A new Solution for the Extension of the Load Range of Impulse Voltage Generators

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Abstract

When testing test objects of high capacitances with lightning impulses the overshoot of 5% in maximum limits the maximum load of an impulse generator. With an extension of the Marx-circuit it is possible to extend the load range of impulse generators for lightning impulse tests. An overshoot compensation can be designed as an external attention or can be integrated into the single stages of an impulse generator.

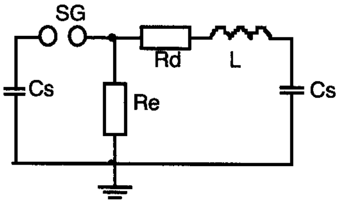


Fig. 1 Equivalent circuit of an impulse generator

C_s Impulse capacitance
R_e Tail resistor
R_d Front resistor
L Test circuit inductance
SG Firing sphere gap
C_b Load capacitance

1. Introduction

Equipments of power transmission systems have to be tested with impulse voltage to proof the withstand capability against lightning overvoltages or surges due to switching operations. The wave shape of the impulses and the test procedures are recommended in IEC 60 [1].

Impulse voltages are generated by impulse generators, the circuit is described 1923 by Marx [2]. To calculate the wave shape or the elements of the impulse circuit the Marx generator is reduced to an equivalent circuit shown in fig. 1. When Cs is charged to U_o the spark gap SG is fired the load capacitance C_b is charged by the impulse capacitance C_s damped by the front resistor R_d. The time constant C_b R_d determines the front time of the wave shape. C_s and C_b are discharged parallel by the tail resistor R_e, the time constant (C_s+C_b) R_e determines the tail of the wave shape.

The inductance L is the total inductance of the test circuit, it is the sum of the internal inductance of the impulse generator and the external inductance of the total test configuration. Because of this inductance the load capacitance is charged by a damped oscillating circuit. At low load capacitance and high front resistors the oscillating circuit is aperiodic damped, at high load capacitances and low front resistors the wave front is oscillating. The IEC 60-1 allows an overshoot at the peak of 5% in maximum compared to a mean curve approximated through the oscillation. For a given test circuit the theoretical maximum load capacitance is given if the front resistor has a value which generates a front time of 1.56 µs and an overshoot of 5%.

For test objects with high capacitance it is not possible to meet the requirements of the IEC 60-1. This paper describes a new solution of a test circuit to test high capacitances within the requirements of IEC 60-1.

2. Impulse circuit with overshoot compensation

In the past all solutions to increase the theoretical maximum load capacitance were special designed generators to reduce the internal inductance of the impulse generator. One solution is a zick-zack arrangement of the stages where the magnetic field of one stage is partly compensated by the next stage. Another possibility is to separate the stages into parallel branches, arranged in such a way that the two paths of the impulse current turns in opposite directions.

However, these solutions reduces only the inductance of the generator. Responsible for the overshoot is the inductance of the total test loop. The possible reduction of internal generator inductance to the total loop inductance is in the range of typically 15%. Therefore any reduction of the generator inductance influences the theoretical maximum load capacitance marginally only.

The new impulse circuit described here does not reduce the inductance of the generator or the test loop, it compensates the oscillations on the test object by additional passive elements [3].

Fig. 2 shows one solution of the extended impulse circuit. In series to the impulse generator are connected a compensating capacitor C_c and in parallel a resistor R_c. The overshoot compensation (marked by dotted line) and the capacitance of the test object forms a low-pass filter. The high frequencies of the front of an overshooting impulse are more damped than the lower frequencies of the tail. The damping by the low-pass filter reduces the applied voltage at C_b during the front rise

Fig. 3 shows the calculated frequency response of an overshoot compensation with

C_c = 5 nF
R_c = 80 Ω
L_c = 1.5 µH
C_b = 10 nF.

These low-pass filter damps very high frequencies of more than 100 kHz are typical for the front of lightning impulses.

