SIX-STEP VSI – 120° CONDUCTION MODE

WAVEFORM & HARMONIC ANALYSIS

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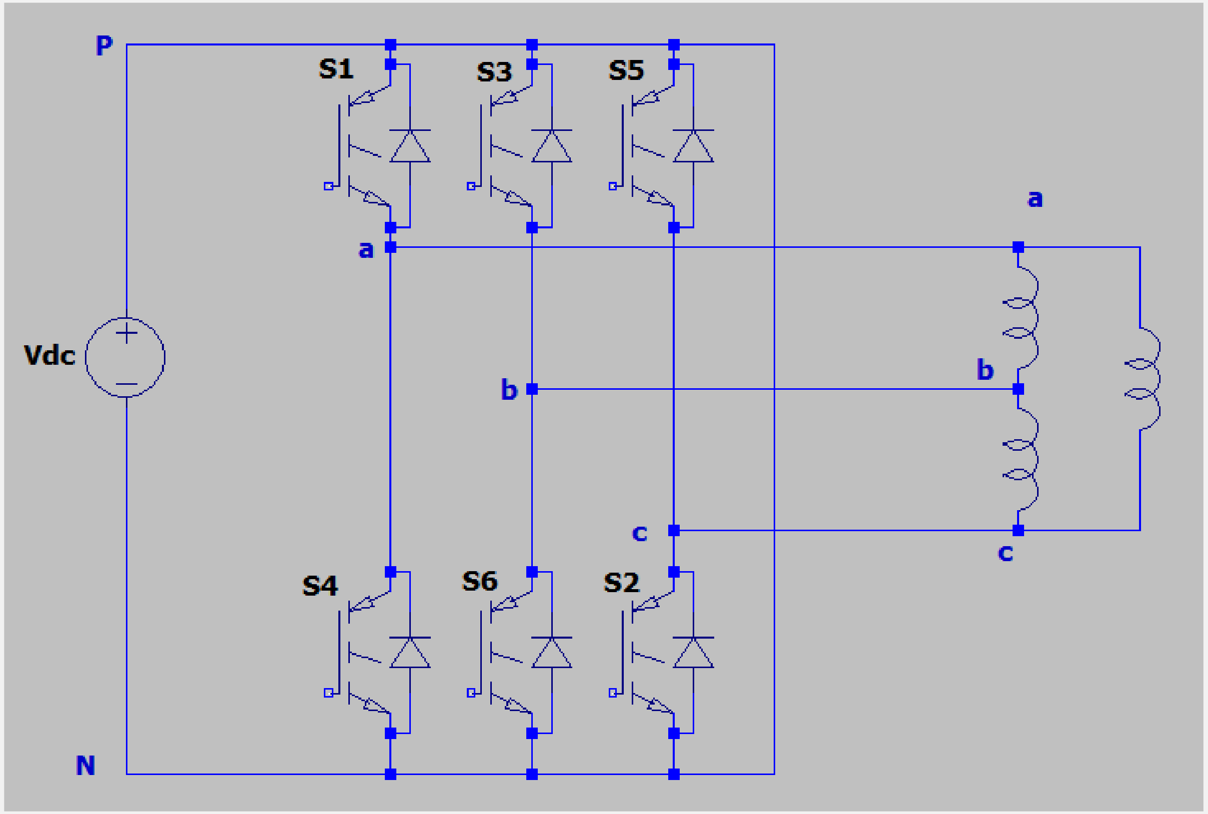
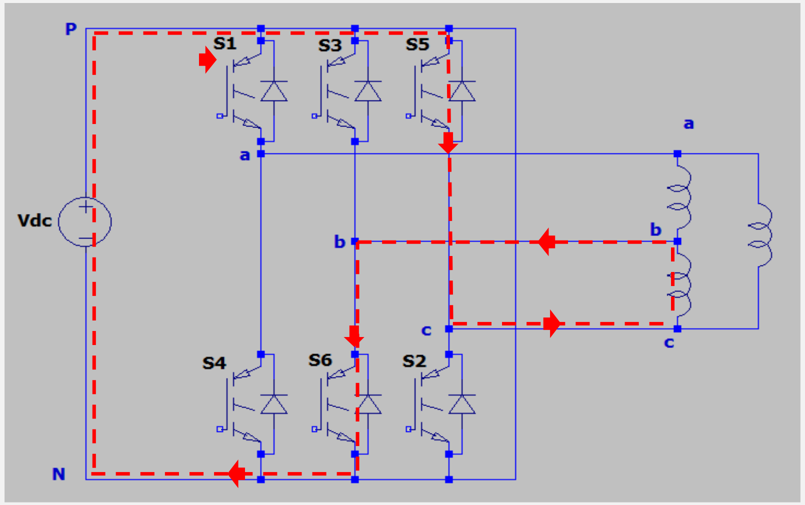
CIRCUIT



