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Modeling Algorithms for Sags with Exponential Fronts and Other Types of Electromagnetic Disturbances from Power Supply Network

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***Abstract*—This paper describes modeling algorithms in order to obtain different types of electromagnetic disturbances from the power supply network. The main algorithm is designed for voltage sags with exponential fronts and uses an exponential function for each sag front. It also uses the data range translation to an adequate specified range in order to obtain the desired waveshape and the use of of the algorithm within a virtual signal generator with GUI, obtained with the help of a sound card, for the research of these disturbances which affect the power quality.**

***Index Terms*—voltage sag, power quality, electromagnetic compatibility, data acquisition board.**

I. Introduction

In the last decades electronics and telecommunications have known an unprecedented development, the number of non-linear loads (power electronics) has increased. New more energy efficient devices and equipments, controlled by microprocessors, have appeared. They are also more sensitive to electromagnetic disturbances, produced by neighborhood devices or as a result of the shared infrastructure, which can affect the power quality for many industries or even for the domestic consumers. A poor power quality can cause the malfuction of electrical and electronic devices and equipments, instability, short lifetime. In case of computers the disturbances can lead to: corrupted files, loosing files and to the destruction of the hardware components. Additional costs can occur for both, suppliers and consumers (for example, after a power interruption on a production line a certain time is needed to restart which leads to a reduction in production) [3], [5], [6], [8], [9].

Simultaneously, the expansion of the suppliers, the competition on the market, the increase of the studies in this field, the better informed customers have led nowdays to higher requirements for power quality. Both categories, the suppliers and the consumers are more concerned about the power quality. In order to satisfy consumers' requirements, suppliers have invested in more energy efficient equipments. Frequently, just these are affected by power problems and they become in turn disturbances sources.

The electromagnetic compatibility problems are not new. First law in this field, as can be considered nowadays, was approved a long time ago in 1892, in Germany [11]. Today, by electromagnetic compatibility (EMC) it is understood the capability of an equipment or system to operate without emitting electromagnetic disturbances with intolerable levels for anything from its ambience [3], [6], [8].

The assurance of the power quality is related to the power delivery without the interruption of sinusoidal voltage with the amplitude and frequency maintained between certain standard s determined tolerances. For this purpose, power quality indicators are used, which allow the measurment and the evaluation of the quality level of the power supply network in a certain point and at a certain moment. There are international standards which are used to set up national standards. If in the past the power quality referred to the ability to supply the electric power without interruptions, nowdays due to the above mentioned elements the customers's requirements are higher than ever before.

The electromagnetic disturbances which can appear in the power supply networks are classified in more categories, presented as follows [6]: transient phenomenons, short duration variations, long duration variations, voltage imbalances, waveform distortions, power frequency variations and flickers.

The voltage imbalances represent the fourth category and are caused by the different effective values of phase voltages or of the phase angles between the consecutive phases.

The waveform distortions are the fifth category and represent waveform deviations from ideal sine wave and are divided in four subcategories: DC offset, harmonics, interharmonics and noise.

The causes for the presence of DC offset in a power supply network are: geomagnetic disturbances, switching mode power supply or switching on/off of a synchronous machine.

The noise, in this context, represents the unwanted electrical signals with broadband spectral content lower than 200 KHz, superimposed upon the power system voltage or current in phase conductor, or found on neutral conductors or signal lines [2]. The causes are the following: switching power supply, control circuits, arcing equipment, power electronic devices.

The classification of the electromagnetic disturbances can be different from one country to another or from one continent to another.

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II. Transient Disturbances

The transient disturbances are quick variations of the voltage, of the current or of both and can be of two kinds, impulsive and oscillatory transient. The first category has exponential rise and falling fronts and is characterized by magnitude, rise time (the time required for a signal to rise from 10% value to 90% value of step height), decay time (the time until a signal is greater than ½ from its magnitude) and its spectral content. In order to generate a biexponential impulse we can use the formula shown below

$$s(t) = at^{b}\mathrm{e}^{-ct} \tag{1}$$

where the parameters a, b and c allow the regulation of the magnitude, the rise time and the impulse duration. The second category is characterized by magnitude, decay time and the predominant frequency content. This category is divided into four subcategories: high frequency (>500 KHz), average frequency (5-500 KHz), low frequency (0.3-5 KHz) and very low frequency (<300 Hz) [2]. Such a signal can be obtained by multiplying a biexponetial impulse (using the formula (1)) with a sinusoidal signal described by the following formula:

$$s_S(t) = A\sin(2\pi ft + \phi_i) \tag{2}$$

where A is the amplitude, f the frequency and ϕ_i the initial phase.

The typical causes of the transient voltages are: lightnings, short-circuits, burning of fuses, connecting and disconnecting of loads (capacitor banks etc).

A transient disturbance can have a short duration and a high frequency, consequently in order to acquire such signals the following requirements have to be met: wideband circuits and high sampling rates for data acquisition board. The quantity of the data collected is large because of the high sampling rate.

