ANALYSIS OF A SERIAL THYRISTOR INVERTER WITH FORCED COMMUTATION

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Summary

In this article an analysis of a serial thyristor inverter with forced commutation is implemented. The approach, typical for the analysis of semiconductor R,L,C inverters, is applied. The three possible modes of operation, namely resonant, aperiodical and critically aperiodical are considered and the main parameters of the inverter circuit are derived in a normalized form. The results may be useful for obtaining the characteristics of this type of inverters.

The serial thyristor inverter (Fig.1) may fall in the so-called mode of forced commutation, when the controlling frequency $\omega=2\pi f$ or the parameters of the serial R, L, C circuit varies. This mode of operation is characterized with the fact that before the time interval of conduction of the one couple of diagonally placed thyristors is completed the other two diagonally placed thyristors are turned on. Thus the input current of the inverter is discontinuous. This mode is usually undesired, because the circuit turn off time is relatively small and the voltages across the thyristors are relatively high. A close look into the electromagnetic processes, taking place in the inverter circuit shows that in this case the same approach for the analysis can be applied as for the analysis of semiconductor RLC inverters [1], [2], [3] with a small deviation.

The equivalent circuit and the waveforms of the main quantities of the serial thyristor inverter with forced commutation are shown in Fig.2 and Fig.3 respectively. It can be seen from them that initial and the final conditions for the reactive elements in the steady state can be expressed in the following manner

(1) $$i(0) = i(\theta_0) = I_0$$

(2) $$v(0) = -v(\theta_0) = -V_0$$

The correlation between the R, L, C parameters of the serial thyristor inverter circuit can be different, so from a theoretical point of view the inverter can work either in a resonant mode of operation, either in an aperiodiacal mode of operation, either in a critically aperiodical mode of operation. For the resonant mode of operation the main parameters of the inverter circuit are summarized in Table 1, for the aperiodical mode of operation - in Table 2 and for the critically aperiodical mode of operation - in Table 3 respectively.

The results for the parameters of the inverter circuit can be processed by a computer and the main characteristics of the inverter circuit can be obtained.

Table 1

Variable	Expression
R [Ω]	$< 2\sqrt{\frac{L}{C}}$ (resonant mode)
δ [S^{-1}]	$R/(2L)$
ω_0 [S^{-1}]	$\sqrt{\frac{1}{LC} - \delta^2}$
i [A]	$\frac{V_d + V_0}{\omega_0 L} e^{-\delta t} \sin \omega_0 t + I_0 e^{-\delta t} (\cos \omega_0 t - \frac{\delta}{\omega_0} \sin \omega_0 t)$
v [V]	$V_d - (V_d + V_0) e^{-\delta t} (\cos \omega_0 t + \frac{\delta}{\omega_0} \sin \omega_0 t) + \frac{I_0}{\omega_0 C} e^{-\delta t} \sin \omega_0 t$
θ [-]	$\omega_0 t$
θ_0 [-]	$\pi \omega_0 / \omega$
a [-]	$\frac{I_0 \omega_0 L}{V_d + V_0} = \frac{\sin \theta_0}{e^{\frac{\delta}{\omega_0}\theta_0} - \cos \theta_0 + \frac{\delta}{\omega_0} \sin \theta_0}$
K [-]	$\frac{1}{1 + e^{-\frac{\delta}{\omega_0}\theta_0} [(-a + \frac{\delta}{\omega_0} - a\frac{\delta^2}{\omega_0^2}) \sin \theta_0 + \cos \theta_0]}$
V_0' [-]= =V_{Cm}' [-]	$\frac{V_0}{V_d} = \frac{V_{Cm}}{V_d} = 2K - 1$
$i'(\theta)$ [-]	$\frac{i(\theta)\omega_0 L}{V_d} = 2K e^{-\frac{\delta}{\omega_0}\theta} [(1 - a\frac{\delta}{\omega_0}) \sin \theta + a \cos \theta]$
$v'(\theta)$ [-]	$\frac{v(\theta)}{V_d} = 1 - 2K e^{-\frac{\delta}{\omega_0}\theta} [(-a + \frac{\delta}{\omega_0} - a\frac{\delta^2}{\omega_0^2}) \sin \theta + \cos \theta]$
I_d' [-]	$\frac{I_d \omega_0 L}{V_d} = \frac{1}{\theta_0} \int_0^{\theta_0} i_d(\theta) d\theta = \frac{2(2K-1)\omega_0^2}{\theta_0(\omega_0^2 + \delta^2)}$
I_0' [-]	$\frac{I_0 \omega_0 L}{V_d} = 2Ka$
I' [-]	$\frac{I \omega_0 L}{V_d} = \sqrt{\frac{\omega_0}{\delta} \cdot \frac{I_d'}{2}}$
v_{TS}' [-] (not conducting)	$\frac{v_{TS}}{V_d} = 1 - \frac{di'(\theta)}{d\theta} = 1 + 2K e^{-\frac{\delta}{\omega_0}\theta} [(a + \frac{\delta}{\omega_0} - a\frac{\delta^2}{\omega_0^2}) \sin \theta + (2a\frac{\delta}{\omega_0} - 1) \cos \theta]$

