PARTICULARITY OF THE RESPONSE OF A POWER LINE IN MODULATION MODE IN TERMS OF AMPLITUDE, FREQUENCY AND PHASE ANGLE

PARTICULARITATEA RĂSPUNSULUI UNEI LINII ELECTRICE ÎN REGIM DE MODULARE ÎN TERMENI DE AMPLITUDINE, FRECVENȚĂ ȘI UNGHI DE FAZĂ

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Abstract: *The purpose is to analyze the similarity of the reaction of the power line at the random variations of voltage, frequency and phase angle in the permanent mode of the power line in alternating current. The research is based on the application of the theory of modulation of electrical signals in radio circuits. The possibility of analyzing the variation processes with the model of the single-tone modulator signal was argued. It has been shown that the similarity of the power line reaction to amplitude modulation or angular modulation is determined by the identity of the harmonic spectra of the modulated signal, regardless of the physical essence of the modulation process. The upper limit of the modulator signal frequency are below the frequency deviation limit of the power system.*

Keywords: amplitude, frequency, phase modulation, harmonic spectrum, frequency band, single tone modulation model, modulation index

Rezumat: *Scopul investigației constă în analiza similitudinii reacției liniei electrice la variațiile aleatoare ale tensiunii, frecvenței și unghiului de fază în regimul permanent al liniei electrice în curent alternativ. Cercetrea se bazează pe aplicarea teoriei modulației semnalelor electrice în circuitele radio. S-a argumentat posibilitatea analizei variației amplitudinii, frecvenței și fazei cu modelul semnalului modulator cu un singur ton. S-a demonstrat, că similitudinea reacției liniei electrice la modulația în amplitudine sau modulația unghiulară se determină de identitatea spectrelor de armonici ale semnalului modulat, indiferent de esența fizică a procesului de modulație. Valorile limita de sus a frecvenței semnalului modulator sunt sub limita deviației frecvenței sistemului electroenergetic.*

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Cuvinte cheie: modulație în amplitudine, frecvență, fază, spectrul de armonici, banda de frecvență, modelul modulației cu un singur ton, indice de modulație

1. Introduction

Unified power systems provide advantages in the security of electricity supply to final consumers, with the ability to adapt to random variations in load in different consumption nodes. Variations of load lead to deviations in the frequency of the energy system and to pulsations of active and reactive power that can affect the stability of the operation of the power system and the stability of the voltage in the electrical networks [1]. The disadvantage consist is the rapid spread of disruptions, which can lead to system accidents with power outages for consumers in large areas of the country [2, 3].

The variation in voltage and frequency over time leads to pulsations of the values of power flows in the electrical networks [4], as well as these pulsations can be conditioned by the development of the infrastructure element currently defined as “microgrid” [5] and the increase of intermittent generation in modern power systems [6].

Energetics development planning must be linked to the country's energy policy objectives and the capacity to achieve these objectives in the set terms [7 - 9]. Frequently, as a difficulty of promoting the concept of parallel operation of electric power systems is found the inconsistency of frequency maintenance standards in electric power systems, which would have benefits in parallel operation. Knowing the peculiarities of the reaction of power systems to variations in voltage and frequency over time may suggest new approaches to the problem of interconnection of both power systems and new structural elements of power systems such as "microgrids" for the formation of unified structures, to the increase of energy seciurity and efficiencyfor the consumer electricity.

The aim of this paper is to analyze the similarity of the reaction of the power line to random variations of voltage, frequency and phase angle in the time domain and establish the functional link of the indices, which characterize these types of modulation for the normal mode operation of the power line.

2. The phenomenon of modulation in electrical networks

Voltage and frequency fluctuations exist in any power supply system and occur due to load change, switching of generators, power lines or loads, etc. [10]. The development of increasing oscillations, conditioned by small load disturbances, can lead to changes in power flows in power lines, changes in operating parameters, as well as, in some cases, the creation of conditions for loss of operating stability (collapse of the power system). These phenomena are manifested by variations in voltage, frequency and power transmitted through the lines of the power system, including the interconnection lines at the interface of power systems.

The modulation phenomenon in the electrical networks is represented schematically in fig.1, in which the input signals are noted $u_1(t) \equiv p_{1(t)}$, output $u_2(t) \equiv p_2(t)$ and modulating signal (disturbing) $s(t) \equiv p_s(t)$. This structure it prezents the block diagram of the portion of the infrastructure used for the transmission of energy flow, which is modified over time by external and / or internal disturbances (fig.1). The amplitude, frequency or phase of the disturbing signal may be periodic, non-periodic, including random time functions.

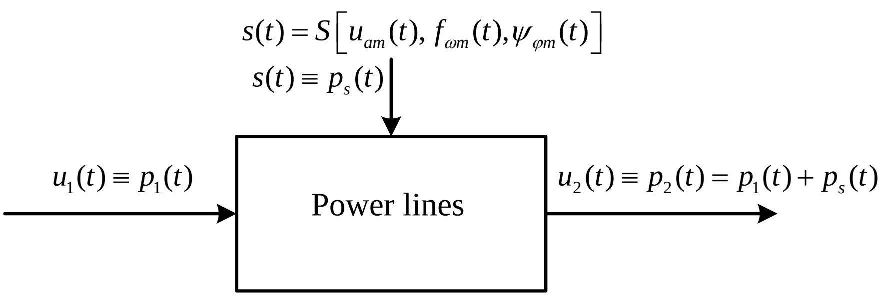

Figure 1. Electric line in disturbance mode

In this context, the analysis of the variation of frequency and voltage, which lead to fluctuations of power transmitted through electricity networks is of both scientific and practical interest for managing the operation of the power system at variable loads, including the development of optimal control algorithms with control equipment of the electrical networks regime.

Electrical signals can be classified according to several signs: deterministic and non-deterministic (random), periodic and non-periodic, etc. Measurable signals characterize both the parameters of the transmitted energy flows and the quality indices of electricity. Amplitude, frequency and phase values are used as measurable parameters. We will indicate the peculiarity, that in fact, the measured signals are generally random quantities, whose values have variations over time. These variations have an impact on the operating regime of the electricity networks and on the quality indices of the electricity transmitted through these networks.

In general, the effects that may occur due to the variation over time of the instantaneous voltage $u_{am}(t)$, frequency $f_{\omega m}(t)$ and the total phase $\psi_{\varphi m}(t)$ in power lines can be perceived as the reaction of the power line to the phenomenon of disturbance of the line regime by the modulating signal s(t). The function of the modulating signal can be presented by the operator S:

$$s(t) = S[u_{am}(t), f_{\omega m}(t), \psi_{\varphi m}(t)]. \quad (1)$$

Parameter $\psi_{\varphi m}(t)$ in relation (1) is defined as the total phase of the modulating signal $s(t)$. For the modulator signal $s(t)$ the instantaneous value of the angular frequency can be calculated using the relation [11]:

$$\omega_{\varphi m} = \frac{d\psi_{\varphi m}(t)}{dt} \quad (2)$$

In general, the instantaneous voltage of the electrical network in a network node is presented by relation:

$$u(t) = U_m(t)\cos\left[\omega(t)t + \varphi(t)\right], \quad (3)$$

in which $u(t)$ - the instantaneous value of the voltage; $U_m(t)$ - voltage amplitude; $\omega(t)$ - the instantaneous angular frequency of the voltage; $\varphi(t)$ - phase of the voltage.