III. Short and Long Duration Variations

The short duration variations are divided into: interruptions, undervoltages (sags) and overvoltages (swells). Each category has three subcategories function on the duration: instantaneous, momentary and temporary. First category is characterized by duration and the last two by rms variation in time, magnitude and duration.

The long duration variations can have two types, interruptions and slow voltage variations.

The overvoltages can be caused by lightning or by switching off large loads.

The main causes for the interruptions and the undervoltages are: system faults, switching on large loads and overloaded circuits.

A few examples to describe the effects of the voltage variations on equipments are presented bellow. Overvoltages affect the insulations of the cables and of the equipments (but usually insignificant), they increase the induction motors torque and their starting current which increases the voltage sag in the neighborhood loads, the life length of the incandescent lamps is reduced, but fluorescent lamps are less affected. They increase the magnetization current of transformers and as a result they will increase waveform distortion. The undervoltages decrease induction motors torque and the temperature rises at full-load, they increase the life length of the incandescent lamps but can not compensate the effect of overvoltages; fluorescent lamps decrease light, the electronic equipment shows an increase of the current which leads to higher losses and to a reduced lifetime.

A new approaches to the power quality is the immunity testing of loads by using a voltage sag generator, too. It becomes more complex because of the adoption of new standards: CBEMA curve (Computer Business Equipment Manufactures Association) and the successor of CBEMA, SEMI F47 (Semiconductor Equipment and Materials International) [9].

The IEEE 1159-1995 standard [15], [6] define sag as a decrease between 0.1 and 0.9 per unit (p.u.) in the rms value of the power supply voltage or of the current with a duration range of 0.5 cycle to 1 minute (in UE countries the supply voltage frequency is 50 Hz and the duration range between 10 ms and 60 s). Supplementary, the IEEE 1159 classifies the sags according to their duration in three subcategories: instantaneous (10 ms-600 ms), momentary (600 ms-3 s) and temporary (3 s-60 s).

The waveshape can be rectangular (when the voltage is constant), exponential (sag with exponential fronts) or complex (when the voltage varies in stairs).

Next, it is described a method to obtain a voltage sag with exponential fronts and desired waveshape by data range translation. For every exponential front it is used a exponential function with a corresponding time constant. If we apply an exponential function to an ordered data sequence $x_1, x_2, \ldots, x_N$ we obtain an ordered data sequence $y_1, y_2, \ldots, y_N$ with the data range $[y_1, y_N]$. But if we want to translate the data range $[y_1, y_N]$ to a new desired range $[v_3, v_4]$ we must use the next system of equations

$$\begin{cases} \alpha y_1 + \beta = v_3 \\ \alpha y_N + \beta = v_4 \end{cases} \tag{3}$$

and we will find the values of the parameters α and β in order to achieve the translation for the data sequence $y_1, y_2, \ldots, y_N$.

In figure 1 a) it is presented an exponential front with the data range $[B_1, B_2]$ and figure 1 b) contains a sag with N-1 fronts. By using a few exponentials fronts with the data range $[0,1]$, such as the front in figure 1 a), we intend to build a sag with exponential fronts just like in figure 1 b). Generally case for an exponential front i we want to translate the data range $[B_1, B_2]$ to $[A_{i-1}, A_i]$. For this case $y_1 = B_1$, $y_N = B_2$, $v_3 = A_{i-1}$ and $v_4 = A_i$. With these new notations the system of equations (3) becomes

$$\begin{cases} \alpha B_1 + \beta = A_{i-1} \\ \alpha B_2 + \beta = A_i \end{cases} \tag{4}$$

but $B_1=1$ and $B_2=0$, so we have

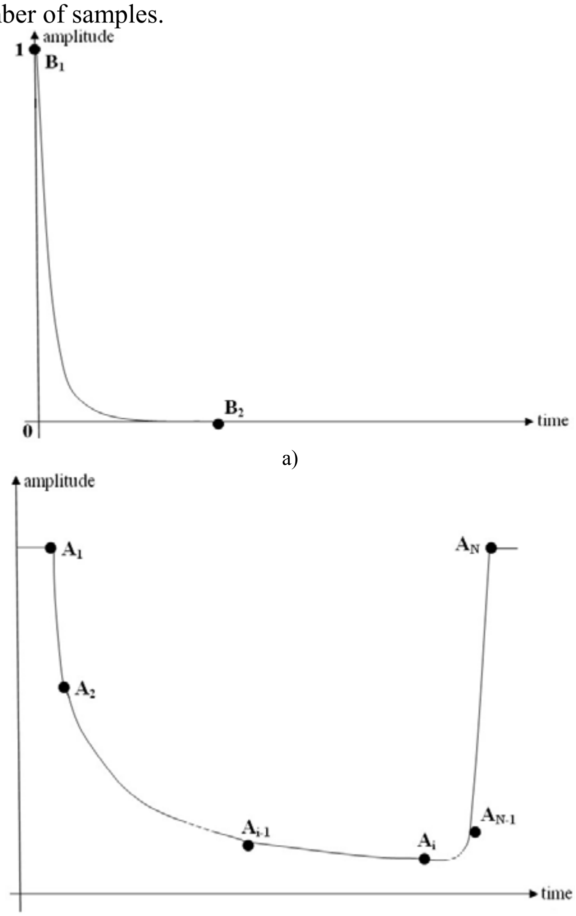
$$\begin{cases} \alpha + \beta = A_{i-1} \\ \beta = A_i \end{cases} \quad (5)$$

and the solutions are $\alpha=A_{i-1}-A_i$ and $\beta=A_i$.

