Dimensioning of Tell-Tale Spark Gaps for Valve Arresters in HVDC Converter Stations

Dr. Kadry Sadek Peter Luetzelberger Marcus Haeusler

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

Keywords

Metal oxide arresters, HVDC converter stations, EMTDC

Abstract

In HVDC converter stations built in the recent years gapless ZnO arresters are in operation for overvoltage protection of the individual station components. Tell-tale spark gaps are often used for monitoring the surge arrester stresses. For the arresters protecting the thyristor valves the steady state voltage stresses are quite different compared to typical arresters stresses in ac systems. In order to provide data of the actual voltage shape a computer simulation on EMTDC was run. The simulation results show that the fast transients occuring during turn-on and turn-off processes of the valves have a significant impact on the steady state power rating of the trigger resistors of the tell-tale spark gaps.

1.1 Introduction

Surge arresters are used for overvoltage protection in power systems. In HVDC converter stations built in the last few years gapless metal oxide arresters (typically zinc oxide) are succesfully used for protection of the individual station components.

One very common method for monitoring arrester activities is using small spark gaps in series to the arrester while the low voltage side of the arrester has to be isolated from ground. These gaps are often used as triggering signal for impulse counters. Additionally the gap itself can be used as tell-tale spark gap providing the function of a very simple but useful surge recorder. In this case the gap basically consists of two pairs of counting electrodes with an interposed spacer ring. During faults current spots are produced on these counting electrodes providing important information about the fault. The approximate magnitude and polarity of the arrester currents and possible follow currents can be determined. This is necessary for detection of stresses and possible overloading of surge arresters and is additionally useful for examination of faults in power systems.

For triggering the spark gaps resistors are connected in parallel. During faults the metal oxide arresters get low-ohmic leading to large discharge currents which bypass the triggering resistors through the spark gap. During non-fault operation the arrester leakage current exclusively flows through the resistors.

Tell-tale spark gaps are typically dimensioned for ac network applications. Regarding HVDC stations the steady state voltage stresses of the thyristor valve arresters are quite different. Fast transients occur due to turn-on and turn-off processes of the individual valves. This paper reports the investigations of the behavior of the tell-tale spark gap during non-fault operation (steady state), i.e. the arrester is not active. The thyristor valve voltages and the corresponding arrester leakage current were analysed in order to adequately dimension the tell-tale spark gap triggering resistors.

1.2 Simulation Model

For examination of this phenomena a computer simulation was run. The simulation was done with the electromagnetic transient program EMTDC with the graphical interface PSCAD. An existing model of a HVDC converter station with simplified control functions was available. Modern HVDC systems consist of two thyristor six-pulse bridges connected in series. The basic equivalent circuit of the resulting 12-pulse bridge with the connected ac system is shown below:

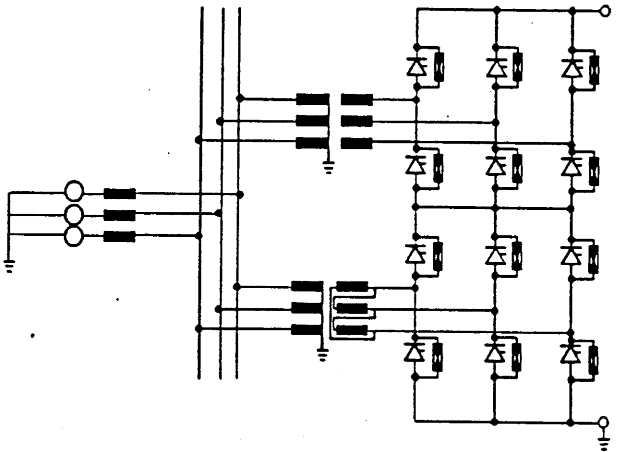

Fig. 1: 12-pulse thyristor bridge with connected ac system

The ac system is modelled as three-phase voltage source. The internal impedance represents the corresponding short circuit capacity. The thyristor bridge is connected with the ac system via the converter transformers. Two three-phase converter transformers of the EMTDC library were used. Saturation effects are included in this model but have no impact on this study. The ac system impedance plus the transformer leakage reactance (shown in Fig. 1) have a significant influence on the wave shape of the valve voltages and therefore on the metal oxide arrester connected in parallel.

