Comparison between Calculation of Zero-Sequence Harmonic Currents generated in HVDC Converter Stations

Dr. Kadry Sadek Peter Luetzelberger Lutz Kirschner

SIEMENS AG, Dep. EVHV 33
Postfach 3220
D-91050 Erlangen
Germany

Keywords

Three-pulse harmonics, zero-sequence harmonic currents, stray capacitances, EMTDC, neutral capacitor

Abstract

Zero-sequence harmonic currents are generated in every HVDC transmission system. They appear from three pulse harmonic currents flowing through stray capacitances or capacitive connections to ground. On the DC-side of a converter station these disturbing harmonic currents enter the line and contribute to telephone interference. DC-filter design has to take into account these harmonics to limit their impact. This paper presents an analysis of zero-sequence harmonic currents flowing on the AC- and DC-side of HVDC transmission schemes. It will show from simulation results whether a simple analytical representation is sufficient to include the impact of zero-sequence currents for filter performance and rating calculations or whether a more detailed simulation has to be carried out.

Introduction

A special group of non-characteristic harmonics are the *three-pulse harmonics*. Their occurrence is explained from rapid voltage changes across stray capacitances resulting from the switching of the thyristor valves. Stray capacitances are distributed everywhere in the converter station. Zero-sequence harmonic currents are 3-pulse currents flowing through ground connections in the station. Transformer stray capacitances have the main impact on zero-sequence harmonic currents. Using the *Three Pulse Model* [1] of a converter their existence can be explained analytically. They can also be shown using a digital simulation if the stray capacitances are included in the modeling of a converter station. In the following the occurrence and distribution of these three pulse harmonic currents flowing to ground will be stated.

A comparison will be carried out between zero-sequence currents calculated from the time-domain simulation and the analytical calculation of the three-pulse model.

1 System description

A long distance transmission system is analysed (see **Figure 1**). DC transmission line length is about 1000 km. The converter operates in monopolar ground return mode. For connections to ground stray capacitances of the transformers and bushings as well as neutral capacitors and electrode lines are foreseen.

2 Simulation Model

The system is modelled with standard EMTDC library tools.

Transformers are represented as two three-phase two winding transformers (star-star and star-delta) per side including losses and saturation effects. Most impact on zero-sequence harmonic currents has the capacitive coupling from transformer low voltage side to ground and the (isolated) star-point capacitive coupling to ground.

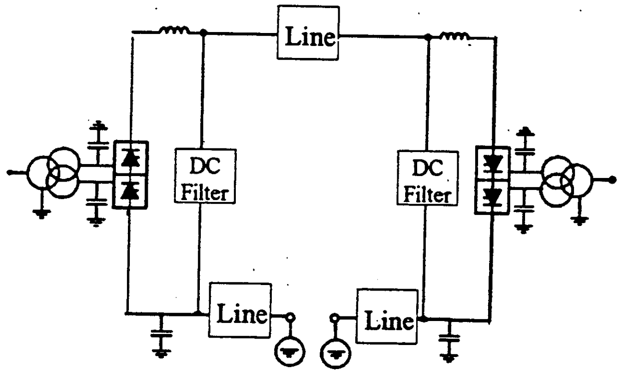


Figure 1: Analysed System

Stray capacitances are normally distributed parameters. To include their impact in the simulation the transformer and bushing stray capacitances are modelled as concentrated capacitances connected symmetrically along the winding. Equivalent capacitances are used which combines winding (terminal to terminal as well as phase to ground), bushing. and tank (to ground) capacitances.

The valves consist of two series connected 6-pulse groups. The valve damping circuit is provided by a RC-branch across each valve.

The DC-line and electrode lines are represented using a frequency dependant model. This insures a correct modelling of the line impedance for the harmonic penetration.

For special interest is the neutral capacitor at the converter station electrode line: It represents a connection to ground which decrease for higher harmonics. The simulation model also includes a simplified control system which allows to start up the simulation run from all quantities zero to a user defined operating point given by DC-voltage V_d and DC-current I_d.