Generally, we consider the front i of a voltage sag as described in the next relation

$$front_i = \exp(t_i x_j),\ i = \overline{1, \mathrm{N}},\ j = \overline{1, N_{Si}} \quad (6)$$

where t_i is the time constant, N is the number of considered points to obtain the desired sag (figure 1 b) and N_{Si} is the number of samples.



a)

b)

Fig. 1. Front translation

By using the solutions of the system of equation (5) the data range translation for the front i can be done with relation

$$front\_tr_i = front_i \bullet (A_{i-1} - A_i) + A_i \quad (7)$$

But the relation (7) was obtained for a descending front, when the difference $A_{i-1}-A_i$ is positive. In the case of ascending front the difference is negative and we must to use module of difference

$$front\_tr_i = front_i \bullet |(A_{i-1} - A_i)| + A_i \quad (8)$$

The complete algorithm structure designed to obtain a voltage sag with exponential fronts and with the desired rise times is presented bellow.

The data about the desired sag waveshape: the amplitudes until which every front decreases, the durations and the rise times are stored in three vectors and initially are considered known. These values will be used for the data range translation of every sag front and to obtain the desired rise time of each front, in the second loop.

If the number of fronts for a sag is noted as $N_f=N-1$, the first step consists in accomplish the main loop to cover all N_f fronts. For each of them a exponential function is generated, using the value -1000 as time constant (this value is used to obtain an almost vertical front which has a small rise time). This value will be adjusted later in another loop to obtain the desired rise time, stored in the vector of rise times, mentioned in previous paragraph. For each exponential front, by addition, we use an adaptive step in order to obtain larger rise times. The number of samples needed for front i is the following

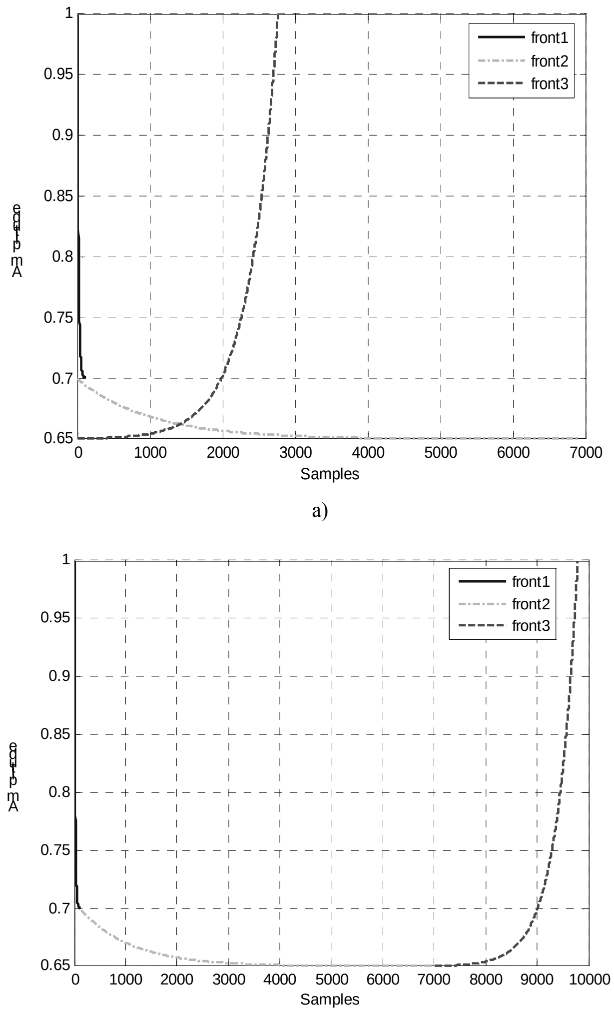
$$N_{Si} = \frac{T_i}{T_S} \quad (9)$$

where T_i is the duration and T_s is the sample period. By using the relation (6) it is obtained an exponential front with N_{Si} samples and the data range *[0,1]*. Than the data range is translated to the new desired range $[A_{i-1},A_i]$ using the values from vector of amplitudes and relation (8).

A second loop inside the main loop, above described, is used for the rise time adjustment of each exponential front i by decreasing the time constant with an adaptive step, initially equal to 0.1. First, in this loop, the rise time of the front is calculated. If the value is smaller than the desired one from vector of rise times the step increases twice, and if is not, the step decreases 50 percent and the value of time constant is decrised with the step. After each modification of the time constant, it follows a recalculation of the front samples by using the relation (6) and a new data range translation, because the front data range is affected by the time constant modification.