For examination of the transient thyristor switch on and off procedures a more detailed representation of the valves is necessary. The simulation model was extended by several components which were expected to have an impact on this simulation. This was done for one converter side only (rectifier in this case).

Converter transformers stray capacitances

Three different types of transformer stray capacitances have been considered:

- $C_{winding}$: capacitances between primary and secondary windings,
- C_{tank}: capacitances from primary and secondary windings to the tank (grounded),
- $C_{bushing}$: capacitances of the transformer bushings to ground.

For single phase transformers the following equivalent capacitances for the simulation can be derived:

- C_1: total capacitance of secondary star-point to ground

  $C_1 = 3*C_{bushing} + 3*1/2*C_{winding} + 3*1/2*C_{tank}$
- C_2: total capacitance of secondary star winding to ground

  $C_2 = C_{bushing} + 1/2*C_{tank}$
- C_3: total capacitance of secondary delta winding to ground

  $C_3 = 2*C_{bushing} + 1/2*C_{winding} + 2*1/2*C_{tank}$
- C_4: total capacitance of secondary to primary windings

  $C_4 = 1/2*C_{winding}$

The resulting converter transformer simulation model is shown in Fig.2:

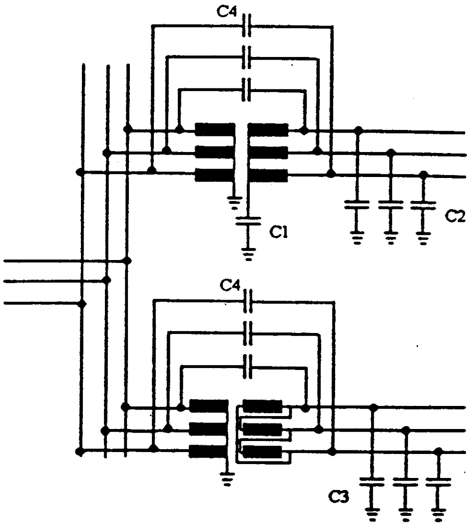

Fig. 2: Equivalent transformer stray capacitances

Thyristor valves

In EMTDC a complete model of a six-pulse bridge exists. In this model the thyristors are represented as ideal switches, i.e. a large ohmic impedance during switch off and a small ohmic impedance during switch on status. A snubber circuit consisting of a R/C-impedance can be connected in parallel (R_{th} and C_{th} in Fig. 3). This model is sufficient for most transient studies, especially if transient faults on the ac or on the dc side have to be examined. For analysing the valve voltages during steady state operation of the HVDC converters a more detailed representation of the six-pulse bridge model was necessary. Therefore the following components were added to the model:

- valve reactors L_v and stray capacitances C_v:
  In series to each valve a saturable reactor is connected. During switching-on procedure of the valve it limits the current increase di/dt to permit an optimized current distribution on the thyristor disk. Its characteristic provides a small inductance for currents above some hundreds amperes and a larger inductance for smaller currents. A saturable reactor model for EMTDC was developed by using an existing subroutine for transformers. Additionally, a stray capacitance C_v across the valve was considered.

- grading capacitors C_{gr}:
  Each valve consists of a series connection of several thyristors. For an equal voltage sharing between the individual thyristors, in parallel grading capacitors are connected.

Metal oxide surge arresters

In EMTDC metal oxide surge arresters are modelled as non-linear resistance (varistor). This model is sufficient for simulations examining the correct protection function of the arresters and for determining the absorbed energy during various system faults. For examination of the steady state operation of the converters the arresters can be assumed to be not active.

The aim of this simulation is to study the stresses of the trigger resistors of the tell-tale spark gaps in series to the surge arresters during steady state operation of the converters (non-fault). The arrester disks themselves can then be represented as a large ohmic impedance R_{arr}.