The functions presented in relations (1) and (3) can be used to analyze the impact of various influencing factors, including, randomly, on the process of power transmission through power lines, including in the interconnection power lines of two power systems.

In order to obtain quantitative data that characterize the process of electricity transmission in a variation of parameters over time, it is useful to examine the particularities of the amplitude, frequency and phase modulation phenomena in power grid networks, which are random.

3. Generalities regarding the amplitude modulation phenomenon

Modulation of the signal amplitude in the linear circuit, for example, due to the variation of the voltage on the bars of the power plant or transformer station can lead to the appearance of low frequency subharmonics according to the mechanism for performing the amplitude modulation. In normal operating regimes of electrical networks these voltage deviations are limited to the level of ΔU=$\pm 5\%$; $\pm 10\%$ [12]. These values, depending on the rated voltage of the power line, can be accepted as limit parameters of the amplitude fluctuation in normal operation of the power grid. This restriction allows us to define the frequency band of the voltage amplitude modulation signal, using the durations of the prescribed time intervals for measuring the values of the permissible voltage deviations in the electrical networks [12].

The measurement standards of the electricity quality indices set out the procedures and conditions for carrying out the measurements, for example, for slow and rapid variations in voltage over time. Results of measurements performed over time with duration $t = 10$ min, which corresponds to the multiple time with 1008 periods of the AC mains voltage, are used in the experimental determination of the short-term flicker dose. Voltage aberration measurements are performed for time intervals of 2 hours and over a week. Measurements of voltage variation over large time intervals allow the detection and estimation of amplitude oscillation characteristics, which can be considered as characteristics of the amplitude modulation signal.

For example, those deviations, which are determined for shorter time intervals as $t \leq 60s$, are considered as rapid variations. The characteristic of the relative variation of the voltage is determined by measurements in observation periods exceeding 500 ms with the smallest time decreting step equal to 10 ms [13]. This requirement can be interpreted as a parameter of the time of rapid oscillation, for example, $T_{\Delta T} \geq 500ms$, which can be used as a reference to estimate the frequency value of the mains amplitude modulation signal. The maximum frequency of the modulating signal will be estimated from the relation $f_{\Omega u} = \frac{1}{T_{\Delta T}}$.

For rapid voltage variations with measurement duration $T_{\Delta T} \geq 500ms$, the angular frequency of the modulation signal will be equal to:

$$\Omega_u = 2\pi f_{\Omega u} = \frac{2\pi}{\Delta T} = 12.56\, rad/s \qquad (4)$$

Estimating the value of the modulator signal frequency based on the recommended time intervals for performing the measurements [12, 13] indicates that these frequencies will have a value below 12.56 rad / s. For example, the estimated value of the modulation signal frequency for the measurement time $T_{\Delta T} = 60s$ is equal $\Omega_u^{60} \approx 0.052\, rad/s$. These estimates of the upper limit of the modulator equivalent signal frequency can be used as primary data to determine the value of the frequency modulation coefficient due to the variation of the network voltage over time.

In the paper [14] are presented experimental data on the voltage variation in the 10 kV network, which shows that the period of slow voltage evolution is approx. 25 min. For this time interval (the period of the oscillation wave of the modulating signal $T_{\Delta T} \approx 25\, min = 1500\, s$), the amplitude modulation wave oscillation will have the value of $\Omega_u = \frac{2\pi}{T_{\Delta T}} = 4.18 * 10^{-3} rad/s$. These preliminary observations, based on the prescriptions of the normative documents in force and measurements in the electricity network, allow us to form the quantitative benchmarks necessary to analyze the impact of the variation phenomenon in time of the network regime parameters on power transmission processes through lines, in case the harmonic spectrum of the modulated signal is known. Thus, the analysis of the impact of variations in voltage, frequency and phase in the power line is reduced to determining the harmonic spectrum of a signal equivalent to these variations in voltage, frequency and phase in the power line. To determine the harmonic spectrum generated by the variation in time of the parameters of the power line regime, we will use some theoretical aspects, which are used to describe and analyze the processes of modulation of electrical signals in radio circuits [15].

3.1. Amplitude modulation in the electrical network

In the AC power system, the fundamental frequency can be defined as the carrier oscillation $\omega_0 = 2\pi f_0$. The carrier wave signal is described of relationship $u_1(t) = U_{m1}\cos(\omega_0 t + \varphi_{u1})$ or relationship $u_1(t) = U_{m1}\cos\psi_{u1}(t)$, in which U_{m1}- the amplitude of the carrier wave harmonic; ω_0, φ_{u1} - the angular frequency and the initial phase of the carrier wave. Parameter $\psi_{u1}(t) = \omega_0 t + \varphi_{u1}(t)$ shows the total phase of the oscillation signal of the carrier wave [11, 15].

In general, the instantaneous voltage of the electrical network can be presented by the relationship:

$$u_{am} = U_m(t)cos\big(\omega_0 t + \varphi_u(t)\big). \tag{5}$$

in which $u_{am}(t)$ - the instantaneous value of the modulated signal; $U_m, \varphi_u(t)$ - the amplitude and voltage phase, which can also be time functions.

When the amplitude is forced to change over time U_m, of the phase $\varphi_u(t)$, hence and of the total phase $\psi_u(t)$, the modulation regime of the electrical signal in the examined circuit takes place. We will mention that these forced changes can be conditioned by different factors, including random factors.

Modulation in amplitude, phase or frequency is distinguished. Frequency modulation and phase modulation are closely linked. The difference between frequency modulation and phase modulation is manifested only in the nature of the change in time of the total phase $\psi_u(t)$.

For the amplitude modulation case the condition will be met $\frac{d\varphi_u(t)}{dt} = 0$ and the modulation process is described by the relationship, which results from (5):

$$u_{am} = U_m(t)cos(\omega_0 t + \varphi_0), \tag{6}$$

in which $u_{am}(t)$ - the instantaneous value of the modulated voltage; U_m - function of variation in time of the amplitude of the carrier wave (winding curve); ω_0, φ_0- the frequency and the initial phase of the voltage (oscillator signal).

The time variation of the voltage amplitude $U_m(t)$ forms the modulated voltage winding curve. The modulation signal is presented by the function $s(t)$, which is generally a non-sinusoidal function [15], but for which the interval of evolution or the period of repetition can be defined. For these conditions the amplitude of the coating curve $U_{mu}(t)$ of the modulated signal based on the voltage variation mechanism of the electrical network will be presented by the relation:

$$U_{mu}(t) = U_m + k_{am}s(t), \tag{7}$$

where: U_m - the amplitude of the carrier wave, which for the electrical network with the frequency $f_0 = f_{nom} = 50Hz$ is determined by the nominal value of the voltage $U_m = \sqrt{2}U_{nom}$; k_{am} - proportionality coefficient.

