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New Method for Analysis and Design Consideration of Voltage Source Inverters

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Abstract: This manuscript proposes a new unified approach for the analysis of voltage source inverters that summarizes and unifies the operating modes of a whole class of inverters powered by a voltage source: resonant, aperiodic and voltage source inverters. The study was performed on a full-bridge circuit of a series RLC inverter with reverse diodes, operating in aperiodic mode. Based on the community of processes in the power circuits, the expressions for the current through the load and the voltage of the capacitor in condensed form with their initial phases are determined. These basic ratios are presented in a normalized form according to the control frequency, thus summarizing the operation of the inverters with a control frequency below and above the quasi-resonant. A methodology for designing a voltage source inverter was developed, considered as a special case of a series RLC inverter with inverse diodes when operating in aperiodic mode and super-quasi-resonant frequency. The reliability of the obtained results was verified by comparison with the use of the classical methodology for design and computer simulations. The presented approach is useful from a methodological point of view, as it allows us, with a unified approach and through general mathematical expressions, to describe and study the processes in a significant part of DC/AC converters.

Keywords: analysis and simulation; voltage source inverters; design consideration; series RLC circuits

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1. Introduction

Power electronics is an interdisciplinary field that combines knowledge from many of the applied and basic sciences. Emerging crises related to the lack of energy and resources are an opportunity and a catalyst for the implementation and enforcement of innovations, processes and products that were inefficient before their occurrence. In this aspect, power electronics has established itself as a key technology for meeting the energy and technological needs of society and industry. Thus, achieving optimal design of power electronic devices and systems is a constant object of research interest and has a great impact on human development and ensuring the desired quality of life.

Voltage source inverters (VSIs) are widely used in industry and in households, in uninterruptible and backup power supply systems, decentralized electricity generation, intelligent drives and many other areas [1–4]. Typically, these circuits use two main modes of operation: single-polar square-wave rectangular pulses (Square-Wave Operation) and pulse packets within the output voltage period (Unipolar or Bipolar PWM Operation). In practice, in most cases, the design of these devices starts from the most severe case—working with a dense pulse with a duty cycle of 50%. When a VSI is working in other modes, numerical coefficients are introduced to correct and adapt the initially determined values, according to the specific operating mode [5–8].

In this sense, the improvement and optimization of the analysis and methodology for the design of inverters with square-wave operation has a direct impact on a fairly wide class of power circuits. Usually, the analysis of this type of inverter is performed on the basis of Fourier decomposition of the voltage of the AC circuit (determination of the amplitudes of the harmonic components). In practice, most often, only the fundamental harmonic is used, and on this basis, the equivalent parameters of the load are determined. To improve accuracy, some authors suggest taking into account the influence of the next few harmonics (usually three to five) [7–9].

In this context, the aim of this paper is to propose a new method for the analysis and design of VSIs, summarizing and unifying the operating modes of a whole class of inverters powered by a voltage source: resonant, aperiodic and voltage source inverters. The proposed approach is based on a description of the actual form of current in the AC circuit of the inverter, using for its analytical determination a special-case generalized analysis of serial RLC inverters, presented in [10,11].

Resonant inverters are a variant of series RLC inverters and—due to their widespread use for high-efficiency, high-frequency energy sources for the implementation of various technologies—are the subject of numerous studies [12–15]. On the other hand, when the load is changed, for example, during an industrial process, aperiodic modes are also possible. A special case of an aperiodic mode is the operation with an infinitely large value of the resonant capacitor $C = \infty$, which converts the series RLC circuit into RL. In essence, this is the typical load of the voltage source inverter. This presentation allows us to unify in a general approach the operation of series RLC inverters in resonant and aperiodic mode and, on this basis, to create a methodology for designing voltage source inverters.

It is known that the topologies of series RLC inverters may or may not contain reverse diodes, but since the analysis of inverters without reverse diodes is a special case of the analysis of inverters with reverse diodes, the main relationships are obtained herein based on an analysis of series RLC inverters with reverse diodes.

2. Basic Ratios

Various configurations of series RLC inverters (full-bridge, half-bridge, with zero output of the output transformer) are known, and the specific dependences of currents and voltages in them are determined on the basis of derived values for the bridge circuit using appropriate numerical coefficients that take into account the specific topology [12,14,16]. Figure 1 shows the circuit of a series full-bridge RLC inverter with reverse diodes. It consists of a transistor bridge (VT_1–VT_4), a series RLC circuit and reverse diodes VD_1–VD_4 (which can be built into the transistors).

