Intersystem Faults in Multi-Circuit Overhead Transmission Lines of Different Voltages and Frequencies

A. Novitskiy[1], D. Westermann[1]

[1] Department of Power Systems
Faculty of Electrical Engineering and Information Technology
Ilmenau University of Technology
P.O.B. 100565, 98684 Ilmenau (Germany)
Phone/Fax number: +0049 (3677) 691490/+0049 (3677) 691496
e-mail: Alexander.Novitzkij@TU-ilmenau.de, Dirk.Westermann@TU-ilmenau.de

Abstract. The use of multi-circuit overhead transmission lines (OHL) of different voltages and frequencies located on the same pylons is widespread. It means that in case of an intersystem fault the network equipment in both systems will be influenced by current and voltages at frequencies which were not designed for equipment operation. It can result in a damage of the network equipment. The effects of intersystem faults in the electrical network containing multi-circuit OHLs with power circuits of different rated frequencies is studied in the paper. A novel simplified method for the estimation of the energy released by an intersystem fault is suggested.

Key words

Multi-circuit transmission lines, harmonic impedance, intersystem fault, Petersen coil.

1. Introduction

The use of multi-circuit overhead transmission lines (OHL) of different voltages located on the same pylons is widespread nowadays. In some cases power circuits of a multi-circuit OHL are operating at different frequencies. It means that if an intersystem fault occurs the network equipment in both systems will be influenced by current and voltages at frequencies which were not designed for equipment operation. It can result in a damage of the network equipment.

There are many publications about intersystem faults between power circuits of the same frequency [1 – 4]. In some publications the influences of intersystem faults in hybrid AC/DC overhead transmission lines are analysed [4 – 6]. But there are a few publications concerning intersystem faults between power circuits of different frequencies [7, 8].

The analysis of the effects caused by intersystem faults in networks containing power circuits of different rated frequencies is complicated due to the fact that the network impedance at a non-rated frequency is usually unknown.

The effects of intersystem faults in the electrical network containing multi-circuit OHLs with power circuits of different rated frequencies is studied in the paper.

Analytic consideration of the intersystem fault under study is presented.

A practical approach based on the on-site measurements for the determination of network harmonic impedance is described. Consideration of the determined impedance values in the mathematical model of a real network is discussed.

Results of mathematical simulations of intersystem faults in a real network containing multiple multi-circuit OHLs of different rated voltages and frequencies are presented in the paper.

A novel simplified method for the estimation of the energy released by an intersystem fault is suggested.

It is shown that the harmonic impedance has a significant influence on the characteristics of the intersystem fault.

2. Analytic Considerations

An intersystem fault in the electrical network containing multi-circuit OHL with power circuits of different rated frequencies can be simplified considered as single pole ground faults via some equivalent impedances for both affected systems. The fault currents paths and the equivalent impedances are dependent on star point grounding, rated voltages and frequencies in the systems under consideration.

Fig. 1 shows the simplified equivalent circuit diagram for the analysis of an intersystem fault. Low-ohmic grounded three-phase 50 Hz network and resonant earthed 16.7 Hz two-phase network are presented in Fig. 1.

Low values of equipment impedances in the 50 Hz network at the frequency 16.7 Hz determine the 16.7 Hz fault current paths mainly through star points of the three-phase network to the ground.

Petersen coil impedances in the 16.7 Hz network are high at the frequency 50 Hz. It determines the 50 Hz fault current paths mainly through equivalent phase-to-ground impedances of transmission lines in the two-phase network to the ground. It means that the values of the equivalent phase-to-ground input impedance of the 16.7 Hz network at the frequency 50 Hz are decisive for the characterization of the effects of the intersystem fault under conditions presented in Fig. 1.

Other effect of high values of the impedances of 16.7 Hz Petersen coils at the frequency 50 Hz is the presence of significant 50 Hz phase-to-ground voltages at the star points of two-phase network during intersystem faults.

3. Case Study

Fig. 2 shows the real 16.7 Hz network containing multi-circuit OHLs (A, B, C, D, E, F and G) with power circuits of different rated frequencies and voltages. The lengths of all OHLs are presented in Fig. 2.

Fig. 3 shows an example of the typical common pylon of multi-circuit OHLs combined 50 Hz and 16.7 Hz lines in the network under consideration.

