# SIMULATION AND EXPERIMENT FOR SURGE IMMUNITY ACCORDING TO EN 61000-4-5

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## ABSTRACT

The scope of this paper is the presentation of Electromagnetic Compatibility (EMC) in relation to the interference caused by surge voltages. For this purpose, the EN 61000-4-5 Standard has been instituted, describing the procedure of testing and verification of a device for immunity against surge voltages. The investigation of the above mentioned immunity is very important, as surge voltages are a very common and usual phenomenon. Their causes are either natural (lightning) or man-made (switching transients). Specifically, an investigation of the test set-up defined by the EN 61000-4-5 Standard was made. The simulation by computer of the coupling network located between the device under test and the power supply network was done using the PSPICE program and a 3-phase coupling network was constructed. Measurements and tests were performed. This construction and also the methodology described can become a useful tool for anyone who wishes to perform simple tests to a device for immunity in surge voltages according to the mentioned Standard.

**Keywords:** Coupling Network, Electromagnetic Compatibility (EMC), European Standard EN 61000-4-5, PSPICE Simulation, Switching Transient

## 1. INTRODUCTION

Electromagnetic compatibility (EMC) is defined as the capability of systems or equipment to be operated in the intended operational environment at designed levels of efficiency without degradation due to electromagnetic interactions [1]. EMC is an important factor for the test and certification of every device. Interconnected devices or devices connected to a public low voltage network or even devices operating next to each other must fulfil certain EMC tests.

A very common cause for overvoltages on the power network is lightning or the switching transients. As far as the overvoltages between phase and earth, or between phases is concerned, the European Standard EN 61000-4-5 [2] has been introduced. This Standard describes the test and measurements techniques for the immunity caused by overcurrents or overvoltages. It is very important since overvoltages can occur in every day life. Therefore, a device connected to the public power network must be certified that fulfils certain overvoltage tests.

Surges impinging on electronic equipment may cause hardware damage and complete failure, or in lesser cases, operational upset. Below some level dependent on equipment design, no effect is observed. Above this level, a surge may cause the operation of the equipment to change state, without any long-term effect on the circuit components. But, at a higher level, there may be enough energy to cause breakdown in critical components. The maximum voltage that is likely to occur is limited by flashover considerations. For instance in a typical domestic mains supply no more than about 6kV can be withstood by the wiring components. The designer has to know what surge voltage can be sustained by the product's interfaces without protection, and what voltage is expected in the protection zone in which the product will be used, in order to decide whether any of these interfaces need additional protection. Figure 1 [3] gives an indication of the relationship between surge parameters and these effects.

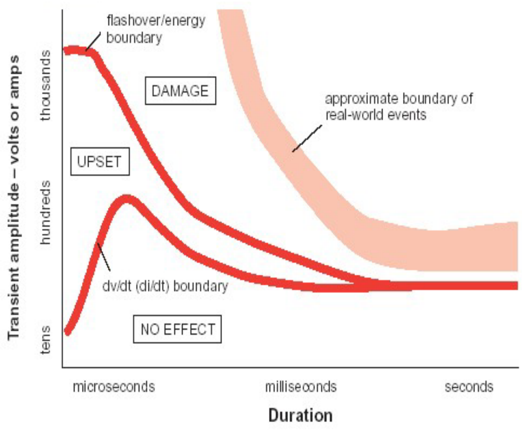


Figure 1: Relationships between surge parameters and equipment effects [3]

In this paper two aspects for the Standard are examined. First of all a computer simulation using the PSPICE program is obtained for coupling on a.c. lines for 1-phase and 3-phase lines. Also, the construction of a 3-phase coupling network is presented and a comparison between that and a CDN (Coupling Decoupling Network) sold in the European market is obtained.

## 2. THE EUROPEAN STANDARD 61000-4-5

EN 61000-4-5 prescribes the test set up for capacitive coupling on a.c. lines for 1-phase and 3-phase lines. At the part of the power supply circuit there is a coupling network. Its function is to prevent the effect on other connected devices to the network from the overvoltage of the EUT (Equipment Under Test). In other words it is a filter limiting the simulated lightning on the EUT, preventing the transient phenomenon to affect the power supply network. EN 61000-4-5 prescribes tests for simulating the effects of lightning discharges as well as voltage surges caused by switching disturbances in power stations.

