# Waveform Norms For Protection Devices

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***Abstract***—Waveform norms to describe large amounts of measured data are revisited and their practical meaning for the test of protection devices is explained. The norms can also be used to describe the residuals of protection devices. It is shown that the norm values strongly depend on the application of the protection device, namely operating bandwidth and operating voltage.

Keywords - waveform norms; protection device residuals;

## I. INTRODUCTION

In mathematics norms are used for functional analysis to describe certain properties of vectors or matrices. In Electromagnetics it was proposed to use norms to describe a systems response to electromagnetic excitation [1, 2].
Often during HPEM-tests many system responses are measured, corrected and extrapolated and something must be done to reduce the amount of data in a way useful to assess the overall behavior of the system in the given HPEM-environment. One possibility is to define several observables that can be easily computed from the measured data and that are helpful to summarize similarities and differences between different waveforms. The concept of norms to bound electromagnetic response of complex systems can also be used in time-domain [3].

## II. PRACTICAL WAVEFORM NORMS

Various norms can be useful to reduce measured spectral or time-domain data to a few key parameters represented by simple scalars.

TABLE I USEFUL WAVEFORM QUANTITIES FOR ELECTRICAL STRESS CHARACTERIZATION

| **Quantity** | **Definition** | **Phenomenon** |
|---|---|---|
| Peak Value | $[I(t)]_{max}$ ; $[V(t)]_{max}$ | Junction or Dielectric Breakdown |
| Maximum Rate of Rise | $\left[\frac{\partial}{\partial t}I(t)\right]_{max}$ ; $\left[\frac{\partial}{\partial t}V(t)\right]_{max}$ | Mutual coupling; radiation |
| Total Impulse | $\int_0^\infty I(t)dt$ ; $\int_0^\infty V(t)dt$ | Toggling of digital circuits |
| Peak Impulse | $\left[\int_0^\infty I(t)dt\right]_{max}$ ; $\left[\int_0^\infty V(t)dt\right]_{max}$ | Total Charge |
| Rectified Impulse | $\int_0^\infty \lvert I(t)\rvert dt$ ; $\int_0^\infty \lvert U(t)\rvert dt$ | Thermal heating |
| Action [a] Integral | $\int_0^\infty I^2(t)dt$ ; $\int_0^\infty V^2(t)dt$ | Thermal fusing |

a Better known as Melting Integral in fuse technology

The norms listed in TABLE I were found to be useful [4] for an analysis of a time-domain waveform either for current *I(t)* or voltage *V(t)*. In addition for engineering purposes other waveforms parameters, which are not true mathematical norms, may be used e.g. rise time, fall time or time to peak.

## III. NORMS FOR PROTECTION DEVICES

For the test of protection devices (device under test DUT) usually three norms are defined: the peak value, the rate of rise and the action integral (pulse energy). In addition rise time and fall time may be helpful.
In principle norms can be defined for both sides of a DUT, for the test pulse at the input of the DUT and for the description of the permitted residuals at the output of the DUT. Of course the norm values of the test pulse and the residuals are very different. While the test pulse may be the same for all DUT's the permitted residual norms have to be chosen carefully according to the DUT technical data; e.g. a data line filter for a broadband application may have a much higher rate of rise than a power line filter, but the peak value may be lower because the operating voltage is lower. A published example is an Ethernet filter which has a high bandwidth but low operating voltage [5].
In conclusion the residual values of a protection device have to be defined based on the normal operating parameters of the protection device, namely operating voltage, operating current and signal bandwidth of the DUT. The residual voltage must be low enough not do cause any breakdown and the residual energy must be low enough not to cause a thermal damage to the downstream electronics.
Some proposals for realistic residual values will be shown during the presentation.

## REFERENCES

[1] Carl E. Baum, “Norms and Eigenvector Norms,” Mathematics Notes, Summa Foundation, Note 63, 27 Nov. 1977
[2] Carl E. Baum, “Energy Norms and 2-Norms,” Mathematics Notes, Summa Foundation, Note 89, 29 April 1988.
[3] Carl E. Baum, “Black Box Bounds,” Interaction Notes, Summa Foundation, Note 429, 19 May 1983.
[4] Frederick M. Tesche, “CW Test Manual” 1994, published as Measurement Note, Summa Foundation, Note 64, 15 May 2013
[5] Aswin R, “Challenges in Designing and Testing of EMP Ethernet (RJ45) Filter” ASIAEM Bengaluru, 24-27 July 2017