3.2. Applicability of the single-tone amplitude modulation model

The function $s(t)$ from relation (6) has in general present as non-sinusoidal function, either periodic or non-periodic. For these conditions the signal $s(t)$ it can be presented by a spectrum of harmonics, obtained with the application of the Fourier transform [16]:

$$s(t) = \sum_{n=-\infty}^{+\infty} C_n\, e^{j(n\omega_1 t+\varphi_n)} = \sum_{n=-\infty}^{+\infty} C_n\, e^{jn\omega_1 t} e^{j\varphi_n}. \tag{8}$$

Considering that the function $s(t)$ has derivatives of order (m - 1), and the derivative m is continuous over the function definition interval, the values of the coefficients of the Fourier transform change slowly according to the ratio $\frac{1}{n^m}$. As a result of this finding, it turns out that for the coefficients a_n and b_n of the Fourier transform of the function $s(t)$ the conditions will be met $|a_n| < \frac{C}{n^m}$, $|b_n| < \frac{C}{n^m}$, where C = const.; n=1, 2, 3, 4,….- the order of the higher harmonics of the signal transformed into the spectrum [16]. For $m > 1$ the harmonic series has a fast convergence, and for $m = 1$ this process has a slower evolutionary character. For functions with symmetrical shape the coefficient m=2, and for the sinusoidal signal it has the value m=3 [16], thus ensuring a fairly rapid convergence of the Fourier series. Next, we will use this property to argue the possibility of limiting the number of higher harmonics on the description of the modulated signal when applying the process of analyzing the reaction of the circuit to modulation with the single-tone signal.

When accepting the hypothesis, that the voltage deviations have a relatively symmetrical character with respect to the time axis (we appeal to the restriction $\Delta U_{\max} \leq \pm 0.1 U_{nom}$ [13]) maximum voltage change characteristic, it turns out, that the Fourier transform consists of odd harmonics. For symmetric voltage deviations, the coefficients of the real component and the imaginary component of the odd third order harmonic will have the following values: $a_3 \leq \frac{1}{3^2} \approx 0.11$ și $b_3 \leq \frac{1}{3^2} \approx 0.11$. The amplitude of the third order harmonic of the spectrum has the value

$A_3 \leq 0.16A_1$, so its share is below the value of 16% from the amplitude of the fundamental harmonic of the analyzed signal. At the first approximation, it allows us to present the relation that describes the phenomenon of amplitude modulation in the electrical network with the help of a harmonic function $s(t)$, which has the fundamental angular frequency Ω_u and phase φ_0^u. Equivalent modulation function $s_u(t)$ of the carrier wave voltage has the amplitude $S_0 \equiv U_{mu}$ and can be presented in the first approximation as a single-tone harmonic oscillation:

$$s_u(t) = S_0 \cos(\Omega_u t + \varphi_0^u \qquad (9)$$

3.3. The frequency spectrum to amplitude modulation

Taking into account relations (7) and (9), the modulated signal winding curve was presented by the relation:

$$U_m(t) = U_m + U_{mu} \cos(\Omega_u t + \varphi_0^u), \qquad (10)$$

where Ω_u- angular frequency of the modulating signal, determined by the characteristic of the variation in time of the mains voltage; φ_0^u - the initial phase of the coating curve; U_m - the amplitude of the carrier oscillation; $U_{mu} = k_{am} S_0$ - the amplitude of the wrapping curve for the case of single tone modulation.

The relations (5) and (10), it shows that the instantaneous value of the modulated voltage, due to the variation of the mains voltage, will be presented by the following expression:

$$u_{am}(t) = U_m(1 + m_u\, cos\,(\Omega_u t + \varphi_0^u))\cos(\omega_0 t + \varphi_0) \qquad (11)$$

in which, $m_u = \frac{U_{mu}}{U_m} < 1$ - amplitude modulation coefficient; ω_0 - angular frequency in the power system; Ω_u - frequency of the modulating signal, equivalent to the character of the voltage variation in the power line.

The value of the voltage modulation coefficient (index) m_u is calculated with relationship [17]:

$$m_u = \frac{U_{max} - U_{min}}{U_{max} + U_{min}} \qquad (12)$$

where $U_{max} = 1.1U_{nom}$ - the maximum permissible value of the mains voltage deviation; $U_{max} = 0.9U_{nom}$- the minimum permissible value of the mains voltage deviation; U_{nom} - rated mains voltage.

From equation (12) it follows that the modulation coefficient m_u, due to the variation of the mains voltage, it will have the maximum allowable value $m_u = 0.1$.

By transforming the product of the trigonometric functions in equation (12), considering that the initial phase of the carrier oscillation $\varphi_0 = 0$ and modulation wave $\varphi_0^u = 0$, the following relation is obtained:

$$u_{am}(t) = U_m \cos\omega_0 t + \frac{m_u U_m}{2}\cos(\omega_0 + \Omega_u)\,t + \frac{m_u U_m}{2}\cos(\omega_0 - \Omega_u)\,t \qquad (13)$$

Modulation oscillation frequency is lower than carrier wave oscillation frequency.

Frequency band B_u of the spectrum obtained by amplitude modulation has the value $B_u = \omega_{\sup} - \omega_{\inf} = \omega_0 + \Omega_u - \omega_0 + \Omega_u = 2\Omega_u$.

It follows from (13) that when the condition is met $\Omega_u << \omega_0$, what is observed for electrical networks, frequency Ω_u determines only the bandwidth of the frequency spectrum $B_u = 2\Omega_u$ and has no influence on the amplitude of the lateral harmonics of the spectrum. The amplitudes of the lateral harmonics are determined by the modulation coefficient of the amplitude of the carrier oscillation wave m_u.

4. Angular modulation

The frequency and phase of the carrier wave signal when performing the frequency and phase modulation change in proportion to the time variation of the modulating signal. The mechanism for performing the frequency or phase modulation results from relation (5) to the fulfillment of the conditions: $U_m(t) = U_m = const.$ and $\omega_0 = const.$ The total phase of the frequency modulated signal is described by the relationship, $\psi_\omega(t) = \omega_0 t + k_\omega s_\omega(t)$, where k_ω - proportionality coefficient, and $s_\omega(t)$ - modulation function.

Instantaneous frequency $\omega_\omega(t)$ is determined as the first derivative (see (2)) of the total phase $\omega_\omega(t) = \frac{d\psi_\omega(t)}{dt}$, and the total instantaneous phase of the modulated signal is determined by integrating the instantaneous frequency [15]:

$$\psi_\omega(t) = \int_0^t \omega_\omega(\tau)d\tau + \varphi_0 \qquad (14)$$

This kinship of the parameters of the instantaneous frequency and the instantaneous total phase of the modulated signal indicates to the community of these two angular modulation mechanisms and the identity of the result obtained as a result of the frequency modulation or the phase modulation.

Differentiating the argument of relation (5) allows us to determine the instantaneous angular frequency at the angular modulation $\omega_{\varphi}(t) = \frac{d\psi_{\varphi}(t)}{dt} = \omega_0 + \frac{d\varphi(t)}{dt}$. The derivative $\frac{d\varphi(t)}{dt}$ causes the instantaneous frequency to deviate $\omega_{\varphi}(t)$ from the frequency of the carrier wave ω_0. In this context, frequency deviation $\Delta\omega$ in the electric power system conditioned by different influencing factors it can be seen as an angular modulation exerted by the signal $s_{\omega}(t)$. Any change in frequency leads to a change in phase and vice versa, any change in phase conditioned by frequency modulation leads to a change in frequency. This trivial finding emphasizes that frequency variation and phase variation do not exist separately, because these effects can only exist simultaneously, so in torque in electrical networks.

