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NONLINEAR CIRCUIT ELEMENTS INFLUENCE ON THE POWER NETWORK

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Abstract

This paper presents the most important nonlinear circuit elements, the equivalent circuits and the causes of nonlinearity. This is important because the power quality in the power network is strongly influenced by the nonlinear characteristics of the elements and nonlinear functions of different equipments. Some circuits and circuit elements, transformers, induction motors, frequency converters, were studied. The voltage and the current waveform were analysed and the frequency spectra were shown to establish the most considerable harmonics. It is important to study the nonlinear circuits and analyze the harmonic spectra of the distorted current for different inductive load to design the right filter for reducing or eliminating the harmonics. The theoretical background of the distorting state is also presented, what kind of losses appear, and how these losses influence the harmonics. It is shown the reason for what coil and capacitor have nonlinear characteristics and by what is expressed.

Keywords: nonlinear circuit elements, distorting state, power quality, harmonic spectra

1. Introduction

The energy and the power supply quality is a very important component in most categories of activity. The quality of energy affects the right function of different devices, equipments and instruments. Because of nonlinear characteristics elements and/or nonlinear function of different equipments the current and voltage waveforms will be distorted and this propagates in the supply net and that influences the voltage in the network. In a harmonic polluted electrical network the active power losses increase, over voltages and over currents occur, overheating and abnormal functions appear. It is important to know the elements, circuits and equipments with nonlinear characteristics, the introduced harmonics, to design the suitable circuits to reduce or to eliminate them. [12]

The energy and power quality is important for consumer and provider too. It is an important requirement of consumer to ensure the quality of the energy in normal limits, becausethe modern equipments are sensible to energy changes and disturbances. The energy and powerare determinated through voltage and current, so these define the quality of these too. The evaluation of the voltage and the current are made through indicators whose values are established based on specific requirements and standards. The efficiency of industrial activities depend largely on supply voltage,whose variations must be within acceptable limits. [4]

The power quality defined by the users'side contain characteristics of the power supply which enables a proper work of equipments. Any distortion or variation in voltage, current or frequency may cause failure. Today the electricity is considered a basic right, and should be present always with optimal characteristics. [1], [2] ,[3]

In many cases the customers' equipment and devices are the causes of the voltage or current variations. The power electronic equipments have become more sensitive to voltage disturbances, and cause disturbances for other users too. The different power electronic equipments, nonlinear loads, switching power supply, electrical motors deforms the current signal which propagate in electric network. The produced electromagnetic disturbances affect the power quality at other consumers. The consumers must monitorand diminish their own disturbance. So the power quality problem can be solved through collaboration between energy suppliers and customers.

To avoid the misunderstandings referring to the power or energy quality, indicators have been determinated, and performance criteria have been standardized. The standardization is important because there are a lot of energy producers and energy suppliers. At the same time there are used modern data acquisition systems for continuous voltage and current monitoring to determine the disturbances and distorting cases. The adopted standads related to the power quality handle and define these disturbances and fluctuations both in time domain and frequency domain. [2], [6]

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

In case of distorted signal or sinusoids in noise due to nonlinear circuits the ever known relations cannot be used.

The distorted current signal can be written as a sum of sinusoidal components, using the Fourier series:

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

Where for *n=1* we obtain the basic component and for *n≥2* we obtain the harmonics of the current, I_0 is the constant component. The relation to determinate the total active power changes also:

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

The relationship is good if the load is linear and doesn't depend on current or voltage. The total reactive power can be written as a sum of components suitable for each harmonic:

$$Q = \sum_{n=1}^{\infty} Q_n = \sum_{n=1}^{\infty} U_n I_n \sin(\alpha_n) \quad (3)$$

For the distorting case the expression of the apparent power contains another term corresponding to the harmonics:

$$S^2 = \sum_{n=0}^{\infty} U_n^2 \cdot \sum_{n=0}^{\infty} I_n^2 = P^2 + Q^2 + D^2 \quad (4)$$

The distorting power D [VAD] depends on the harmonic's level and phase difference.

$$D^2 = \sum_{\substack{k,j=1 \\ k \neq j}}^{\infty} \left(U_k^2 I_j^2 + U_j^2 I_k^2 - 2U_k U_j \cos\varphi_{kj} \right) \quad (5)$$

Where U_k, U_j, I_k, I_j are the different voltage and current harmonics through the load.

