# Short-Time Fourier Transform for Different Impulse Measurements

E. Onal , J. Dikun

*Abstract*—**The aim of this paper is to point out the advantages of the use of the time-frequency analysis in the digital processing of the waveforms recorded in the high voltage impulse tests. Impulse voltage tests are essential to inspect and test insulation integrity of high voltage apparatus. The measured waveforms in practice may contain oscillations and overshoots due to contribution of different noise sources. The different methods incorporating signal-processing method such as wavelets and Short Time Fourier Transform are proposed for failure identification. It is now possible to distinguish failure during lightning tests as well as chopped lightning impulse tests. The method is experimentally validated on a transformer winding. Obtained voltage waveforms usually have some sort of interferences originated from the different sources. These interferences have to be removed from the original impulse data in order to evaluate the waveform characteristics precisely. In this paper two impulse signal are given concerned with the methods used for the time-frequency analysis. The impulse signals are at the pressure of 1 and 3 bar. In this study pressure of the signal are taken as a parameter. Signals are compared according to pressure by using time frequency analysis. Time-frequency analysis is powerful signal processing tool in order to recognize the noise of impulse voltage data. Thus the sources of the noise can be found and eliminated.**

*Index Terms*—**Impulse Voltage, Time-Frequency Analysis, Short-Time Fourier Transform.**

## I. INTRODUCTION

IMPULSE voltage test on high-voltage equipment is essential to evaluate the insulation integrity and to identify the ability to withstand over-voltages encountered during operation. The significance of chopped impulse application is of paramount importance in impulse testing of transformer. The measured waveforms in practice may contain oscillations and overshoots due to contribution of different noise sources. One of the major challenges of impulse voltage and current measurements is the existence of noise that affects the precise identification of impulse parameters. The measurement of lightning impulses with superimposed overshoot or oscillation has been the subject of extensive studies in the last few years in light of results of an important study [1-2] with regard to the relationship of the effective peak voltage and the overshoot frequency. The main findings of the study are the test voltage equation for the determination of the effective peak voltage. The evaluation of the overshoot and the test voltage from an output waveform is performed with the residual filtering method. Basically the evaluation of the high voltage impulse signals consists on the evaluation of the peak amplitude ($U_{max}$) and three time parameters ($T_1$: Front time, $T_2$: Time to half value for full impulse and $T_c$: Cut-off time ). When the level of disturbance in signals is low, computation of these parameters are also quite simple but when the disturbance level rises, they get much more difficult. In terms of frequency contents, there are three kinds of disturbance: Oscillation on the test circuit, electromagnetic disturbance and digitizer noise. The results show that those three disturbance types have different frequency characteristics [3]. The oscillations due to the test circuit have frequency above 500kHz, the electromagnetic disturbance usually is characterized by frequencies in the range of several hundreds of kilohertz (more than 500kHz) up to a few megahertz (less than 10MHz) and the digitizer noise that come from digitizers used in high voltage test halls and these frequencies are clearly above 10MHz. Taking this information into account, the standard states that the evaluation of the HV impulse parameters must be based on the low voltage part of high voltage signal that is actually applied to the equipment under test. The characterization of HV impulses is based on the evaluation peak and time parameters so their spectrum is important to detect the presence of disturbance. Thus, all of the disturbances having frequency above 500 kHz can be removed from the low voltage part before the evaluation of the impulse parameters. For this reason it is very important to know the sources and eliminate the noises [4].

The attention of many researchers has been focused on the disturbances caused by the combination of a high rate of rise of impulses with the stray capacitances and inductances that are present in the circuit. The measuring circuit, as well as the generating circuit, should be as free as possible from oscillations and overshoot. Oscillations can only be accepted if it is certain that they are produced by the test object in connection with the high voltage circuit. It is necessary to ensure that they are generated in the measuring system, e.g. in the low voltage arm of the divider. For this reason in this study, the effect of impulse voltage at the pressure of 1 and 3 bars are considered. It is important to examine the above atmospheric pressure because circuit breakers are used in high pressure like 2-3 bars. It has many advantages over existing methods, since it does not assume any model for estimating the mean-curve, is interactive in nature, suitable for full and chopped impulses, does not introduce distortions due to its application, is easy to implement and does not call for changes to existing standards.

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## II. TIME-FREQUENCY ANALYSIS

In this section, mathematical background to be used in this application is focused on the Short-Time Fourier Transform (STFT) techniques and coherence analysis which is presented as cross spectral property between two signals [5].

