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Preconditioning Circuit for Electrical Power System Disturbances Measurement

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Abstract – This paper is focused on how to reduce the amplitude of electrical disturbances which appears in the electrical power systems to a low voltage supported by the acquisition boards, without loosing any important disturbances. Is well known the fact that the maximum input voltage of the most popular acquisition boards is about ±10V. The disturbances may heave 10kV amplitude, and if we simply divide the input voltage by 1000 to reduce the 10kV to 10V, the main power system voltage (220V) will be reduced to 0.22V which is too low to obtain a sufficient accuracy in the measurement process, counting that the most of the disturbances have amplitudes in the area of 0-100V.

Keywords: power system, disturbance, voltage divisor, nonlinear

I. INTRODUCTION

The power quality study involves an important step, i.e., monitoring the actual voltage and current waveforms, classifies these waveforms and displays them when certain thresholds are exceeded. These waveforms exhibit certain distinguishing characteristics and can be identified to belong to a certain waveform class. The classification scheme has to be robust and accurate to handle the noisy data collected from the transmission or distribution networks.

The main problem in the electrical power systems is monitoring and detecting of disturbances. Because of the multitudes of types the disturbances are, each disturbances with her specificity, it is difficult to detect and capture such types of disturbances. The common types of disturbances are that can produce little variations of the power system voltage around 220V. Another type of disturbances is the disturbances with amplitudes between 500V and 2kV, and last one with amplitudes over 2kV, disturbances which occurs very rare.

II. THE METHOD PROPOSED

The method proposed in this paper is focused on how to divide the input voltage to a value that complies with the acquisition board, without losing any type of disturbances. This method consists in the use of a functional transformer [4][5] with the transfer function presented in figure 2. Because most of the disturbances present smaller variations around 220V, the first cut point is set to 500V to preserve sufficient the amplitude of the output signal. Very small disturbances around the 220V can be now analyzed. The second segment is from 0.5kV to 2kV where is to found the disturbances which occur more rarely then the first class, and the last segment represent the disturbances which appears very rare in the signal.

After the acquisition process, the signal is processed for detecting the disturbances, and if the algorithm found any disturbances, the signal is reverted to the original shape and then recorded to a file to be analyzed or viewed later [5][6].

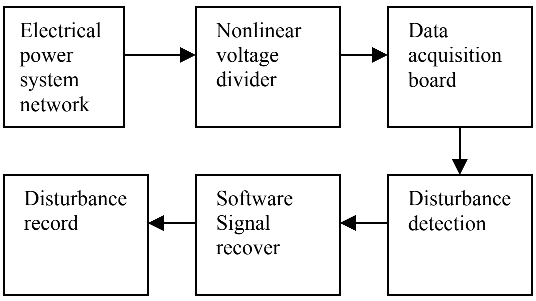

Fig. 1. Bloc diagram

The functional transformer uses a operational amplifier with very low bias current because the value of the input resistor R_{in}. If the value of R_{in} increases, the voltage on that resistor increases. This voltage must be insignificant in rapport with the input signal. If the input resistance decreases, the value of R_2 and R_4 becomes comparable with the conduction resistance of the diode D_2 and D_4. For this purpose was chosen the AD8616 operational amplifier produced by Analog Devices. This OA has an input bias current of 200 fA..

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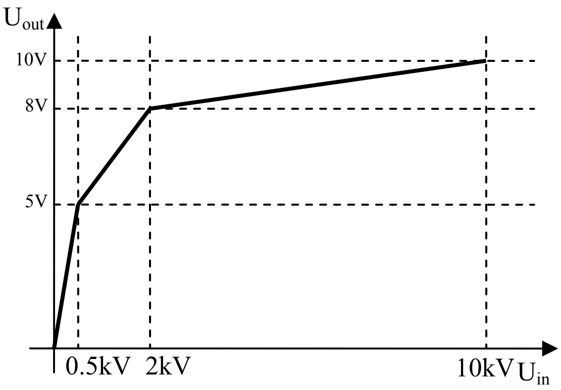

Fig. 2. The transfer function of the circuit

The schematic diagram of the functional transformer is presented in fig. 3. This is a classical functional transformer with diodes.