In some cases the distorting power can be approximated with I_d and U_d which are the deforming residues for current and voltage of the periodical non-sinusoidal signal [1], [3], [5].

Different indicators are used to describe the distorting state, shape coefficient, peak coefficient, distortion coefficient, harmonics level and frequency, current deviation coefficient. These indicators can't be used separately because can give wrong results.

An important characteristic, which is given by all measurement instruments, is the power factor. In distorting state the power factor depends on the level of distorting power:

$$k_P = \frac{P_f}{S_f} = \frac{P_f}{\sqrt{P_f^2 + Q_f^2 + D_f^2}} \quad (6)$$

Another important characteristic is the Total Harmonic Distortion (THD), which shows how much of the distortion is due to the harmonics in the signal. In power network the THD must be low as possible. THD is defined as the ratio of the equivalent root mean square current (RMS) of all the harmonic frequencies I_{efn}, over the RMS current of the basic frequency I_{ef1}.

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} I_{efn}^2}}{I_{ef1}} \quad (7)$$

THD and power factor are dependent on each other, in power systems low THD means high power factor. [3],[13]

2. Nonlinear circuit elements

There are a lot of circuit elements with nonlinear characteristic. The circuit elements resistance, coil and capacitor are real elements with losses and can be replaced through equivalent circuits. These equivalent circuits include all parameters that appear during operation. For this reason and because some parameters are depending on current or voltage value, the real circuit elements have nonlinear characteristics. These circuit elements powered with a sinusoidal voltage distort the current signal and in addition to the basic signal harmonics appear. To each harmonic coresponds a power consumption. [9], [10]

A frequently used element is the inductance, which is present in many forms in a lot of devices and circuits. An inductance with ferromagnetic core in addition to the proper inductivity present the resistance of the wire, an equivalent capacitor due to turns, capacitors to the gound, a resistor due to the losses in core through foucault current and a resistor due to the nonlinear characteristic B=f(H) of the core. The equivalent circuit for a real inductance is presented on figure 1.

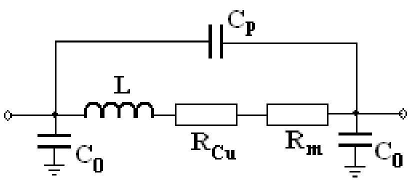

Fig. 1: The equivalent circuit for an inductance

All materials used for the core of the inductance have a nonlinear characteristic in alternating case, thanks to the lag phenomenon between magnetic induction B and magnetic field H. This is indicated through the cycle of hystheresis of the magnetic material. The relative magnetic permeability is a complex quantity.

$$\underline{\mu}_r = \frac{1}{\mu_0}\frac{\underline{B}}{\underline{H}} = \mu_r' - j\mu_r'' \qquad (8)$$

The impedance of the real inductance includes the relative magnetic permeability too.

$$\underline{Z}_L = R_{Cu} + j\omega\left(\underline{\mu}_r L\right) \qquad (9)$$

Likewise the capacitor is a nonlinear circuit element also. The nonlinearity is due to the dielectric material in which appears the polarisation and the electrical induction D is delayed behind the variation of the electrical field E. The capacitor presents losses suitable for leakage current through dielectrical material. The equivalent circuit for a real capacitor is presented on figure 2.

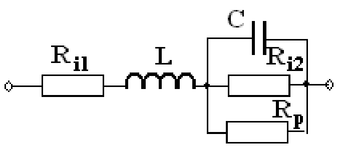

Fig. 2: The equivalent circuit for a real capacitor

R_{i1}, L, R_{i2} models the imperfection of the dielectric material and R_p models the power losses.

The relative electrical permittivity is also a complex quantity.

$$\underline{\varepsilon}_r = \frac{1}{\varepsilon_0}\frac{\underline{D}}{\underline{E}} = \frac{1}{\varepsilon_0}\frac{D}{E}e^{-j\delta} = \varepsilon_r' - j\varepsilon_r'' \qquad (10)$$

Where δ is the delay angle between the electrical field E and electrical induction D, $tg\delta$ indicate all losses and it is an important characteristic of large capacitors used in power circuits.