For consideration of the leakage current the arrester has to be represented by an additional capacitor C_{arr} in parallel to the ohmic impedance R_{arr}. This model considers especially the arrester housing stray capacitances. Measurements on installed arresters in ac systems have shown that the capacitive component is dominant part within the arrester leakage current. Modelling the stray capacitances is also important for considering effects due to the special type of steady state voltage stressing of the arresters. Ac system frequency voltages are overlayed by voltage impulses of short duration during switch-on and switch-off procedures of the valves. For these steep front surges inherent inductances and stray capacitances have to be considered.

Tell-tale spark gap

In series to the metal oxide arrester the resistor for triggering the spark gap is connected to ground. The spark gap itself was neglected assuming that no spark-over voltage appears. This is a worst case assumption for dimensionsing the trigger resistor. During simulation the current through the trigger resistor was monitored. This current represents the arrester leakage current.

The simplified equivalent circuit for the simulation model of the complete arrester connected to a thyristor valve is shown below:

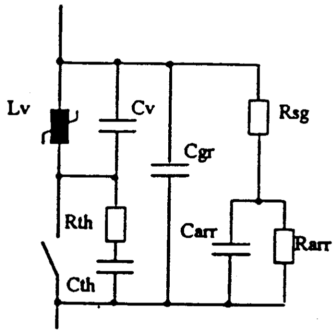

Fig. 3: Valve and arrester model

1.3 Results of the Simulation

The time step chosen for this simulation was 1 microsecond. Therefore transients up to about 100 kHz can be simulated. Smaller time steps were found not to significantly change the results. To ramp up to a steady state operation point 300msec simulation time were needed. This required about 15 minutes calculation time. Then a snapshot file was saved. Starting from the snapshot file one more cycle was calculated (16.66 msec at 60 Hz). The resistor current of the tell-tale spark gap was monitored. The „multiplot"-feature of PSCAD was used to calculate the r.m.s. value of this current. The calculated power rating P_{sg} of the trigger resistor is:

$$P_{sg} = R_{sg} * I_{r.m.s.}^2$$

The influence of several simulation components on the wave shape of the thyristor voltage and on the attached tell-tale spark gap circuit is shown below.

Influence of Firing Angles

Power and reactive power of HVDC transmission systems can be controlled independently of each other within a certain range of operation. This is done by selecting appropriate firing and extinction angles on the rectifier and inverter station. Depending on the firing angle the voltage shape of the thyristor valve voltage changes significantly. In Fig. 4 and 5 two extreme operation points are shown: In Fig. 4 the nominal operation point (firing angle 15 deg.) and in Fig. 5 zero-power operation (firing angle approx. 90 deg.).

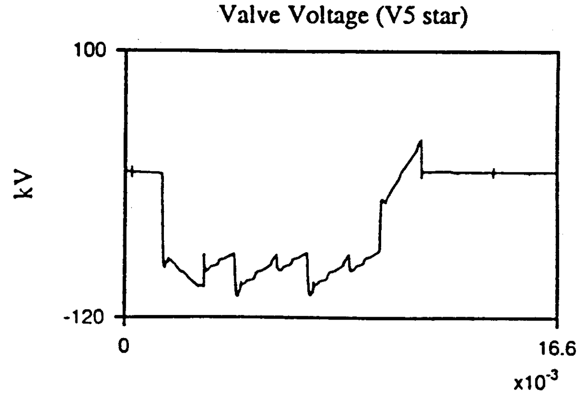

Fig. 4: Valve voltage, firing angle=15 deg.

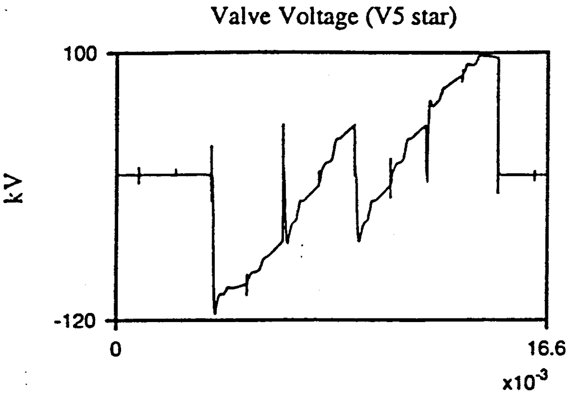

Fig. 5: Valve voltage, firing angle approx. 90 deg.

