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Generating Control Signals in the Electro-energy Networks Using Passive Elements

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Abstract**—**This paper presents a new method of generating signals for managing on the assumed radial electro-energetic network with three load branches. The time dependant load is added on the buses that separate branch loads with a task to generate control signals. The procedure must determine (e.m.f.) of the equivalent source in an equivalent scheme relating to network and source when the nonlinear resistance is switched in parallel or in a regular power grid. The expressions from which the power losses and usable power of generated signals could be determined are derived. The adjustable part of MATLAB software package is used for the verification procedure.

Keywords—*generating, electrical network, signals, passive elements*

I. INTRODUCTION

In normal mode, a simpler analysis of three-phase electrical networks is achieved by reducing the equivalent single-phase scheme [1,2]. This is possible only if all three phases and all of three if all parts of electrical networks have the same impedance Z , where electricity is flowing through i of the same module, and on impedance the same voltage modules react V [5,6].

Signal with a given frequency, intended for realization of the functions of management or protection in electro-energy network, with the help of some TCs system could be generated by active or passive process [3,4].

In the active procedure, a specific signal generator of the set frequency, switches on in parallel manner to one of the nodes of the network, thus creating necessary component of the voltage frequency.

The passive process reduces the inclusion of resistors or other devices on the bus network, via controllable or unmanaged valves that are capable of sufficiently high frequency management to burden or relieve network [7,8,9]. In order to have a passive process implemented in distribution networks there must be only one power source[13,14, and 15]. As such source is mainly used transformer a rarely synchronous generator Fig.1 [10,11 and 12].

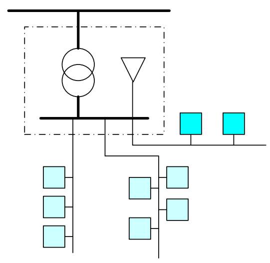

Fig.1. Turning the device for generating signals on the bus bars in the electrical network

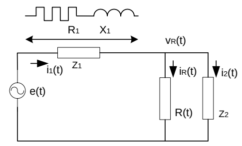

Fig.2. Equivalent scheme that suits turning on of the device for generating signals to the network.

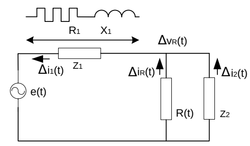

Fig.3. Equivalent schemes and directions of electricity increment

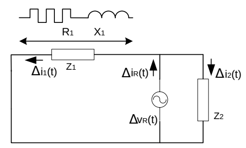

Fig.4. Equivalent schemes with an equivalent voltage source

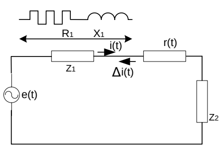

Fig.5. Regularly - serial engaging resistors with resistance r (t) managing electricity network

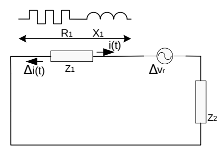

Fig.6. Regularly - serial engaging resistors with resistance r (t) managing electricity network

This papers describes the generation of the control signal through the time-dependent resistor. Section II presents the mathematical form, all the electrical parameters of equivalent circuits, devices for load management. In Section III there are estimated losses of strength in generating and introduction of signals in the network, parallel / regularly included resistance. Section IV presents the adapted model of MATLAB, which describes the passive introduction of the control signal in the electrical network. Conclusion and future work are presented in the final section.

II. Calculation and Analysis

The unit for load management is connected directly to the bus bars. The system has been shown in Fig. 1. In the equivalent circuit, the device for load management is presented as a time-dependent resistor resistance R(t), whose frequency can be expressed as an odd or even time sing in relation to the frequency of the fundamental harmonic voltage network. Simple equivalent circuit, Fig.2, contains impedance Z_1 - (if the secondary transformer is power supply, it is its reactance transformer dissipation, and if it is a synchronous generator then the impedance is equal to the reactance component of the inverse sequence generator) and the impedance Z_2, which represents general impedance of all loads that are broken down to bus subs.

