

$$L = \frac{X_c}{2\pi f \times n_h^2} \tag{10}$$

$$R = \frac{X_L}{Q_f} \hat{n} n_h^2 \tag{11}$$

Q_f Quality factor

- Installation harmonic filter with system and analyze harmonic current in the path of system and inspects performance of harmonic filter.

$$I_{RMS, Li} = \sqrt{(I_{Fi, l} \times 1.1)^2 + \sum_{h=2}^n I_{Fi, h}^2} \tag{12}$$

$I_{Fi, l}$ Current use in filter i at fundament frequency
 $I_{Fi, h}$ Harmonic current i at harmonic filter
 $I_{RMS, Li}$ Totally current that use in filter

Technique of intervening firing method

The basic modal of phase control converter, that uses for experiment show in fig.3 can able show below.

$$v_d(t) = [S_a(t) S_b(t) S_c(t)] \begin{bmatrix} v_{an}(t) \\ v_{bn}(t) \\ v_{cn}(t) \end{bmatrix} \tag{13}$$

$$\begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix} = \begin{bmatrix} S_a(t) \\ S_b(t) \\ S_c(t) \end{bmatrix} i_d(t) \tag{14}$$

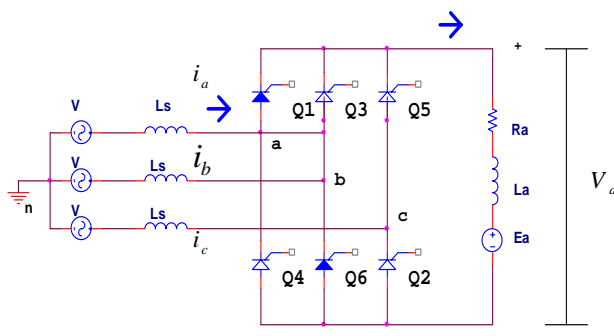


Fig.1 Three-phase thyristor control converter

Equation $S_a(t)$, $S_b(t)$ and $S_c(t)$ are switching function vector formula $S(t)$ of switching function can find like this

$$S(t) = \begin{bmatrix} S_x(t) \\ S_y(t) \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 0 & -\sqrt{3}/2 & \sqrt{3}/2 \\ 1 & -1/2 & -1/2 \end{bmatrix} \begin{bmatrix} S_a(t) \\ S_b(t) \\ S_c(t) \end{bmatrix} \tag{15}$$

Input voltage

$$\begin{bmatrix} v_{an}(t) \\ v_{bn}(t) \\ v_{cn}(t) \end{bmatrix} = \begin{bmatrix} \sqrt{2} V_{an} \sin(\omega t) \\ \sqrt{2} V_{an} \sin(\omega t - 2/3\pi) \\ \sqrt{2} V_{an} \sin(\omega t - 4/3\pi) \end{bmatrix} \tag{16}$$

Table 1 value of switching function

Conducting Switches	$S_a(t)$	$S_b(t)$	$S_c(t)$	$S(t)$
Q_5 and Q_0	0	-1	1	S_1
Q_1 and Q_6	1	-1	0	S_2
Q_1 and Q_2	1	0	-1	S_3
Q_3 and Q_2	0	1	1	S_4
Q_3 and Q_4	-1	1	0	S_5
Q_5 and Q_4	-1	0	1	S_6
Q_1 and Q_4	0	0	0	S_0
Q_3 and Q_6	0	0	0	S_0
Q_5 and Q_2	0	0	0	S_0

Technique of intervene firing method at the pulse of the 6 pulse phase control converter in every 1/6 period. This article S_0 will be create. Consider the first 1/6 period before intervening firing of i_{G1} , at $\omega t = 0$. Thyristor Q_3 , Q_4 enable a both and when there are intervening firing of i_{G1} , at $\omega t = 0$ Thyristor Q1 Trig when $v_{ab} > 0$ in 1/6 period. Q_1 will be turned on and Q_3 turn off then vector of o/p. v_d and input current $i_a, i_b, i_c = 0$ when i_{G5} Trig and Q_5 also. When $v_{ca} > 0$ in 1/6 period, Q_5 turn on and Q_1 turn off when output voltage, v_d become to v_{ca} . The sequence of Trig will be repeat. The result is value distortion in o/p voltage v_d reduction.