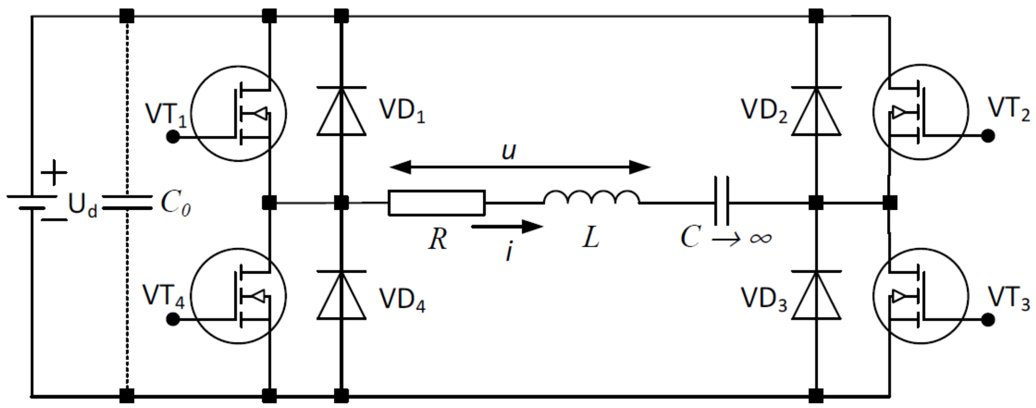

Figure 1. Full-bridge series RLC inverter.

A characteristic of this topology is that, depending on the relationship between the parameters of the AC circuit, it operates in resonant or aperiodic mode. The analysis of the inverter is made assuming the ideality of all circuit elements.

The considered series RLC circuit is described by the following differential equation, regarding the capacitor voltage [13,14,17]:

$$LC\frac{d^2u_c}{dt^2} + RC\frac{du_c}{dt} + u_c = u_{SW}, \quad (1)$$

where u_{SW} is the input voltage supplied to the series RLC circuit. It is formed by the sequential operation of the semiconductor switches (transistors and reverse diodes) of the inverter with switching frequency $f = 1/T$.

When working in the established mode and with fulfillment of the condition for resonance $R < 2\sqrt{\frac{L}{C}}$ for the considered scheme, the following expressions of the current through the inductance and the voltage of the capacitor are valid [10,17]:

$$\begin{aligned} i_L(t) &= \frac{U_d+U_C(0)}{\omega_0 L}e^{-\delta t}\sin\omega_0 t - I_L(0)e^{-\delta t}\left(\cos\omega_0 t - \frac{\delta}{\omega_0}\sin\omega_0 t\right) \\ u_C(t) &= U_d - (U_d+U_C(0))e^{-\delta t}\left(\frac{\delta}{\omega_0}\sin\omega_0 t + \cos\omega_0 t\right) - \frac{I_L(0)}{\omega_0 C}e^{-\delta t}\sin\omega_0 t \end{aligned} \tag{2}$$

where $I_L(0)$ and $U_C(0)$ are the initial conditions of the state variables, R is the load resistance, L and C are the resonant inductance and resonant capacitance, U_d is the supply voltage, $\omega_0 = \sqrt{\frac{1}{LC} - \delta^2}$ is the resonant frequency, and $\delta = \frac{R}{2L}$ is the attenuation of the series resonant circuit.

On the other hand, in order for the inverter to operate in aperiodic mode, the condition $R > 2\sqrt{\frac{L}{C}}$ must be met, in which case the state variables are defined as follows [10,11]:

$$\begin{aligned} i_L(t) &= \frac{U_d+U_C(0)}{\Omega_0 L}e^{-\delta t}sh\Omega_0 t - I_L(0)e^{-\delta t}\left(ch\Omega_0 t - \frac{\delta}{\Omega_0}sh\Omega_0 t\right) \\ u_C(t) &= U_d - (U_d+U_C(0))e^{-\delta t}\left(\frac{\delta}{\Omega_0}sh\Omega_0 t + ch\Omega_0 t\right) - \frac{I_L(0)}{\Omega_0 C}e^{-\delta t}sh\Omega_0 t \end{aligned} \tag{3}$$

where $\Omega_0 = \sqrt{\delta^2 - \frac{1}{LC}}$ is a quasi-resonant frequency, and the other values have the same meaning as in the case of operation in resonant mode.