EN 61000-4-5 requires that the generator is capable of applying surge pulses at a rate of "at least one per minute". The test also requires the pulse to be applied for various angles ($0^o$, $90^o$, $180^o$ etc) of the power input waveform. The peak voltage level of the surge pulse is adjusted in steps starting at some voltage levels. In total, 320 pulses are required. The simulator must have sufficient energy available to complete this test in a timely matter.

The surge generator called up in the test according to EN 61000-4-5 has a combination of current and voltage waveforms specified, since protective devices in the EUT will inherently switch from high to low impedance as they operate. A simplified circuit diagram of the wave generator is shown in figure 2.

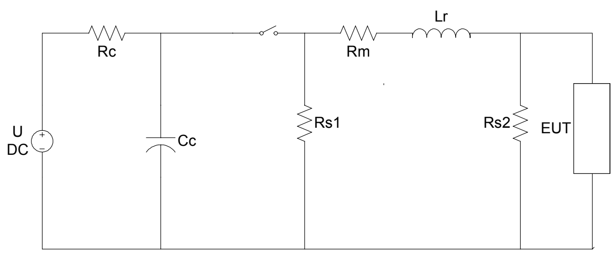


Figure 2: Simplified circuit diagram of the combination wave generator.

Part of the surge will be delivered into a high impedance and part into a low impedance. The values of the generator's circuit elements are defined so that the generator delivers a 1.2/50μs voltage surge across a high-resistance load (more than 100Ω) and 8/20μs current surge into a short circuit. These are shown in figures 3 and 4.

At this point it is fundamental a comparison between the standard lightning impulse voltage generator and the surge generator described in the EN 61000-4-5, to be made. The Standard (IEC 60-1) for the lightning impulse generator [4] defines that the tolerances of the test voltage must be for the peak value ±3%, for the front time ±30%, which are exactly the same with these of the surge generator.

The difference between these two types of generators is related with the test current. The Standard for the lightning impulse current generator [4] defines that the tolerances of the peak current must be for the peak value ±10% and for the front time ±10%, while for the surge generator according to EN 61000-4-5, both these tolerances are defined to be ±20%. Consequently, due to this difference a misunderstanding between the lightning impulse current generator and the surge generator must be avoided.

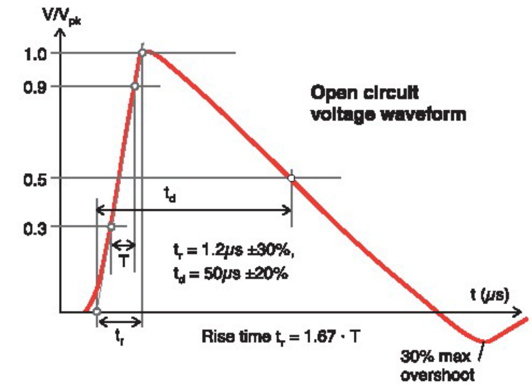


Figure 3: Open circuit voltage waveform (1.2/50μs) for the generator defined in the EN 61000-4-5

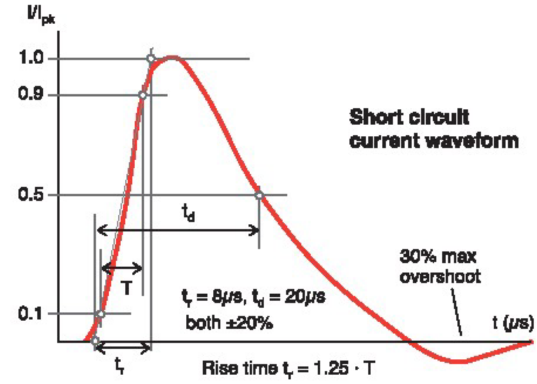


Figure 4: Short circuit current waveform (8/20μs) for the generator defined in the EN 61000-4-5

