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VIRTUAL INSTRUMENT FOR MODELLING AND MEASURING THE DISTORTING STATE

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ABSTRACT

This paper presents a virtual instrument developed in LabView for modeling generating a distorting voltage by adding harmonics with different level and phase to the base signal. The other virtual instrument models the single-phase power system and calculates the power and energy proper to the harmonics. The virtual instrument can be enlarged very easy for three-phase power system. Developing proper conditional circuits for current and voltage acquisition the virtual instrument can be modify to measure real data. The designed virtual instrument calculates from the acquired data the active and reactive power, the power factor and the frequency and level of the harmonics in case of non-sinusoidal signals.

Keywords: virtual instrument, distorting state, harmonics spectrum, power measuring

1. Introduction

The energy is the most important staple in all categories of activity. The quality of energy affects the right use and function of different instruments, devices and equipments. Because of nonlinear characteristics elements and/or nonlinear function of different equipments the current and voltage curves will be distorted and this propagates in the supply net and that will be influenced and distorted. In a harmonic polluted electrical network increase the active power losses, occurs over voltages and over currents, appears over heating and abnormal functions.

It is important to known the elements and circuits with nonlinear characteristics, the type of introduced harmonics, the possibility to measure and eliminate them.

The accurate measurements and right uses of power and energy is an important requirement for both any energy consumers and energy producers too. The power and energy are measured in DC and AC circuits, one-phase systems and three-phase systems, at industry and/or high frequencies. In all cases the precision of the measurements depend on the used method, the sample rate, the used equipments and the calculation ability.

There are a lot of quantities and characteristics through which the quality of power and energy can be determinate.

In a one-phase system the relations for the active power P and reactive power Q are:

$$P = U \cdot I \cdot \cos\alpha \qquad (1)$$
$$Q = U \cdot I \cdot \sin\alpha$$

The electronic instruments determine these values using the definition and work with continuous signals.

$$P = \frac{1}{T}\cdot\int_0^T p(t)dt = \frac{1}{T}\cdot\int_0^T u(t)\cdot i(t)dt = \frac{1}{T}\cdot\int_0^T U_m\sin(\omega t)\cdot I_m\sin(\omega t+\alpha)dt \qquad (2)$$

In a digital measurement system the relations used for power measurement are different because it works with discrete signals. The integral is replaced with a sum of product between a voltage and a current sample and the time interval for witch we calculate the active power, the average value, can be selected as one or more period of the signal.

$$P = \frac{1}{n}\sum_1^n u(t_k)\cdot i(t_k) \qquad (3)$$

Where $u(t_k), i(t_k)$ are the voltage and current samples at the moment t_k and n are is the number of samples for the chosen time interval.

For the apparent power the relations change as follow:

$$S^2 = U_{ef}^2 \cdot I_{ef}^2 \Rightarrow$$
$$S^2 = \frac{1}{n^2}\cdot\sum_1^n u_k^2 \cdot \sum_1^n i_k^2 \qquad (4)$$

The reactive power Q is obtained from:

$$Q^2 = S^2 - P^2 \qquad (5)$$

In case of distorted signal or sinusoids in noise the above mentioned relations aren’t useful and it is important to know the properties and nature of the harmonics. [1], [2], [12], [15] The distorted signal, voltage or current, can be written as a sum of sinusoidal components, using the Fourier series:

$$i(t) = I_0 + \sum_{n=1}^{\infty} I_n \sin(n\omega t + \alpha_n) \quad (6)$$

Where for *n=1* we obtain the fundamental signal and for *n≥2* we obtain the harmonics. This leads to the following relation for the active power.

$$P = P_0 + \sum_{n=1}^{\infty} P_n = RI_0^2 + \sum_{n=1}^{\infty} RI_n^2 \quad (7)$$

The relationship is quite if *R* is linear and doesn't depend on current or voltage. The reactive power has also more components:

$$Q = \sum_{n=1}^{\infty} Q_n = \sum_{n=1}^{\infty} U_n I_n \sin(\alpha_n) \quad (8)$$