The relations that show the size and electrical parameter of the scheme Fig.2, in mathematical form are:

$$v_R = e\frac{Z_2R(t)}{Z_1Z_2 + Z_1R(t) + Z_2R(t)} \tag{1}$$

$$i_1 = e\frac{Z_2 + R(t)}{Z_1Z_2 + Z_1R(t) + Z_2R(t)} \tag{2}$$

$$i_2 = e\frac{R(t)}{Z_1Z_2 + Z_1R(t) + Z_2R(t)} \tag{3}$$

$$i_R = e\frac{Z_2}{Z_1Z_2 + Z_1R(t) + Z_2R(t)} \tag{4}$$

Differentials (Increase) of variable electrical quantities, compared to growth resistance values $R(t)$, are:

$$\Delta v_R = e\frac{Z_1Z_2^2}{[Z_1Z_2 + Z_1R(t) + Z_2R(t)]^2}\Delta R \tag{5}$$

$$\Delta i_1 = -e\frac{Z_2^2}{[Z_1Z_2 + Z_1R(t) + Z_2R(t)]^2}\Delta R \tag{6}$$

$$\Delta i_2 = e\frac{Z_1Z_2}{[Z_1Z_2 + Z_1R(t) + Z_2R(t)]^2}\Delta R \tag{7}$$

$$\Delta i_R = -e\frac{Z_2(Z_1 + Z_2)}{[Z_1Z_2 + Z_1R(t) + Z_2R(t)]^2}\Delta R \tag{8}$$

Direction of current increase is determined by relations as shown in Fig.3. It is very important to determine the relationship between the voltage and current at the place where the nonlinear resistance R(t) is involved, and current population growth rate in the separate branches of the equivalent scheme in Fig. 3. With the assumed current directions in the diagram, Fig. 3, relations can be established, i.e. determined the ratio of growth voltages and currents:

$$Z_1 = \frac{\Delta v_R}{\Delta i_1} \tag{9}$$

$$Z_2 = \frac{\Delta v_R}{\Delta i_2} \tag{10}$$

$$\frac{\Delta v_R}{\Delta i_R} = \frac{Z_1Z_2}{Z_1 + Z_2} \tag{11}$$

Direction of current increase, depending on the growth rate of voltage and current show that the scheme, which includes a time-variable resistance (or so-called nonlinear resistance), can be transformed into similar where that resistance could be substituted with voltage source Δv_R, Fig.4 , where in their proper shape, electricity source *e* and nonlinear resistance R(*t*)are left out With the scheme in Fig.4, and based upon the known values of e.m.f. equivalent source Δv_R a calculation can be made of the current and signal voltage which is generated (produced) on passive way in spread distributive electricity network when the basic element for network management (nonlinear resistance) is in parallel included in the network.

The signal for control in the TCs system could also be generated so that the non-linear resistance $r(t)$ of the network could be switched to line Fig.5. In this case, the values of current and voltage in circuit will be determined according to the relation:

$$i_1 = e\frac{1}{Z_1 + Z_2 + r(t)} \tag{12}$$

$$v_r = e\frac{r(t)}{Z_1 + Z_2 + r(t)} \tag{13}$$

Residual values of these quantities depending on the variables *r (t)* can be determined by:

$$\Delta i_1 = -e\frac{1}{[Z_1 + Z_2 + r(t)]^2}\Delta r \tag{14}$$

$$\Delta v_r = e\frac{Z_1 + Z_2}{[Z_1 + Z_2 + r(t)]^2}\Delta r \tag{15}$$

Current increase $\Delta i(t)$ have opposite direction than current has $i(t)$. Omitting the sign of the current increment can be, as in the case of the parallel inclusion of non-linear resistance, determine the ratio of increment between voltages and currents.

$$\frac{\Delta v_r}{\Delta i} = Z_1 + Z_2 \tag{16}$$

The result confirms the regular inclusion of non-linear resistance network in order to handle the load in the network, the equivalent circuit corresponding to this process contains the correct execution Δv_r, and basic electricity source $e(t)$, is not directly included in the scheme Fig. 6.

From the scheme Fig.4 and Fig.6, it's clear that the passive process of generating a signal in a formal sense, is identical with an active way of generating a signal and corresponds to a parallel or ordinal inclusion of a special generator for generating the control signal. However, this conclusion is only suitable to schemes with linear parameters.

For the implementation of schemes with equivalent sources in the first step must be determined the level of the signal. This can be done in easy way, if the nonlinear resistance, which is controlled loads in the network, is replaced by value of the control conductivity $g(t)$, i.e.

$$R(t) = \frac{1}{g(t)} \tag{17}$$

From the system of equations (1,2,3) the relation of voltage can then be written in the form:

$$v_R = e\frac{Z_2}{Z_1Z_2g(t) + Z_1 + Z_2} \tag{18}$$

Since the electric network of alternating current is considered, then two variables are in expression. Because of this fact, total differential of the two components must be determined: $dv_R = dv_{\mathrm{Re}} + dv_{Rg}$.