Table 2

Variable	Expression
R [Ω]	$> 2\sqrt{\frac{L}{C}}$ (aperiodical mode)
$\delta [S^{-1}]$	$R/(2L)$
Ω $[S^{-1}]$	$\sqrt{\delta^2 - \frac{1}{LC}}$
i [A]	$\frac{V_d + V_0}{\Omega L} e^{-\delta t} sh\Omega t + I_0 e^{-\delta t}(ch\Omega t - \frac{\delta}{\Omega} sh\Omega t)$
v [V]	$V_d - (V_d + V_0)e^{-\delta t}(ch\Omega t + \frac{\delta}{\Omega} sh\Omega t) + \frac{I_0}{\Omega C} e^{-\delta t} sh\Omega t$
θ [-]	Ωt
θ_0 [-]	$\pi\Omega / \omega$
a [-]	$\frac{I_0 \Omega L}{V_d + V_0} = \frac{sh\theta_0}{e^{\frac{\delta}{\Omega}\theta_0} - ch\theta_0 + \frac{\delta}{\Omega} sh\theta_0}$
K [-]	$\frac{1}{1 + e^{-\frac{\delta}{\Omega}\theta_0}[(a + \frac{\delta}{\Omega} - a\frac{\delta^2}{\Omega^2})sh\theta_0 + ch\theta_0]}$
V_0' [-]= $=V_{Cm}'$ [-]	$\frac{V_0}{V_d} = \frac{V_{Cm}}{V_d} = 2K - 1$
$i'(\theta)$ [-]	$\frac{i(\theta)\Omega L}{V_d} = 2Ke^{-\frac{\delta}{\Omega}\theta}[(1 - a\frac{\delta}{\Omega})sh\theta + ach\theta]$
$v'(\theta)$ [-]	$\frac{v(\theta)}{V_d} = 1 - 2Ke^{-\frac{\delta}{\Omega}\theta}[(a + \frac{\delta}{\Omega} - a\frac{\delta^2}{\Omega^2})sh\theta + ch\theta]$
I_d' [-]	$\frac{I_d \Omega L}{V_d} = \frac{1}{\theta_0}\int_0^{\theta_0} i_d(\theta)d\theta = \frac{2(2K-1)\Omega^2}{\theta_0(\delta^2 - \Omega^2)}$
I_0' [-]	$\frac{I_0 \Omega L}{V_d} = 2Ka$
I' [-]	$\frac{I\Omega L}{U_d} = \sqrt{\frac{\Omega}{\delta} \cdot \frac{I_d'}{2}}$
v_{VS}' [-] (not conducting)	$\frac{v_{VS}}{V_d} = 1 - \frac{di'(\theta)}{d\theta} = 1 + 2Ke^{-\frac{\delta}{\Omega}\theta}[(-a + \frac{\delta}{\Omega} - a\frac{\delta^2}{\Omega^2})sh\theta + (2a\frac{\delta}{\Omega} - 1)ch\theta]$