By analogy with the analysis of series RLC inverters operating in resonant (oscillating) mode, in the analysis of series RLC inverters operating in aperiodic mode, the coefficients are entered as follows:

- $k_A = \frac{1}{1-e^{-\frac{\delta\pi}{\Omega_0}}}$—coefficient of aperiodicity;
- $\nu_A = \frac{\omega}{\Omega_0}$—quasi-frequency coefficient, and $c\omega = 2\pi f$ denotes the circular control frequency.

From the joint solution of (3) using the conditions for periodicity of the current through the load and the voltage of the capacitor, i.e., $i\left(\frac{\pi}{\omega}\right) = I_L(0)$ and $u_C\left(\frac{\pi}{\omega}\right) = U_C(0)$, the values of the initial current and voltage are determined:

$$I_L(0) = \frac{2K_{ap}U_d}{\Omega_0 L}a_{ap} \text{ and } U_C(0) = \left(2K_{ap} - 1\right)U_d,$$

where $K_{ap} = \frac{1}{1-h_{ap}e^{\frac{-\delta\pi}{\Omega_0}}} = \frac{1}{1-h_{ap}\left(\frac{k_A-1}{k_A}\right)^{\frac{1}{\nu_A}}}$ is a value characterizing the series RLC circuit, called the aperiodicity factor in RLC inverters with reverse diodes, operating in aperiodic mode, and with h_{ap} and a_{ap} as follows:

$$h_{ap} = \frac{-\frac{1}{\pi}\ln\left(\frac{k_A}{k_A-1}\right)sh\frac{\pi}{\nu_A} - ch\frac{\pi}{\nu_A} - \left(\frac{k_A-1}{k_A}\right)^{\frac{1}{\nu_A}}}{1+\left(\frac{k_A-1}{k_A}\right)^{\frac{1}{\nu_A}}\left(ch\frac{\pi}{\nu_A} - \frac{1}{\pi}\ln\left(\frac{k_A}{k_A-1}\right)sh\frac{\pi}{\nu_A}\right)},$$

$$a_{ap} = \frac{sh\frac{\pi}{\nu_A}}{\left(\frac{k_A}{k_A-1}\right)^{\frac{1}{\nu_A}} + ch\frac{\pi}{\nu_A} - \frac{1}{\pi}\ln\left(\frac{k_A}{k_A-1}\right)sh\frac{\pi}{\nu_A}}.$$

After substituting the initial current and voltage into (3), the following system of equations is obtained for the state variables:

$$i_L(t) = \frac{2K_{ap}U_d}{\Omega_0 L}D_A e^{-\delta t}sh\left(\Omega_0 t - \psi'_A\right), u_C(t) = U_d - 2K_{ap}U_d E_A e^{-\delta t}sh\left(\Omega_0 t + \phi'_A\right) \tag{4}$$

where $D_A = \sqrt{\left(1 + a_{ap}\frac{\delta}{\Omega_0}\right)^2 - a_{ap}^2}$, $\psi'_A = arth\frac{a_{ap}}{1+a_{ap}\frac{\delta}{\Omega_0}}$, $E_A = \sqrt{\left(\frac{\delta}{\Omega_0} - a_{ap} + a_{ap}\left(\frac{\delta}{\Omega_0}\right)^2\right)^2 - 1}$ and $\phi'_A = arth\frac{1}{\frac{\delta}{\Omega_0} - a_{ap} + a_{ap}\left(\frac{\delta}{\Omega_0}\right)^2}$.

In the further analysis of the scheme, it is convenient to perform normalization on the control frequency ω, where the expressions for $i(\theta)$ and $u_C(\theta)$ take the form:

$$\begin{aligned} i_L(\theta) &= \frac{2K_{ap}U_d}{\Omega_0 L} D_A\, e^{-\delta\frac{\theta}{\omega}} sh\frac{\pi}{\lambda_A}(\theta - \psi_A) \\ u_C(\theta) &= U_d - 2K_{ap}U_d E_A e^{-\delta\frac{\theta}{\omega}} sh\frac{\pi}{\lambda_A}(\theta + \phi_A) \end{aligned} \tag{5}$$

where $\theta = \omega t$, $\lambda_A = \frac{\pi\omega}{\Omega_0}$, $\psi_A = \frac{\lambda_A}{\pi}\psi'_A$ и $\phi_A = \frac{\lambda_A}{\pi}\phi'_A$.