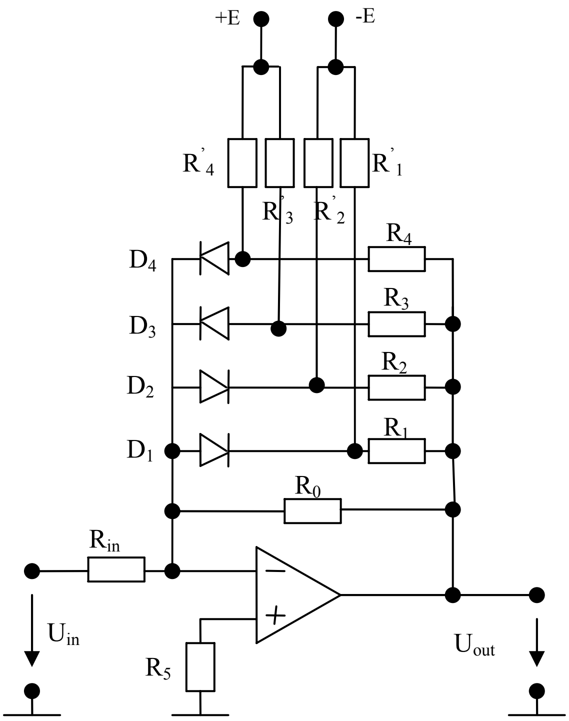

Fig. 3. Circuit schematic

The value of the input resistance R_{in} was chosen after multiples calculus and simulations to be 1MΩ. Starting from this values has been computed the values for the other resistors in the circuit. The first voltage divider consisting in R_{in} and R_0 must realize the first segment of the transfer function. If the input voltage exceeds the value of 500V, the diode D_1 begins to conduct and the resistor R_1 is introduced in the circuit. The result is that the resistor R_1 is now in parallel with resistor R_0 and the division ratio of the voltage divider is considerably higher then in the first case. If the input voltage is higher than 2kV, the diode D_1 is still conducting and the diode D_2 begins to conduct. In this case, the resistor R_0 is in parallel with R_1 and R_2. The division ratio is in this case bigger then the second case, end very big comparing to the first case. The resistances R_0, R_1 and R_2 is controlling the input voltage breakpoints, and the resistors R_0 , R'_1 and R'_2 is controlling the output voltage breakpoints. For the case presented here, it is possible to calculate the points of the transfer function, by determining the slope of each segment.

$$a_k = \frac{U_{out_{k+1}} - U_{out_k}}{U_{in_{k+1}} - U_{in_k}} \tag{1}$$

After each slope is calculated, next is to calculate the division ratio of each divider, and the values of resistances composing the divider with relation (2).

$$\begin{aligned} &R_0 = a_0 \cdot R_{in} \\ &R_{ech1} = a_1 \cdot R_{in}, \quad R_{ech1} = R_0 \parallel R_1 \\ &R_{ech2} = a_2 \cdot R_{in}, \quad R_{ech2} = R_0 \parallel R_1 \parallel R_2 \end{aligned} \tag{2}$$

The last step in the projecting of the circuit is to establish the breakpoints of the output voltage.

$$\begin{aligned} R'_1 &= R_1 \frac{V_{D1} - E}{V_{Out1} - V_{D1}} \\ R'_2 &= R_2 \frac{V_{D1} - E}{V_{Out2} - V_{D1}} \end{aligned} \tag{3}$$

III. EXPERIMENTAL RESULTS

The circuit was simulated in PSpice using the model provided especially for AD8616 by Analog Devices. The results are very close to the projecting data. The figure 4 shows the transfer characteristic of the circuit.

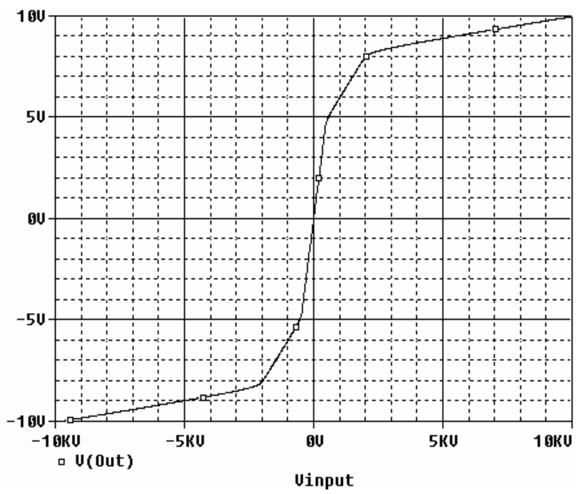

Fig. 4. Circuit transfer function simulated in PSpice

One thing that is interesting is the error on the breakpoints. Serious contributions to these types of error have the internal resistance of the diodes used, and the forward voltage drop of the diodes. This is a disadvantage of this kind of voltage divider.