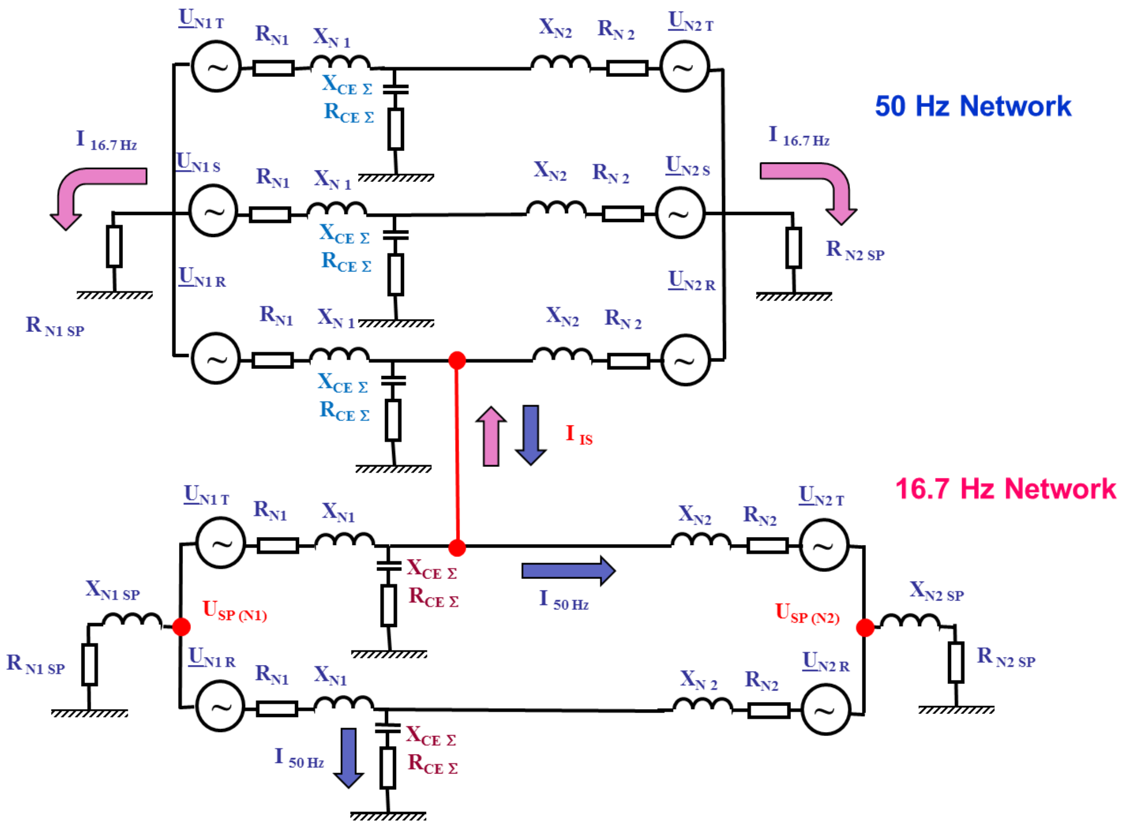

Fig. 1. Equivalent circuit diagram for the analysis of an intersystem fault

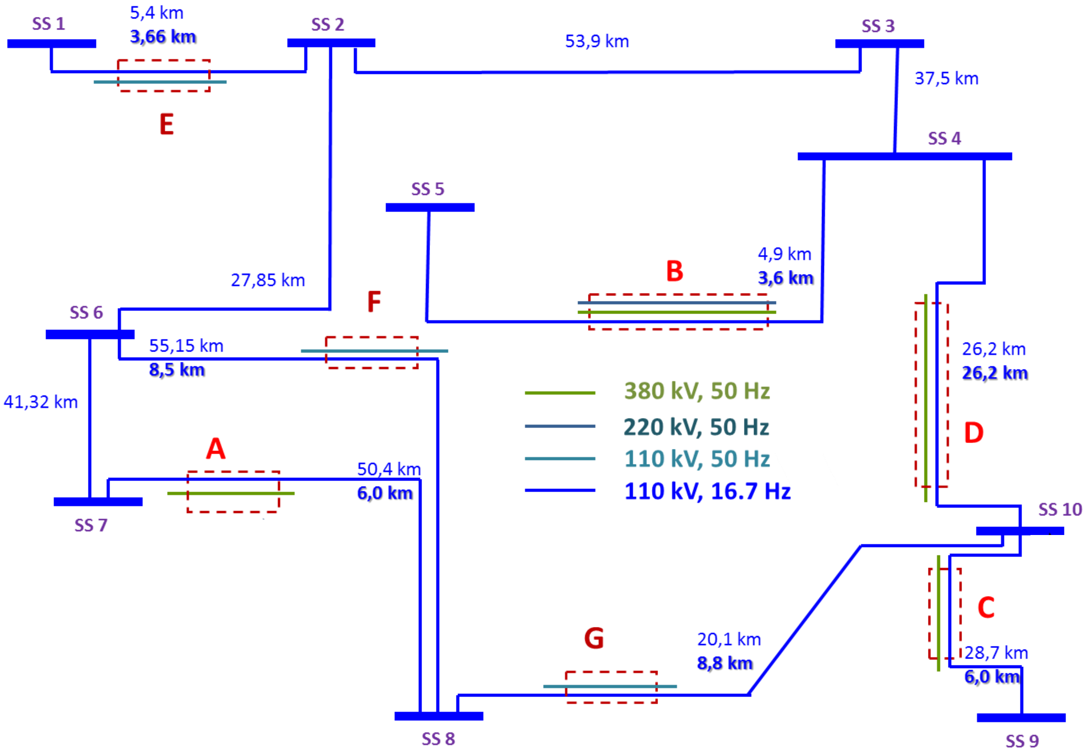

Fig. 2. Network for the intersystem fault analysis (lengths of multi-circuit OHL used common pylons are noted in bold type)

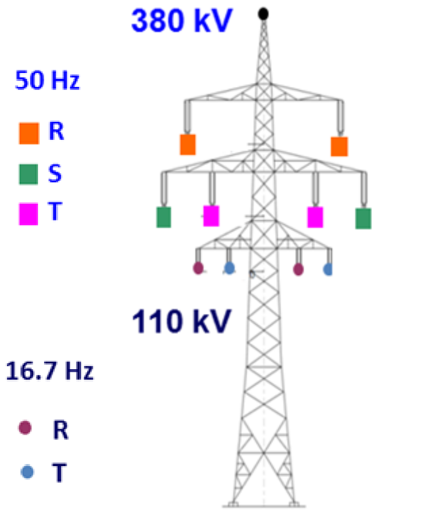

Fig. 3. Typical pylon of a multi-circuit OHL

4. Network Impedance Determination

The frequency 50 Hz is an interharmonic of the fundamental frequency 16.7 Hz and is very close to the 3rd harmonic.
The CIGRE technique for the harmonic emission level evaluation from an individual distorting load [9] was used for the experimental determination of the equivalent phase-to-ground input impedance values of the 16.7 Hz network at the frequency 50 Hz. Fig. 4 and 5 show the determined impedance values.
The determined values of network impedance were used for the choice of network equivalent circuits for the frequency 50 Hz and were implemented into the mathematical model.