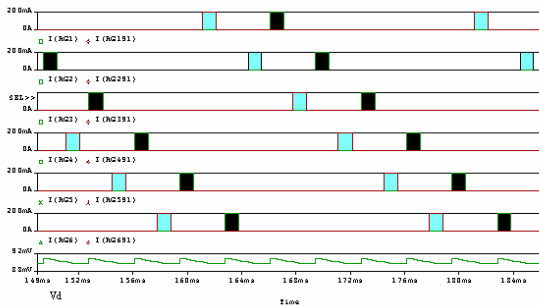


Fig 2 at $\alpha = 80^\circ, \beta = 20^\circ$

The value of distortion harmonic, V_d, V_{dmax}, I_a, S and V_{ripple} compute from equation below.

$$v_d(t) = v_d + \sum_{n=1}^{\infty} \sqrt{2} V_n \sin(n\omega t + \psi_n) \quad (17)$$

$$v_{ab}(t) = \sqrt{2} V_{ab} \sin(\omega t + \frac{\pi}{6}) \quad (18)$$

$$V_{ripple} = \sqrt{\sum_{n=1}^{\infty} V_n^2} \quad (19)$$

$$I_a = \sqrt{\sum_{n=1}^{\infty} I_n^2} \quad (20)$$

$$S = 3V_{an} I_a \quad (21)$$

Result of experiment

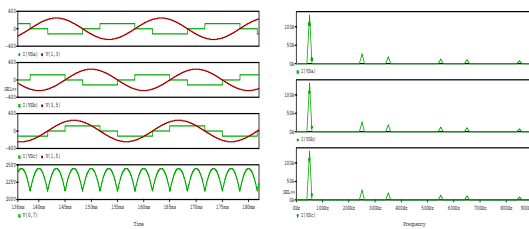


Fig 3 graph and current spectrum before take filter at $\alpha = 0^\circ$

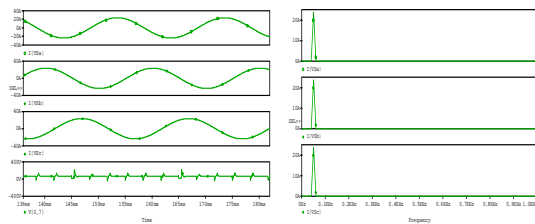


Fig 4 graph and current spectrum behind take filter at 5th, 7th and line reactor at $\alpha = 0^\circ$

Table 2 percentage of current harmonic $THD_i(\%)$ at $\alpha = 0^\circ, 30^\circ, 60^\circ$

Test Condition	$THD_i(\%)$		
	$\alpha = 0^\circ$	$\alpha = 30^\circ$	$\alpha = 60^\circ$
No Filters	24.61	27.16	27.36
Harmonic Filter $C_s = 240 \mu F, L_s = 1.84 mH$ $C_r = 150 \mu F, L_r = 1.38 mH$	2.98	4.35	4.65

The result of intervene firing

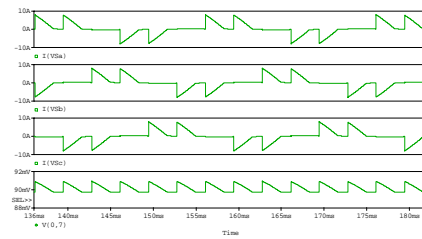


Fig 5 current graph i_a, i_b, i_c and voltage V_d at $\alpha = 80^\circ, \beta = 60^\circ$

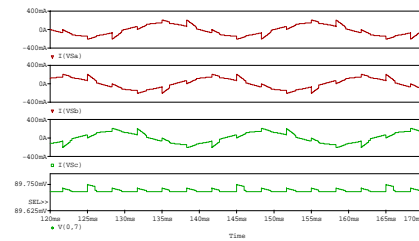


Fig 6 current graph i_a, i_b, i_c and voltage V_d at $\alpha = 120^\circ, \beta = 20^\circ$

Table 3 value of current harmonic $THD_i(\%)$ at $\alpha = 30^\circ - 120^\circ, \beta = 0^\circ - 60^\circ$ comparison with normally trig

Double Firing		$THD_i(\%)$	Firing	$THD_i(\%)$
α	β		α	
30	0	27.39	30	27.16
60	0	27.82	60	27.36
60	30	27.32	60	27.36
80	60	12.35	80	28.81
120	30	10.83	120	32.03
120	60	10.22	120	32.03

From fig. 3 and 4 $\alpha = 0^\circ, 30^\circ, 60^\circ$ harmonic filter passive can able reduction distortion harmonic but we consider THD(%) when the value of Trig's angle increase to much then input current and output voltage reduction the quality of filter reduction also.

Summarize

Reduction distortion harmonic from 6-pulse phase control converter show by to change space vector then can able make zero vector of output voltage and input current become to zero via every 1/6 period when comparison with passive harmonic filter

Reference

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