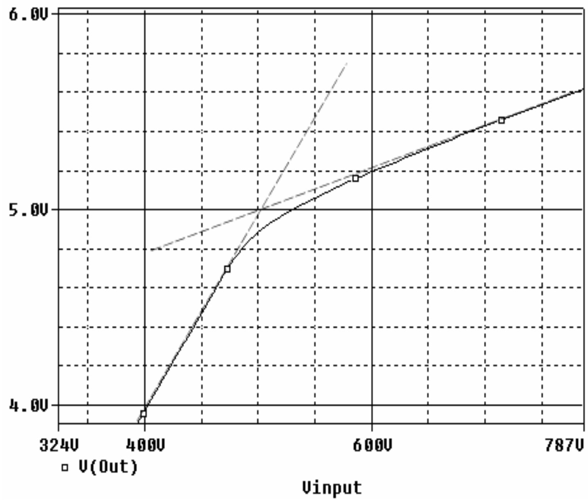

Fig. 5. Errors at 500V

As it can be seen in the figure 5, the ideal breakpoint (marked with dashed lines) is exactly at 500V and 5V. The real characteristic has a rounding error due to the fact that the diodes don't enter in the conductive state instantaneously. This error has a quantum of 1% from the output voltage.

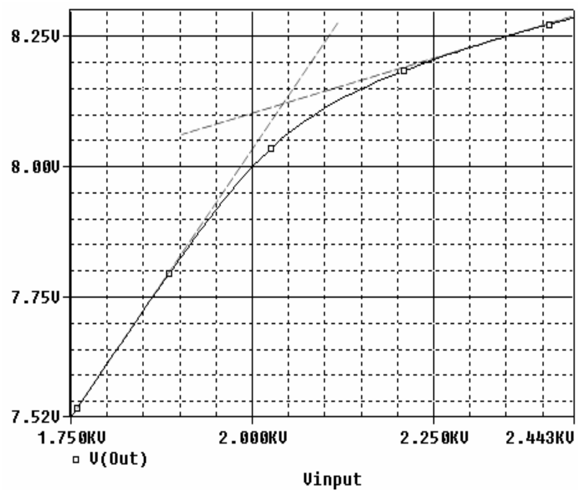

Fig. 6. Errors at 2kV

On the second breakpoint the error is significantly higher because of propagation from the first breakpoint. In plus, here is another error due to the fact that in the calculus of R_1 has been made some approximations about the forward drop voltage of the diode D2. The maximum error at this breakpoint is 1.5%.

In the last case, the error at 10kV is 0.2%. This error is made by the approximation of the value of diode D_2 conducting resistance, since its value is comparable with resistor R_2. To minimize this error the value of R_2 must be 5-10 times bigger than conducting resistance of diode D_2. But this is not possible, because increasing the value of R_2 will increase the value of the resistor R_{in} which is not a good idea as mentioned earlier in this paper.

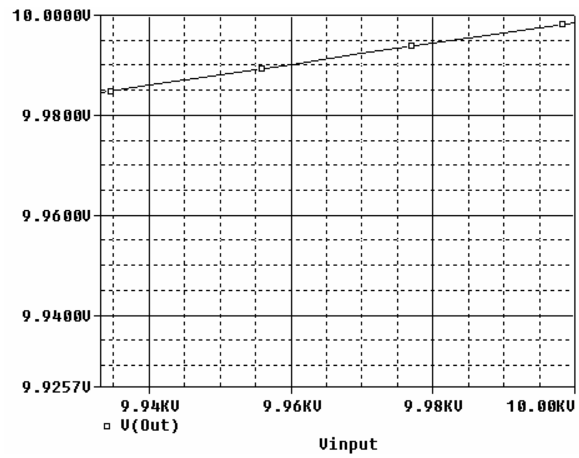

Fig. 7. Errors at 10kV

A parameter who might keep in count is the temperature. The temperature can modify the internal resistance and the forward drop voltage of the diodes. The influence of the temperature is shown in the figures below for each breakpoint.