### *A. Short-Time Fourier Transform*

The signal to be transformed is multiplied by a window function which is defined for a short time period and then it can be represented by the integral form of the classical Fourier transform sliding the window function along the time axis. In application there are so many window type, however, one of the most popular one is "Hanning type windowing". The shape of this window function is appeared as a Gaussian function at around the zero value [6]. In this manner, Short-Time Fourier Transform of a given signal x(t) is described as below:

$$\mathrm{STFT}\{x(t)\} \equiv X(\tau,\omega) = \int_{-\infty}^{\infty} x(t)\omega(t-\tau)e^{-j\omega t}\,dt \qquad (1)$$

For discrete case, STFT of discrete time domain signal x[n] is given by the following equality

$$\mathrm{STFT}\{x[n]\} \equiv X(m,\omega) = \sum_{n=-\infty}^{\infty} x[n]\,\omega[n-m]e^{-j\omega n} \quad (2)$$

## III. MEASUREMENT SYSTEM AND DATA

The lightning impulse voltages used in this study are produced by a 1 MV, 50 kJ, Marx type impulse generator (Fig. 2). The voltages are measured by means of a capacitive divider and a HIAS 743 digital oscilloscope with 12 bit real vertical resolution at 120 Mega sample / sec. All data have sample frequency of 1 Giga sample /sec. Experimental set-up is shown in Fig. 1. The present paper describes a study of two full impulse signal analysis of Sulphur-hexafluoride ($SF_6$) at the pressure of 1 and 3 bar. Sulphur-hexafluoride gas due to its exceptional insulating and arc-extinguishing properties has been widely employed as insulation of high voltage power apparatus.

Signals are carried out using rod-plane electrode with a rod diameter of 1 mm and electrode gap spacing is 5 cm. Rod electrode is connected to high voltage while plane electrode is earthed. Electrodes are mounted in a pressure vessel of 120 mm diameter and 600 mm length. The full impulse signals are shown in figure 3 and figure 4 for the pressure of 1 and 3 bar respectively. All measurements of the experimental study are given in IEC standard.

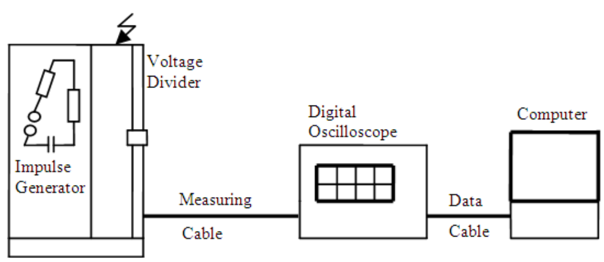


Fig. 1. Experimental set up

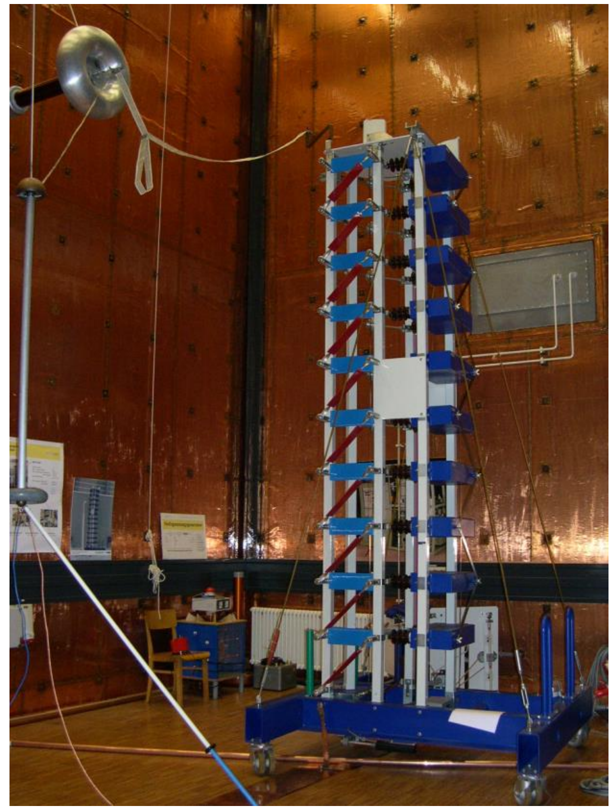

Fig.2. 1 MV Marx impulse generator

T1 and Umax values of the signals which have the pressure of 1 bar and 3 bar are 0.968 µs, 167.1 kV and 0.997 µs, 286.5 kV respectively. The signal evaluation of the pressure value in time-frequency analysis is carried out by using STFT. The impulse signals are compared over a wide range from 0 to 500 MHz, which is the spectrum of the impulse.