Finally, it is created a vector with a size equal to sum of the fronts sizes and in another loop the sag is build by using the exponential fronts obtained before (figure 2 b).

In the Figure 2 there are presented the main steps of the algorithm to obtain a sag formed of 3 exponential fronts: data ranges translation of exponential fronts (figure 2 a) and sag building (figure 2 b).



a)

b)

Fig. 2. Generation of sag with three fronts

IV. Harmonics and interharmonics

Harmonics are signals having frequencies that are integer multiples of the frequency at which the supply system is designed to operate. They are caused by the system resonance and the consumers with nonlinear loads such as: computers, UPS, fluorescent lighting tubes.

Interharmonics are signals having frequencies that are non integer multiples of frequency at which the supply system is designed to operate. The main causes are cyclo-converters, induction motors and static frequency converters.

A periodic discreet signal $v(n)$ of finite length L can be decomposed into a Fourier series in harmonic form by using the next relation [3]

$$v(n) = \sum_{k=1}^{K} a_k \cos(n\omega_k + \phi_k) + \omega(n) \tag{10}$$

where K is the number of sinusoidal components, a_k is the magnitude, $\omega_k=2\pi f_k$ is the harmonic or interharmonic frequency, ϕ_k is the initial phase angle and $\omega(n)$ is the noise.

The frequency resolution of model is high , but it is assumed that the model order K is known and this fact is not usually true for applications.

Next, a simple algorithm to implement the equation (10) is presented. First, the value of K is chosen, and then the number of considered sinusoidal components. After that we need three vectors of size K to keep the values of the magnitudes, the frequencies and of the initial phases for each sinusoidal component. These data are read and finally it is build a loop to generate all the K sinusoidal components, where for each iteration a sinusoidal component is calculated, which is added to the previous component. After the loop exit the signal $v(n)$ is obtained.

V. Frequency variations

The power frequency variations are frequency deviations from the specified nominal value of the power supply system and they are caused by the power transmission faults, or by switching off large loads. Sometimes unbalances may occur between the generation and the electric power consumption. The effects are the following: decreases in the rotation speed of the electrical motors, increases of the power losses in transformers (due to magnetic core saturation) and wear of the generators.

Next it is described an algorithm to obtain a sinusoidal signal containing a portion affected by a frequency variation. First it is calculated the number of signal samples that are affected, as difference between a start sample for the frequency variation and a stop sample $Ns= S_{stop}- S_{start}$. Than by using the power supply frequency f (50 Hz or 60 Hz), the new desired frequency f_n and N_s a constant step is calculated

$$step = \frac{f_n - f}{S_{stop} - S_{start}} \tag{11}$$

where S_{stop} is the stop sample and S_{start} is the start sample.

In a loop with Ns iterations the value of f is increased if $f_n>f$, or it is decreased in negative case, with the previous calculated step at each iteration. With these new frequencies the values of the sinusoidal signal samples are calculated and and are replaced in the initial sinusoidal signal, after the loop exit, the resultant signal will contain a frequency variation between f and f_n.

VI. Flickers

The flicker represents the brightness fluctuations of lamps caused by low frequency magnitude variations of the power supply voltage. It is present since the beginning of the power distribution systems. The flicker effect on humans is cumulative. Flicker severity is appreciated function of the human eyes discomfort, long-term flicker causes eye tiredness, vision problems (the consequences could be reduced concentration levels, deterioration in work quality and accidents) or even epileptic seizures. Precision electronic equipments suffer a negative influence. Possible sources are: arc furnaces, condenser batteries, welding installations, compressors, starting of high power motors and small loads like boilers, power regulators, electric saws and hammers, pumps, cranes and elevators, sometimes low-frequency voltage interharmonics.

One of the main sources of flickers is the electric arc furnaces (EAF), used in steel plants, because the arc resistances have non-linear variations during the melting process.

Usually the main aspect in the study of electromagnetic disturbances is the effect on the equipment, but in the case of the flicker the effect on human has priority. A disadvantage is the individual response to flicker, which is different from one person to another. The same thing also occurs in the case of the type of the lamp: florescent lamps are more sensitive to frequency flicker than incandescent lamps, but the amplitude of the response is smaller.

IEC1000-3 standard, elaborated by International Electrotechnical Commission, establishes the flicker test methodes for devices and it is complex because it try to reduce the variables frequency, amplitude, duration and the human response to a single numerical value. If a device passes the test it is not guaranteed that it will not cause problems in any conditions, but the results obtained are useful for comparisons with other devices.

The eye-brain set perceives the flicker if its frequency is inside the range from 0.5 Hz to 25 Hz and the sensitivity is a function of frequency [4]. Frequencies bellow 0.5 Hz are not annoying. The maximum flicker frequency depends on environment illumination and is around 30 Hz. If the frequency is higher than 30 Hz the eye-brain set perceives continuous light. The human eye is very sensitive to light level, even variations in brightness of less than *1%* are detected. The flicker perception threshold for smooth sinusoidal variations and square waves is different. The first category is less perceptible, especially at low frequencies. Around the peak sensitivity at *8.8 Hz* there are perceived voltage variations of *0.2 %*. The second category has a similar response at medium and high frequencies and the sensitivity is a little higher.