In both cases the valve voltage is overlayed by voltage peaks. This takes place over the whole range of the shown system period (T=16.6 ms for 60 Hz) while the peaks during non-conducting mode of the regarded valve are more significant. These voltages are caused by commutation procedures of the other valves of both six-pulse bridges. A comparison of both operation points shows that large firing angles up to 90° lead to very steep voltage changes across the valves and the arresters connected in parallel. The arrester stray capacitances then produce current peaks which significantly influence the r.m.s. value of the arrester leakage current. These current stresses are decisive for the power rating of the spark gap trigger resistor.

A comparison of the influence of different firing angles on the arrester leakage current is shown in Table 1. The corresponding power rating of the spark gap trigger resistor is shown in the last row. This example is based on system data of a typical 600 MW HVDC back-to-back link. Anyway, the qualitative behaviour of this effect is valid for other configurations, too.

Firing Angle	Direct Voltage Ud	Direct Current Id	I_{sg} [r.m.s.]	P_{sg}
89°	2 kV	550 A_{dc}	53 mA	102.3 W
58°	97 kV	620 A_{dc}	45 mA	73.5 W
38°	146 kV	830 A_{dc}	34 mA	40.9 W
31°	147 kV	2880 A_{dc}	27 mA	27.2 W
15°	162 kV	3730 A_{dc}	9 mA	3.1 W

Table 1: Influence of firing angles on arrester leakage currents

Influence of Commutation Reactances

The commutation of the direct current from one valve to the next is influenced by the ac network impedance and the transformer leakage reactance. While the transformer reactances are fixed the ac system loading varies in a certain range. In Figures 6 to 9 the results for two extreme load conditions are shown. For the nominal operation point the valve voltage of one valve and the corresponding arrester leakage currents are shown. For Figures 6 and 7 the network was assumed to be very strong while for Figures 8 and 9 a weak ac system was considered.