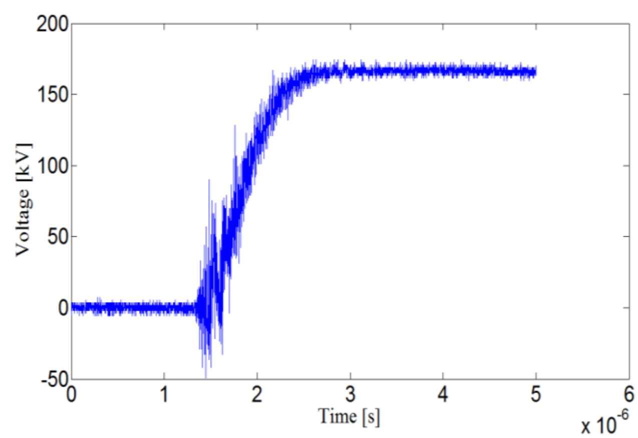


**Fig. 3.** Full Impulse Voltage Signal for the pressure of 1 bar

These spectrums are shown in figure 5 and figure 6. When the spectrums are examined, it is shown that especially in the range of frequency of 0-4 MHz frequencies are the same and predominant. There are the weak same frequencies which have between 4-500 MHz for two signals. The reason of this is that the frequencies in this range belong to test circuit. In some cases, the oscillations or the overshoot can be eliminated or reduced by improving the electric circuit.

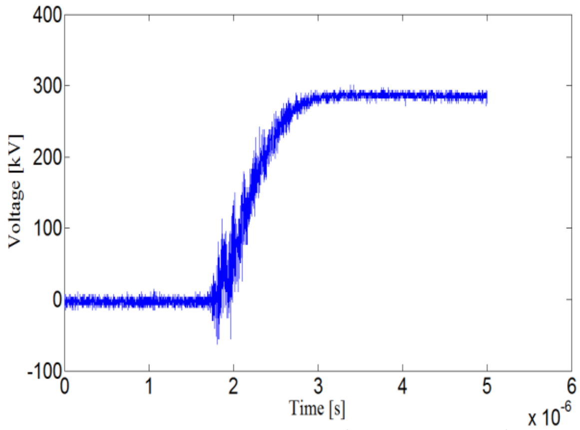


Fig. 4. Full Impulse Voltage Signal for the pressure of 3 bars

It is difficult to establish traceability of the test results and compare them with those of other high-voltage (HV) testing laboratories. All the disturbances with frequencies above 500 kHz must be removed from the lightning voltage waveform before the evaluation of the impulse parameters [7-9]. Removal of noise with low frequency is comparatively difficult as to removal of noise with high frequency.

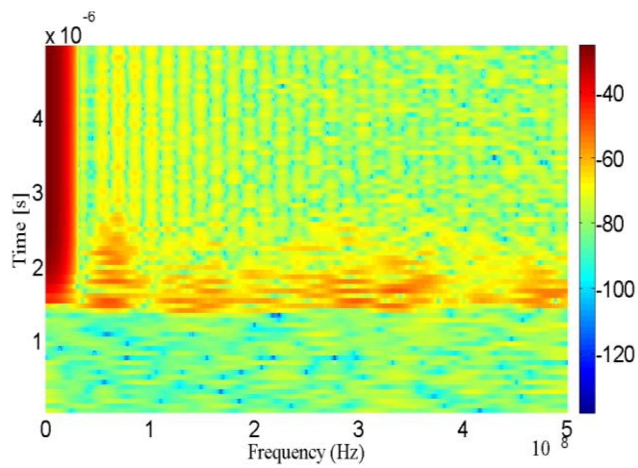


Fig. 4. Time-Frequency Analysis for Impulse Voltage Signal for the pressure of 1 bar

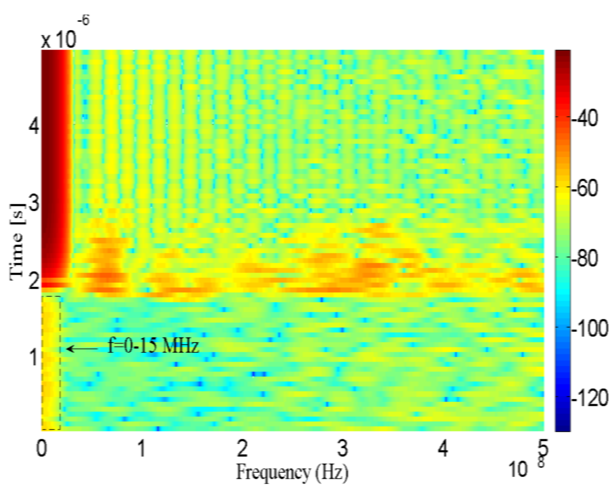


Fig. 5. Time-Frequency Analysis for Impulse Voltage Signal for the pressure of 3 bars