## 3. PSPICE SIMULATION FOR THE CIRCUIT OF THE EUROPEAN STANDARD 61000-4-5

The PSPICE program [4] has been used for the simulation of the test set-up defined by the EN 61000-4-5 Standard of the coupling network located between the device under test and the power supply network. The examined overvoltages are both for a.c. lines for 1-phase and 3-phase lines. The simulated surge generator was adjusted to produce an output voltage of 75kV. In the below voltage waveforms of the PSPICE simulations the a.c. voltage waveform of the network is depicted with the red, thick line, which dots are marked with the symbol "+", while the surge's waveform is depicted with the green, thin line, which dots are marked with the symbol

“□”. It must be also mentioned that the colour of the probes are the same with the colours of the respective waveforms.

**Test set-up for capacitive coupling on 1-phase a.c. lines**

According to EN 61000-4-5 two circuits were designed with PSPICE. The first circuit shown in figure 5 was designed for overvoltage between phase and neutral, while the other, shown in figure 7 was designed for overvoltage between phase and earth. For the first circuit the values of L, C were 1.5mH and 18μF while for the second circuit the values of L, C were 1.5mH and 9μF. The simulation results are shown in figures 6 and 8. The waveforms of figure 6 refer to the test set-up of figure 5, while those of figure 8 refer to the circuit of figure 7.

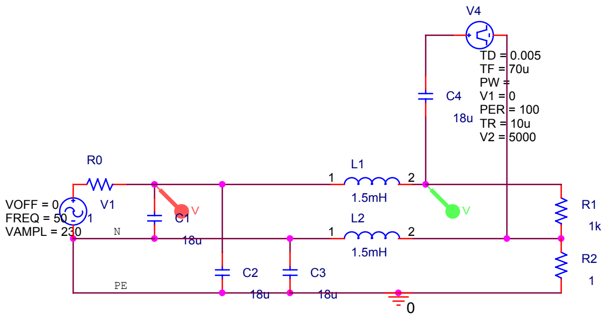


Figure 5: Test set-up for capacitive coupling on a.c. (1-phase) line, designed in PSPICE (overvoltage between phase and neutral).

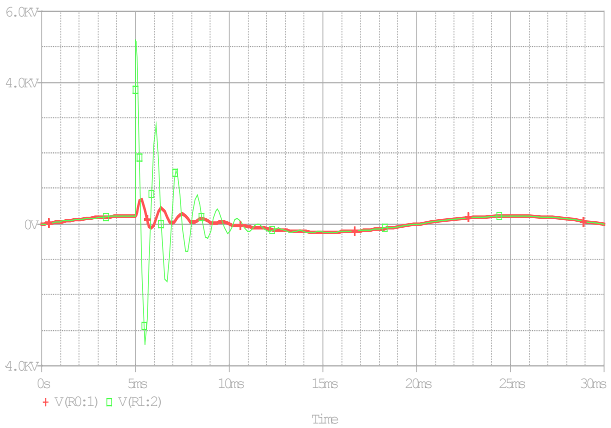


Figure 6: Voltage waveform for the circuit of figure 5

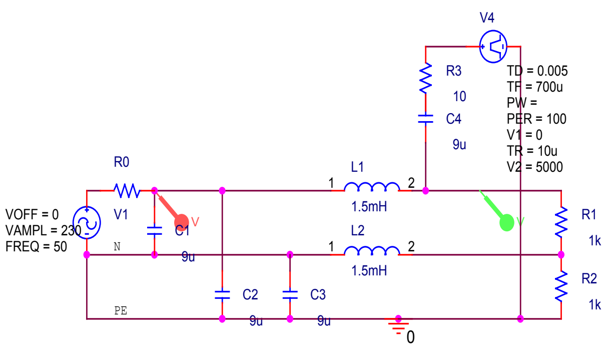


Figure 7: Test set-up for capacitive coupling on a.c. (1-phase) line, designed in PSPICE (overvoltage between phase and earth).