Change of value v_R, that depends on variable e i.e. function $v_R = f(e)$, it's not the priority here.

Attention will be focused on the consideration of other differential frequency components:

$$dv_{Rg}(t) = -e\frac{Z_1Z_2^2}{[Z_1Z_2g(t) + Z_1 + Z_2]^2}dg(t) \tag{19}$$

The denominator in the expression (18) could be written in expression:

$$Z_1 + Z_2 + Z_1Z_2g(t) = Z_1Z_2[\frac{Z_1 + Z_2}{Z_1Z_2} + g(t)] \tag{20}$$

The first member within the middle brackets represents the general scheme of electrical conductivity of equivalent network in relation to the electrical source with voltage Δv_R Fig. 4.

In real terms to generate the control signal, this conductivity $\frac{Z_1 + Z_2}{Z_1Z_2} \approx (10 \div 100)g(t)$, a few tens or hundreds of times exceeds the control conductivity for managing workloads $g(t)$. For this reason, the value of conductivity *g(t)* can be neglected and written the approximate expression:

$$dv_{Rg}(t) \approx -e\frac{Z_1Z_2^2}{[Z_1 + Z_2]^2}dg(t) \tag{21}$$

In accordance with the terms of the considered task, conductivity *g (t)* periodically changes, which means that the current flowing through this conductivity will be periodically changed. This current can be broken down into harmonious members according to the rules Fourier transformation.

$$i_g = \sum_{k=0}^{\infty} i_{gk} \Leftrightarrow i_g = \sum_{k=0}^{\infty} i_{gk} /:V \Leftrightarrow \frac{i_g}{V} = \sum_{k=0}^{\infty}\frac{i_{gk}}{V}$$

Here is , $i_{gk} = I_m c_k^{`} \sin(k\omega\, t + \varphi_k)$,

where is:

$I_m -$ amplitude value of the current through the conductance $g(t)$;

c_k - coefficient of current development functions in Fourier series.

Dividing both sides of the equation *V* with the value of the voltage fed to the ends of the controlled load obtains equation of conductivity:

$$g(t) = \sum_{k=0}^{\infty} g_k(t) \tag{22}$$

Where is: $g_k(t) = \frac{\sqrt{2}I}{V}c_k^{`}\sin(k\omega\, t + \varphi_k)$; and $I = \frac{I_m}{\sqrt{2}}$ – fictitious calculation value numerically equal to the effective value of the harmonic (simple periodical) values of current amplitude I_m.

Equation (22) relates to the following interpretation: instead conductivity *g (t)* that would periodically oscillate by an arbitrary periodic legality, the equivalent scheme introduces a series of parallel conductance involved where each oscillates on a harmonic law. If the value of the controlled load resistance is equal to: $R = \frac{V}{i}$ you then get:

$$g_k(t) = \frac{\sqrt{2}}{R}c_k^{`}\sin(k\omega\, t + \varphi_k); \tag{22`}$$

From (22`) differential conductivity will then be equal to

$$dg_k(t) = \frac{\sqrt{2}}{R}c_k^{`}k\omega\cos(k\omega\, t + \varphi_k)dt \tag{23}$$

From equations (20), (21) , (22) i (22`) can be extracted partial differential voltage with a frequency $k-$ of that accordion:

$$dv_g = -e\frac{Z_1 Z_2^2}{(Z_1+Z_2)^2}\frac{\sqrt{2}}{R}c_k^{`}k\omega\cos(k\omega\, t+\varphi_k)dt \qquad (24)$$

By integration (24) we receive voltage value:

$$\int dv_{gk} \approx \int -e\frac{Z_1 Z_2^2}{(Z_1+Z_2)^2}\frac{\sqrt{2}}{R}c_k^{`}k\omega\cos(k\omega\, t+\varphi_k)dt$$

$$v_{gk} = -e\frac{Z_1 Z_2^2}{(Z_1+Z_2)^2}\frac{\sqrt{2}}{R}c_k^{`}\sin(k\omega\, t+\varphi_k) \qquad (25)$$

Integration constant in this case is not of great importance and that is why it was omitted.