In order for the modulated signal oscillation to be considered close to the harmonic oscillation by shape it is necessary that the frequency variation $\Delta\omega(t) = \omega(t) - \omega_0$ during the period $T_0 = \frac{2\pi}{\omega_0}$ have a small value compared to the frequency ω (t) for the given time [15]. Taking into account this observation, as well as the requirements for industrial frequency stability [12, 13], it can be seen that this provision is fully met for power systems. As a result, the modulation signal $s_{\omega}(t)$ of frequency (or phase angle function $s_{\varphi}(t)$) it can be matched to a trigonometric oscillating function, for example, $s_{\omega}(t) \equiv \cos\,(\Omega_{\omega}t + \varphi_0^{\Omega})$ or in phase modulation $s_{\varphi}(t) \equiv \cos\,(\Omega_{\varphi}t + \varphi_0^{\varphi})$.

Considering for simplicity, as the initial phase $\varphi_0^{\Omega} = \varphi_0^{\omega} = 0$, the frequency modulation signal will be presented by the relationship:

$$s_{\omega}(t) = U_{m\Omega} cos\Omega_{\omega}t, \tag{15}$$

where $U_{m\Omega}$- the amplitude of the frequency modulation signal voltage.

The function $s_{\omega}(t)$ of (15) describes the winding curve of the variation of the amplitude of the mains voltage generated by the instantaneous variation phenomenon $\omega_{\omega}(t)$ (or phase angle $\varphi_{\varphi}(t)$) in the circuit. In this context, the impact of frequency variation or phase variation has signs of kinship with the phenomenon of amplitude modulation, because even in this case a resulting signal is obtained with time variation of amplitude, which is perceived as the envelope curve and is described by the equation:

$$u_{\omega m}(t) = U_m cos\psi(t). \tag{16}$$

4.1. Frequency modulation. Frequency spectrum

Frequency modulation provides for the variation of the frequency over time under the action of the modulating signal $s_{\omega}(t)$. In frequency modulation, the amplitudes and initial phases of the carrier wave signal and the modulator signal have constant values. The evolution over time of the instantaneous frequency of the modulated signal is described by the relation:

$$\omega(t) = \omega_0 + k_{\omega} s_{\omega}(t), \qquad (17)$$

in which ω_0- carrier wave frequency; $\Delta\omega(\mathrm{t})$ - the deviation of the instantaneous frequency from the carrier wave frequency for the time moment t; k_{ω} - the proportionality coefficient of the frequency modulating signal; $s_{\omega}(t)$ - the frequency modulating signal for which the condition is met $\Omega_{\omega} < \omega_0$; Ω_{ω} - the angular frequency of the frequency modulating signal.

It follows from equation (17) that for the value of the function $s_{\omega}(t) = 0$ instantaneous frequency $\omega(t) = \omega_0$, so it coincides with the frequency of the carrier wave.

Considering that in electrical networks the instantaneous angular frequency of the frequency modulating signal is described by a trigonometric function, the relation (17), for single-tone frequency modulation, can be presented by the expression:

$$\omega_0(t) = \omega_0 + k_{\omega} U_{m\Omega} cos\Omega_{\omega} t = \omega_0 + \Delta\omega cos\Omega_{\omega} t \qquad (18)$$

in which $\Delta\omega = k_{\omega} U_{m\Omega}$ - frequency deviation, which is considered equal to the maximum frequency deviation in the electrical network $\Delta\omega = \Delta\omega_{\omega.max}$; k_{ω} - the proportionality coefficient of the frequency modulating signal; $U_{m\Omega}$ - the amplitude of the frequency modulating signal voltage; $\omega_0, \Omega_{\omega}$ - angular frequency of the carrier wave oscillation and the frequency modulator signal oscillation. We will mention that the parameter k_{ω}can have unit value, therefore $k_{\omega} = 1$, because it is a function of transferring the modulating signal formation block $s_{\omega}(t)$.

From equation (18), taking into account the relation (17),wil be determine the instantaneous total phase of the oscillation for the frequency modulation regime:

$$\psi_{\omega}(t) = \int_0^t [\omega_0 + \Delta\omega cos\Omega_{\omega}\tau]\, d\tau = \omega_0 t + m_{\omega} sin\Omega_{\omega} t \qquad (19)$$

in which $m_{\omega} = \frac{\Delta\omega}{\Omega_{\omega}}$ - frequency modulation index or coefficient.

In (19) the term $(m_{\omega} sin\Omega_{\omega} t)$ shows the evolution function of the phase angle of the modulated signal compared to the initial phase φ_0^{Ω} of the resulting signal oscillation, which appears as a reaction to the frequency modulation process, so $\Delta\varphi_\omega(t) = \varphi_\omega(t) - \varphi_0 = m_\omega sin\Omega_\omega t$.

We will mention that when the condition is met $\Delta\omega<\Omega_\omega$, frequency modulation index $m_\omega < 1$, and this modulation is considered of conditioned by the rapid processes of frequency variation. Otherwise, $\Delta\omega > \Omega_\omega$, the parameter $m_\omega > 1$, therefore, the process of slow the frequency modulation takes place in the electrical network.

Instant total phase $\psi_\omega(t)$ of the voltage oscillation $u_\omega(t)$ modulated in frequency for $\varphi_0 = \varphi_0^\Omega = 0$ includes the periodic additional term $\frac{\Delta\omega}{\Omega_\omega} sin\Omega_\omega t = m_\omega sin\Omega_\omega t$. This term in (19) can be defined as the instantaneous phase of the voltage resulting in the frequency modulation process $\Delta\varphi_\omega(t) = \frac{\Delta\omega}{\Omega_\omega} sin\Omega_\omega t$, and the ratio $\frac{\Delta\omega}{\Omega_\omega} = \Delta\varphi_{max}$ - the amplitude of the phase oscillation of the frequency modulated signal in relation to the value of the initial phase φ_0^Ω of the modulating signal.

In order to simplify the analysis of the frequency modulation process, it was considered, as the initial phase of the modulating signal $\varphi_0^\Omega = 0$. Appearance in the modulated signal of the component $m_\omega sin\Omega_\omega t$ can be seen as a circuit reaction conditioned by the frequency modulation mechanism, which leads to the change of the phase of the modulated signal. Considering that $\varphi_0 = \varphi_0^\Omega = 0$, for frequency modulation the relation is obtained:

$$u_\omega(t) = U_{m\omega} cos(\omega_0 t + m_\omega sin\Omega_\omega t). \quad (20)$$

After developing the function (20) in the Fourier series and performing some transformations for $m_\omega \ll 1$ se obține relația, care descrie cu o bună aproximație spectrul modulației în frecvență cu un singur ton [15]:

$$\begin{gathered} u_\omega(t) \approx U_{m\omega} cos(\omega_0 t - m_\omega sin\Omega_\omega t) = \\ = U_{m\omega}\left[cos\omega_0 t + \frac{m_\omega}{2}\cos(\omega_0 + \Omega_\omega)\, t - \frac{m_\omega}{2}\cos(\omega_0 - \Omega_\omega)\, t\right]. \end{gathered} \quad (21)$$

The structure of the relations (13) and (21) presented in the frequency domain are practically identical, as they include the same number of terms of the harmonic spectrum. The only difference is that one of the terms of frequency modulation, which shows the amplitude of the harmonic with the lower side frequency $\omega_{inf} = \omega_0 - \Omega_\omega$, has the phase difference equal to π radians (is in opposite with the harmonic with the lower lateral frequency of the spectrum obtained at amplitude modulation).