Figure 8: Voltage waveform for the circuit of figure 7

**Test set-up for capacitive coupling on 3-phase a.c. lines**

According to EN-61000-4-5, circuits for the test set-up for a capacitive coupling on 3-phase a.c. lines were designed with PSPICE. The first circuit shown in figure 9 was designed for overvoltage between two phases, while the other, shown in figure 11 was designed for overvoltage between phase and earth. For the first circuit the values of L, C were 1.5mH and 18μF, while for the second circuit the values of L, C were 1.5mH and 9μF, respectively. The simulation results can be seen in figures 10 and 12, respectively.

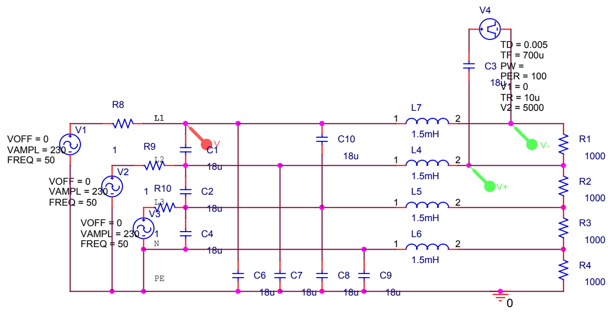


Figure 9: Test set-up for capacitive coupling on a.c. (3-phase) line (overvoltage between 2 phases).

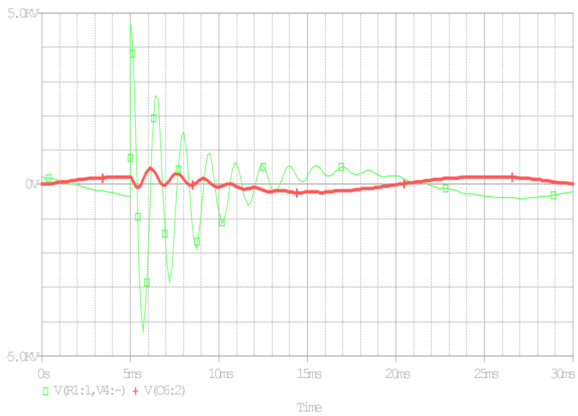


Figure 10: Voltage waveform for the circuit of figure 9

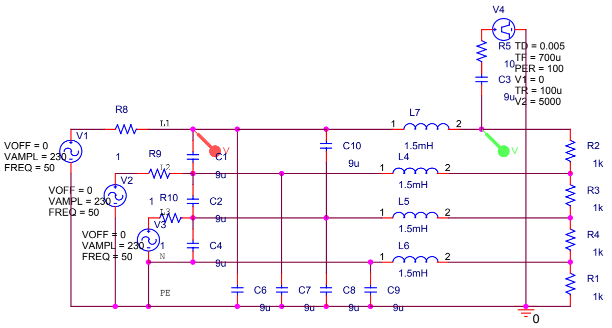


Figure 11: Test set-up for capacitive coupling on a.c. (3-phase) line, designed in PSPICE (overvoltage between phase and earth).

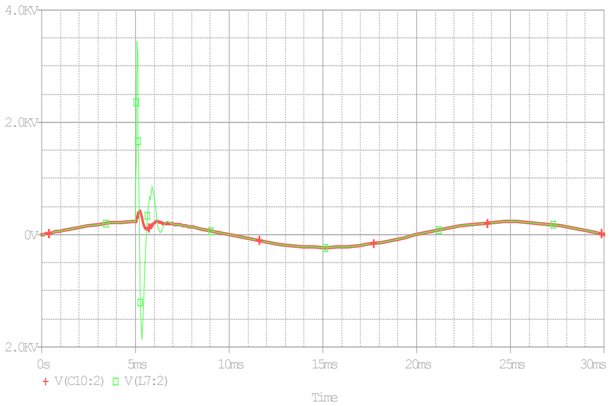


Figure 12: Voltage waveform for the circuit of figure 11

In all the above cases in order to measure the voltage probes have been used with reference point the earth. The only case where a differential probe was unavoidable to be used was in the case of the overvoltage between 2 phases (figure 9). Also, it is obvious that the proposed filter of the Standard, which shelters the overvoltage pulse from affecting the power supply network, is not perfect. The disturbance comes and it is measured at the input capacitor.

