. If the connection between the secondary substations' earthings breaks, it is highly probable that the whole cable is broken and the network automation systems detect the problem. It is extremely rare that the connection through the concentric screen would break by itself. Therefore, periodic inspections seem to be not so essential.
2. Random sample measurements: As some part of the medium voltage network is disconnected, for example due to maintenance work, the connections through the metallic screens are recommended to inspect.

Renewed measuring strategy would decrease significantly the annual costs of the earthing measurements and the results would be more reliable.

Recommended further actions

According to the results of the theoretical study and on-site measurements, there is a need to consider some changes in guidance and standards. The standards EN 61936-1, EN 50522 and the Finnish SFS 6001 do not clearly consider the case of connected earthings in non-urban areas. As a key recommendation of this study, the connected earthings should have a separate section in the standards.

Results of the study will be presented to Finnish SK99 standardization committee, which is responsible of SFS 6001 standard. As soon as the feedback from the committee is received, further actions are planned (for example, need for changes in the network design guidance, discussion with the network information system providers and discussion with relevant CENELEC committees).

REFERENCES

[1] A. Mäkinen, 2017, Report on the Earthing Systems in Medium Voltage Networks, Tampere University of Technology, Tampere, Finland (in Finnish).