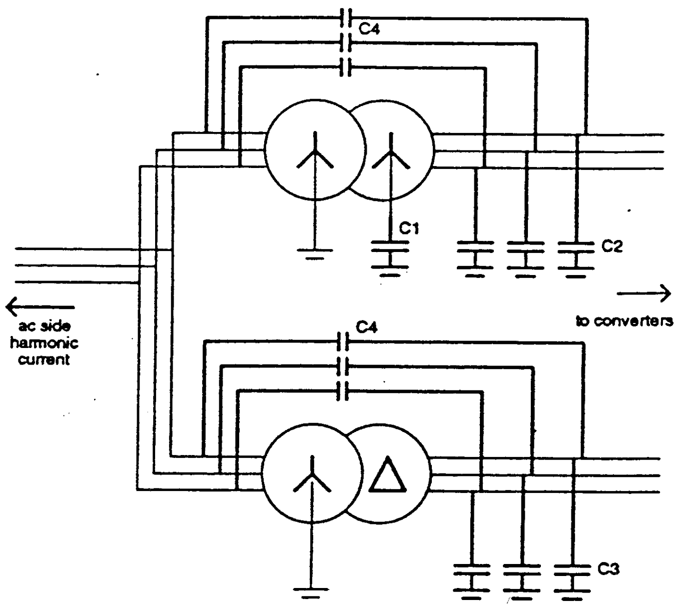


Figure 2: Converter Transformer Stray Capacitances

The model is built up in EMTDC with PSCAD, a graphical interface, which is able to implement easily all necessary functions and to carry out all calculations and plottings. The simulation program runs at a time step of 5μsec. After 600msec needed to ramp up to a steady state operating point, one cycle was analysed. EMTDC needs less than 5 minutes to complete one run. Due to the in-built multiple-run feature, enabling the program to perform several runs with different operating points automatically, EMTDC can easily be used to scan the whole operating range within less than one hour. The harmonics were calculated by fourier-analysing the results (the fourieranalysis is part of EMTDC).

2.1 Operating Condition

The effect of zero sequence current flowing is dependant on DC-load level and firing angle. Account must also be taken to the operating mode: Highest zero-sequence harmonic currents occur in monopolar ground return mode. The harmonics in this case enter the DC-system via the ground electrode line and the surge capacitor. The system has to operate at high firing angles. In this case maximum voltage jumps occur at the transformer secondary bushings (see Figure 3). The stray capacitances are stressed with maximum *du/dt* leading to high current jumps which flow to ground. The operating condition chosen here is given at nominal DC-voltage (500kV) and minimum DC-current (180A).

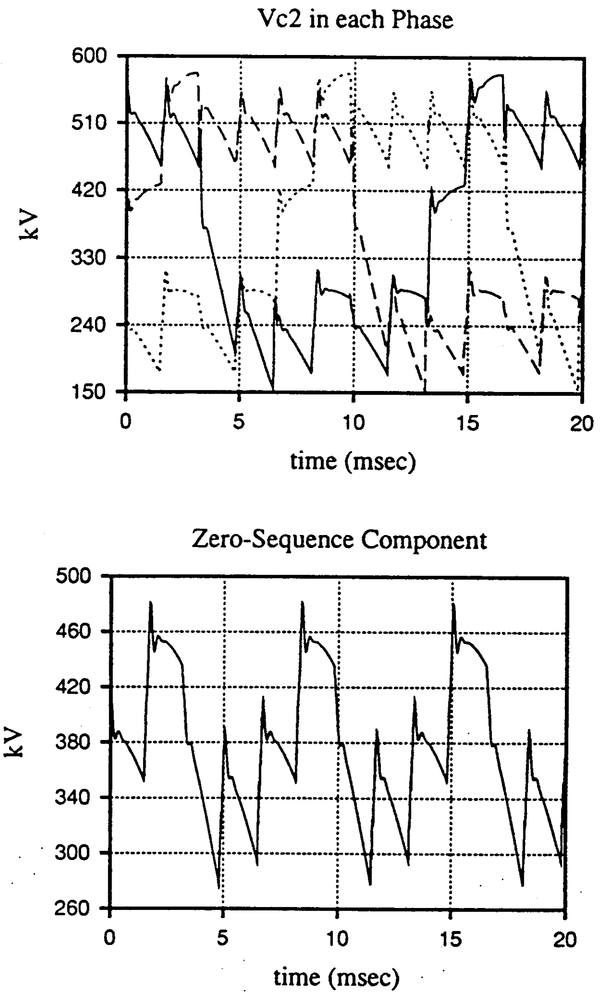


Figure 3: Voltage across transformer stray capacitances and resulting zero-sequence Component

2.2 Time step

In the analysis only harmonics up to the 50th are taken into account. This refers to 2500 Hz. Transformer stray capacitances have typical values in the range of 1 to 5nF (single phase three winding transformers). The equivalent capacitances used in the simulation are multiples of these. The highest current through these capacitances is given by the maximum *du/dt* voltage derivation across the capacitance. The voltage jump is normally limited by the RC-damping circuit of the valve at turn off. Due to the time the thyristor needs to block the time step is chosen as 5μsec. This leads to a maximum frequency of 100kHz. Resonances between stray capacitances and inductances (as far as considered) up to 2,5 mH are therefore considered.