A first remark for the simulation voltage waveforms previously described is that for the overvoltage case between phase and neutral (figure 6) and the overvoltage case between 2 phases (figure 10) there is an oscillation. At the overvoltage case between phase and earth for both the 1-phase and 3-phase circuits (figures 8 and 12) there is a negative pulse after the overvoltage and until the phenomenon is damped. The duration of the overvoltage in figure 8 is very short in comparison with the oscillation case of figure 10. This happens because in the case of the 1-phase overvoltage between phase and earth there is a faster damping due to the discharge resistance next to the overvoltage generator, as it is shown in figure 7.

## Test set-up for capacitive coupling on 3-phase a.c. lines (phase-earth fault) for different loads

For the load of the circuit described in figure 9, where an overvoltage between phase and earth occurs, different load cases are examined. Simulations using PSPICE are made for capacitive load, inductive load and for an R, L, C combination load. The 3-phase loads are assumed symmetrical for all cases. At the capacitive load each capacitor is 9μF and at the inductive load each inductance is 10mH or 0.01mH (two cases of inductive load are examined). The R, L, C combination load is 10 Ohm, 1mH and 10nF respectively. The voltage waveforms of the simulations are shown in figures 13-16.

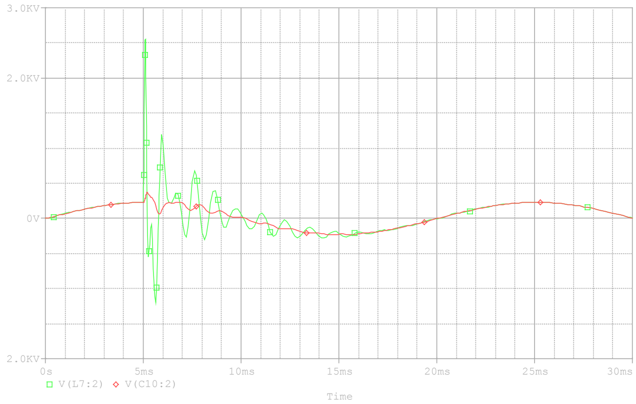


Figure 13: Voltage waveform for capacitive load (each cpacitor is 9μF)

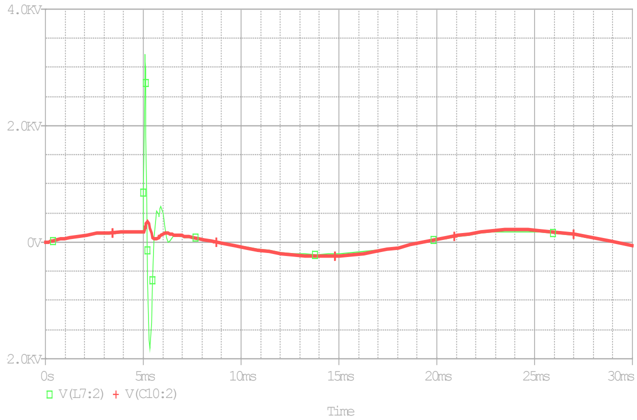


Figure 14: Voltage waveform for inductive load (each inductance is 10mH)

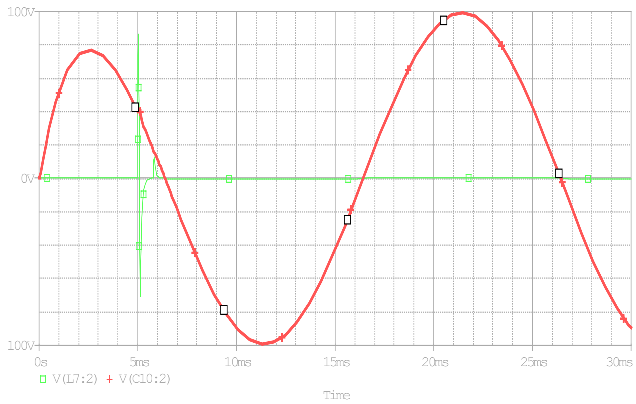


Figure 15: Voltage waveform for inductive load (each inductance is 0.01mH)