The inductance and capacitor are reactive power consumer and the uncontrolled reactive power flow causes voltage deviations.

The capacitor batteries are used to bring the power factor to admissible value. But these remain coupled after the load is disconnected and distorts the voltage signal. The capacitor batteries coupling are followed by transient states, which produce other types of disturbances.

Beside these two circuit elements there are circuits which contain electronic devices with nonlinear characteristics, diodes, transistors, thyristors, or there are circuits which are functioning in switching mode. In normal state functioning, powered with sinusoidal voltage, the current will be distorted and additional power consumption appears.

3. Distorted current analysis

For studying and processing the current and voltage signal form, a power quality measurement instrument was used.

The Qualistar Plus CA8335 instrument is an electrical network power and quality analyzer and can be used for quick testing of electrical network and effective analysis of the results. The instrument can be connected to the PC and using the DataView software the measured quantyties can be downloaded and analyzed. [8]

Several loads were monitored and the current signal was processed. The most important were transformers, electrical motors, computers, frequency converters.

The voltage and current waveform for a transformer with no load is presented on figure 3. The voltage is sinusoidal, but the current waveform is distorted showing the presence of the third harmonic which is confirmed by the frequency spectra on the figure 4. The 5th harmonic has a considerable influence. The THD is also very high.

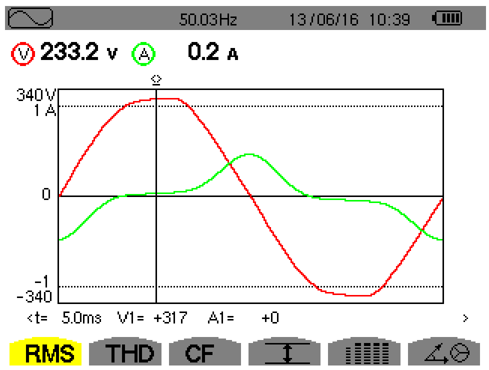

Fig. 3: The voltage and current waveform for a transformer

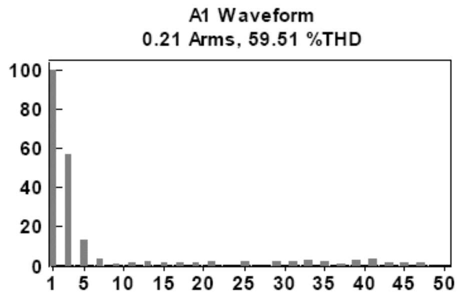

Fig.4. The frequency spectra of the current through a transformer.

In many applications a drilling machine is used. Figure 5 and 6 shows the current waveform and the frequency spectra of the current.

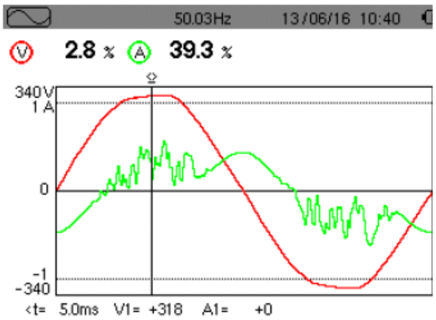

Fig. 5: The absorbed current for a drilling machine

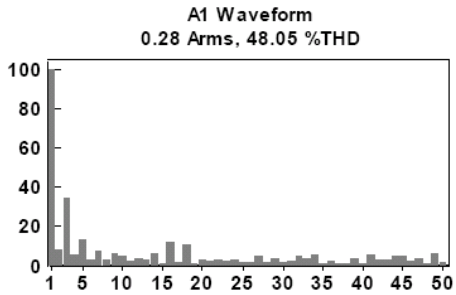

Fig. 6: The frequency spectra in case of a drilling machine

The autotransformer is also an often used circuit element. The load in the secondary can be resistive or inductive. Figure 7 shows the voltage and current signal of an autotransformer with resistive load and figure 8 shows the frequency spectra of the current.