For flickers modeling can be used the next formula [1]

$$v(t) = \{A_0 + \sum_{i=1}^{M} A_i \cos(\omega_{fi} t + \phi_{fi})\} \cos(\omega_0 t + \phi_0) \quad (12)$$

where A_0 is the amplitude of the nominal power system voltage, ω_0 is the nominal power frequency, ϕ_0 is the nominal phase angle, A_i is the amplitude of the flicker voltage, ω_{fi} it is the frequency, ϕ_{fi} its phase angle and M is the expected number of flickers. The signal $v(t)$ is called amplitude modulation signal.

The signal $v(t)$ can have a sinusoidal variation or a square variation.

VII. Signal generator GUI and experimental results

This virtual signal generator with Graphical User Interface (GUI) was developed in the Matlab environment by using a sound card as hardware part. It can be used by user with low level of knowledge about the electromagnetic disturbances without having to write any code line. An analog oscilloscope is useful for visualizing the signals after selecting a proper time base.

In the next figure, there are presented the elements of the graphical user interface, each one having attached a suggestive label. The left part contains two elements, for the visualization of selected disturbance and of the output signal. The rest of the elements are situated on the right side and allow: the loading of data file with a recorded disturbed signal, saving a profile file in ASCII format which contains the file name and parameters values inserted by keyboard, opening or loading of a profile file, inserting the parameters of the sinusoidal signal (number of desired periods, sampling frequency and visualization of sampling frequency range), over which it can be overlapped a voltage sag with exponential fronts beginning from a specified start sample, inserting the parameters of the desired sag (amplitudes, durations and rise times of exponential fronts), a transient disturbance (impulse or oscillatory), harmonics, flicker, frequency variation and short or long duration variation. The area from the right down corner (control) allows starting/stopping of the sound card and the closing of the application.

The value of sample rate is chosen in the interval supported by the hardware, which will be displayed with th use of the Range button. The minimum value is usually 8000 Hz, and the maximum value is 44100 Hz or 96000 Hz at the more recent cards.

The signal from fig. 4 is obtained by introducing for the sinusoidal signal the folllowing parameters: amplitude, frequency, sampling frequency, number of periods with values of 220, 50, 44100, 1. The parameters a, b, c of the biexponential impulse have the values of: 1000, 0.5, 0.5. The visualization of the output signal is possible after selecting a time base suitable for the visualization only of a period of the output signal, in order to distinguish the details of the wave shape.

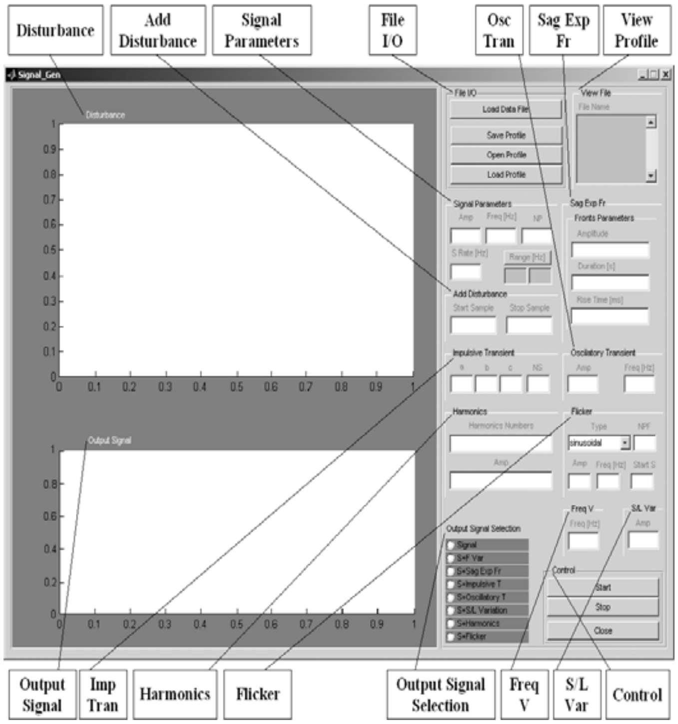


Fig. 3. Elements of graphical user interface

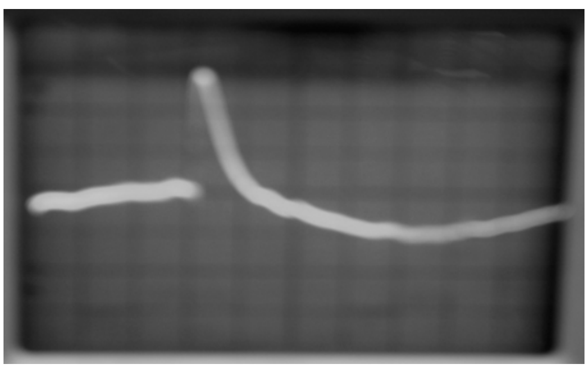


Fig. 4. Sinusoidal signal containing an impulsive transient

Further on, in order to obtain the signal from Fig. 5, the parameters amplitude, frequency, sampling frequency, number of periods of the sinusoidal signal, upon which it is overlapped the transitory disturbance, have the same values as the previous output signal. The damp sinusoidal signal from Fig. 5 has the amplitude and the frequency 220, 500 and the biexponential impulse has the parameters a, b, c with the values 10, 0.5, 3.5.