On expression (25) the voltage v_{gk} oscillates on harmonium law as a suitable component of conductance. Effective value of this voltage is:

$$V_{gk} = e\frac{Z_1 Z_2^2}{(Z_1+Z_2)^2}\frac{c_k^{`}}{R} \qquad (26)$$

and that expression defines e.m.f. of equivalent source in equivalent scheme Fig.4. At the same time, this value determines the voltage level of the frequency signal $V_s^{`}$. which reacts on resistance of the load in parallel inclusion of control resistance.

$$V_s^{`} = e\frac{c_k^{`}}{R}\frac{Z_1 Z_2^2}{(Z_1+Z_2)^2} \qquad (27)$$

Value $(\frac{Z_2}{Z_1+Z_2})^2$ defines the load of consumption (or receiver) to the level of the generated signal. Most frequently this influence is negligible and the signal level is mainly determined by its own electrical resistance sources and the value of resistance R.

When the signal is introduced into the network " serial " (via included control resistance in series to the network) differential voltage on the control of resistance $r(t)$ will have the form:

$$dv_r(t) = e\frac{Z_1+Z_2}{[r(t)+Z_1+Z_2]^2}dr(t) \qquad (28)$$

If $r(t) << (Z_1+Z_2)$ can be written as an approximate expression:

$$dv_r(t) \approx e\frac{1}{[Z_1+Z_2]}dr(t) \qquad (29)$$

It is obvious that in sinusoidal (harmonic) oscillations time oscillations of resistance *r (t)* and voltage drop, will have a harmonious character on resistance. The voltage value can be decomposed into Fourier series:

$$v(t) = \sum_{k=0}^{\infty} v_k(t) \qquad (30)$$

where $v_k = V_m c_k^{``}\sin(k\omega\, t+\varphi_k)$ a $V_m -$ is an amplitude value of the voltage resistance . If both sides of the equation divide the value of the current that passes through the resistance $r(t)$, we get:

$$r(t) = \sum_{k=0}^{\infty} r_k(t) \qquad (31)$$

In this way, instead of resistance, which can be changed by arbitrary simple-periodical legality, in the equivalent scheme was introduced an order of involved series of harmonically variable resistance:

$r = \frac{V_m}{I_m}$ maximum of resistance value.

The differential of resistance is:

$$dr_k(t) = \sqrt{2}rc_k^{``}k\omega\cos(k\omega\, t+\varphi_k)dt \qquad (32)$$

Partial differential of voltage is:

$$dv_{rk}(t) = e\frac{\sqrt{2}}{Z_1+Z_2}rc_k^{``}k\omega\cos(k\omega\, t+\varphi_k)dt \quad (33)$$

After integration and omitting of constant of integration which does not have any importance, we the voltage:

$v_{rk} = e\frac{\sqrt{2}}{Z_1+Z_2}rc_k^{``}\sin(k\omega\, t+\varphi_k)$ of effective values: $V_{rk} = e\frac{1}{Z_1+Z_2}rc_k^{``}$.

In accordance with the reasoning when the signal is introduced via the serial resistance associated with the network, this value is e.m.f. equivalent sources in the replacement scheme, Fig.6. The voltage signal is:

$$V_c^{``} = e\frac{Z_2}{(Z_1+Z_2)^2}rc_k^{``} \qquad (34)$$

III. Estimation

The parameter that determines the impact load is calculated from equation(34): $V_c^{``} = e\frac{Z_2^2}{(Z_1+Z_2)^2}\frac{r}{Z_2}c_k^{``}$

Comparison of this formula with (27) the expression, which refers to the parallel " introduction " signal when the signal level is directly proportional to its own impedance sources *Z1* with the " series " the introduction of a signal, the signal level is inversely proportional to the value of the load impedance.

The ratio of the value of the signal level in parallel $V_s^{`}$ and serial signal introduction $V_s^{``}$ is:

$$\frac{V_s^{``}}{V_s^{`}} = \frac{c_k^{`}}{c_k^{``}}\frac{Z_1 Z_2}{r\cdot R} \qquad (35)$$

If we use the same harmonic from the specter, the signals are generated in the same way (for eg. with using unmanaged valve / rectifier inverter) then: $c_k^{`} = c_k^{"}$. When comparing different ways of introducing a signal to the network, logical requirement is that the generated signal levels are equal, $V_s^{`} = V_s^{"}$. In this case, one obtains the following relationship between the values of resistance to be used in the process of the network management.

$$r \cdot R = \left| Z_1 \cdot Z_2 \right| \tag{36}$$

The power losses in the process of generating a signal when the resistance management $R(t)$ included parallel on the network is $P^{`} = \lambda \dfrac{V^2}{R(t)}$ where $V-$ rms value of the voltage on the feeder resistance management $R(t)$ a $\lambda -$ is nonlinearity coefficient of that resistance. If the nonlinear resistance is Ventils uncontrolled diode then is $\lambda = 0.5$.