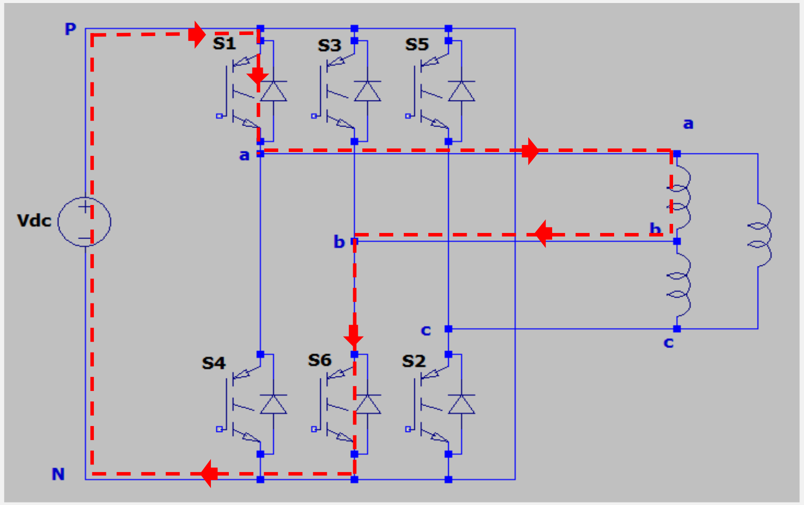
STATES



<u>56</u> (S5 and S6 conduct)

$V_{bc} = -V_{dc}$

$V_{ab} = V_{ca} = V_{dc}/2$

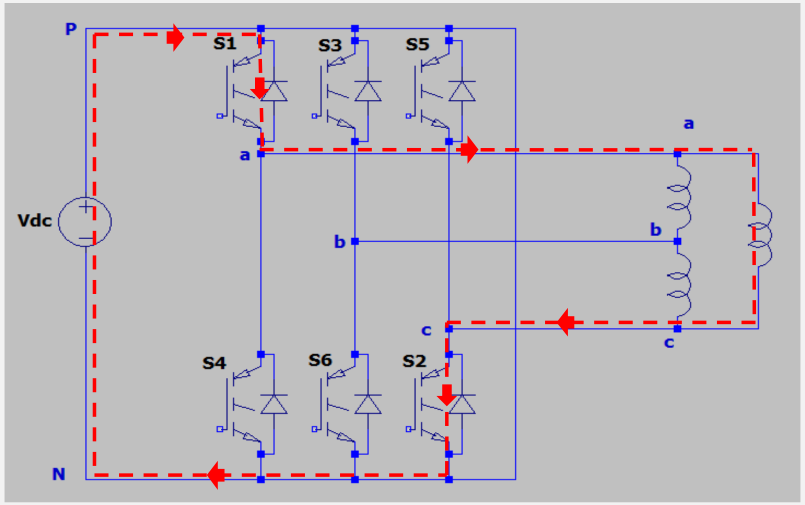


<u>61</u>(S6 and S1 conduct)