In this case the expression for the apparent power becomes:

$$S^2 = \sum_{n=0}^{\infty} U_n^2 \cdot \sum_{n=0}^{\infty} I_n^2 = P^2 + Q^2 + D^2 \quad (9)$$

Where *D* is the distorting power and depends on the harmonic's level and phase difference.

$$D^2 = \sum_{\substack{k,j=1 \\ k \neq j}}^{\infty} \left(U_k^2 I_j^2 + U_j^2 I_k^2 - 2U_k U_j \cos\varphi_{kj} \right) \quad (10)$$

In some cases we can use instead of the upper expression more simple relations, in following cases: if the voltage is a sinusoid or the distorting coefficient $k_{du} \leq 20\%$:

$$D \approx U_{ef} \cdot I_d \quad (11)$$

If the voltage is non-sinusoidal and $k_{du} \geq 20\%$, the distorting power can be calculated:

$$D \approx U_{ef} \cdot I_d + U_d \cdot I_{ef} \quad (12)$$

Where I_d and U_d are the deforming residue for current and voltage of the periodical non-sinusoidal signal [1],[5].

The deforming residue for a non-sinusoidal voltage is determinate through the following relationship:

$$U_d = \sqrt{U_{eftot}^2 - U_{ef1}^2} \quad (13)$$

For the distorting state we can calculate a fictive power defined as:

$$W = \sqrt{S^2 - P^2} = \sqrt{Q^2 + D^2} \quad \text{[VArd]} \quad (14)$$

The distorting state can be characterized using different indicators, such as shape coefficient, peak coefficient, distortion coefficient, harmonics level, current or voltage deviation coefficient and telephonic influence indicator. These indicators can't be used separately because can give wrong results.

In a three-phase system the active power and the reactive power is:

$$P_{tr} = 3P_{faza}$$
$$Q_{tr} = 3Q_{faza} \quad (15)$$

The distorting power and the fictive power are smaller:

$$D_{tr} < 3D_{faza}$$
$$W_{tr} < 3W_{faza} \quad (16)$$

In the same way the total apparent power in a three-phase system functioning in distorting state is less then the sum of the apparent powers for phases:

$$S_{tr} = \sqrt{P_{tr}^2 + Q_{tr}^2 + D_{tr}^2} < 3S_f = 3U_{ef} I_{ef} \quad (17)$$

For consumers an important characteristic is the power factor. In one-phase system functioning in distorting state the power factor is determinate by:

$$k_P = \frac{P_f}{S_f} = \frac{P_f}{\sqrt{P_f^2 + Q_f^2 + D_f^2}} \quad (18)$$

From this relationship results the power factor depends on the distorting state caused by the load, and is less even if the load has no reactive power consumption.

In a three-phase system functioning in distorting state and consider the 17 relationship the power factor is larger:

$$k_{Ptr} = \frac{P_{tr}}{S_{tr}} = \frac{3P_f}{S_{tr}} > k_P \quad (19)$$

The accurate determination of the power factor can be made by special instruments, static energy-meter data acquisition systems or by power spectrum determination [1], [11], [13].

2. Virtual instrument for distorting voltage generation

Studying different phenomenon we consider for the variation mode a perfect sinus variation mode. In reality over the useful signal overlaps a noise. If the noise effect is neglected an idealization of the measuring signal is made, but this causes less accuracy in the measuring process.