2.3 Results of the Simulation

2.3.1 AC-Side Currents

The major part of the zero-sequence harmonic currents enter ground through the stray capacitances on the transformer secondary side. They flow through the grounding of the converter. Only a small fraction enters the dc path to the other converter; the influence of this effect can be neglected. The zero-sequence harmonic currents do not significantly enter the ac system: Due to its winding only the star-star transformer is able to induce a zero-sequence component on the high voltage AC-side. Although the secondary winding is isolated against ground a stray capacitance from star-point to ground exists (see Figure 2). The current through this capacitance is transferred to the ac-side with transformer turns-ratio [2]. The other way to enter the ac-system is via the winding capacities. shows the AC-side harmonic currents which flow on the primary side of the converter transformer. The resulting primary side zero-sequence harmonic currents are smaller than the positive sequence currents.

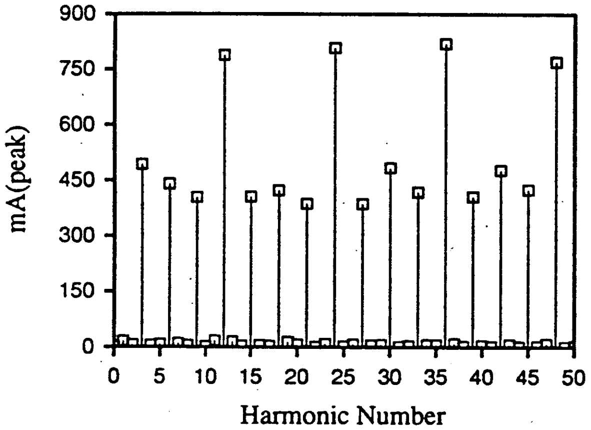


Figure 4: AC-Side Zero-Sequence Harmonic Currents (A_{peak})

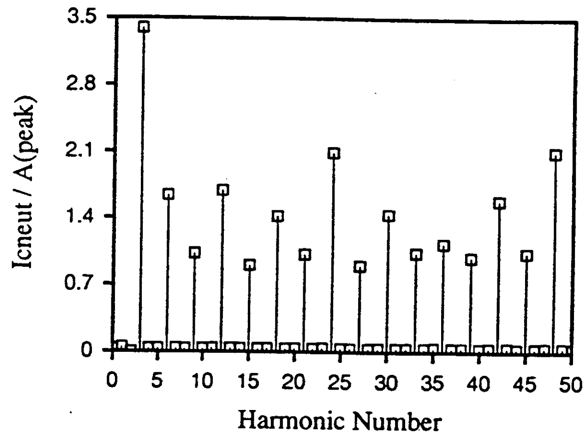
2.3.2 DC Side Harmonic Currents

Harmonic currents generated from the transformer secondary stray capacitances flow to station ground. The possibility to re-enter the system is given through

- the electrode line,
- the neutral capacitor,

on both sides of the converter station. Only a small fraction of zero-sequence harmonic currents enters the dc path from the other converter side. This influence can therefore be neglected.

Most of the harmonics flow through the electrode line and neutral capacitor of the generating station. They are split between both. Because of the decreasing reactance the main part of this current flows through the neutral capacitor. For analysis electrode line current as well as the neutral capacitor current is taken into account. The results are shown in Figure 5.



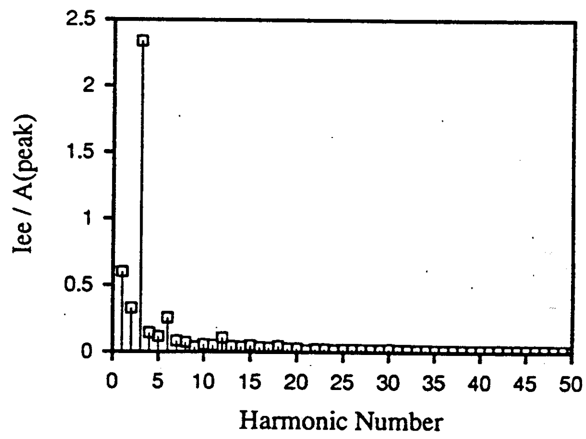


Figure 5: Neutral Capacitor (I_{cneut}) and Electrode Line (I_{ee}) Harmonic Current

3 Analytical Model

The analytical model for representing zero-sequence harmonic currents is the Three-pulse Model. The model is described by *Shore and Andersson* [1] in detail.