The signal from Fig. 6 is obtained by introducing for the sinusoidal signal the parameters amplitude, frequency, sampling frequency, number of periods with values 220, 50, 10000, 6, and for the short duration variation the parameters amplitude, start sample and stop sample with the values 0, 400, 800. Visualization on oscilloscope can be done again by selecting a proper time base.

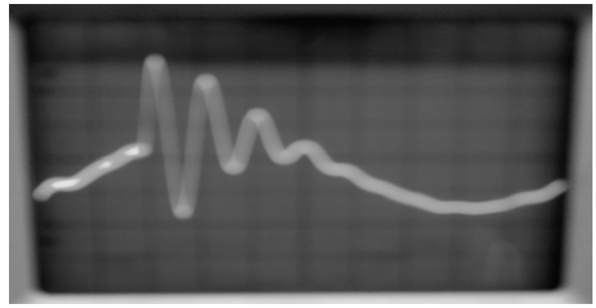


Fig. 5. Sinusoidal signal containing an oscillatory transient

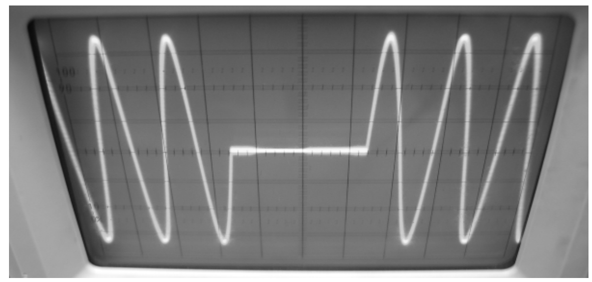


Fig. 6. Sinusoidal signal containing an interruption

In order to obtain the signal from fig. 7 the parameters amplitude, frequency, sampling frequency, number of periods of the sinusoidal signal, have the same values as the previous output signal from fig. 6, and for the short duration variation the amplitude is 320. The start sample and the stop sample have the same values as the previous output signal.

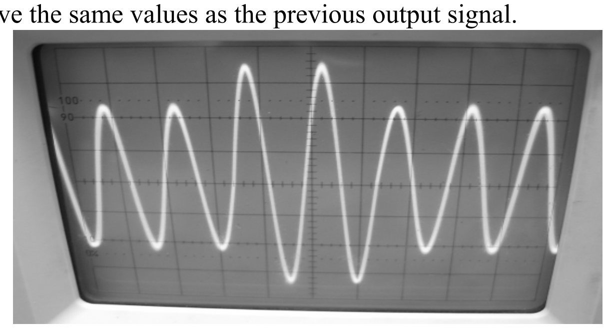


Fig. 7. Sinusoidal signal containing an overvoltage

The sinusoidal signal disturbed with a rectangular sag of Figure 8, it is obtained by using the same values for sinusoidal signal parameters as in the amplitude of previous case. The only difference is the short duration variation which is 132.

The signal from Fig. 9 is obtained by introducing for the sinusoidal signal the following parameters: frequency, sampling frequency, number of periods with values 50, 40000 Hz, 30. The sag fronts have the following amplitudes, durations and rise times [0.6 0.5 0.75 0.76 1], [0.014 0.078 0.0062 0.0303 0.0052] and [10 60 5 25 3].