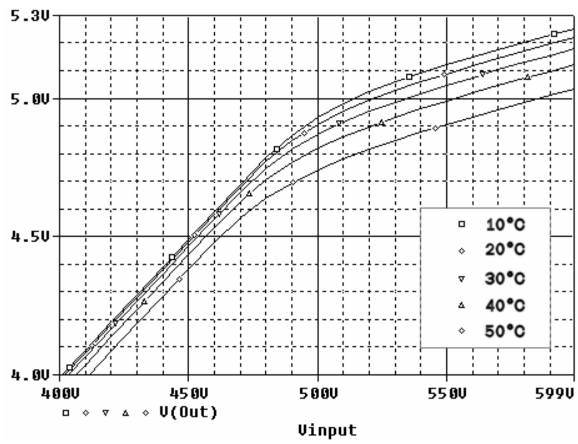

Fig. 8. The influence of the temperature at 500V

The temperature can modify the internal resistance and the opening voltage of the diodes, raising the error of the circuit.

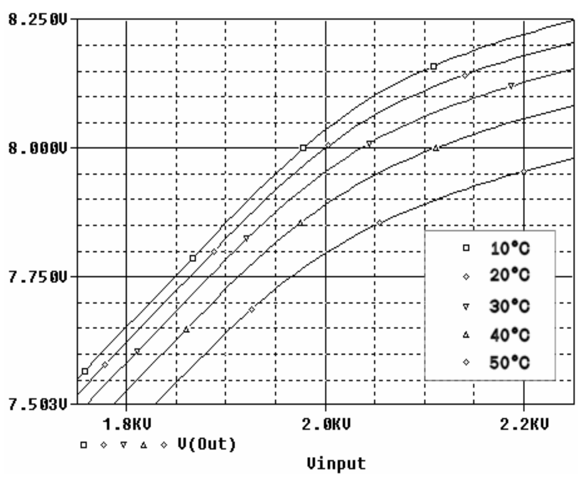

Fig. 9. The influence of the temperature at 2kV

It can be seen that the higher the temperature, the higher is the error.

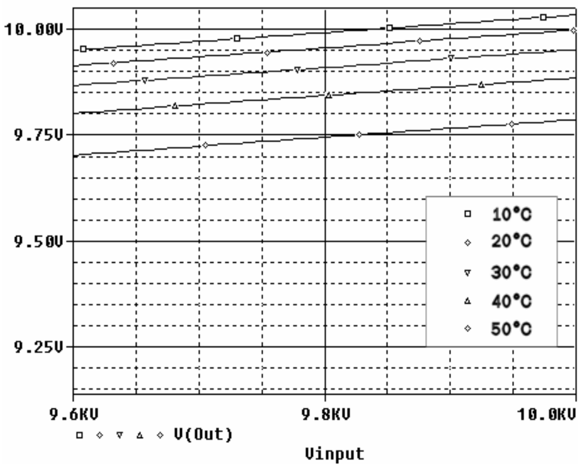

Fig. 10. The influence of the temperature at10kV

These variations of the output voltage with temperature must be eliminated.