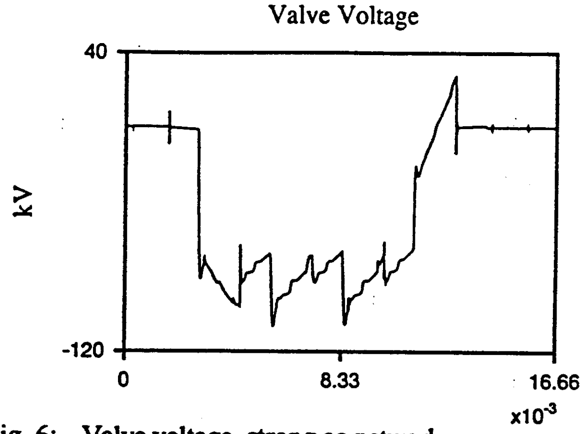

Fig. 6: Valve voltage, strong ac network

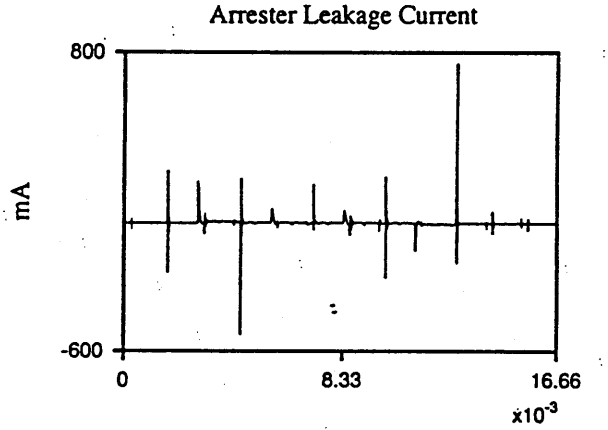

Fig. 7: Arrester leakage current, strong ac network, $I_{r.m.s.}$= 19 mA

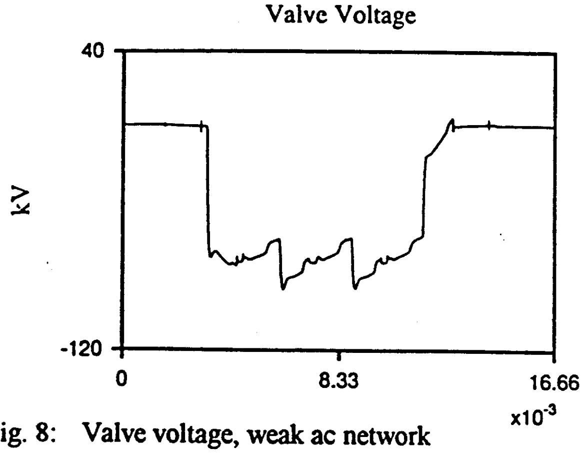

Fig. 8: Valve voltage, weak ac network

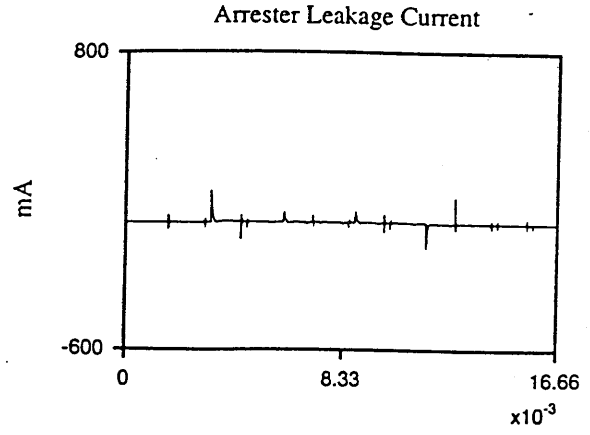

Fig. 9: Arrester leakage current, weak ac network, $I_{r.m.s.}$= 9 mA

The transient phenomena occuring during valve switching are obviously much more damped in the weak ac system configuration. As a result the current peaks through the spark gap trigger resistor are significant smaller and its root mean square is only half of the value occuring during strong ac system configuration.

Influence of Stray Capacitances:

Modelling of the transformer stray capacitances to ground was described previously. These capacitances have significant influence on the shape of the valve voltages. The transient voltage changes are much more pronounced when these capacitances are considered in the model. In Figure 10 the valve voltage is shown for a simulation without modelling of the transformer stray capacitances. Except of these stray capacitances this model is identical to the model used getting the valve voltage in Figure 6.

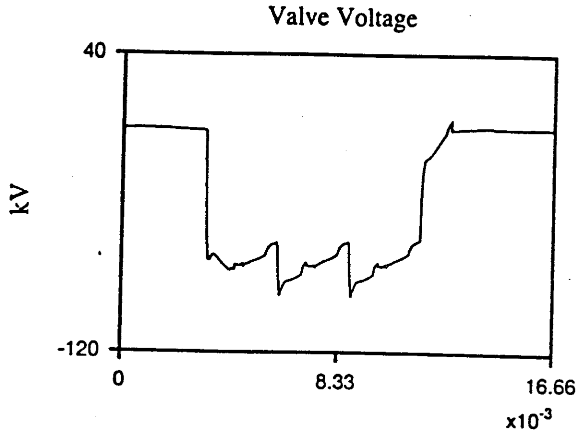

Fig. 10: Valve voltage, without transformer stray capacitances

1.4 Conclusions

The wave shape of the valve voltage of valve arresters in HVDC converter stations was investigated during steady state operation of the converters. The well-known transients occuring during thyristor switching on and off have a significant impact on this voltage shape. For simulation of these transients the valve model has to include stray capacitances and valve reactors. The arrester connected in parallel has to be modelled with its terminal stray capacitances since the capacitive component of the leakage current is dominant. The influence of changes in the ac system impedance caused by different loading conditions cannot be neglected. The commutation reactances and so the commutation process is basically influenced by this effect. Finally, the simulation model has to include the transformer stray capacitances. Equivalent circuits for capacitances to ground are derived.

For the tell-tale spark gaps of the arresters connected in parallel to the thyristor valves the transients have to be considered for power rating of the corresponding grading resistors.