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Study Committee A2

Power Transformers and Reactors

Paper ID 11065

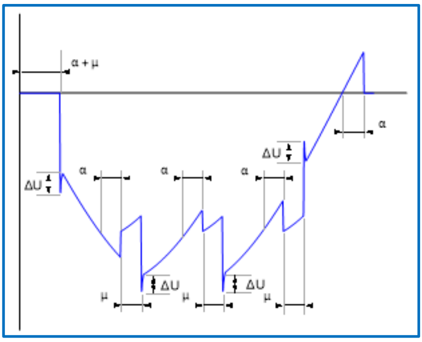
Impact of Transient Voltage Generated by Valve Commutation on HVDC Transformer

Dr. René WIMMER*[1], Thomas HAMMER[1], Thomas MANTHE[1], Volker HUSSENNETHER[1], Marcus HÄUSLER[1], ZhuSheng CHI[2], Wie, RUAN[2], Thomas STROF[3], Sebastian REHKOPF[3], Moritz BENGLER[3], Anniyappan PALANI[3]

[2] SIEMENS Energy - DE, [2] SIEMENS Energy - CN, [3] Maschinenfabrik Reinhausen

Motivation

Figure 1: Effect of commutation on the AC voltage shape at the converter side



with α = firing angle
μ = overlapping angle
ΔU = overshoot

Question:
Which effect will have such transient signals to the tap winding with a step voltage of ~4kV of a 1050kV AC line winding?
Did the provided insulation coordination cover the voltage stress on the tap winding?
How did the transient coupling effects between valve- and tap winding looks like?

Objects of investigation

Table 1: Data of investigated HVDC transformer

	Line Winding	Valve Winding
Rated power	493.1 MVA	493.1 MVA
Rated current (@rated tap position)	814	5104A
Rated voltage	1050kV/√3	Y: 96.6kV
Impedance voltage	(20±0.8)%	
Tap range	-9/+21*0.65%	
Grounding type of line side neutral point	direct earthed	
DC bias current	10A	
Type	single-phase two- winding, oil-immersed	
Transportation limits	(L×W×H) (mm); weight: 13000×5000×5000; 400 t	

Table 2: Test Voltage Level of the HVDC transformer

	Duration in min	Line Winding in kV (Terminal 1.1)	Valve Winding in kV
U_m		1100	400kV DC-Level
$AC_{applied}$	60		473
$AC_{applied}$	1	95	-
ACSD	1	-	-
ACLD	5	1100	176
ACLD	60	953	152
$SI_{Pot.}$	-		1175
$SI_{ind.}$	-	1800	253
LI	(FW / CW)	2250/2400	
LI	(FW / CW)		1300/1430
$DC_{applied}$	120		639
PR	90/90/45		458

Figure 2: Picture of transformer:

Experimental setup & test results

Simulation of the transient voltages

- The investigations are performed on a Line Commutated Converter (LCC) bipolar system
- Three representative operating points are selected:
  - Case 1 and 2: typical rectifier operating points for steady state operation for nominal and partial load
  - Case 3: quasi-stationary operating point when bringing a second 12-pulse group into service

Table 3: Investigated operating points

LCC Operating Points	DC Line Current Id	Firing Angle of Valves α
Nominal load:	6250 A_{DC}	15°
Partial load:	2800A_{DC}	18°
Deblock 2nd group:	6250A_{DC}	70°

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Figure 3: Basic representation of the complete simulation model:

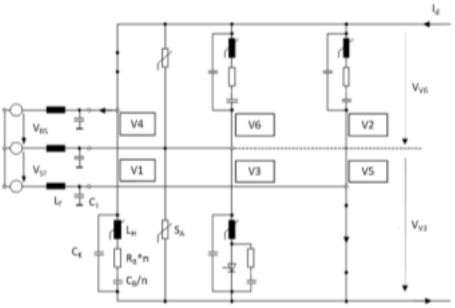
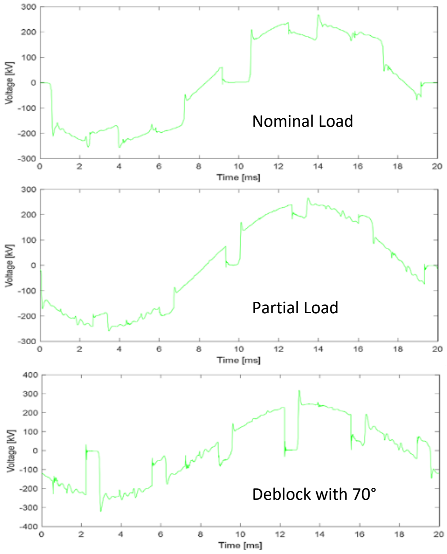


Table 4: Explanation of the abbreviation acc. Figure 3

V_{RS}, V_{ST}, V_{TR}	Phase-to-Phase Voltages Line Side
L_T	Converter Transformer Impedance
V1 … V6	Converter Valves
S_A	Surge Arrester
L_H	Saturable Valve Reactor
n	Number of Thyristor Levels
R_B	Snubber Resistor
C_B	Snubber Capacitor
C_K	Grading Capacitor
V_{V1} … V_{V6}	Valve Voltages
I_d	DC Line Current

Figure 4: Results of the commutation simulation



Transient Simulation of Transformer

- Simulation is based on a white box model using lumped parameter approach built from circuit parameters as self- and mutual inductances, capacitances and resistances
- complex model has few restrictions, e.g. grounded loops and connections between transformer, filter and grid impedance are not modeled