Expression (5) describes the fact that at an angle $\theta = \psi_A$, the load current becomes zero.

The analysis of the current expression determines that the maximum value of the current through the inductor and the load is obtained at angle $\theta_m = \frac{\lambda_A}{\pi} arth\frac{\frac{\pi}{\lambda_A}}{\frac{\delta}{\omega}} + \psi_A$, and this value is:

$$I_{\max} = i_L(\theta_m) = \frac{2K_{ap}U_d}{\Omega_0 L} D_A\, e^{-\delta\frac{\theta_m}{\omega}} sh\frac{\pi}{\lambda_A}(\theta_m - \psi_A), \tag{6}$$

The average value of the current through the semiconductor switches (transistors) is determined by the integral:

$$I_{av} = \frac{1}{2\pi}\int_{\psi_A}^{\pi} i_L(\theta)d\theta = \frac{1}{2\pi}\int_{\psi_A}^{\pi} \frac{2K_{ap}U_d}{\Omega_0 L} D_A\, e^{-\delta\frac{\theta}{\omega}} sh\frac{\pi}{\lambda_A}(\theta - \psi_A)d\theta, \tag{7}$$

and its solution is then obtained as follows:

$$I_{av} = \frac{2K_{ap}U_d D_A}{2\pi\Omega L F_A}\left(e^{-\frac{\delta}{\omega}\pi} ch\left(\alpha + \frac{\pi}{\lambda_A}(\pi - \psi_A)\right) - e^{-\frac{\delta}{\omega}\psi_A} ch\alpha\right), \tag{8}$$

where $F_A = \sqrt{\left(\frac{\pi}{\lambda_A}\right)^2 - \left(\frac{\delta}{\omega}\right)^2}$ and $\alpha = arth\frac{\frac{\delta}{\omega}}{\frac{\pi}{\lambda_A}}$.

The average current consumed by the DC power supply is found via the expression:

$$I_d = \frac{1}{\pi}\int_{0}^{\pi} i_L(\theta)d\vartheta = \frac{1}{\pi}\int_{0}^{\pi} \frac{2K_{ap}U_d}{\Omega_0 L} D_A\, e^{-\delta\frac{\theta}{\omega}} sh\frac{\pi}{\lambda_A}(\theta - \psi_A)d\theta, \tag{9}$$

Its solution is obtained accordingly:

$$I_d = \frac{2K_{ap}U_d D_A}{\pi\Omega_0 L F_A}\left(e^{-\frac{\delta\pi}{\omega}} ch\left(\alpha + \frac{\pi}{\lambda_A}(\pi - \psi_A)\right) - ch\left(\alpha - \frac{\pi}{\lambda_A}\psi_A\right)\right) \tag{10}$$

The average current through the reverse diodes is determined by the expression:

$$I_{dav} = I_{av} - \frac{I_d}{2} \tag{11}$$

The maximum value of the voltage on the capacitor is obtained at the moment corresponding to the angle ψ_A and is:

$$U_{C\max} = U_d - 2K_{ap}U_d E_A e^{-\delta\frac{\psi_A}{\omega}} sh\frac{\pi}{\lambda_A}(\psi_A + \phi_A) \tag{12}$$

The RMS value of the load current is:

$$I = \sqrt{\frac{1}{\pi}\int_{0}^{\pi} i_L^2(\theta)d\vartheta} = \sqrt{\frac{1}{\pi}\int_{0}^{\pi}\left(\frac{2K_{ap}U_d}{\Omega_0 L} D_A\, e^{-\delta\frac{\theta}{\omega}} sh\frac{\pi}{\lambda_A}(\theta - \psi_A)\right)^2 d\theta} = \frac{K_{ap}U_d D_A}{\Omega_0 L} G_A \tag{13}$$

where $G_A = \sqrt{\frac{1}{\pi}\left(\frac{1}{F_A}\left(e^{-2\pi\frac{\delta}{\omega}}ch(X) - ch(Y)\right) - \frac{\omega}{\delta}\left(e^{-2\pi\frac{\delta}{\omega}} - 1\right)\right)}$, $X = \alpha + \frac{\pi}{\lambda_A}(2\pi - 2\psi_A)$ and $Y = \alpha - \frac{\pi}{\lambda_A}2\psi_A$.