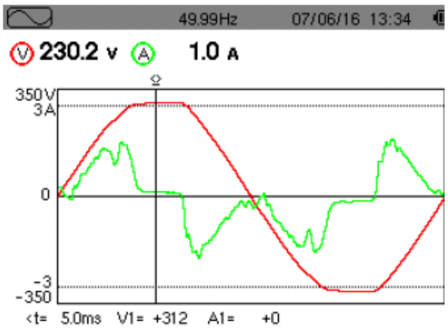

Fig. 7: The voltage and current waveform for an autotransformer

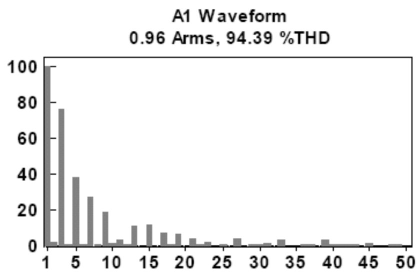

Fig. 8: The current's frequency spectra

If the load is inductive, the current is more distorted and THD is very high. Figure 9 and 10 present the waveforms for this case.

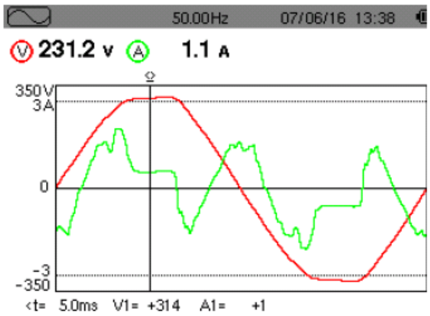

Fig. 9: The voltage and current waveform for an autotransformer with inductive load

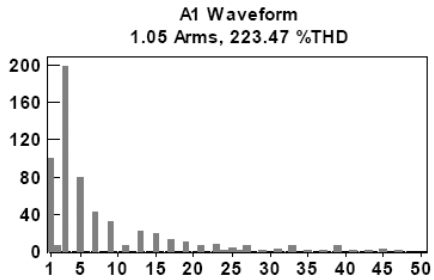

Fig. 10: The current's frequency spectra with inductive load

The frequency converters are very popular because they provide the speed control of the induction motor. For small motors the frequency converter is powered with 230V, but in general, in case of larger motors, they are powered from three-phase network with 380V.

If the motor is powered directly from the network, the power factor is very low 0.464, the THD is admissible, but the speed of the motor cannot be controlled. Using a power frequency converter the power factor is better, 0.614, but harmonics appeared and the THD is increased to 112.53%. Figure 11 and 12 shows the waveform of the current and the suitable harmonics.

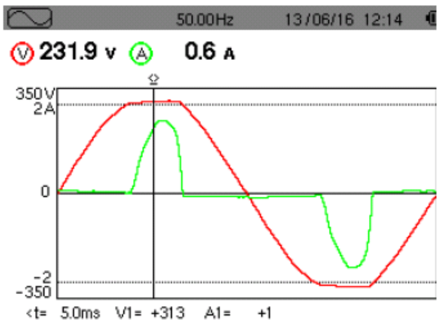

Fig. 11: The voltage and current waveform for a frequency converter

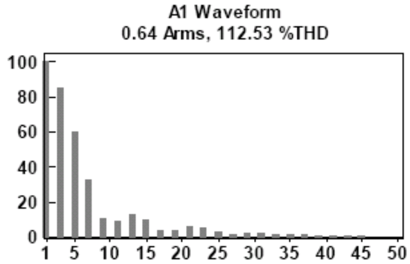

Fig. 12: The frequency spectra for the current

Analyzing these cases can be said that transformers and induction motors, both having coils and ferromagnetic material in their construction, distort hard the waveform of the current, harmonics of higher rank with significant amplitudes appearing. Similarly the frequency converters, even though there are benefits, cause distorting cases. For this reason they are delivered and used with filter to prevent the propagation of the harmonics in the net.

4. Conclusions

The power quality in the power network is strongly influenced by nonlinear characteristic elements and nonlinear functions of different equipments. It is important to study these circuits and analyze the harmonic spectra of the distorted current for different inductive load to design the right filter and to eliminate or reduce the harmonics.

It is also important to know the theoretical background of the distorting case, for what circuit elements have nonlinear characteristics, and what forms have they.

A couple of circuits and circuit elements were studied, the current waveform and the frequency spectra to show the most considerable harmonics. For all studied cases harmonics up to 20 ranks are important.

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