Preserving the symmetry and coincidence of the amplitude values for the case that the modulus of the proportionality coefficients $|k_u| = |k_\omega| = 1$, it also ensures the coincidence of the values of the amplitudes of the lateral harmonics of the frequency spectra of the resulting signal modulated in amplitude and frequency, so $\frac{m_u U_m}{2} = \frac{m_\omega U_m}{2}$. From another point of view, the phase difference equal to π radians of the amplitude (13) and frequency (21) spectrum harmonics does not influence the power balance in the in the power line circuit in modulation mode.

4.2. Phase modulation. Frequency spectrum

In the case of phase modulation, the modulation signal changes the initial phase φ_0 of the modulated signal by the value $\Delta\varphi(t)$:

$$\varphi(t) = \varphi_0 + \Delta\varphi(t) = \varphi_0 + k_\varphi s_\varphi(t), \qquad (22)$$

in which k_φ - the proportionality coefficient of the phase modulating signal; $s_\varphi(t) = U_{m\varphi} cos\Omega_\varphi t$ - phase modulator signal, which shows the single-tone carrier wave voltage winding curve; $U_{m\varphi}$ - the amplitude of the phase modulator signal voltage; Ω_φ - phase modulation wave frequency.

The instantaneous total phase of the carrier wave is described by the relationship:

$$\psi_\varphi(t) = \omega_0 t + \varphi_0 + k_\varphi U_{m\varphi} cos\Omega_\varphi t = \omega_0 t + \varphi_0 + \Delta\varphi_{max} cos\Omega_\varphi t, \qquad (23)$$

in which $\Delta\varphi_{max} = k_\varphi U_{m\varphi}$ - phase deviation amplitude for the phase modulation regime, which is called the phase deviation.

Phase deviation $\Delta\varphi_{max}$ depends only on the amplitude of the modulator signal voltage $U_{m\varphi}$ and does not depend on frequency Ω_φ of this signal. By analogy, with frequency modulation, the phase deviation may be called the phase modulation index or coefficient, which may be noted as $m_\varphi = \Delta\varphi_{max} = k_\varphi U_{m\varphi}$. Following this finding, the general expression of the phase modulated voltage for $\varphi_0 = \varphi_0^\Omega = 0$ will be next:

$$u_\varphi(t) = U_{m\varphi} cos\psi_\varphi(t) = U_{m\varphi} \cos\left[\omega_0 t + m_\varphi cos\Omega_\varphi t\right]. \qquad (24)$$

Equation (24) can be presented as follows:

$$u_\varphi(t) = U_{m\varphi}[cos\omega_0 t \cdot \cos\left(m_\varphi cos\Omega_\varphi t\right) - sin\omega_0 t \cdot \cos\left(m_\varphi cos\Omega_\varphi t\right)]. \qquad (25)$$

The Fourier series developments of the relationship (25) [15, 18], brings us to the expression:

$$u_\varphi(t) = U_{m\varphi} J_0(m_\varphi) cos\omega_0 t + U_{m\varphi} \sum_{n=1}^{\infty} [J_n(m_\varphi) \cos(\omega_0 + n\Omega_\varphi)\, t + (-1) J_n(m_\varphi) \cos(\omega_0 - n\Omega_\varphi)\, t] \quad (26)$$

For a single tone narrowband modulation, only the 0th and 1st order terms of the Bessel function of the first case have a significant amplitude, and the other Fourier series coefficients can be neglected [18]. Because to the approximation $J_0(m_\varphi) \approx 1$ și $J_{10}(m_\varphi) \approx \frac{1}{2}$ [15, 16], the approximation relation of the phase modulated signal will be described by the expression:

$$u_\varphi(t) \approx U_{m\varphi}[cos\omega_0 t + \frac{m_\varphi}{2} \cos(\omega_0 + \Omega_\varphi)\, t - \frac{m_\varphi}{2} \cos(\omega_0 - \Omega_\varphi)\, t] \quad (27)$$

The structure of equation (27) is similar to the structure of equation (21). The values of the amplitudes of the lateral harmonics of the modulated signal spectrum are determined by the amplitude of the carrier wave voltage and by the respective value of the frequency and phase modulation coefficients. Based on the similarity of the structure of relations (13), (21) and (27), it can be hypothesized that the impact of modulations in amplitude, frequency and phase manifests itself at the first approximation in the form of variation of the resulting signal amplitude, which in the frequency range can be presented by the spectrum consisting of three harmonics with frequencies $\omega_{\inf} = \omega_0 - \Omega_{m(\omega,\varphi)}$, ω_0, $\omega_{\sup} = \omega_0 + \Omega_{m(\omega,\varphi)}$.

5. Frequency band of the modulated signal

In radio signal theory [15,18] the spectrum band of the modulated signal is examined. This parameter is determined by the lateral harmonics of the frequency spectrum $\omega_0 \mp n\Omega$ in which $n = 1, 2, 3,..$ The side harmonics ensure the transmission of the information encoded in the modulating signal in the radio circuits, and in the electrical networks these harmonics will characterize the dispersion of the energy (power) transmitted through the power line.

Frequency band occupied by side frequencies $(\omega_0 - n\Omega)$ *și* $(\omega_0 + n\Omega)$ is determined from the share of transmitted power in relation to the power of the modulating signal. It was previously mentioned (see section 4) that in electrical networks it is argued the possibility of describing the voltage variation over time with the application of the modulator signal with a single tone. In this case $n = 1$ and the frequency band for amplitude, frequency and phase modulation will be determined by the relationship:

$$B_u \equiv B_\omega \equiv B_\varphi = \omega_{sup} - \omega_{inf} \quad (28)$$

In amplitude modulation the width of the frequency band is determined from the relation $B_u = 2\Omega_u$. So, in amplitude modulation the frequency band will be wider for fast modulation processes and will have a narrower value for slow modulation processes, which predominates in real regimes in electrical networks.

There are two modes for angular modulation - narrowband modulation $m_{\omega(\varphi)} \ll 1$ and broadband modulation $m_{\omega(\varphi)} \gg 1$. For narrowband frequency modulation $m_\omega \ll 1$, the width of the frequency band is determined by the relationship $B_{\omega(m\ll1)} = 2m_\omega\Omega_\omega$, and for the broadband modulation regime, the bandwidth is calculated with the relation $B_{\omega(m\gg1)} = 2 \cdot \Delta\omega$ [15].

Because narrowband modulation for electrical networks meets the requirements $m_\omega < 1$ and $\Omega_\omega \ll \omega_0$ the fulfillment of the condition can be ascertained $B_{\omega(m\gg1)} > B_{\omega(m\ll1)}$. In this context, the parameter $B_{\omega(m\gg1)}$ provides a more complete description of the information encoded by the modulating signal, as it includes a larger number of lateral harmonics for which $n > 1$, which are energy carriers.

In phase modulation, two approaches to defining the bandwidth of the spectrum are highlighted. The width of the frequency band is determined from the approximate relationship $B_\varphi = 2(m_\varphi = 1)\Omega_\varphi$ [18]. For $m_\varphi < 1$ frequency bandwidth $B_\varphi \approx 2\Omega_\varphi$, and for $m_\varphi > 1$ the frequency band is determined by the relationship $B_\varphi \approx 2m_\varphi\Omega_\varphi$, therefore, the effective band of the phase modulated signals depends on the frequency of the modulating signal.