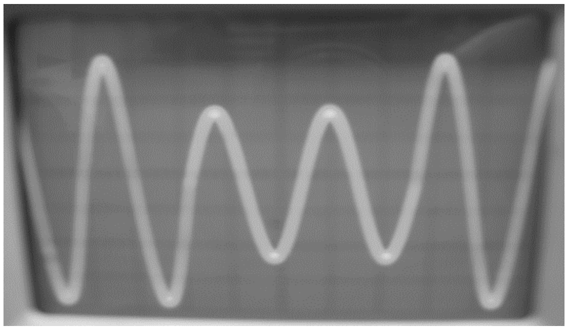
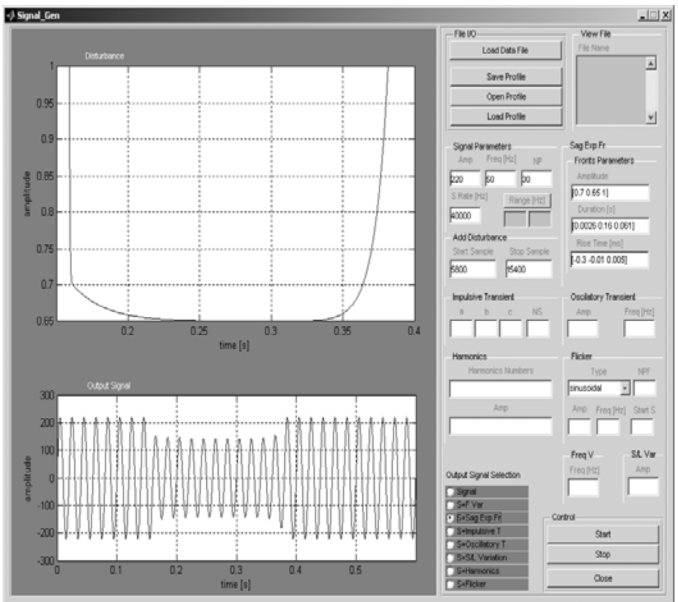
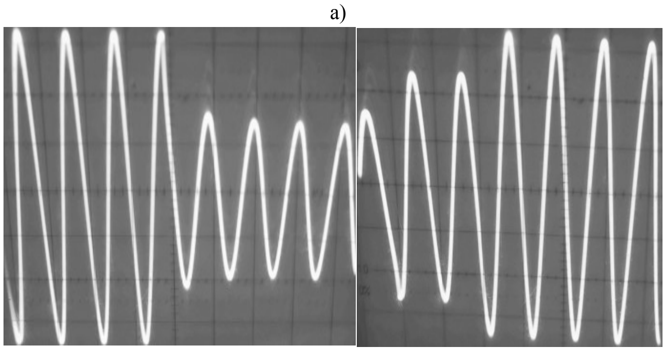


Fig. 8. Sinusoidal signal disturbed with a rectangular sag



a)



b) c)

Fig. 9. Sinusoidal signal containing a sag with exponential fronts

The signal from Fig. 10 is a disturbed sinusoidal signal with the third order harmonic obtained by using the same parameters for sinusoidal signal as in the previous cases and the amplitude for the third harmonic is 70.

The sinusoidal signal disturbed with the third and the fifth harmonic from next figure it is obtained, after the selection of the signal type, by using the parameters amplitude, frequency, sampling frequency, number of periods with values 220, 50, 10000, 4, and the amplitude for the harmonics are 50, 30.

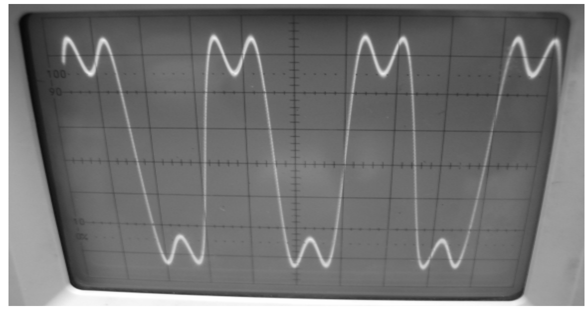


Fig. 10. Disturbed sinusoidal signal with the third harmonic

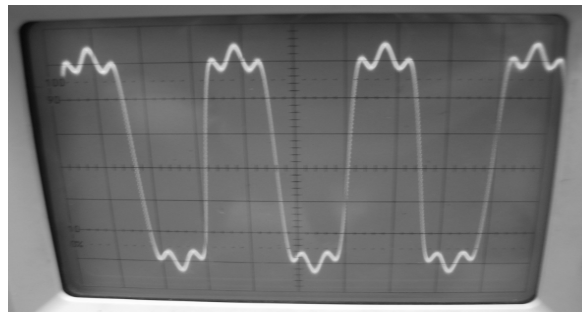


Fig. 11. Disturbed sinusoidal signal with the third and fifth harmonic

The Figure 12 shows a sinusoidal signal containing a region (beginning at a start sample and lasting until the stop sample) a few ascending frequency variations between 50 Hz to 60 Hz (specified under the name Freq V in GUI).

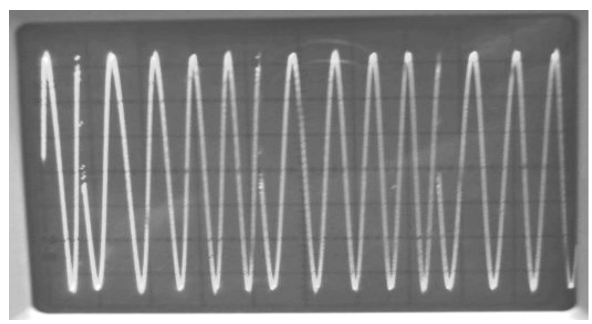


Fig. 12. Sinusoidal signal containing frequency variations

The sinusoidal signal disturbed with a flicker from Figure 13 it is obtained by using the sampling frequency and number of periods with values 44000 and 40, for flicker the type is sinusoidal and the amplitude, the frequency, the start sample and the number of flicker periods are 8, 9, 1 and 8.

The parameters values used to obtain the signal from Figure 14 are the same as in the previous case, the only difference is the flicker type, which is rectangular here.