Using circuit elements with non-linear characteristic and circuits, equipments which operate in anomalous conditions cause a non-sinusoidal current or voltage. The analysis of non-sinusoidal signal is made using Fast Fourier Transform (FFT). Each non-sinusoidal or distorted signal can be written as a sum of sinusoidal signal having different amplitudes and frequencies. [4], [10]

$$x(t) = C_0 + \sum_{n=1}^{\infty} [S_n sin(n\omega t) + C_n cos(n\omega t)] \quad (20)$$

To generate different signals with different characteristics the expression of Fourier coefficient was used:

$$C_0 = \frac{1}{T} \int x(t)dt$$
$$S_n = \frac{2}{T} \int x(t) sin(n\omega t)dt$$
$$C_n = \frac{2}{T} \int x(t) cos(n\omega t)dt \quad (21)$$

It is important to know that the generated signals are numerical signals; they are represented by a series of points and numbers. The numbers of points used to represent a signal form decide the precision of the signal shape. So an important input to generate the signal is *nr.point/per*. [3], [14]

It can be set the *frequency* in [Hz] and the *length* in [sec] of the signal. The length of the signal represents the time length in which the signal will be generated.

The developed virtual instrument let as to switch between a sinusoidal signal generation mode and a distorted signal generation mode. [6]

The front panel of the virtual instrument is presented on figure 1. On the waveform graph can be fallowed how change the signal by adding different harmonics with different amplitude and phase. The power spectrum of the distorted signal is plotted on the waveform graph near by. The phase of the harmonic has no influence on the amplitude spectrum but modifies the waveform shape and some coefficients characteristic to the distorting state. Using this virtual instrument can be study the most important distorted current or voltage forms. In industrial networks appear $(2k+1)f_0$ harmonics (f_0=50Hz).

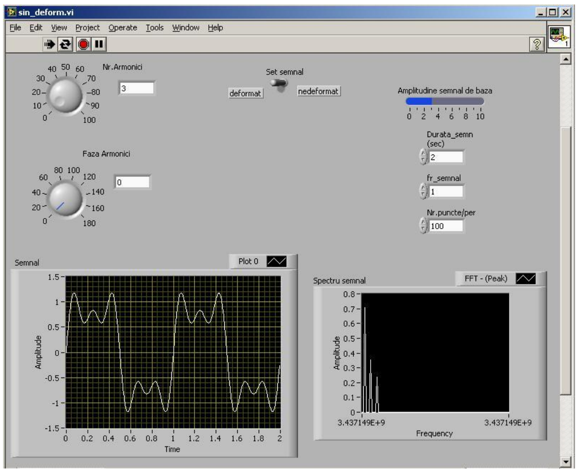

Fig.1. Front panel of the virtual instrument to generate distorted signal

The block diagram of the virtual instrument is presented on the figure 2. The external *For loop* establish the time moments t_k to calculate the signal $x(t_k)$. The inner *For loop* calculates the Fourier coefficients. The *Formula Node* is used to generate the base signal and the harmonics. [3]

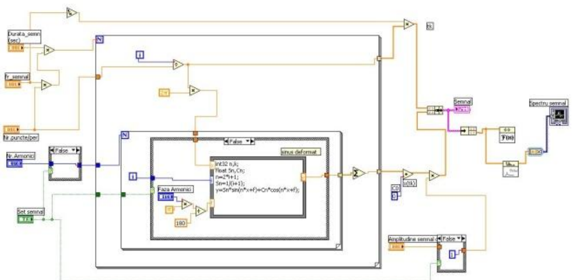

Fig.2. Block diagram of the signal generator

The presented case refers to the situation when the third harmonic appears over the base signal.

3. Virtual instrument for harmonic determination

There are a lot of circuits and circuit elements, with non-linear characteristics (iron core coils, motors, and switched-mode power supply) which supplied with sinusoidal voltage will lead to a distorting current. To analyze this distorting state and to determine the harmonics and the distorting power there was developed a virtual instrument in LabView using a PCI6221 data acquisition board. [6], [7]

The signals corresponding to the voltage and current are captured by a voltage transformer and a LEM type current sensor. The transformation rations are determined by transformation factors which can be changed any time (from the front panel) if we change the sensors. The instrument has two parts; the main part acquires the signals, calculates the effective values, powers and energies and determines the power spectra of the distorting current. The other part was made to simulate the distorting state, to verify the formula used at the calculations and for calibration.

Figure 3 shows the front panel for the current harmonics in case of a switched-mode power supply.