Figure 5: Basic representation of the complete simulation model

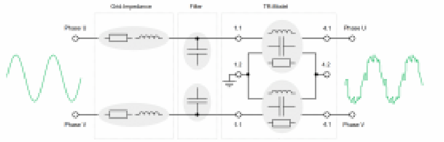
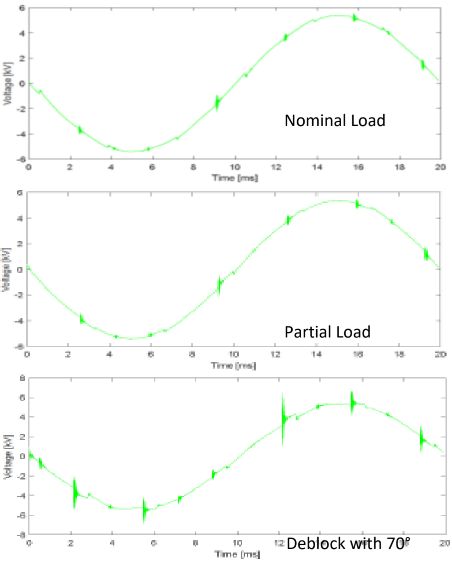


Figure 6: Time characteristic of the voltage drop across one step of the regulation winding



Conclusion of Simulation:

- A relevant effect of transient voltages at nominal and partial load to the step voltage of the tap winding could not be detected.
- Up to 1.2 p.u. peak voltage of the step voltage of the tap winding could be simulated at deblock with 70°. However, during IVPD test the tap winding was stressed with 1.82 p.u. (5min) and 1.58 p.u. (60min) as peak voltage.

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Transient Measurement of Transformer

- Purpose of investigation to verify the simulation model of the transformer
- 2 measurement approaches were used:
  - Using tap connection 1.9, which was led out for testing reason
  - Using a prepared diverter switch which enables a direct measurement

Figure 7: Test Circuit

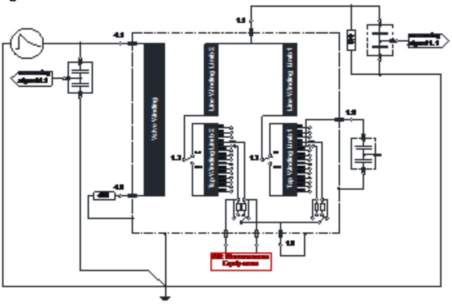

Figure 8: a) Trace of the tap lead 1.9 and b) auxiliary bushing c) Cable connection at diverter switch and d) assembled measuring equipment

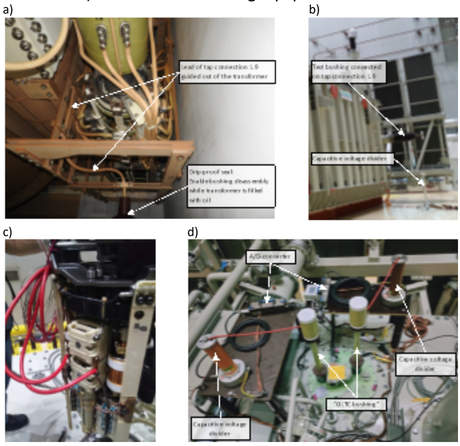

Figure 9: Comparison between both measurements approach

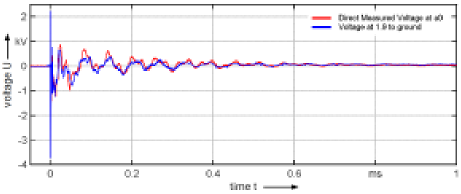

Figure 10: Comparison between measurement at connection 1.9 and simulation

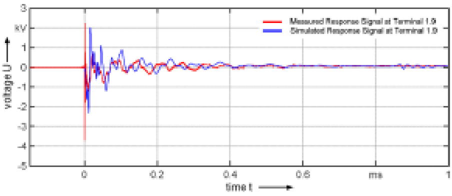

Table 5: Comparison of natural frequencies

	Natural frequency in kHz				
Direct measured signal	7.88	16.3	34.8	40	50
Meas. at terminal 1.9	7.74	16.3	35.2	40	50
Sim. acc. „meas. T 1.9“	8	15	-	37	61

Table 6: Comparison of voltage amplitude

	Max. voltage in kV		U_{max}/250kV in kV	
	Neg. range	Pos. range	Neg. range	Pos. range
Direct meas. signal	-1.22	+0.88	0.49 %	0.35 %
Meas. at terminal 1.9	-1.22	+0.66	0.49 %	0.26 %
Sim. acc. „meas. T 1.9“	-2.33	+2.01	0.93%	0.8%

Conclusion of Measurements

- Both measurement approaches shows a good accordance
- Simulation shows also a good accordance considering the simplifications. However, higher voltage values are always displayed than in reality => worst-case-estimation

Conclusion

- Simulation can be regarded as a worst-case-estimation
- Transient signals generated by the commutations have no significant effect on transient voltages on tap winding
- Small transient voltages in a range of ~ 300 V superimposed to the 50-Hz-voltage can be observed
- These transient voltages on tap winding are sufficient covered by IVPD-test
- No additional measures / tests necessary due to this effect
- Specified transformer insulation coordination is sufficient
- No impact on safe and reliable operation of transformer

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