Power losses for resistance management *r (t)* regularly included in the network is $P^{``} = \lambda \cdot I^2 r(t)$.

where $I -$ is perfect current value in the circuit.

The balance of power dissipation in these two cases is: $\dfrac{P^{"}}{P^{'}} = (\dfrac{I}{V})^2 r(t) R(t) = \dfrac{r \cdot R}{Z_{2o}^2}$ (37)

where $Z_{2o} -$ is an impedance of load on an industrial frequency, $f_o = 50Hz$, i.e. for basic harmonic.

If a constructive relation (37) gets replaced value $r \cdot R$ from equation (19) then the power relation is :

$$\frac{P^{"}}{P^{'}} = \frac{r \cdot R}{Z_{2o}^2} = \frac{\left| Z_1 Z_2 \right|}{Z_{2o}^2} = \left| \frac{Z_1 Z_2}{Z_{2o}^2} \right| \tag{38}$$

Value of impedance has active and reactive resistance, and active resistance – reactance is dependable on frequency and in general sense they multiply with frequency: $f_n = nf_0$,

n – is multiplicand of basic frequency.

For network fed from the transformer

$Z_T = \dfrac{v_{sh-c}(\%)V_L^2}{100 S_n} \cong jX_T$, own source impedance is approximately equal to the impedance of dissipation in the primary a $Z_1 \cong jnX_T$ on frequency $f_n = nf_o = n50Hz$.

By similar reasoning impedance load (network) is: $Z_2 = R_{load} + jnX_{load}$ for frequency $f_n = nf_o = n50Hz$ i.e. $Z_{2o} = R_{load} + jX_{load}$ for basic frequency $f_o = 50Hz$.

Active and reactive component of the impedance load Z_2 is calculated according to the power factor $\cos\varphi$:

$$R_{load} = \frac{V^2}{S_{load}} \cos\varphi \text{ i.e. } X_{load} = \frac{V^2}{S_{load}} \sin\varphi$$

When the value of the power load carried within the limits of the rated power transformer S_{nT} from the limit of resistance, determines the factor $\alpha = [0 \div 1]$, and if:

$$R_{load} = \frac{V^2}{\alpha S_{load}} \cos\varphi \text{ i.e.: } X_{load} = \frac{V^2}{\alpha S_{load}} \sin\varphi$$

Finally, after replacing all previous relation for active and reactive resistance:

$$\frac{P^{"}}{P^{'}} = \left| \frac{Z_1 Z_2}{Z_{2o}^2} \right| = n \cdot \alpha \cdot v_{sh-ci.} \sqrt{n^2 \sin^2\varphi + \cos^2\varphi} \tag{39}$$

According to expression (39) power losses in resistance *r* and *R* does not depend on the absolute values of the parameters that characterize the network (voltage, power transformer power supply, etc.). All parameters in the expression are without dimensions and in real network conditions vary within narrow limits, so the relation is general in nature because they can get the required information for different levels of network voltage and various values of power. From (39) can be determined limit values for frequency control signal for the power losses that are the same for both methods of generating and introducing signals in the network, parallel / regularly included resistance.

IV. SIMULATION

For verification methods passive introduction of the control signal to the electricity network used is adapted part of the package MATLAB psb3phsignalseq. Selected are parameters of the three-phase power supply, which in this case is a source of 35 kV, 10 MVA, 50 Hz ,transformer 35/10 kV, 6 MVA, 50 Hz, measuring block included the sub bus linking 10 kV, 50Hz load 6 MW, 2 MVAr. At the same sub bus at the same time block that simulates the `` parallel`` resistor with the generated frequency signals 50, 75, 100, 150, 250, 350 Hz i.e. 1, 1.5 , 2, 3, 5 and 7 harmonic voltage direct sequencing.