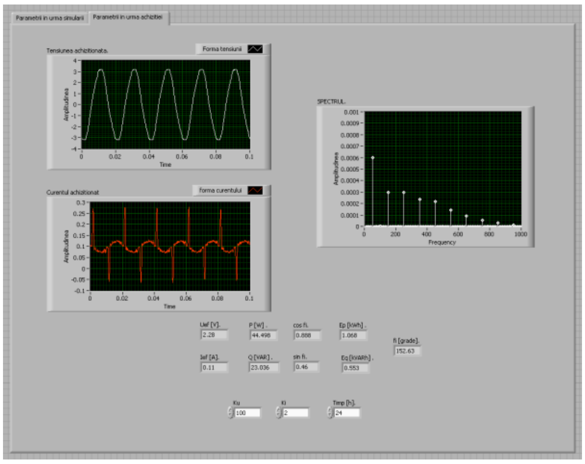

Fig.3. Virtual instrument's front panel for harmonic determination

The main part of the program determines also the phase difference between voltage and current, and calculates the energy for a given time.

Verifying the used formulas and the calibration of the instrument was made in more different ways. First there was developed a virtual instrument with the simulation of the sinusoidal and distorting signal sources, which determines the required parameters and powers (P, Q, D). The distorted current source can be set by the user so the modification of the spectra can be followed. The front panel of the virtual instrument to simulate a distorted current with different parameters is presented on figure 4. The interchange of the instruments (simulation, data acquisition) is made by a tab using a case structure. At the acquisition of the real signals, voltage and current, there were connected different loads: resistive, inductive, switching power supply, etc. and parallel with the developed data acquisition circuit precision digital instruments was used to measure the required powers. To compare the harmonics in the case of a distorting signal, a spectra analyzer (QualistarPlus) was connected to the load's supply wires.

The correction factor, the transformation rate for the voltage k_u was set to 100. In this way if the effective value of the voltage is 230V we shall measure 2.3V. The correction factor for the current was determined starting from the transformation rate of the LEM sensor which is 50A/25mA. The serial connected R_M resistor is 1kΩ, so for a 25mA secondary current we shall have a 2.5V voltage, corresponding to 50A primary current, so the transformation rate is k_i=2.

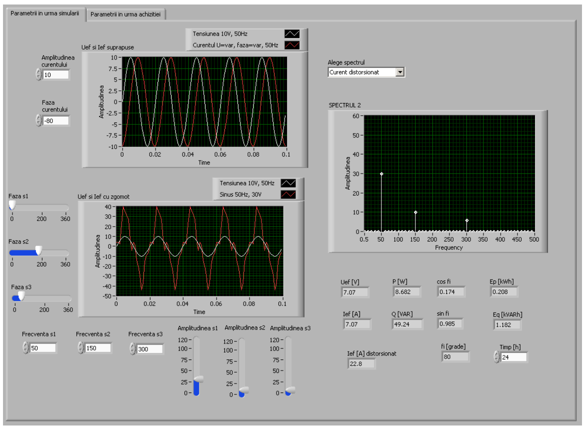

Fig.4. Distorted current source simulation and harmonics

The bloc diagram of the virtual instrument, for real signal processing, is presented on figure 5.

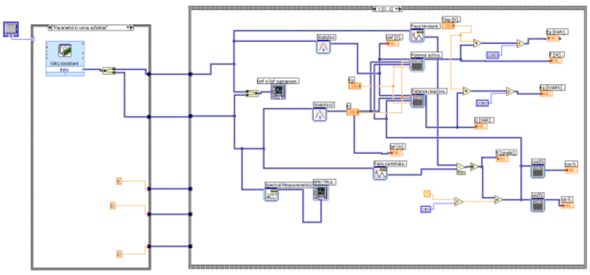

Fig.5. Bloc diagram of the virtual instrument

Real data and simulated data are processed in different way. The selection one or other of the two is made by the same tab using structure format.