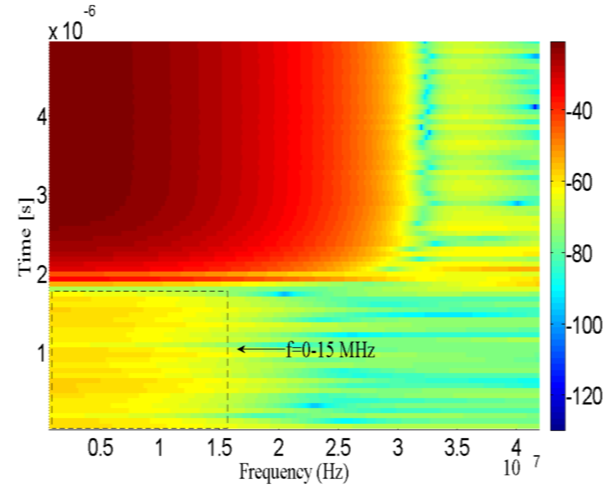


Fig. 6. Detailed Time-Frequency Analysis for Impulse Voltage Signal for the pressure of 3 bars

According to these spectrums, the most important difference in spectrum analysis is shown between the frequency range of 0- 15 MHz. As seen from figure 5, for impulse voltage signal which has the pressure of 3 bar, the frequencies between 0 and 15 MHz are more intensive compared to than that of 1 bar at the time range of 0-2 µs. This case is shown in figure 6 clearly. The common frequencies for the two signals are in the range of 4-500 MHz. These frequencies are occurred at the time range of 1.5 µs-2.5 µs and 2-2.5 µs for the pressure of 1 and 3 bar respectively. These frequencies belong to electromagnetic disturbance and digitizer disturbance coming from environmental. This can be eliminated by using filter and shielding as much as possible. This time range corresponds to the rise time of impulse signals. At this range, corona discharges begin between electrodes before the breakdown phenomena. Corona discharges cause the distortion in the circuit. Electromagnetic interferences radiated from a high voltage impulse generator are mainly caused by the discharges occurring in air gaps, which are used to switching on the impulse generator. Effect of these interferences increases with increase of the applied voltage and decreases with go away the generator. The measuring circuit, as well as the high-voltage generator, should produce or cause as few oscillations and overshoots as possible. Oscillations can only be accepted if it is certain that they are produced by the device under test in connection with the high-voltage generator. It is necessary to ensure that they are generated in the measuring system, e.g. in the low voltage arm of the divider. The increasing pressure creates frequencies which have the range of 0-15 MHz at between 0-1.5 µs. The space charges are pushed back at the time range of 0-1.5 µs for 3 bars. This pressure range can make easy to ionization and weaken the links of SF6 molecules.

## IV. CONCLUSIONS AND DISCUSSIONS

When the interference level is high enough, it might not be possible to distinguish signal parameters from the recorded data. One of the major challenges of impulse voltage and current measurements is the existence of noise that affects the precise identification of impulse parameters [10-12]. In some cases noise interfacing with the measured data can be strong necessitating utilization of de-noising algorithms on measured data, where conventional filtering is inadequate as in the case of white noise [13-14]. This time-frequency analysis has been proven to give quick and reliable results and helps to find the frequency of disturbance. In this study the disturbances noises which are approximately at front of the signal can be reduced by shielding. The electromagnetic interferences in the circuit and the digital recorder quantization noise have been predominant source of error. For our electrode system, the peak of frequency of distortions which has the above 15 MHz belong the digitizers and environmental. As mentioned before, the reason of these situations can be disturbance depending on electrode system. This caused more distortion peaks due to the corona phenomena before the breakdown. The aim of this analysis to determine frequency content of the disturbances whether a given frequency component corresponds to a disturbance that should be removed or not. It can be said that corona begins around the rod electrode. However as in many practical situations, a transient electromagnetic interference can enter the measuring circuit at the divider low-voltage arm, or penetrate through the coaxial cable sheath and the digital recorder enclosure. Ideally, all these devices shall be protected by a perfect electromagnetic shield, but in reality its shielding efficiency decreases with frequency. In this study, the disturbance effect of impulse signal can be reduced in some degree by using shielding cabinet.

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