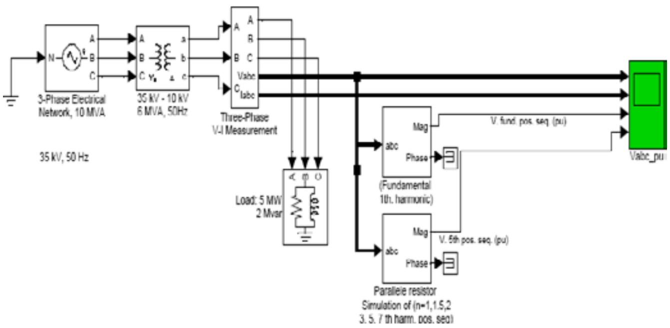

Fig. 7. Simulation signal generating n-order through the parallel sub bus power supply included a block that represents a nonlinear resistor with a time function.

The result of the simulation is presented in diagrams which can be observed frequencies and signal levels expressed in unit, per unit (p.u.) values .

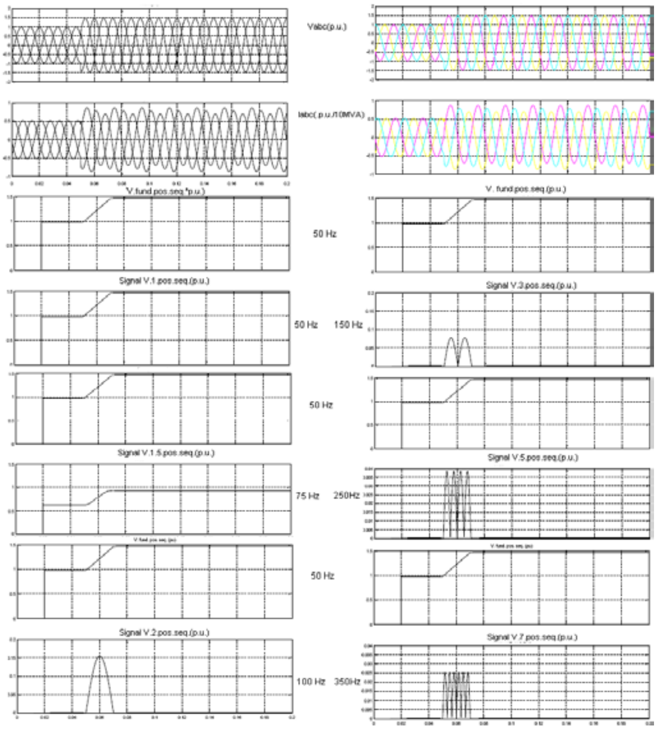

Fig.8. Diagrams unit values fundamental harmonic voltage and current for the selected network and frequencies of the " parallel manner " introduced signals 50 Hz, 75 Hz, 100 Hz, 150 Hz, 250 Hz, 350 Hz.

CONCLUSION

Calculations diagrams, in Fig.8. indicate that the parameter values:

$$\alpha = [0.6 \div 1], v_{Tsh-ci} = [0.08 \div 0.12], \cos\varphi = [0.85 \div 0.95],$$

-dimensionless parameters, frequencies generated by the control signal should be found within the limits of $[175 < f < 350] Hz$ which siuts $[3.5 < n < 7]$.

If the control signal has a lower cut-off frequency, power losses " bulk " introduction is less than the power loss " parallel " the introduction of the signal (it is understood that the levels of the control signal in both ways of introducing the same signal). At higher values of the frequency control signal is more suitable " parallel " way of introducing the signal in the electricity network. Examples budget on selected configurations unilaterally supplied network (radial, ring, mesh with the supporting point [15] show that in the mean values of dimensionless parameters $\alpha = 0.8, v_{Tsh-ci} = 0.1 \cos\varphi = 0.95$ and frequency control signals $f = 100 Hz$ power 'serial' scheme is $P^{``} = 0.2P^{`}$ power 'parallel' schemes.

$f = 500 Hz$ power loss - power " series " scheme amount is 350% power management of " parallel " scheme, i.e. $P^{``} = 3.5P^{`}$ and cutoff frequency at which these two values are equal $P^{``} = P^{`}$ is $[f = 260] Hz$ is determined from (38).

A device with a " parallel " introduction of the control signal in the network is a simpler way that can be installed on the sub bus in the electric network facilities. It's one of the reasons that, although " standard " scheme has lower power losses of the control signal at low frequencies, the application of parallel schemes is more justified. Quite a different situation arises when no signal is introduced into the entire network but only in one part. Then the value of the power loss may play a significant role and can influence so that choice and application of complex devices could be justified.

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