The reasonableness of the examination of the impact of broadband modulation on power transmission processes in electrical networks is also based on the fact that in this case it is not necessary to know the frequency of the modulating signal. The advantage of this observation is that the permissible frequency deviation band in the power system has a known value and is regulated by the parameter defined as the frequency deviati $\Delta\omega$. In normal operating regimes of the electrical networks the frequency variation cannot exceed the frequency deviation (regulated parameter). This regulation of the extreme value of frequency variation ensures us the increase of the certainty of defining the maximum frequency of the modulating signal, which can exist in the normal operating regimes of the electric power systems.

6. The similarity of the reaction of the electrical network to the modulation in amplitude, frequency and phase

The similarity of the structure of the spectrum of the signal modulated in amplitude, frequency and phase, as well as of the spectrum band determines the qualitative identity of the network reaction to these disturbances. The quantitative impact can be estimated based on the restrictions on the permissible values of voltage and frequency deviations in normal operation of the power system.

6.1. Estimation of the similarity of modulation indices in frequency and phase

At frequency modulation the frequency deviation $\Delta\omega_\omega = k_\omega U_{m\omega}$ is proportional to the amplitude of the modulation signal $U_{m\omega}$ and does not depend on the frequency of the modulating signal Ω_ω. For $k_\omega = 1$, is obtaned $\Delta\omega_\omega = U_{m\omega}$. The connection between the derived (secondary) parameter, which shows the frequency variation $\Delta\omega_\omega$, and the frequency of the modulation signal Ω_ω is determined by the relationship $m_\omega = \frac{\Delta\omega_\omega}{\Omega_\omega}$. The parameter m_ω is defined as the frequency modulation index. From the last relation the expression emerges $\Delta\omega_\omega$=$m_\omega\Omega_\omega$. Because, in electrical networks, the frequency variation cannot exceed the frequency deviation $\Delta\omega_\omega$, which is a constant and regulated parameter, it turns out, that the product $m_\omega\Omega_\omega = const$.

For the constant value of the voltage amplitude $U_{m\omega} = const.$, $\Delta\omega_\omega = U_{m\omega} = const.$, the value of the frequency modulation index m_ω changes depending on the index modulation frequency Ω_ω.

In the case of phase modulation, the parameter defined as the phase deviation $\Delta\varphi_\varphi = k_\varphi U_{m\varphi}$ does not depend on the frequency of the modulating signal Ω_φ. Considering that the coefficient of proportionality to the phase modulation $k_\varphi = 1$ și $U_{m\varphi} = const.$, it turns out that $\Delta\varphi_\varphi = U_{m\varphi}$ and shows the amplitude value of the modulated signal phase pulsation.

When modulating the phase, the phenomenon of frequency variation occurs simultaneously $\omega_\varphi(t)$, so $\omega_\varphi(t) \neq \omega_0$. For this modulation regime the frequency deviation $\Delta\omega_\varphi$ in the circuit is a linear function of the modulation frequency Ω_φ. Considering that for $k_\varphi = 1$ phase deviation $\Delta\varphi_{max} = U_{m\varphi} = const.$ (amplitude of phase deviation), the connection between the primary parameter (phase variation) can be determined $\Delta\varphi_{max}$) and changing the value of the secondary parameter (instantaneous frequency variation $\omega_\varphi(t)$), which is calculated with relationship $\Delta\omega_\varphi = \Delta\varphi_{max}\Omega_\varphi$. The last expression shows that the deviation of the phase $\Delta\varphi_{max} = \frac{\Delta\omega_\varphi}{\Omega_\varphi} = m_\varphi$, so it has a structure analogous to the parameter defined as the frequency modulation index.

Applying the restriction, as in the normal operation of the mains frequency deviation $\Delta\omega_{\varphi}$ in phase modulation may not exceed the regulated value of the frequency deviation $\Delta\omega_{\omega}$ in frequency modulation, the condition may be proposed as a criterion for the normal operation of the power system $\Delta\omega_{\varphi} = \Delta\omega_{\omega} \leq \Delta\omega$, regardless of the mechanism of angular modulation in the electrical network.

For $k_{\omega} = k_{\varphi} = 1$, frequency deviation $\Delta\omega_{\omega} = U_{m\omega}$ to frequency modulation and phase deviation $\Delta\varphi_{\varphi} = U_{m\varphi}$ to phase modulation. As a result of this finding, the identity of the frequency deviation and the phase deviation emerges, which can thus be presented $\Delta\omega_{\omega} \equiv \Delta\varphi_{\varphi}$. The difference between frequency modulation and phase modulation is determined by the nature of the evolution of the secondary parameter: phase variation $\Delta\varphi_{\varphi}$ to frequency modulation and frequency variation $\Delta\omega_{\varphi}$ to phase modulation.

In frequency modulation, the phase deviation will depend on the frequency of the modulation signal, which will be calculated with the relation $\Delta\varphi_{\omega} = m_{\omega} = \frac{\Delta\omega_{\omega}}{\Omega_{\omega}}$, and in phase modulation, the frequency will change according to the linear function $\Delta\omega_{\varphi} = m_{\varphi}\Omega_{\varphi}$. As mentioned above, this frequency variation may not exceed the regulated value of frequency deviation in power systems.

When comparing the results of the effects of frequency modulation and phase modulation, it is necessary to take into account the existing regulations for permanent modes of operation, for example, on frequency deviation as a result of frequency modulation and frequency deviation due to phase modulation, which in normal operating regime of electrical networks may not exceed the regulated value $\Delta\omega$, so, at the limit, we will have the fulfillment of the condition $\Delta\omega_{\varphi} = \Delta\omega_{\omega} = \Delta\omega$. From this identity, the equivalence of the values of the frequency modulation index results m_{ω} and the phase modulation index m_{φ}, so $m_{\omega} = m_{\varphi}$.

6.2. Similarity of amplitude and frequency modulation

Quality standards for electricity limit the value of alternating current frequency variation in power systems [13] below the value of frequency deviation $\Delta\omega$. The variation of the instantaneous frequency is presented by the relation $|\Delta\omega(t)|$=$|\omega_0 \pm \omega(t)|$. Taking into account the requirements for maintaining frequency stability in power systems, the instantaneous frequency limit value may be presented as follows:

$$\lim_{t\to\infty} \omega(t) = \omega_0 \mp \Delta\omega, \tag{29}$$

in which $\Delta\omega$ - frequency deviation in power systems.

On the other hand, it follows from the relations describing the harmonic spectrum in single-tone modulation mode (see relations (13), (21) and (27)), it follows that the frequencies of the lateral harmonics of the modulated signal spectrum are determined by the relations:

$$\omega_{inf} = \omega_0 - \Omega; \quad \omega_{sup} = \omega_0 + \Omega, \tag{30}$$

in which Ω - modulator signal frequency, either in amplitude modulation or angular modulation.

Relationships (29) and (30) can be transcribed as follows:

$$\lim_{t\to\infty} \omega(t) = \omega_0 \left(1 \mp \frac{\Delta\omega}{\omega_0}\right); \omega_{inf} = \omega_0 \left(1 - \frac{\Omega}{\omega_0}\right); \quad \omega_{sup} = \omega_0 \left(1 + \frac{\Omega}{\omega_0}\right). \tag{31}$$

It follows from (31) that the variation of the instantaneous angular frequency for the normal operating mode of the electrical networks has the width of the frequency band $\omega_{inf} \leq \omega(t) \leq \omega_{sup}$ for any moment of time.