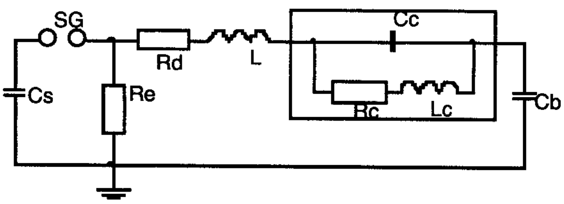


Fig. 2 Equivalent circuit with overshoot compensation

- C_s Impulse capacitance
- R_e Tail resistor
- R_d Front resistor
- L Test circuit inductance
- SG Firing sphere gap
- C_b Load capacitance
- C_c Compensating capacitance
- R_c Compensating resistor
- L_c Inductance of R_c

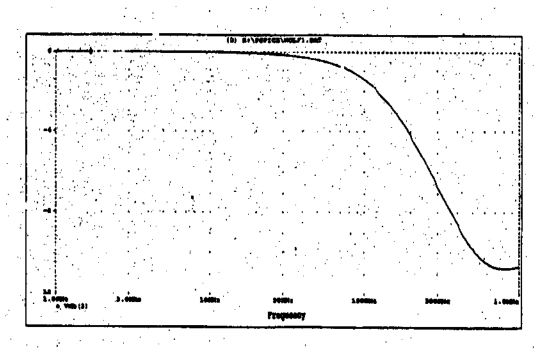


Fig. 3 Frequency response of an ǒvershoot compensation

Fig. 4 shows simulated voltages of a impulse circuit with overshoot compensation with the same values as used for the frequency response in fig. 3.

The calculation of the wave shape of the impulse circuit with overshoot compensation is carried out numerically by a network simulating program with an adapted postprocessing [4].

3. Measuring results

Fig. 5 shows the load diagram of an impulse generator with a total charging voltage of 200 kV in 2 stages and a charging energy of 10 kJ. The theoretically maximum load capacitance C_{max}, limited by 5%

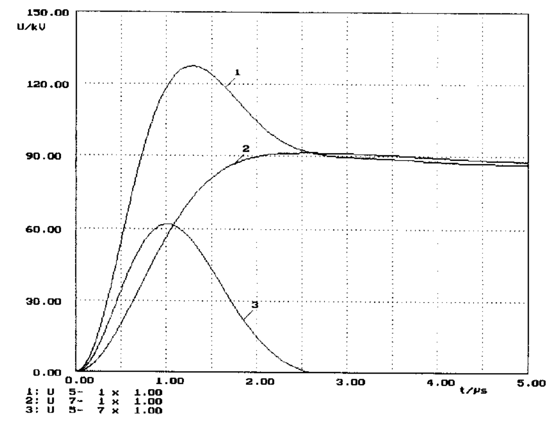


Fig. 4. Wave shape simulations
1 voltage with overshoot (U_{Cc+Cb})
2 voltage without overshoot at load capacitance C_b
3 voltage at the compensation capacitance C_c

overshoot and 1.56 µs front time, of this generator is 25 nF, the real maximum load is 12 nF, using a internal front resistor of 12 Ω per stage and 30 Ω external front resistor.

Fig. 6 shows the measured test voltage of 40 nF load. The impulse do not fulfil the requirements of IEC 60-1, the front time is close to the upper limit, but the overshoot is too high. With an overshoot compensation it is possible to test the load of 40 nF within the IEC 60-1 specifications (fig. 7).

The overshoot compensation also can be used to generate steep front impulses, where at lower capacitances already an overshoot will occur. Fig. 7 shows the measured record of a steep front test of 3 nF.