4. Signal conditioning circuits

To measure real data a PCI6221 data acquisition board was used. To wiring the measured signals to the data acquisition board we need signal conditioning circuits, which allows adapting the amplitude and impedance. We use voltage a current transducers for measuring this quantities in an industrial network.

Figure 6 presents the voltage transducer's circuit.

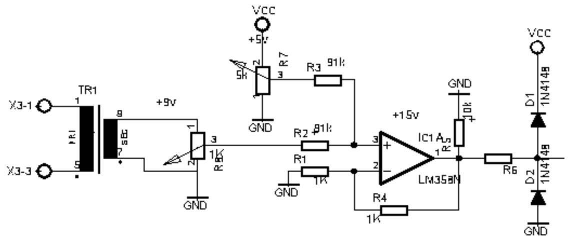

Fig.6. Voltage transducer's circuit

In a single-phase system where the power and energy will be measured has 230V effective voltage and max. 5A. To bring the network's voltage in the measurement system's voltage interval we use a 230V/9V transformer then a resistive divisor. To shift this voltage in 0-5V interval an OA was used [8].

The current sensor is a closed loop Hall effect LEM transducer LA55-Ptype. The closed loop transducers use the Hall generator voltage to create compensation current in a secondary coil to create a total flux, as measured by the Hall generator, equal to zero. In other words, the secondary current, I_S, creates a flux equal in amplitude, but opposite in direction, to the flux created by the primary current. This zero flux condition eliminates the drift of gain with temperature. Inserting a measurement resistor, R_M, in series with the secondary coil creates an output voltage that is an exact image of the measured current. The selected sensor is 50A/25mA. To have 5V at the output by 5A input the inserted resistor is 20kΩ. [9]

The same shift circuit is used to translate the voltage given by the current sensor in the 0-5V interval.

The current sensor and the conditioning circuit are shown on figure 7.

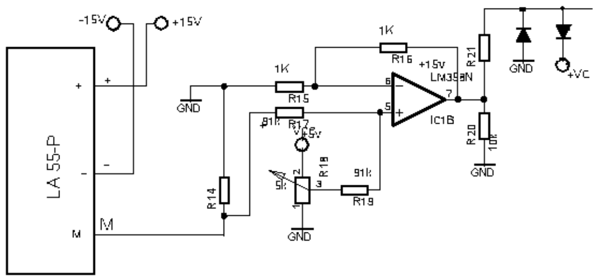

Fig.7. Current sensor and conditioning circuit

A very important requirement is to have both voltage and current sample at the same time, because the measurements and calculations of the different values are made based on the relationship 2 and every difference between the too samples leads to errors. In this case the used data acquisition board has one A/D converter and the voltage and current are sampled successively, the time difference between the two samples must be small as possible.

At the industrial frequency (T=20ms) the approximately 20μs time delay between the voltage and current sample can be neglected. In another way a signal with a frequency 50Hz must be sampled at least with 5 kHz. In this case the sample frequency is set to 20 kHz in the DAQ assistant window (for PCI6221) of the virtual instrument.

5. Conclusions

In this paper there are presented the changes of the powers in a single-phase and three-phase system working in the distorting (non-sinusoidal) state. Two virtual instruments were developed; one for distorted signal generation, to follow the waveform shape modifications by adding harmonics with different amplitude and phase. The other virtual instrument allows the powers measurement and establishes the amplitude spectra in the case of the distorting voltage and current. The data acquisition system was tested in a circuit with resistive and inductive load and was compared with an electrodynamics power measurement instrument having 0.5% precision. The difference was zero by resistive load. The verification in the distorting case was made by an energy quality measurement instrument (QualistarPlus).

The developed virtual instrument in LabView using a data acquisition board allows more flexibility, easy changes possibilities, it is easy to follow the quantities and let as to use directly the definition relationships.

Further developments of the measurement system will be the expansion of the system to monitoring the different characteristics related to the waveform shape and distorting level; and will allow the measurement of the powers in three-phase system and show the phase diagram to.

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