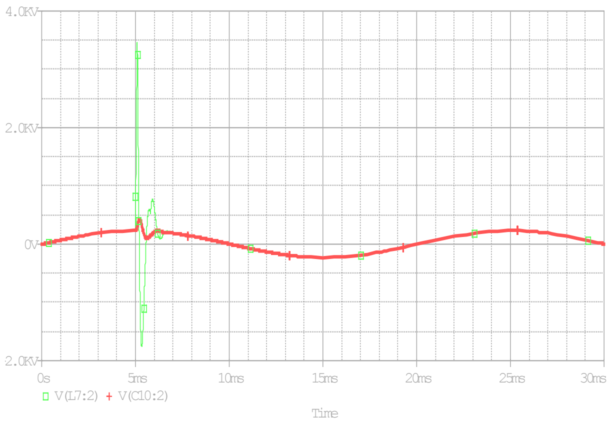


Figure 16: Voltage waveform for R, L, C load (10 Ohm, 1mH, and 10nF respectively)

Comparing the above voltage waveforms for different loads some remarks can be made. In the case of the capacitive load (figure 13) a high intense transient phenomenon concerning the overvoltage damping, can be observed. Also, the maximum value of the overvoltage is less than 2.5kV.

In the first case (figure 14) of the inductive load, where each inductance is 10mH a transient phenomenon of short duration concerning the overvoltage damping, can be observed. In the second case (figure 15) where each inductance is 0.01 mH the transient phenomenon is indifferent.

Finally, in the case of the RLC load the transient phenomenon concerning the overvoltage damping is depending on the resulting load behavior (inductive /capacitive).

## 4. THE CONSTRUCTED 3-PHASE COUPLING NETWORK FOR PHASE-EARTH OVERVOLTAGE ACCORDING TO EN 61000-4-5

A coupling network was constructed in the High Voltage Laboratory of NTUA. With this construction a comparison between it and the one, which is for professional use, can be made. The comparison can be made concerning both the cost and its performance as a filter. Also, this device is a useful tool for a laboratory wanting to carry out experiments on the device defined by the Standard EN 61000-4-5. The constructed 3-phase coupling network can work also as one phase coupling network if one phase and the neutral supply it with one phase supply. According to the Standard in order the tests set up shown in figures 7 (1-phase overvoltage between phase and earth) and 11 (3-phase overvoltage between phase and earth) to be carried out a capacitor and a resistance of 9 μF and 10 Ω respectively, should be added in series with the frequency generator. These two elements were added manually. It should be also mentioned that the operations on the device were made manually, as also for the point choice of the current. The constructed device is shown in figure 17.

Figure 17: The constructed 3-phase coupling network

The above-mentioned coupling network was used for experiments at the laboratory. For the experiment the laboratory equipment was: The Tektronix Oscilloscope TDS 3052, the frequency generators HP 3320B and GW GFG-8015F.

In order to examine the filtering behaviour of the coupling network the frequency generators were connected to it. According to the Standard the coupling network must be capable of cutting down pulses 1.2/50 μs or 8/20 μs, while the sine wave of industrial frequency must pass. The check for the frequency cut down was made for sine waveforms.

Using the digital oscilloscope the waveforms taken are shown in figure 19. Channel 1 shows the input waveform, while channel 2 shows the waveform at the input of the coupling network, which was constructed.

