Study Committee B1

Insulated Cables

10514_2022

Transient Over-Voltage Testing of Cable Systems in MMC-HVDC Links: A Concept Study Including Verification

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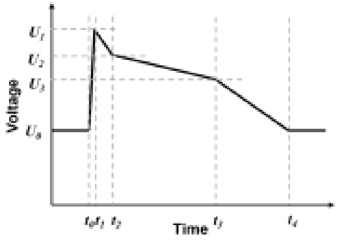
Motivation

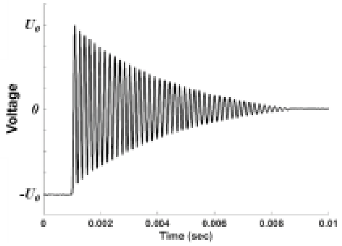
- This poster is motivated by work of JWG B4/B1/C4.73 on the occurrence of Temporary Over-Voltages (TOV) in MMC-HVDC cable systems e.g., caused by failures in the system or switching events.
- TOVs (**LTOV**s) have recently been introduced as “**very slow front temporary overvoltage**”, as well as “**zero crossing damped temporary overvoltage**” and suggested for development testing into CIGRE Recommendations for testing DC cable systems for power transmission at a rated voltage up to and including 800 kV recommendations (CIGRE TB 852 / 853)
- The work presented in this poster deals with the problem of reproduction of those overvoltages using today’s standard high voltage laboratory equipment.

Reference voltage wave shapes

- Simplified model of the **LTOV** [7] with an initial overshoot having a peak at U_1, t_1 = 1 ms with the end of peak at U_2, t_2 = 21 ms, and a plateau U_3, $\mathbf{t_3 \geq 150}$ **ms**.

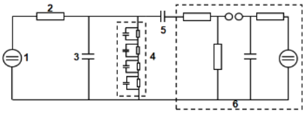


- Example of zero crossing damped oscillation (DOTOV) with frequency 5.7 kHz.



Today’s HV laboratory equipment for HVDC impulse testing

- Impulse generator coupled to a DC circuit. (1. HVDC source, 2. Protection resistor, 3. Cable, 4. Voltage divider, 5. Coupling capacitor, 6. Impulse generator)



- **Limitations** of the double exponential wave shape to generate the reference voltage wave shapes
- Adjustment of time to peak and half-time conflicts with efficiency of the impulse generator (external damping resistors) and availability and size of equipment (per stage capacitance and discharge resistance).
- Full scale 320 / 525 kV limits: **time to peak of up to 8 ms and time to half of up to 25 ms**. Prototype: maximum time to half of up to 60 ms.

Method/Approach

- A theoretical study using a simulation program with integrated circuit emphasis (SPICE) to evaluate circuit concepts for achieving desired LTOV and DOTOV
- Experimental set-ups on laboratory scale to evaluate some of the simulated LTOV generating circuits.

Study Outcome in a Nutshell

LTOV

- Four concepts are presented to generate very slow front temporary overvoltages with a plateau > 150 ms: Two concepts using modification of an impulse generator circuit; Two concepts using a double DC source circuit with fast grounding.
- For one of the double DC source concept practical feasibility has been demonstrated in an HV experiment with 52.5 kV nominal and 105 kV peak voltage.
- For one of the double DC source concept practical feasibility has been demonstrated with 525 kV nominal voltage

DOTOV

- A concept has been proposed including experimental verification on a nominal voltage level of 40 kV.

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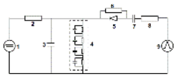
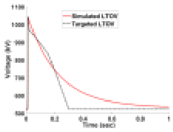
Results simulation study - LTOV

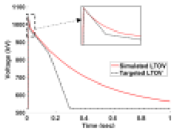
Impulse generator based concepts

- Diode in series with the impulse generator.
- Reproduces the long decay time.



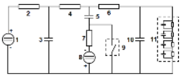


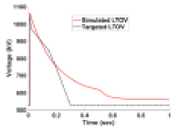
- Reactor & diode circuit in series with the impulse generator.
- Allows for reproduction of initial overshoot.



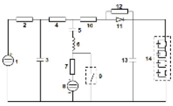
DC Source Based Circuit Concepts

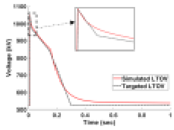
- Two DC sources. One source is coupled to the test object by a capacitance. The long overvoltage is generated by grounding this DC source.
- Reproduces the long decay time.





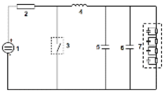
- Two DC sources including a low voltage diode with discharge resistor and reactor in series with the test object.
- Allows for reproduction of initial overshoot.

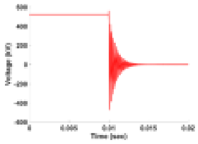




Result simulation study - DOTOV

- Series R-L-C damped circuit in series with a fixed DC source and a grounding switch.
- Test object is pre-charge by a DC source and then discharged.
- Frequency of 5.7 kHz. The first opposite peak has an amplitude of >90% of U_0 .

