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A method for the evaluation of fault current distribution in complex high voltage networks

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ABSTRACT

The paper presents a method for the study of large interconnected earthing systems in High Voltage networks. The mathematical model proposed for calculating the distribution of the Single-line-to-Earth fault current is useful for a methodical and accurate analysis of complex systems having meshed configuration and more sources, and has practical application for the Transmission System Operator. Two case studies are provided. The first one considers a fault occurring inside and outside a station in a real 220 kV transmission network. In the second example, the proposed methodology is compared with the classical "Double-sided elimination" method.

1. Introduction

Evaluating the distribution of the single-line-to-earth (SLTE) fault current among interconnected High Voltage (HV) earth electrodes, requires a significant computational effort due, mainly, to two factors:

- the meshed configuration of these networks;
- the presence of different return path of the zero-sequence currents to the sources.

Moreover, safety issue in HV networks is made more complex by the interconnection between stations, substations and line towers earth electrodes, and the presence of contact points with power systems with lower rated voltage.

Several works in literature deal with the effects of the transmission of part of the SLTE fault current from HV systems to LV systems [5,30,19,20].

For calculating the current transferred towards lower voltage power systems, it is necessary to preliminary evaluated the distribution of this current among the earthing systems and the extraneous-conductive-parts (ECP) in the HV network.

With this aim, [38] have defined the "circuital method" usable for simple systems with only one source and [8,9] has proposed the "double-sided elimination method", validated with experimental measurements [10] and currently used in many projects. However, these methods often require the solution of very complex equations.

In other works [22,28,29,31,35–37], a simpler procedure named "decoupled method" has been proposed, currently adopted by the International Standard (IEC Std 60909-3, 2003).

In very recent years, other accurate methods have been developed [3,4,24,27,34,39,40]. These methods take into account several variables that have great importance for studying unearthed or resonant earthed MV networks, but become negligible in directly earthed HV networks.

All the above-mentioned methods, however, are not easily applicable for evaluating the SLTE fault current distribution in presence of multiple sources, as in the network in Fig. 1.

A general method for solving such complex systems is the "iterative nodal analysis", carried out by [41], that proposes an iterative solution, overcoming the classical problem of the presence of mutual coupling in nodal analysis.

In the present paper, after a brief review of the most recent technical standards on the design of the earthing systems in HV networks [7,16], the authors propose a methodical and accurate analysis of complex interconnected earthing systems.

In [23], an approach for solving complex systems has been proposed too. The authors describe all the elements of the HV network, of the earthing systems and of the stations by multiports. Multiport equations, together with the boundary conditions at the multiport terminal interconnections, build a system of linear equations of relatively low order. Moreover, the multiport method calculates the fault currents by taking into account the presence of the earthing systems.

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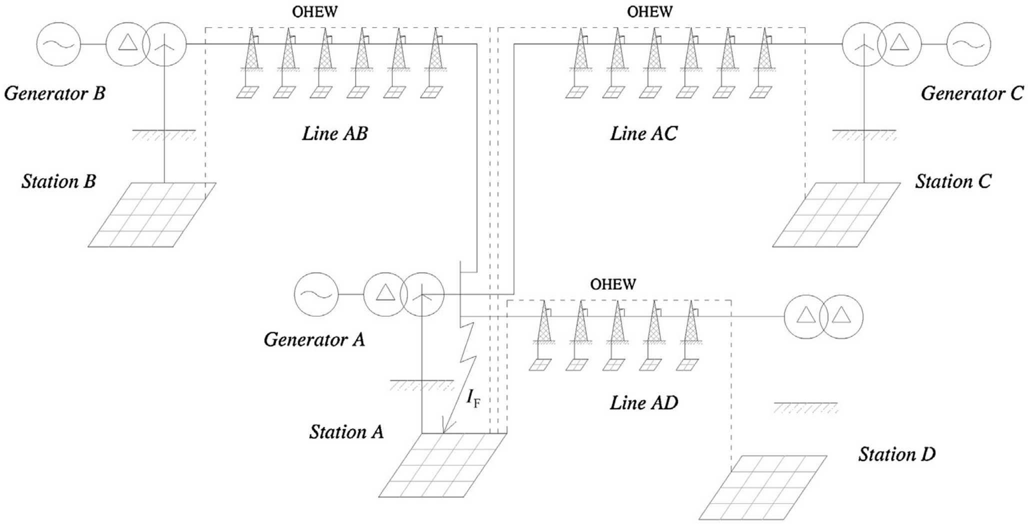

Fig. 1. Typical HV network with multiple sources.