The RMS value of the load voltage is then obtained:

$$U = \frac{2K_{ap}\delta U_d D_A}{\Omega_0}G_A \quad (14)$$

With the help of the expressions found in this way, the values of all basic quantities characterizing the power circuit are determined; on this basis, an engineering methodology for designing series RLC inverters with reverse diodes operating in aperiodic mode is created [10].

The above considerations of aperiodic operation of a series RLC inverter make it possible to present the voltage source inverter as a special case of a series aperiodic RLC inverter with reverse diodes at capacitor value $C = \infty$. In this way, the already defined ratios can be used for the analysis of a voltage inverter, taking into account that when mboxemphC = ∞, we have $\delta = \Omega_0$.

In this situation, the coefficient of aperiodicity acquires a single fixed value, $k_N = \frac{1}{1-e^{-\pi}} = 1.045$.

Then, the expression for the inverter current represented by its initial phase is as follows:

$$i_L(t) = \frac{U_d}{\Omega_0 L}D_N e^{-\delta t} sh\left(\Omega_0 t - \psi'_N\right) = \frac{2U_d}{R}D_N e^{-\delta t} sh\left(\Omega_0 t - \psi'_N\right) \quad (15)$$

where $D_N = \sqrt{(1+a_N)^2 - a_N^2}$, $\psi'_N = arth\frac{a_N}{1+a_N}$ and $a_N = \frac{sh\frac{\pi}{\nu_A}}{\left(\frac{k_N}{k_N-1}\right)^{\frac{1}{\nu_A}} + ch\frac{\pi}{\nu_A} - sh\frac{\pi}{\nu_A}}$.

By normalizing the obtained expression with respect to the control frequency ω, the equation for $i(\theta)$ becomes:

$$i_L(\theta) = \frac{U_d}{\Omega_0 L}D_N\, e^{-\delta\frac{\theta}{\omega}} sh\frac{\pi}{\lambda_A}(\theta - \psi_N) = \frac{2U_d}{R}D_N\, e^{-\delta\frac{\theta}{\omega}} sh\frac{\pi}{\lambda_A}(\theta - \psi_N) \quad (16)$$

where $\theta = \omega t$, $\lambda_A = \frac{\pi\omega}{\Omega_0}$ and $\psi_N = \frac{\lambda_A}{\pi}\psi'_N$.

From expression (27), it is determined that at angle $\theta = \psi_N$, the load current becomes zero.

Figure 2 presents diagrams of the inverter voltage u and the inverter current i_L, which illustrate the mode of operation of the power circuit and give the characteristic angles that give information about the switching of the load current through the semiconductor devices.

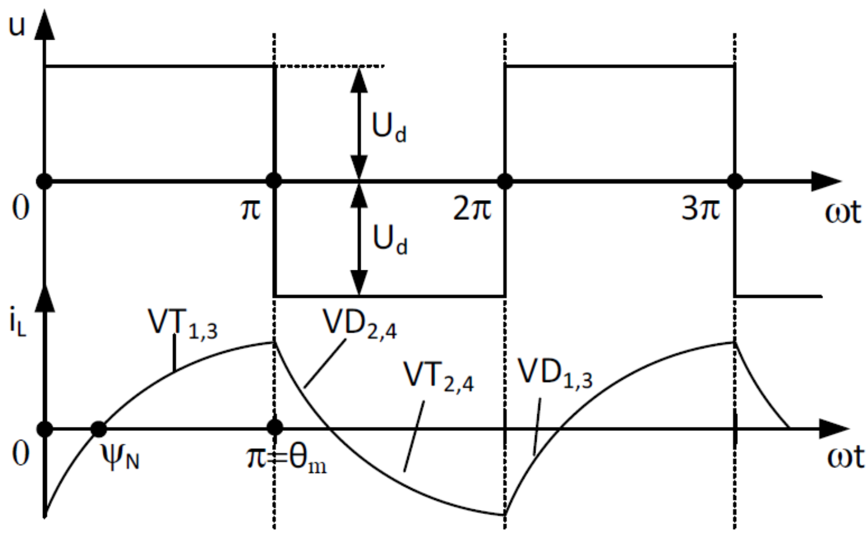

Figure 2. Timing diagrams describing the operation of a voltage source inverter.