For the calculation the converter 6-pulse groups are represented as 3-pulse harmonic voltage sources including their internal resistance (commutating reactance). The 6-pulse harmonic voltages are calculated as given in [1]. The DC-line is modelled by wave equations. The corresponding impedances are calculated as function of the distance from one end. Frequency dependance is also represented. The terminating impedances at both rectifier and inverter consists of the smoothing reactor and the equivalent impedance of the converters. The analysed system is shown in Figure 6. Table 1 shows the amplitude of the three pulse harmonic voltages (U_{3pv}). The currents of the network given in Table 1 are calculated by superposition method. It shows zero-sequence harmonic currents through the electrode line (I_{ee}) and the current through the neutral capacitor ($I_{cneutral}$) which contains the main part of the generated zero-sequence harmonic currents.

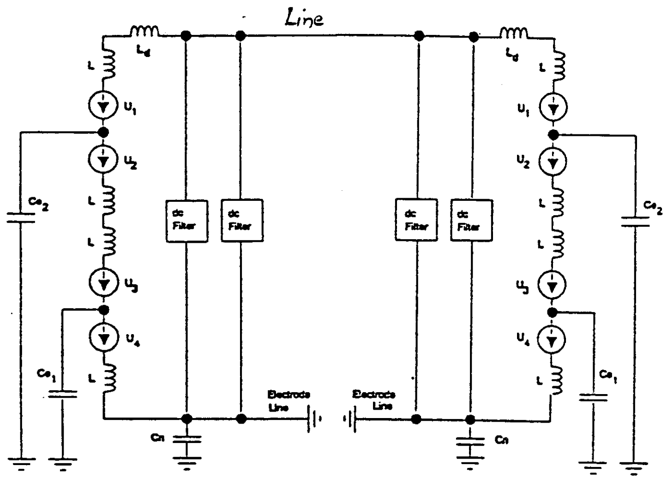


Figure 6: Analysed Network (Analytical)

Harmonic Order ν	U_{3pv} (kV_{peak})	I_{ee} (A_{peak})	$I_{cneutral}$ (A_{peak})
3	29,75	2,17	3,83
6	10,30	0,21	1,56
9	6,20	0,04	1,23
12	4,40	0,13	1,52
15	3,36	0,01	1,00
18	2,67	very small	1,35
21	2,17	very small	1,01
24	1,79	very small	1,98
27	1,49	very small	0,99
30	1,24	very small	1,42
33	1,03	very small	0,95
36	0,85	very small	1,20
39	0,69	very small	1,01
42	0,55	very small	1,62
45	0,43	very small	1,02
48	0,32	very small	2,00

Table 1: Results of the Analytical Calculation

4 Comparison / Conclusion

Zero-sequence harmonic currents are generated from transformer and valve hall bushings stray capacitances on the secondary side of the transformers and flow to ground. They re-enter the system on the DC-side through the neutral capacitor and electrode line. These two DC-side currents through the neutral capacitor and the electrode line are chosen for the comparison between calculations of zero-sequence currents analytcally and using a digital simulation.

The results of the simulation and the analytical calculation of the zero-sequence harmonic currents show there is no significant difference in the results using both methods. Both results only differ in a maximum percentage of 20%. The effect can be modelled in a simulation only by adding the stray capacitances to the branches they belong to. The simulation has the main advantage that influences of additional stray capacitances can be implemented much easier than in the analytical model. It is shown that the simulation model is able to model correct the effect of zero-sequence harmonic currents. Additional influences on these currents can therefore be checked on the basis of this modelling using this simulation method.

References

[1] „A Three Pulse Model of DC side Harmonic Flow in HVDC Systems“, Shore, Andersson, Canelhas, Asplund, IEEE-PD Vol.4, No.3, July 1989

[2] „Zero-Sequence Harmonic Currents Generated by HVDC Converters“, Sadek, Christl, Luetzelberger, ICPST Conference 1994 Beijing China

[3] „Impact of Stray Capacitances on HVDC Harmonics“, Larson, Sublich, Kapoor, IEEE-PD, Vol.4, No.1, January 1989