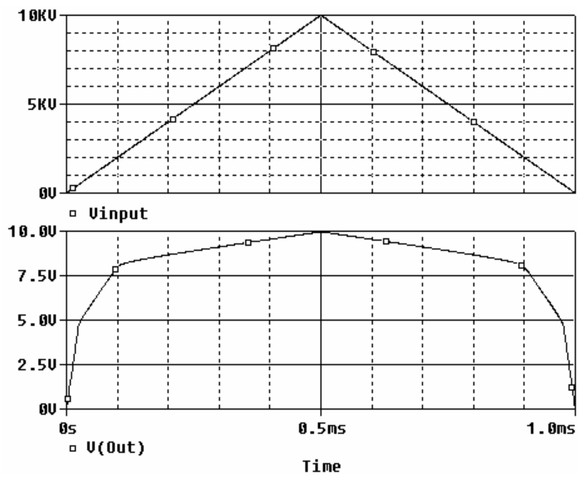

Fig. 11. Input and output signals

To see how the circuit works, at the input was applied a triangular signal because with this shape is more easy to observe how the circuit work. The triangular shape heaves a linear variation, suitable to observe any nonlinearity on the output signal.
The triangular signal has 1 kHz frequency and amplitude of 10kV. At the output of the circuit, the signal presents the 2 breakpoints at 5V and at 8V.
The output signal from the circuit is software recovered to the initial amplitude. In the figure 12 is shown both the input and recovered signal. The recovered signal has not the same shape with the input signal because of the errors on the first and second breakpoints. These errors can be software minimized. The triangular shape can be used in the process of minimizing these errors. The idea is to apply at the input of the circuit a triangular signal and to determine each error and her sign for discrete values of the input voltage. Then, with this values, can be made an interpolation to establish the shape of the variation of the errors.

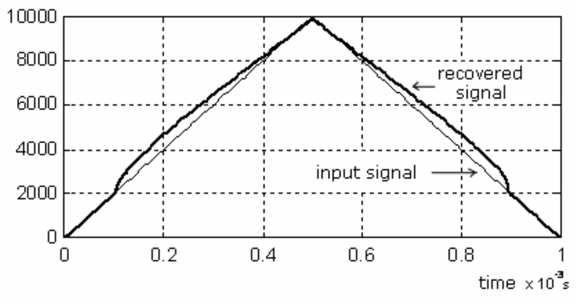

Fig. 12. Software recovered signal

The spectral analysis of the input and recovered signal show a significant modification in the recovered signal spectrum, especially the apparition of the second order harmonics.

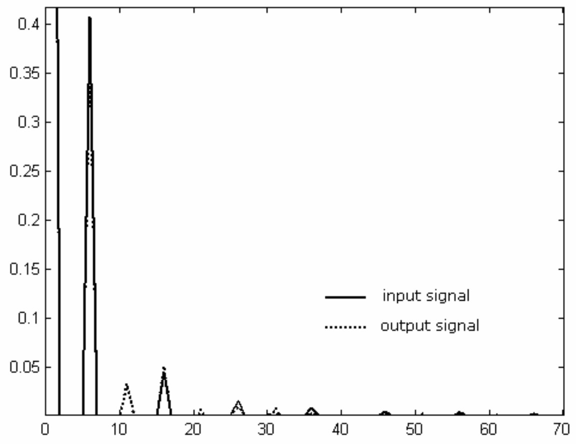

Fig. 13. FFT of the input and recovered signal

Because the triangular signal is rarely present in practical conditions, we are chose two types of signals more present in practical conditions: the spike and the damped oscillatory wave.
Most high amplitude disturbances in the electrical power system heave a spike shape.

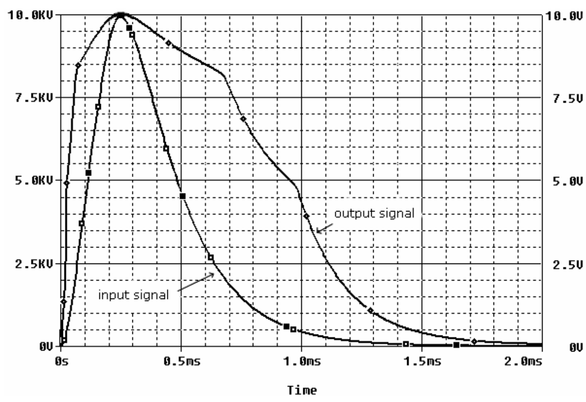

Fig. 14. Spike signal

The spike disturbances are an extremely high and nearly instantaneous increase in voltage with a very short duration measured in microseconds. Spikes are often caused by lightning or by events such as power coming back on after an outage. In the figure 14 is represented a spike input signal and the signal at the output of the circuit.
The signal from the output of the circuit is applied to the recovery block resulting in a signal with the shape verry similar to the shape of the input signal. The error is due to the breakpoints of the transfer characteristic of the circuit. It can be observed in the figure 15 that at 2kV the error heaves an important value (25%), because of propagation of the error from the first breakpoint. At 500V the error is smaller (about 15%), but unfortunately this error amplifies the error at the second breakpoint.