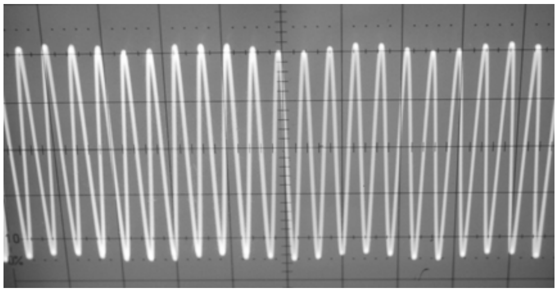


Fig. 13. Flicker with sinusoidal variation

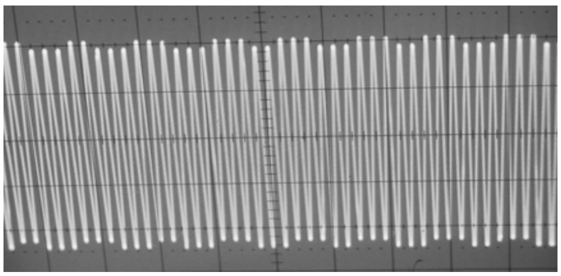


Fig. 14. Flicker with rectangular variation

The power quality monitoring systems are used to obtain data about the power quality, the disturbances causes and the identification of the conditions which can produce equipment faults or destructions. They are used to avoid these events, and they are useful for both categories, suppliers and consumers.

This virtual signal generator is useful for the development of the power quality monitoring systems, where after the implementation, a step by step testing of its modules is necessary, by using sinusoidal signals which contain electromagnetic disturbances (the output range of a sound card is [-1V, 1V], signals with higher amplitudes can be obtained by using an amplification circuit), for didactic purposes or for research in order to better understand the electromagnetic disturbances effects from power supply voltage.

VIII. Conclusions

The algorithms presented in previous sections, integrated in a virtual signal generator, allow the generation of electromagnetic disturbances with any desired waveshape without the building, the dimensioning and the simulation of electric circuits in Simulink or other simulation software applications. Consequently the time needed decreases and there are obtained real electrical signals useful for the development of a power quality monitoring systems, for didactic and research purposes.

To acquire real signals from the power supply network, expensive conditioning circuits are necessary which are not needed for the virtual signal generator.

The user-friendly interactive GUI allows the easy selection of the parameters for the desired output signal by the users with low level of knowledge in the field of electromagnetic disturbances and programming. The selecting flexibility being restricted only by the input/output range limited at [-1V, 1V] and by the maximum sampling frequency. In order to obtain signals with higher amplitudes a data acquisition board or an amplification circuit can be used.

IX. References

[1] A.M. Alkandari, S.A. Soliman, "Measurments of Power System Nominal Voltage and Voltage Flicker Parameters ", *International Journal of Applied Engineering Research*, vol. 2, no.4, pp. 721-735, 2007.

[2] M. Azam, F. Thu, K. Patipati, R. Karanam, "A Dependency Model Based Approach for Identifying and Evaluating Power Quality Problems", *IEEE Trans. Power Delivery*, vol. 19, no.3, pp. 1154-1166, 2004.

[3] M.H.J. Bollen, I.Y.H. Gu, *Signal Processing of Power Quality Disturbances*, John Wiley & Sons, 2006.

[4] G. Diez, L. I. Eguiluz, M. Manana, J. C. Lavandero, A. Ortiz, “Instrumentation and Metodology for Revision of European Flicker Threshold”, in Proc. 2007 PowerTech.

[5] R.C. Dungan, M.F. McGranaghan, S. Santoso, H.W. Beaty, *Electrical Power System Quality*, McGraw-Hill, 2004.

[6] C. Golovanov, *Probleme moderne de măsurare în electroenergetică*, Bucureşti: Editura Tehnică, 2001.

[7] G. Găşpăresc, C. Dughir, "Building A Transient Disturbances Generator With Graphical User Interface in Matlab," *Scientific Bulletin of the "Politehnica" University of Timişoara, Trans. on Electronics and Telecommunications*, vol. 51(65), pp. 49-52, Sep. 2006.

[8] A. Ignea, Introducere în compatibilitatea electromagnetică, Timişoara: Editura de Vest, 1998.

[9] M. Iordache, I. Conecini, Calitatea energiei electrice, Bucureşti: Editura Tehnica, 1997.

[10] M. Kezunovic, "Intelligent Applications in Substations: Disturbance Analysis", in *Proc. 2004 IEEE* PES General Meeting, pp. 719-723.

[11] J. Schlabbach, D. Blume, T. Stephanblome, Voltage Quality in Electrical Power System, The Institution of Electrical Engineers, 2001.

[12] C. C. Shen, A. C. Wang, R. F. Chang and C. N. Lu, "Quantifying Disturbance Level of Voltage Sag Events", in *Proc. 2005 IEEE* PES General Meeting, pp. 2314-2318.

[13] D. J. Won, I. Y. Chung, J. M. Kim, S. I. Moon, J. C. Seo, J. W. Choe, "Development of Power Quality Monitoring System with Central Processing Scheme", in *Proc. 2002 IEEE* PES General Meeting, pp. 915-919.

[14] http://powerquality.com.

[15] www.cda.org.uk.

[16] www.lpqi.org.

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