Following the regulation of the frequency deviation $\Delta\omega$ in electrical networks, the condition is met $\left|\frac{\Omega}{\omega_0}\right| \leq \left|\frac{\Delta\omega}{\omega_0}\right|$. In case of $\left|\frac{\Omega}{\omega_0}\right| > \left|\frac{\Delta\omega}{\omega_0}\right|$, in the electrical network the frequency variation regime will be established with exceeding the regulated value $\Delta\mathrm{f} = \frac{\Delta\omega}{2\pi}$, which is an inadmissible regime of long-term operation of electrical networks.

This observation allows us to consider that in the normal operation of the electrical network the frequency Ω_u of the equivalent amplitude modulator signal, the frequency Ω_ω of the frequency modulation and the frequency Ω_φ of the phase modulation cannot exceed the value of the deviation of the frequency Δω in the electric power systems. Therefore, in any mode of operation of the electrical network with modulation signals in amplitude, frequency or phase, the condition must be met for normal operation $\Omega_u = \Omega_\omega = \Omega_\varphi \leq \Delta\omega$.

In the electrical networks of the Republic of Moldova the extreme value of the modulation index in amplitude $m_{u.max} \leq 0.1$, and the regulated limit value of the angular frequency deviation is determined by the relation $\Delta\omega = 2\pi\,(\Delta f)$, where Δf - regulated deviation of the network frequency in normal operation [13]. These regulated values allow us to estimate the maximum value of the angular frequency of the modulating signal $\Omega_{\omega.max}$, for which identical harmonic spectra of the modulated signal are obtained for amplitude modulation and frequency modulation.

Considering the definition of the frequency modulation index $m_\omega = \frac{\Delta\omega}{\Omega_\omega}$, regulated value of frequency deviation Δf in electrical networks, extreme value of the mains voltage modulation index $m_{u.max} = 0.1$, ensuring the identity of the side harmonics prameters of the harmonic spectra of the modulated signal $\frac{m_u U_{mu}}{2} =$

$\frac{m_\omega U_{m\omega}}{2}$, as well as the equality of modulation indices $m_u = m_\omega$ upon fulfillment of the condition $U_{mu} = U_{m\omega}$, the value of the maximum frequency of the modulating signal will be calculated with the relation:

$$\Omega_{\omega.max} = \frac{2\pi(\Delta f)}{m_{u.max}}. \quad (32)$$

It follows from relation (32) that for the restrictions imposed by the electricity networks for the permanent mode of operation $\Delta U_m \leq 0.1U_m$ and $\Delta\omega(t) \leq \Delta\omega$, for example, frequency deviation $\Delta f = \pm 0.2Hz$ in the electric power system of the Republic of Moldova, the modulating signal can have the maximum value of the angular frequency $\Omega_{\omega.max} = 20\pi|\Delta f| = 20\pi \cdot 0.2 = 4\pi\, rad/s$. Frequency modulating equivalent signal period $T_\Omega = \frac{2\pi}{\Omega_{\omega.max}} = \frac{2\pi}{2\pi} = 0.5s$. The value $T_\Omega = 0.5s$ correlates with the minimum observation time $T_{\Delta U} = 500ms$, recommended for making measurements of the rapid variation of the mains voltage [13], which I said earlier that it can be used as a reference to estimate the duration of the modulator signal period.

For the value estimated as the upper limit of the angular frequency $\Omega_{\omega.max}$ of the equivalent frequency modulating signal (see (32)), the condition is met$m_\omega = \frac{\Delta\omega}{\Omega_{\omega.max}} \geq 1$. As a result of this finding, it appears that in the normal operating regimes of electrical networks with frequency variations over time $\omega(t) \neq \omega_0$ the condition is met $\Delta\omega > \Omega_\omega$. For $\Delta\omega > \Omega_\omega$ the frequency modulation process can be considered as a "*slow modulation*" process with a bandwidth $B_\omega \leq 2\Omega_\omega \leq 2 \cdot \Delta\omega$. This finding indicates the similarity of the mains reaction caused by either amplitude modulation or frequency modulation.

The similarity of the reaction of the circuit to the amplitude modulation and to the angular modulation, also results from the fact that the voltage of the modulating signal in the electrical network can be presented by the relations $U_{mu} = m_u U_m$, $m_\omega = \frac{\Delta\omega}{\Omega_\omega} = \frac{k_\omega U_{m\omega}}{\Omega_\omega}$ și $m_\varphi = \Delta\varphi_{max} = k_\varphi U_{m\varphi}$. From the last two relationships we will have $U_{m\omega} = \frac{m_\omega \Omega_\omega}{k_\omega}$ și $U_{m\varphi} = \frac{m_\varphi}{k_\varphi}$.

For the condition $U_{mu} = U_{m\omega} = U_{m\varphi}$ frequency and phase modulation indices are presented by the relationships:

$$m_\omega = \frac{m_u k_\omega U_m}{\Omega_\omega} = m_u \frac{\Delta\omega}{\Omega_\omega} \quad (33)$$

$$m_\varphi = m_u k_\varphi U_m = m_u \frac{\Delta\varphi_{max}}{\Omega_\varphi} \quad (34)$$

From (33) and (34),we have the equations $m_{\omega}\Omega_{\omega} = m_u\Delta\omega = const$ and $\Delta\omega$ = const (see compartment 6.1) and $m_{\varphi}\Omega_{\varphi} = m_u\Delta\varphi_{max} = const.$ It follows from relations (33) and (34) that for the limit regimes $\Delta\omega = \Omega_{\omega.max}$ the amplitude and frequency modulation indices will have equal values. This confirms the identity of the circuit response to the amplitude and frequency modulation for the imposed restrictions, because identical harmonic spectra are obtained for the modulated signal. We will mention that ensuring the ratio between the frequency modulation index and the amplitude modulation index in accordance with the relation (33) will ensure the identity of the harmonic spectra and for other values of the modulator signal frequency. $\Omega_{\omega} < \Delta\omega$.

Establishing the link between amplitude and frequency modulation indices (see (33)) allows us to study the impact of frequency variation on the share of power transmitted by the lateral harmonics of the spectrum in both amplitude and frequency modulation mode. Knowing the values of the upper limit of the frequency Ω of the modulating equivalent signal, which can physically exist in electrical networks arising from the definition of modulation regime, will be useful in analyzing the power dispersion phenomenon in the power line conditioned by time variations of amplitude, frequency or phase of electrical signals in the permanent power transmission regime.

7. Conclusion

The use of the theory of modulation of electrical signals in the analysis of the permanent regime of power lines can provide new useful information on the particularities of the operating regime with variations in time of the amplitude, frequency or phase of the voltage of the power line.For power systems, amplitude, frequency or phase modulation can be approximated with the harmonic function, called modulator signal. This approximation is true in the case of small variations in amplitude, frequency or phase during the period of the carrier signal, therefore, of the oscillation with the fundamental frequency of the electrical network. The identity of the circuit reaction to amplitude modulation and angular modulation is determined by the restrictions imposed for the operating regimes of electrical networks, which qualitatively and quantitatively is determined by the identity of the modulated signal spectra.