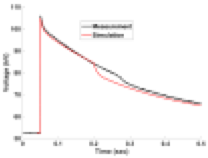




Experimental verification

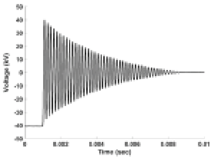
LTOV

- Verification was done for a double DC source concept including a low voltage diode with discharge resistor. Parameters have been adjusted to a nominal voltage level of 52.5 kV.
- A sphere gap was used for DC source grounding, which resulted to less control in switching back the DC source (longer decay time in the measurement).



DOTOV

- Verification was done with a series R-L-C damped circuit in series to the DC source and loas. A sphere gap was used as grounding switch.
- 5.7 kHz, a first opposite peak > 90% U_0 and 36 oscillations until an amplitude below 5% U_0 has been achieved.



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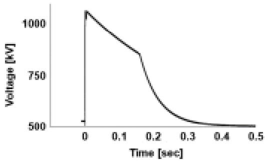
Full scale verification

LTOV

- Verification was done with a double DC circuit without overshoot for a nominal voltage of 525 kV.



Discussion

- Technical hurdles and suspicion on how to generate LTOV ("very slow front temporary overvoltage", CIGRE TB 852/853) type of voltage stress for testing purposes utilizing HV laboratory test equipment have been overcome.
- More complex LTOV waveshapes beyond a double exponential e.g., including peak overshoot, can be generated utilizing available HV laboratory equipment.
- An example for a DOTOV ("zero crossing damped temporary overvoltage", CIGRE TB 852/853) generating circuit was also given and verified.

Remaining items to be resolved prior to standardization

- For the pulse shapes, control, variation, as well as respective measurement and requirement confirmation under execution remains to be addressed.
    - Specifically, double exponential respectively impulse generator based concepts pose challenges in determination and adjustment of pulse maximum and related decay times
    - DC source concepts might be advantageous in terms of a more independent adjustments of peak occurrence and plateau shape.
- Requirements of such pulse shapes need to be settled in a broader community discussion e.g., are the occurrence and wave shape very project specific or do they depend mainly on rather general system configuration settings.
- Do these pulse shapes pose any threats to an HVDC cable system, making a general requirement for testing TOV necessary?

Related literature

[1] Working Group B1.32 CIGRE, "Recommendations for testing DC extruded cable systems for power transmission at a rated voltage up to 500 kV". (TB 496, April 2012).

[2] IEC 62895, "High voltage direct current (HVDC) power transmission – Cables with extruded insulation and their accessories for rated voltages up to 320 kV for land applications – Test methods and requirements". (Edition 1, 2017)

[3] Working Group B1.62 CIGRE, "Recommendations for testing DC extruded cable systems for power transmission at a rated voltage up to and including 800 kV". (TB 852, November 2021).

[4] Working Group B1.66 CIGRE, "Recommendations for testing DC lapped cable systems for power transmission at a rated voltage up to and including 800 kV". (TB 853, November 2021).

[5] JWG B4/B1/C4.73 CIGRE, "Overvoltages in symmetric monopolar HVDC cable systems – a parameter study approach", (CIGRE Symposium Aalborg 2019, Aalborg, Denmark, Jun. 2019).

[6] JWG B4/B1/C4.73 CIGRE, "Overvoltages experienced by DC cables within an HVDC transmission system in a rigid bipolar configuration", (JICABLE'19 - 10th International Conference on Insulated Power Cables, Versailles, France, June 2019).

[7] H. Saad and M. Saltzer, "Current stage and perspectives of studies and simulations on TOV affecting HVDC link", Tutorial 2, (International symposium on HVDC cable systems, Jicable-HVDC'21, Liege, Belgium, November 2021).

[8] T. Karmokar, M. Saltzer, S. Nyberg, S. Mukherjee and P. Lundberg, "Evaluation of 320 kV extruded DC cable system for temporary overvoltages by testing with very long impulse waveform", (CIGRE Session 2018, Paris, France, August 2018).

[9] S. Alapati, F. Fälth, A. Abbasi, B. Nilsson, M. Klang and M. Saltzer, "Testing of 525 kV extruded DC cable system with example of temporary overvoltage having very long impulse waveform", (41st CIGRE international symposium, Ljubljana, 2021).

[10] Heiko Jahn, "Transient overvoltage stresses caused by faults in HVDC cable systems and their simulation in the laboratory" (International symposium on HVDC cable systems, Jicable-HVDC'21, Liege, Belgium, November 2021).

[11] T. Karmokar, A. Wagner, and R. D. Zhang, "Towards defining new requirements for dynamic stress testing of HVDC cable systems up to 525 kV", (International symposium on HVDC cable systems, Jicable-HVDC'21, Liege, Belgium, November 2021).