From the presented diagrams, it can be seen that in this mode, the maximum value of the load current is obtained at angle $\theta_m = \pi$, and it is:

$$I_{\max} = i_L(\theta_m) = i_L(\pi) = \frac{2U_d}{R} D_N\, e^{-\delta\frac{\theta_m}{\omega}} sh\frac{\pi}{\lambda_A}(\theta_m - \psi_N) \quad (17)$$

The average value of the current through the transistors is determined by the integral:

$$I_{av} = \frac{1}{2\pi}\int_{\psi_N}^{\pi} i_L(\theta)d\theta = \frac{1}{2\pi}\int_{\psi_A}^{\pi} \frac{2U_d}{R} D_N\, e^{-\delta\frac{\theta}{\omega}} sh\frac{\pi}{\lambda_A}(\theta - \psi_N)d\theta \quad (18)$$

and after its resolution, we have:

$$I_{av} = \frac{U_d D_N}{\pi R F_A}\left(e^{-\frac{\delta}{\omega}\pi} ch\left(\alpha + \frac{\pi}{\lambda_A}(\pi - \psi_N)\right) - e^{-\frac{\delta}{\omega}\psi_N} ch\alpha\right) \quad (19)$$

where $F_A = \sqrt{\left(\frac{\pi}{\lambda_A}\right)^2 - \left(\frac{\delta}{\omega}\right)^2}$ and $\alpha = arth\frac{\frac{\delta}{\omega}}{\frac{\pi}{\lambda_A}}$.

The average current consumed by the DC power supply is determined by:

$$I_d = \frac{1}{\pi}\int_{0}^{\pi} i_L(\theta)d\vartheta = \frac{1}{\pi}\int_{0}^{\pi} \frac{2U_d}{R} D_N\, e^{-\delta\frac{\theta}{\omega}} sh\frac{\pi}{\lambda_A}(\theta - \psi_N)d\theta \quad (20)$$

and after solving it and making transformations, we obtain:

$$I_d = \frac{2U_d D_N}{\pi R F_A}\left(e^{-\frac{\delta\pi}{\omega}} ch\left(\alpha + \frac{\pi}{\lambda_A}(\pi - \psi_N)\right) - ch\left(\alpha - \frac{\pi}{\lambda_A}\psi_N\right)\right) \quad (21)$$

The average current through the diodes is determined by the expression:

$$I_{dav} = I_{av} - \frac{I_d}{2} \quad (22)$$

The RMS value of the load current is:

$$I = \sqrt{\frac{1}{\pi}\int_{0}^{\pi} i_L^2(\theta)d\vartheta} = \sqrt{\frac{1}{\pi}\int_{0}^{\pi}\left(\frac{2U_d}{R} D_N\, e^{-\delta\frac{\theta}{\omega}} sh\frac{\pi}{\lambda_A}(\theta - \psi_N)\right)^2 d\theta} = \frac{U_d D_N}{R} G_N \quad (23)$$

where

$$G_N = \sqrt{\frac{1}{\pi}\left(\frac{1}{F_A}\left(e^{-2\pi\frac{\delta}{\omega}} sh\left(\alpha + \frac{2\pi}{\lambda_A}(\pi - \psi_N)\right) - sh\left(\alpha - \frac{2\pi}{\lambda_A}\psi_N\right)\right) + \frac{\omega}{\delta}\left(e^{-2\pi\frac{\delta}{\omega}} - 1\right)\right)}$$

For the RMS value of the voltage on the active part of the load R, we get:

$$U = IR = U_d D_N G_N \quad (24)$$

On the other hand, the RMS value of the first harmonic of the output voltage of the voltage source inverter is determined by [9,14]:

$$U = \frac{2\sqrt{2}}{\pi} U_d \quad (25)$$

It should be noted that all the obtained ratios are functions of the aperiodicity coefficients (in the fixed-value regime under consideration) and the quasi-frequency coefficient. The expressions found in this way determine all the basic values needed for the design consideration of voltage source inverters.

3. Design Consideration

Typically, when designing DC–AC converters, the following parameters are set: the active output power P/total output power S, the effective value of the output voltage U, the operating frequency f and the load power factor cos ϕ_T [14,15]. The following is an example sequence for determining the most important parameters required for the design of the considered devices.