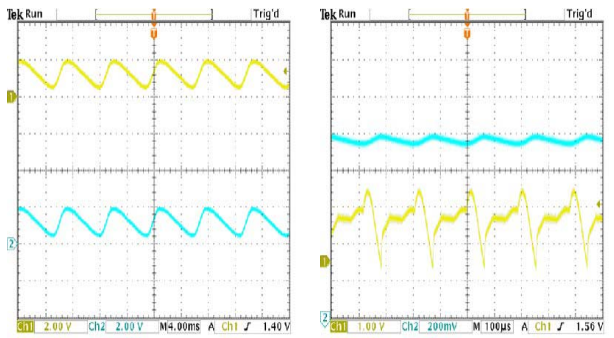


Figure 18: Waveforms for input frequencies 148.8 Hz (left) and 5.2kHz (right)

The constructed coupling network is a band pass filter, designed in order to cut down frequencies similar to the waveforms 1.2/50 μs and 8/20 μs referred in the Standard. Also, it is obvious that sine waveforms of low frequencies pass, as it should happen, since the sine of the industrial frequency must pass.

## 5. TEST OF THE COUPLING NETWORK UNDER SURGE VOLTAGES

The coupling network was finally tested under surge voltages, as the Standard EN 61000-4-5 defines, using the Haefely surge tester (type PC 6-288). The Tektronix TDS 3052 oscilloscope was used in order to measure two voltages. The first voltage was the output voltage of the surge generator to the coupling network, which was measured through an embodied to the generator capacitive divider (1:730). The second voltage was the output voltage of the coupling network, between neutral and earth, which was measured through an also capacitive divider (1:410). An RC adaptation of 10 Ω and 9 μF was used between the coupling network and the surge generator. In figure 19 these two waveforms are shown for positive surges of 1 and 2 kV respectively.

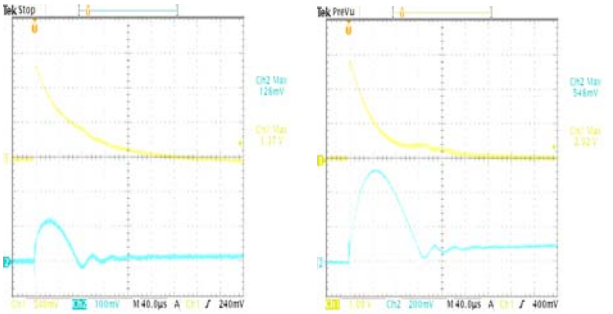

Figure 19: Positive surge voltages of 1kV (left) and 2 kV (right)

From figure 19 it is obvious that the coupling network works satisfactory. The voltages to the power supply network (output of the coupling network) are low. For the test at 1 kV the waveform of the coupling network is 53 Volts, while for 2 kV is 225Volts. These values and the values of the two other voltage levels (500 Volts and 4kV) are accepted according to the Standard. The EN 61000-4-5 defines that the voltage to the power supply shouldn't exceed the 15% of the surge voltage.

## 6. APPLICATION

The constructed coupling network was used at various 1-phase EUT (Equipment Under Test). The results were compared and validated using a CDN (Coupling Decoupling Network) sold in the European market. Also, plenty of tests were carried out for various EUT, using the constructed CDN and the CDN available in the European market. The surge generators, which were used, were the NSG 2050 of Schaffner and the PC 6-288 of Asea-Haefely.

These tests gave similar results following the methodology of the EN 61000-06-01 [6]. The comparison made was a proof that the constructed coupling network is ideal for precompliance tests and it is very useful for educational purposes, due to its low cost; the cost of the constructed 3-phase coupling network was 5 times lower than the mean cost of a usual CDN available in the market.

## 7. CONCLUSIONS

An investigation of the test set-up defined by the EN 61000-4-5 Standard was made. The computer simulation of the coupling network located between the device under test and the power supply network was done using the PSPICE program and a 3-phase coupling network was constructed. Measurements and tests were performed. This construction and also the methodology described can become a useful tool for anyone who wishes to perform simple tests to a device for immunity against surge voltages according to the EN 61000-4-5 Standard.

The behaviour of the constructed coupling network is just like a filter. It cuts down very high waveforms of some kHz as the EN 61000-4-5 defines. Also, its function under surge voltages is extremely satisfactory for all the test voltage levels (500V, 1kV, 2kV, 4kV) and in accordance to the Standard. The low cost and the satisfactory operation, with small variations in comparison to the professional version make it ideal for experiments and educational purposes.

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