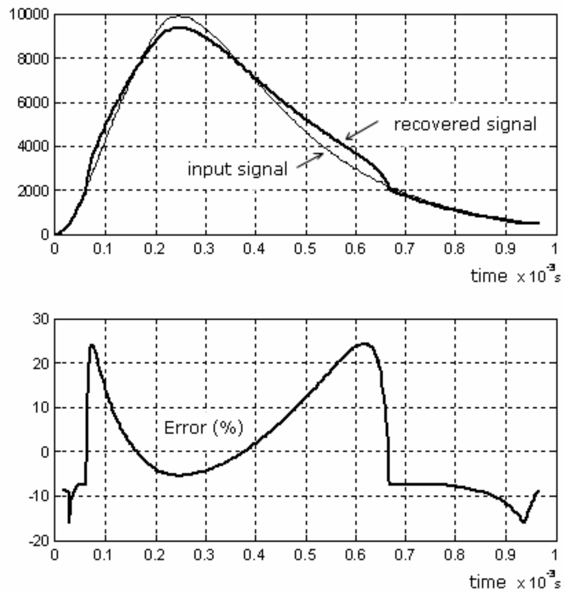

Fig. 15. Biexponential signal applied at the input and the recovered signal

At the 10kV, the recovered signal is smaller than the input signal, at this point the error is about 5%.

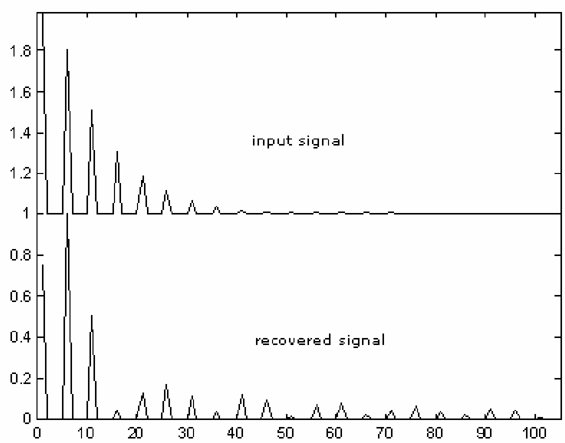

Fig. 16. Spectrum of the spike input and recovered signal

To minimize this errors, it can be observed that if to the output signal is applied a constant voltage, the error can be reduced at about 10%.
In the spectrum of the recovered signal can be observed an increased number of high frequency harmonics. This harmonics is generated by the circuit transfer function around the 2kV breakpoint. The transition around the 2kV is not smooth, which generate the high frequency harmonics.
Another type of disturbances is the sag disturbances. Sag is defined as a short duration drop in voltage. The amplitude of the electrical power system decreases to 0.9 of their nominal value, but this is not always done instantaneously. Such type of disturbances is presented in the figure 17.

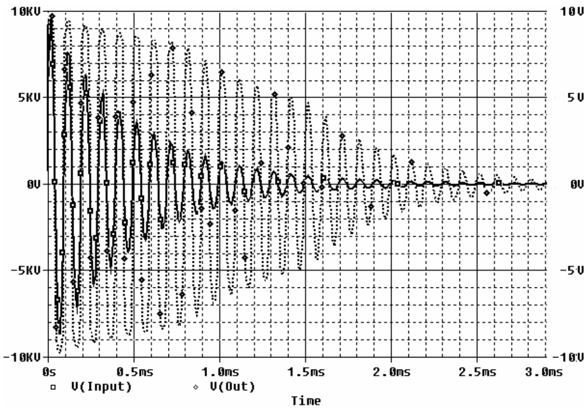

Fig. 17. Damped oscillatory wave

Basically, this disturbance consists in a sine wave with the amplitude varying over an exponential shape. With continuous line is plotted the input signal, and with dotted line is plotted the signal at the output of the circuit.