The similarity of the reaction of the power line, regardless of the physics of the modulation process either in amplitude, frequency or phase, is manifested by the variation in time of the amplitude of the power line voltage at the fundamental frequency of the power system. These variations in amplitude over time occur at a much lower frequency than the fundamental frequency of the power system. The upper limit values of the modulator signal frequency are below the frequency deviation limit of the power system.

The presentation of the network reaction through the amplitude modulation index opens the possibility to investigate the impact of angular modulation on the power share transmitted by the power line by the lateral harmonics of the spectrum in modulation mode, the estimation of the transmitted power dispersion factor and the reasoned formulation of technical requirements power flow control equipment transmitted in a controlled manner through these lines, including, for control algorithms with this intelligent equipment.

R E F E R E N C E S

[1] РД 34.20.578-77:“Metodicheskiye ukazaniya po opredeleniyu ustoychivosti energosistem,” [Guidelines for determining the stability of energy systems], Moscow: SOYUZTECHENERGO, 1979, 157p. (in Russian).

[2] *V.M.Postolatiy*. “Nekotoryye aspekty obrazovaniya edinogo rynka YES «YEVRELEKTRIK» i Moldovy sredi stran SNG,”[Some aspects of the formation of a single EU market “EURELECTRIC” and Moldova among the CIS countries]. Problemele energeticii regionale, no. 1/ 2005, pp. 1 - 8, 2006, ISSN 1857-0070.(in Russian).

[3] *V.M.Postolaty, G.N. Chobyrka, E.V. Bykova, M.V. Kiorsak and other*, “Sovremennyye problemy i vozmozhnyye napravleniya dal’neyshego razvitiya elektroenergetiki Respubliki Moldova,” [Modern problems and possible directions for further development of electric power engineering of the Republic of Moldova]. Proceedings of the International Conference Energy of Moldova 2005 (EM 2005), Ch.: TASM, 2005, pp. 1-6, ISSBN *(in Russian)*.

[4] *Rishag Khusseyn Tani*, “Regulirovaniye chastoty i obmennoy moshchnosti v ob”yedinennoy energosisteme,”[Frequency and Exchange Power Regulation in a Integrated Power System], *Thesis PhD, Specialty 05.14.02: Power plants and energy systems, SPb., 2005 143 c. RSL OD, 61: 05-5 / 2275.(in Russian)*

[5] *M.Chindriş, A.Cziker, Anca Miron, D Sacerdoţianu*, “Generare distribuită de mică putere pentru integrarea resurselor regenerabile în reţelele de distribuţie de joasă tensiune,” [Low power distributed generation for the integration of renewable resources in low voltage distribution networks], Problemele energeticii regionale, no.2 (31), 2018, pp.11-21, ISSN 1857-0070, DOI: 10.5281/zenodo.1208190

[6] *M. Scherer*, “Frequency Control in the European Power System Considering the Organisational Structure and Division of Responsibilities,” Thesis for the degree of DOCTOR OF SCIENCES of ETH ZURICH (Dr. sc. ETH Zurich), DISS. ETH NO. 23490, 2016, 218p. doi.org/10.3929/ethz-a-010692129.

[7] Strategia Energetică a Republicii Moldova pînă în anul 2030 [The Energy Strategy of the Republic of Moldova until 2030]. http://lex.justice.md/md/346670/ Accessed 2019.03.31.

[8] Energy policy: general principles. https://www.europarl.europa.eu/factsheets/ro/sheet/68/politica-energetica-principii-generale. Accesed 2020-05-23.

[9] Strategia sectorială de cheltuieli CBTM 2020-2022 pe sectorul energtetic [Sectoral strategy of CBTM 2020-2022 expenditures on the energy sector], https://mei.gov.md/ro/content/strategii-de-cheltuieli-domeniul-energetic, Accesed 2020-06-15.

[10] *Yu. P. Zakharov*,”Identifikatsiya nizkochastotnykh kolebaniy v elektroenergeticheskoy sisteme i otsenka uchastiya sinkhronnogo generatora v ikh dempfirovanii,” [Identification of low-frequency oscillations in the electric power system and assessment of the participation of a synchronous generator in their damping], Abstract of dissertation for the degree PhD, 05.14.02 - Power plants and power systems. Yekaterinburg, 2013, 23p.

[11] *A.V. Dar'yan*, „Obshchaya teoriya svyazi,”[General Theory of Communication]. Kurs lektsiy. Yer.: RAU, 2017. – 130 p. ISBN 978-9939-67-176-5.

[12] Ghid de Aplicare - Calitatea Energiei Electrice. Perturbaţii de tensiune. Standard EN 50160. Caracteristicile tensiunii în reţelele de distribuţie publice [Application Guide - Electricity Quality. Voltage disturbances. Standard EN 50160. Voltage characteristics in public distribution networks]/ Henryk Markiewicz & Antoni Klajn, Wroclaw University of Technology Iulie 2004, 12p. http://www.sier.ro/Articolul_5_4_2.pdf.

[13] GOST 30804.3.3—2013, “Ogranicheniye izmeneniy napryazheniya, kolebaniy napryazheniya i flikera v nizkovol'tnykh sistemakh elektrosnabzheniya obshchego naznacheniya. Tekhnicheskiye sredstva s potreblyayemym tokom ne boleye 16 A (v odnoy faze), podklyuchayenyea”[Limiting voltage changes, voltage fluctuations and flicker in low-voltage general-purpose power supply systems. Technical equipment with a current consumption of not more than 16 A (in one phase), connected to the electric network if certain connection conditions are not met]. Moskva: Standartinform, 2014.

[14] *D.S. Osipov*, “Modeli i metody veyvlet analiza nesinusoidal'nykh nestatsionarnykh rezhimov elektricheskikh setey 0,4–110 kV” [Models and methods of wavelet analysis of non-sinusoidal non-stationary modes of electrical networks 0.4-110 kV]. Dissertatsiya na soiskaniye uchenoy stepeni doktora tekhnicheskikh nauk. Spetsialinosti 05.14.02 - Elektrostantsii i elektroenergeticheskiye sistemy. Omsk, 2019, -305c.

[15] *I.S. Gonorovskiy*. “Radiotekhnicheskiye tsepi i signaly,” [Radio circuits and signals]. Textbook for high schools. - 4th edition, revised and supplemented. - M .: Radio and communications, 1986. - 512 p.

[16] *I.N.Bronshteyn, S.A. Semendyayev*. “Spravochnik po matematike” [Reference book of mathematical], M.:1967, 608s.

[17] *V. I. Zykov, A. B. Mosyagin, V. T. Oleynikov*, "Sbornik zadach po kursu «ASU i SVYAZ'» " [Collection of tasks on the course" «AUTOMATIC CONTROL SYSTEMS and COMMUNICATION»], Ucheb. posobiye. – M.: Akademiya GPS MCHS Rossii, 2010. – 168 s. ISBN 978-5-9229-0025-6.

[18] *C. Strîmbu*, “Semnale şi Circuite Electronice - Analiza şi Prelucrarea Semnalelor”[Electronic Signals and Circuits - Signal Analysis and Processing]; Braşov: Academia Forţelor Aeriene “Henri Coandă”, 2007; 120 pagini. ISBN 978-973-8415-46-1.