Table 3

Variable	Expression
R [Ω]	$2\sqrt{\frac{L}{C}}$ (critically aperiodical mode)
$\delta\,[S^{-1}]$	$R/(2L)$
i [A]	$\frac{V_d+V_0}{\delta L}e^{-\delta t}\delta t+I_0e^{-\delta t}(1-\delta t)$
v [V]	$V_d-(V_d+V_0)e^{-\delta t}(1+\delta t)+\frac{I_0}{\delta C}e^{-\delta t}\delta t$
θ [-]	δt
θ_0 [-]	$\pi\delta/\omega$
a [-]	$\frac{I_0\delta L}{V_d+V_0}=\frac{\theta_0}{e^{\theta_0}-1+\theta_0}$
K [-]	$\frac{1}{1+e^{-\theta_0}[(1-a)\theta_0+1]}$
V_0' [-]= =V_{Cm}' [-]	$\frac{V_0}{V_d}=\frac{V_{Cm}}{V_d}=2K-1$
$i'(\theta)$ [-]	$\frac{i(\theta)\delta L}{V_d}=2Ke^{-\theta}[(1-a)\theta+a]$
$v'(\theta)$ [-]	$\frac{v(\theta)}{V_d}=1-2Ke^{-\theta}[(1-a)\theta+1]$
I_d' [-]	$\frac{I_d\delta L}{V_d}=\frac{1}{\theta_0}\int_0^{\theta_0}i_d(\theta)d\theta=\frac{2(2K-1)}{\theta_0}$
I_0' [-]	$\frac{I_0\delta L}{V_d}=2Ka$
I' [-]	$\frac{I\delta L}{V_d}=\sqrt{\frac{I_d'}{2}}$
v_{TS}' [-] (not conducting)	$\frac{v_{TS}}{V_d}=1-\frac{di'(\theta)}{d\theta}=1+2Ke^{-\theta}[(1-a)\theta+2a-1]$

References

1. Karov R. D. "On the general theory of serial inverters with and without free wheeling diodes" Proceedings of the Scientific Conference "The Day of the Radio", v. III, Electronic Technique, 7.5.1975. (in Bulg.)
2. Popov E. I. "Investigation of transistor RLC inverters in an aperiodical mode of operation" Proceedings of the V[th] National Scientific and Applied Science Conference with International Participation "Electronic Technique – ET'96", 27-29.9.1996, Sozopol, Bulgaria (in Bulg.)
3. Popov E. I. "Investigation of transistor RLC inverters in a critically-aperiodical mode of operation" Proceedings of the V[th] National Scientific and Applied Science Conference with International Participation "Electronic Technique – ET'96", 27-29.9.1996, Sozopol, Bulgaria (in Bulg.)

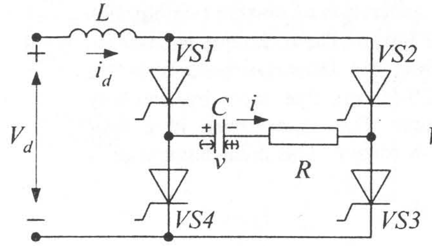

Fig.1

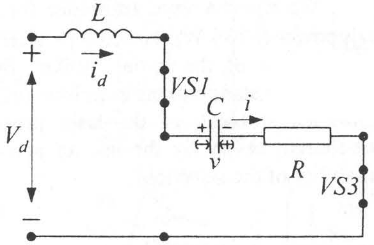

Fig.2

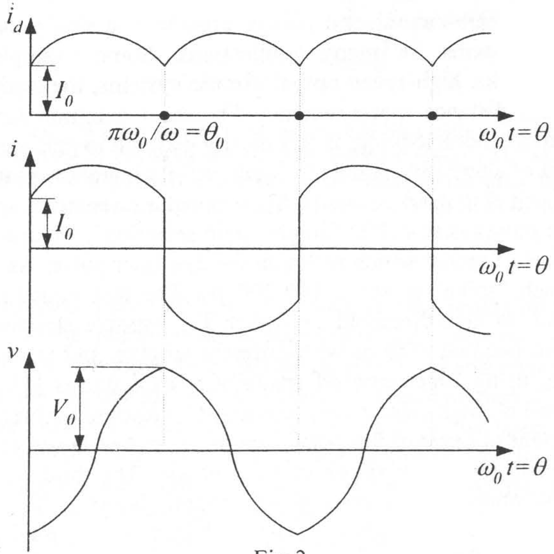

Fig.3