In the present paper a method is proposed allowing a further simplification of the mathematical model of the complex interconnected earthing system, by overtaking the multiport representation and providing equations easily solvable by commercial spreadsheet applications.

This simplification, together with the adoption of spread-sheet tools for the calculations, leads to great advantages given that, in this way, it is not necessary to have recourse to more expensive and, sometimes, less user-friendly simulation tools.

Differently from the multiport method, the proposed one has recourse to the application of (IEC 60909-0, 2001) for calculating the fault current and therefore introduce an approximation by neglecting the effects of the earthing systems of transmission lines and transformer stations. This approximation is normally accepted in the calculations because it does not introduce significant errors, due to the very low value of the equivalent earth impedance in interconnected HV earthing systems. Anyway, as an alternative to the IEC 60909-0 method for calculating the fault current, it is possible to refer to [13], that proposes an identical approach taking into account also the presence of interconnected earthing systems in the equivalent zero-sequence impedance calculation.

In the final part of the paper two application examples are provided. The first one considers a SLTE fault occurring inside and outside a station in a real 220 kV transmission network built in a territory with high resistivity soil. In the second example, the proposed methodology is compared with the classical “double-sided elimination” method [8].

2. International regulatory framework

The European regulatory framework for the design, management and testing of earthing systems in HV networks is composed by:

- IEC Standard 60909 series, giving a procedure for the calculation of the short-circuit current;
- IEC Standard 61936-1, providing common rules for the design and the erection of power installations in systems with nominal voltages above 1 kV a.c;
- IEC/TS Standard 60479-1,regarding the effects of currents on human beings;
- EN Standard 50522, providing the requirements for the design and erection of earthing systems of electrical installations, in systems with nominal voltage above 1 kV a.c.

Starting from the 1st of November 2013, IEC Standard 61936-1 and EN Standard 50522, together supersede [6].

According to the regulatory framework, safety for human beings against electric shocks during a fault to earth is assured if one of the three following conditions occurs:

- the earth potential rise U_E does not exceed double the value of the permissible touch voltage U_{Tp}, calculated according to IEC 61936-1 as function of the time duration ($U_E \leq 2 \times U_{\mathrm{Tp}}$);
- the earth potential rise U_E does not exceed four time the value of the permissible touch voltage U_{Tp} ($U_E \leq 4 \times U_{\mathrm{Tp}}$), and recognized specific measures M are taken (for details see Annex E of EN 50522);
- the maximum touch voltage $U_{\mathrm{T,max}}$ does not exceed the permissible touch voltage U_{Tp} ($U_{\mathrm{T,max}} \leq U_{\mathrm{Tp}}$).

Therefore, for checking these conditions, the earthing system designer must preliminary calculate the Earth Potential Rise (EPR) or the maximum touch voltage.

This calculation needs the designer exactly knows the fault current distribution between all the interconnected earth electrodes.

3. The general analysis methodology

The proposed work considers only meshed transmission networks with overhead lines external to urban areas and close to generators where fault currents are very high and safety problems are more serious.

In the following the SLTE fault is supposed to occur inside a generic station A, for two reasons:

- this case giving rise to the most hazardous situations with respect to the fault at a line tower where the presence of persons is highly improbable;
- this case giving rise to the most hazardous situations due to the higher values of transferred voltages towards interconnected lower voltage power systems.

Nevertheless, the proposed methodology can be applied also to the most generic case of fault outside a station.

As a SLTE fault occurs inside station A, part of the fault current I_F is injected in the soil by the local earthing grid and part, going through the Overhead Earth Wires (OHEW), by the feet of the line towers.