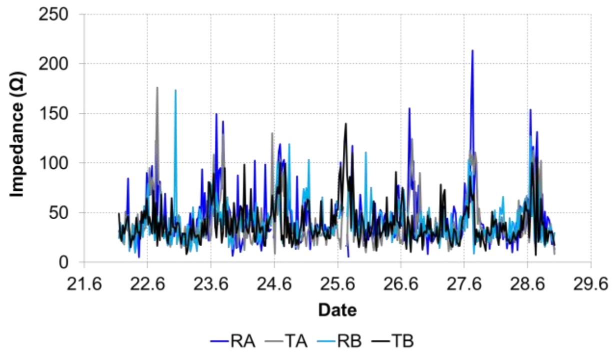

Fig. 4. Time courses of 50 Hz impedances

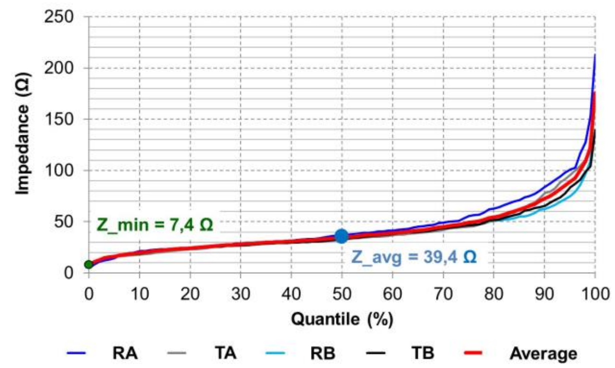

Fig. 5. Cumulative frequency distributions of 50 Hz impedances

5. Mathematical Modelling of the Network

Mathematical model of the network shown in Fig 2 was created using MATLAB/Simulink software package. Multi-circuit transmission lines and other OHLs were modelled as distributed parameter line blocks with consideration of all conductors and earth wires.
The standard MATLAB function *power_lineparam* [10] was used for the parameterization of simulated OHL blocks. This function computes matrices of RLC parameters of overhead multi-conductor line from its conductor characteristics and tower geometry. Self and mutual resistance, inductance, potential coefficients terms are determined taking into account conductor and ground skin effects (depending on the considered ground resistivity).

6. Results of Computations

Main simulation results are presented in Fig. 6 and 7. It can be seen in Fig, 6 and 7 that the calculated 50 Hz values are depending on the equivalent network impedance of the 16.7 Hz network at the frequency 50 Hz.
The 50 Hz star point voltages at the Petersen coil locations (substations SS 2 and SS 5) in cases of minimal (Z_min) and average (Z_avg) values of the 50 Hz equivalent input impedance of the 16.7 Hz network are presented in Fig. 6.
It can be seen from Fig. 6 that 50 Hz star point voltages in the 16.7 Hz network can override the values of 200 kV. It is much more than the phase-to-phase rated voltage 110 kV of the 16.7 Hz network. And it is significantly higher than the phase-to-star point rated voltage 55 kV in the two-phase 16.7 Hz network.

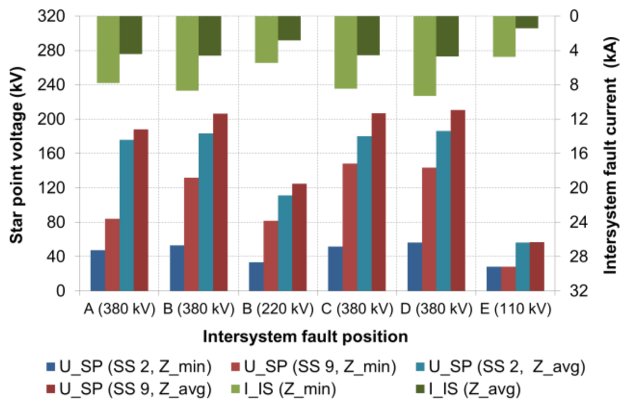

Fig. 6. 50 Hz intersystem fault currents and 50 Hz voltages on the Petersen coils at the star points of 16.7 Hz network (RMS values)

Simplified estimations of the thermal energy which can be released during the intersystem faults were carried out taking into account the assumptions for the estimation of thermal equivalent short-circuit current I_{th} in [11]:

$$I_{th} = I_k'' \sqrt{m+n} \qquad (1)$$

where I_{th} - thermal equivalent short-circuit current,

$I_k^{''}$ - initial symmetrical short-circuit current,

m, n - factors.

In case of the intersystem faults under study it can be simplified assumed that $I_k^{''} = I_{IS}$ and $m = n = 1$.

The estimation of the released thermal energy can be carried out as follows:

$$W_{IS} = \sqrt{2} \times I_{IS} \times U_{Res} \times T_k \qquad (2)$$

where W_{IS} - intersystem fault energy,

I_{IS} - intersystem fault current,

U_{Res} - residual voltages at the fault location,

T_k - duration of the intersystem fault.

Taking into consideration the duration T_k = 0.15 s based on a typical reaction time of protection devices and circuit breakers on a fault in the 380 kV network the corresponding energy values can be calculated.

The intersystem fault energy values determined according to (2) are presented in Fig. 7. It can be seen in Fig. 7 that the calculated intersystem fault energy values can reach the level over 320 MVAs. It must be noted that this energy values are based on the apparent power estimation.