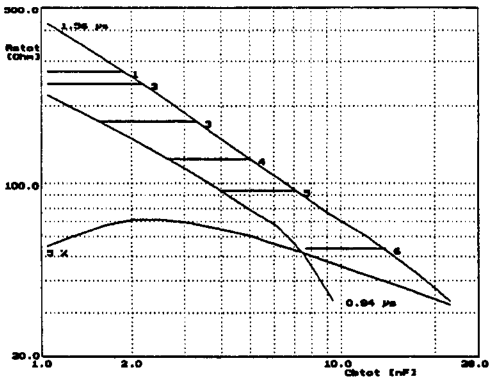


Fig. 5 Load diagram of an impulse generator 200 kV, 10 kJ

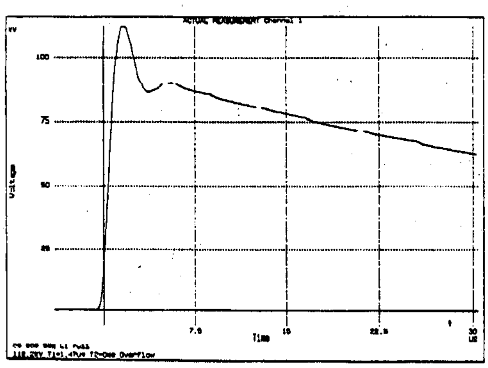


Fig.6. Test of 40 nF without overshoot compensation

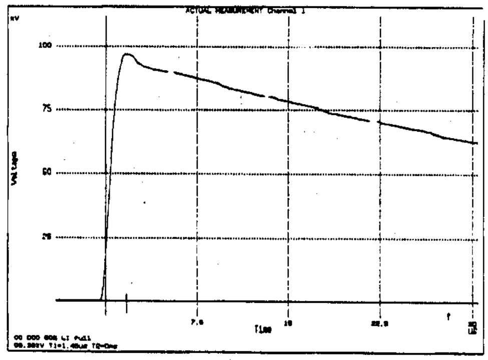
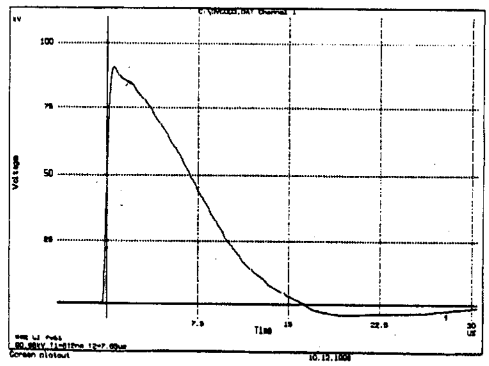


Fig. 7. Test of 40 nF with overshoot compensation

Fig. 8. Steep front test of 3 nF with overshoot compensation



4. Realisation of overshoot compensation

Depending on the type and the size of the impulse generator the overshoot compensation can be designed as an external attachment with one or more capacitances and resistors in parallel. Especially for generators with a higher number of stages it is advantageous the overshoot compensation is distributed to the stages of the generator.

Fig. 9 shows a possible designs of an overshoot compensation as external attachment, fig. 10 the arrangement with distributed elements for an impulse generator with a charging voltage of 200 kV per stage.

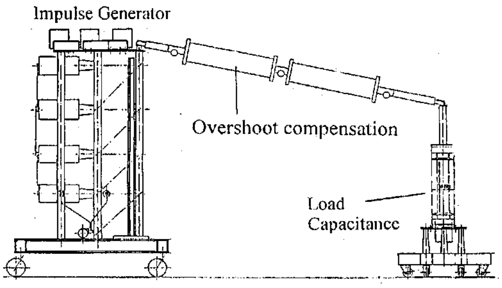


Fig. 9 External overshoot compensation

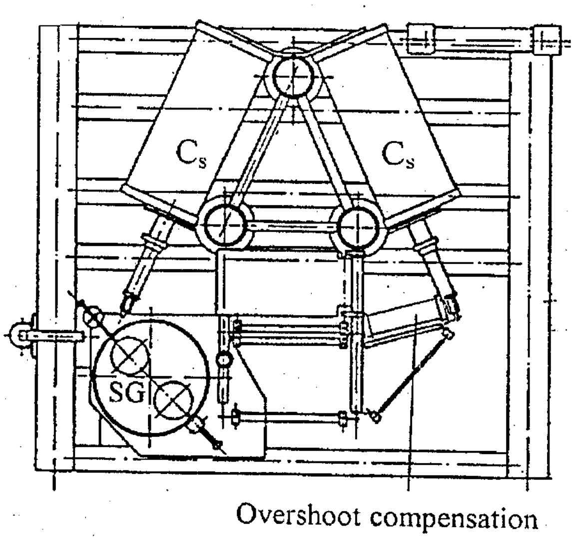


Fig. 10. Distributed overshoot compensation

5. References

[1] IEC 60-1, 1989, High-voltage test techniques, Part 1: General definitions and test requirements.

[2] Marx, E.: Versuche und Massenprüfungen mit der Stoßspannungsprüfanlage im zentralen elektroteschnischen Versuchsfeld der Hermsdorf-Schomburg GmbH. ETZ 45(1924) S. 652

[3] Blitzimpulsspannungs-Prüfschaltung für grosse Kapazitäten. German Patent Application No. 196 39 023.0, 23.09.1996

[4] Wolf, J.: Zum rechnergestützten Entwurf von Hochspannungsprüfanlagen. Thesis TU Dresden 1988

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