1. The value of the quasi-frequency coefficient is determined by the relationship between the load power factor and its parameters:

$$\nu = 2\sqrt{\frac{1-\cos^2\phi_T}{\cos^2\phi_T}} \tag{26}$$

2. At the selected control frequency, the attenuation of the series circuit is found:

$$\delta = \Omega_0 = \frac{\omega}{\nu} = \frac{2\pi f}{\nu} \tag{27}$$

3. From expression 25, at a set RMS value of the output voltage, the required value of the input voltage is determined. If this value is not relevant to the DC power supply, then either a DC–DC converter at the inverter input or an inverter transformer at the output should be used.
4. The active component of the load resistance is determined from the set active output power of the converter:

$$R = \frac{U^2}{P} = \frac{U^2}{S}\cos\phi_T \tag{28}$$

5. The inductive component of the load resistance is found from the load power factor:

$$L = \frac{tg\phi_T R}{2\pi f} \tag{29}$$

6. Expressions 17, 19, 21 and 22 determine the maximum value of the current of the transistors, the average value of the current through the transistors, the average value of the current consumed by the DC power supply and the average value of the current through the reverse diodes. In this way, it is possible to choose the power semiconductor devices, as well as the other circuit elements.

4. Verification of the Methodology

The validity of the proposed analysis and the methodology created on its basis are verified herein by designing a computational example of a full-bridge voltage source inverter (Figure 1).

The design was performed according to two methodologies—the one presented above and the classical methodology, developed on the basis of analysis in the established mode of operation of a voltage source inverter [12].

The following output data were used in the design: operating frequency 500 Hz, power factor cos ϕ_T = 0.303, RMS value of the first harmonic of the output voltage U = 100 V, total output power S = 1000 VA. Since there is no difference in the two methodologies employed herein for determining the input voltage values and the load parameters, the following values of the circuit elements were obtained as a result of the design: load resistance R = 3.033 Ω and load inductance L = 3.033 mH. From expression 25, the required value of the input voltage was found, which provided the reference U_d = 111 V.

Table 1 compares the results obtained from the design of the selected power scheme. The reliability of the proposed approach was verified by a comparison with the design obtained using the classical methodology. Verification of the results obtained from the design was also performed against computer simulations (LTspice).

Table 1. Values of quantities obtained from the design of a voltage source inverter and the results of computer simulations.

Parameter	Proposed Methodology	Standard Methodology [12]	Computer Simulation
$I_{\max}$, A	16.897	16.922	16.902
I_d, A	2.769	2.774	2.771
I_{av}, A	2.888	2.893	2.89
I_{dav}, A	1.504	1.506	1.505
I, A	10.064	10.08	10.064
U, V	100	100	99.99

From the data presented in Table 1, it is established that by using the presented design methodology, a very good accuracy was achieved—the biggest difference between the values calculated and those obtained from simulations and from the use of the standard methodology is less than 0.5%. The deviations are mainly due to rounding in calculation procedures and differences in the models used for verification. Taking into account that in the construction of power electronic devices, the building elements usually have a parameter tolerance of around or over 20%, the proposed methodology gives excellent results.

5. Conclusions

This paper presents an analysis of a full-bridge circuit of series RLC inverters with reverse diodes when operating in aperiodic mode. The expressions for the state variables in normalized form according to the control frequency were determined. This makes it possible to study the operation of inverters in a wide range of changes in control frequency, in different operating modes. On this basis, a new approach was proposed for the analysis of voltage source inverters, presented as a special case of series RLC inverters and an infinitely large value of the capacitor. In this way, the analysis and design of a whole class of inverters powered by a voltage source is summarized and unified: resonant, aperiodic and voltage source inverters. Based on the obtained basic ratios, a methodology for designing a voltage source inverter was created herein. The reliability of the obtained results was verified by comparison with the use of a classical design methodology and computer simulations.

As a result of the research, it was proved that the developed new design method is not inferior in accuracy to the existing ones and also represents a development and generalization of the theory of autonomous inverters. On the other hand, the derived ratios allow us to make an assessment of the influence of the circuit parameters on the operating modes.

The presented approach is useful from a methodological point of view, as it allows us, with a unified approach and through general mathematical expressions, to describe and study the processes in a significant part of DC/AC converters. This is very useful for application in the teaching of power electronics, as most students have relatively weak basic training and have difficulty mastering the curriculum. In addition, by applying different optimization procedures, with certain target functions selected, optimal design is achieved according to a certain criterion. In this way, an optimal synthesis of control is realized, which is extremely important in the numerous practical applications of voltage source inverters [18–21]. On the other hand, the unified approach to analysis makes it possible to automate the process of designing power electronic devices, as well as to integrate artificial intelligence techniques in their development.

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