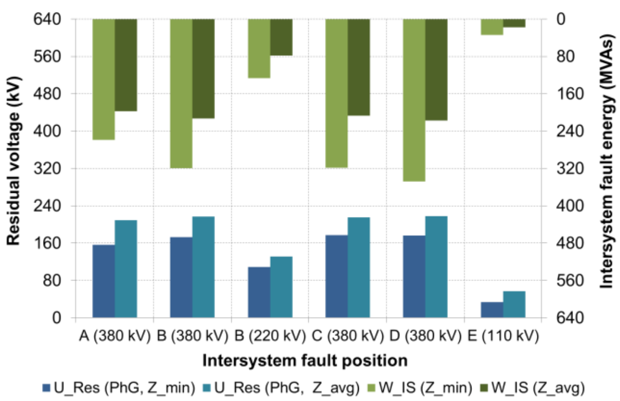

Fig. 7. 50 Hz phase-to-ground residual voltages at the fault location (RMS values) and 50 Hz intersystem fault energy

Energy capabilities of high voltage surge arresters are usually specified in kJ/kV [12]. The maximal value of the energy capability for the surge arresters up to 800 kV is given in [12] as 15.4 kJ/kV. Taking into account the energy values presented in Fig. 7 it can be concluded that the estimated values of the thermal energy are significantly higher than the energy capabilities of conventional high voltage surge arresters. It corresponds with the information in [8].

7. Conclusion

The analysis of intersystem faults in electrical networks containing multi-circuit overhead transmission lines of different voltages and frequencies was carried out.

It was shown that the harmonic impedance of the network has a significant influence on the characteristics of the intersystem fault.

A novel simplified method for the estimation of the energy released by an intersystem fault was suggested.

It was shown that the estimated values of the thermal energy which can be released by intersystem faults can be significantly higher than the energy capabilities of conventional high voltage surge arresters.

References

[1] C. Koreman, W. Kersten, “Performance Testing of Relays for Intersystem Faults in Combined 380 kV / 110 kV Lines”, in Proc. 5th Int. Conf. Developments in Power System Protection, 1993, pp. 145-148.

[2] R. Kumala, P. Sowa, “Intersystem faults in the coupled high-voltage line working on the same tower construction”, Przegląd Elektrotechniczny, R. 90, nr 4, pp. 141-144, 2014.

[3] R. Kumala, P. Sowa, “Comparison of the Intersystem Faults In Multi-Voltage Lines Working On the Lattice and Tubular Poles”, IJAREEIE, Vol. 4, Issue 9, pp. 7409-7417, Sept. 2015.

[4] M. Kielbon, P. Sowa, “Electromagnetic Transient Components Induced by Faults in the Different Coupled Transmission Line”, in Proc. IPST 1999, pp. 169-172.

[5] C. Romeis, J. Jaeger, T. Keil, C. Butterer, “Protection coordination aspects of AC/DC hybrid line corridors”, IEEE PES General Meeting, 2015.

[6] C. Petino, D. Eichhoff, P. Tünnerhoff, A. Schnettler, “System protection during contact faults in hybrid AC/DC transmission systems”, in Proc. CIGRE Int. Symp. Across Borders – HVDC Systems and Market Integration, 2015.

[7] Wissenschaftliches Gutachten 110-kV-Leitungsverbindung Almtal –Kremstal, Endbericht, TU Graz, 2010, Available: http://www.110kv-ade.at/sites/default/files/Gutachten%20TU%20Graz.pdf.

[8] M. Gorski, A. Steimel, C. Heising, “Netzsysteme auf Gemeinschaftsgestängen und mögliche Lösungsstrategien für Zwischensystemfehler”, 2012 Available: https://www.avasition.de/images/PDF/20120712_Netzsysteme_Zwischensystemfehler.pdf.

[9] Review of Methods for Measurement and Evaluation of the Harmonic Emission from an Individual Distorting Load. CIGRE 36.05 / CIRED 2 Joint WG CC02 (Voltage Quality), 1999.

[10] Mathworks Documentation Center. SimPowerSystems. Function power_lineparam. © 1994-2016 The MathWorks, Inc. Available: http://www.mathworks.de/de/help/physmod/sps/powersys/ref/power_lineparam.html.

[11] IEC 60909-0. Short-circuit currents in three-phase a.c. systems –Part 0: Calculation of currents.

[12] ABB High Voltage Surge Arresters, Byuer´s Guide, Edition 11, 2014-05.