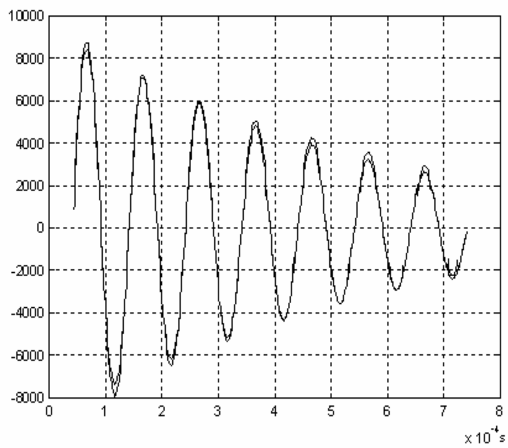

Fig. 18. Damped oscillatory wave at the input of the circuit and after the software recovery

The signal of the output of the circuit is applied to the recovery block to reconstruct its original shape. The differences between the input and the recovered signal are relatively small, the maximum errors being 10%. In this case, the error at 2kV is smaller than the case of the spike. In the figure 19 is represented the relative errors at the peaks of the damped oscillatory wave.

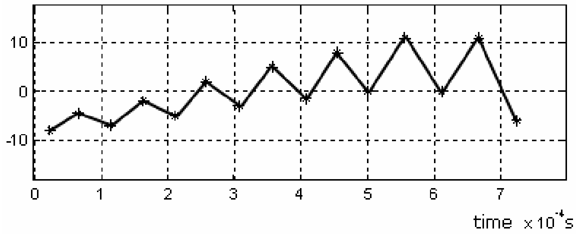

Fig. 19. The relative errors of the maximum amplitude of damped oscillatory wave after the software recovery

Around the value of 10kV the errors are negatives and their values are under 10%, being smaller around 6kV and increasing again when the amplitude of the signal becomes around 2kV. The bigger value of the errors for smaller amplitudes of the signal is not an inconvenient. It can be observed that the errors for the positive and negative side of the signal are not the same value and sign. This is caused by the diodes on the positive and negative side of the functional transformer, diodes which don't heave the same conductive resistance and the forward drop voltage. To prevent this, the diodes must be carefully selected.
Like in the other cases, the spectrum of the recovered signal presents high frequency harmonics.
This harmonics is produced, like in the cases above, by the breakpoints of the circuit and it is necessarily to reduce their amplitude.

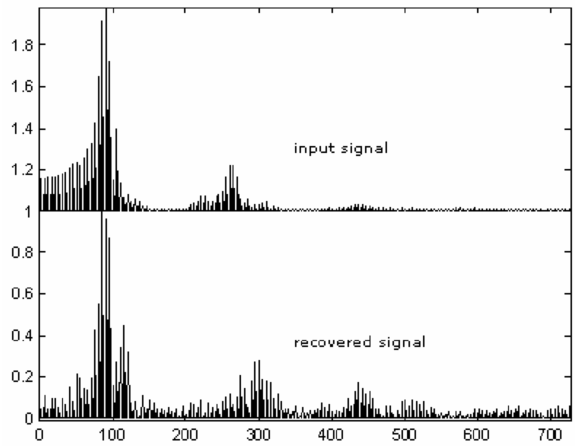

Fig. 20. Spectrum of the damped oscillatory wave

IV. CONCLUSIONS

Analyzing an important parameter of the signal, the power of the input and recovered signal, it has been observed that the relative error of the power of the triangular output signal is 6%, so the power of the output signal is 0.06 times bigger than the input signal power. For the spike signal, the relative error of the power of the signal is 1.86%, and for the dumped oscillatory wave, this error is -6.1%.
For the spike signal we observed that the rise time of the recovered signal is decreased with about 10% from the input signal, and the time at half amplitude is increased with 11% from the input signal.
To maintain the accuracy of the output voltage the circuit must be compensated with the temperature. A maximum error value of 5% is satisfactory for the goal proposed. To maintain the error at this point it's necessarily to thermally isolate the circuit. A ±2 ºC in temperature variations is maximum allowed. To reduce the errors caused by the diodes, it must be known the conductive resistance and the forward drop voltage. The diodes are the elements that generate the biggest error in the circuit. The diodes must be selected carefully to heave the same parameters. The errors at the first and second breakpoint can be software corrected, once their shape is known. For that, the software recovery circuit must heave a self calibration circuit to minimize this type of errors.
Another source of errors is the resistive elements of the circuit like resistors and PCB. All resistances must heave a maximum error of 0.5%.

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