$V_{ab} = V_{dc}$

$V_{ca} = V_{bc} = - V_{dc}/2$

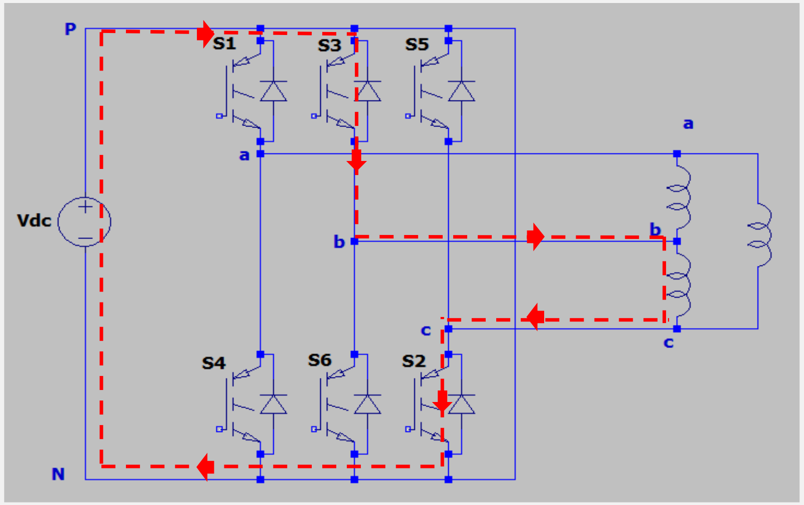
STATES



<u>12</u>(S1 and S2 conduct)

Vca = -Vdc

Vbc = Vab = Vdc/2

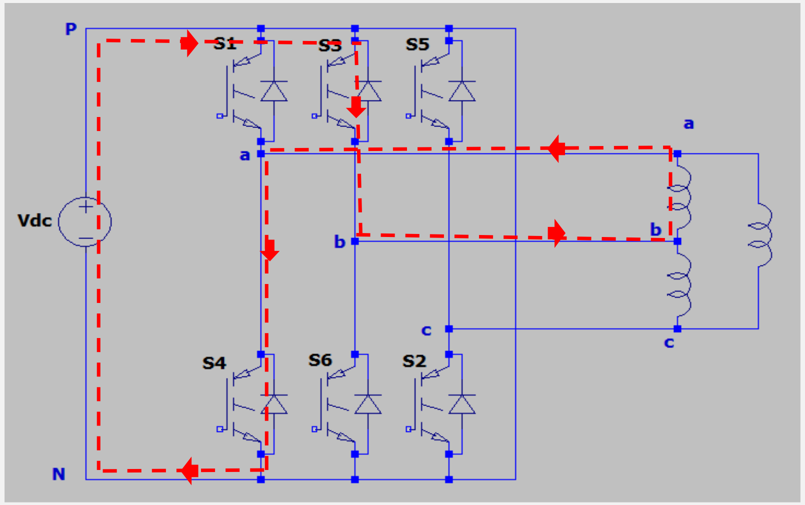


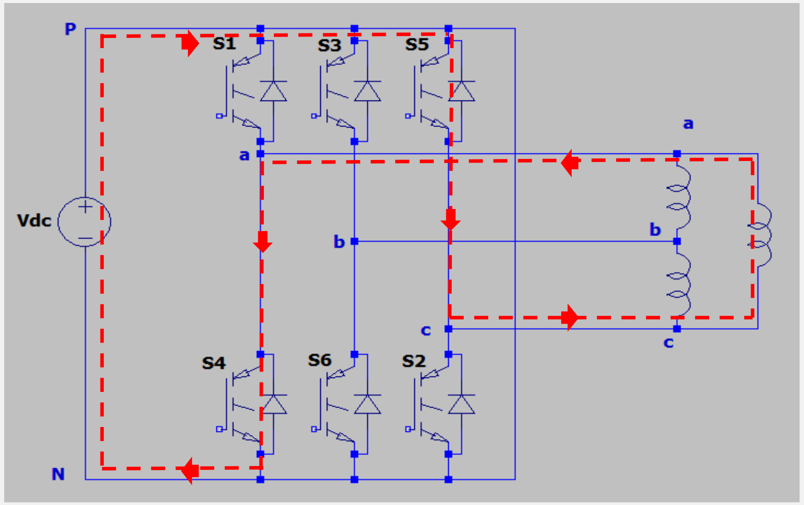
<u>23</u>(S2 and S3 conduct)

Vbc = Vdc

Vab = Vca = - Vdc/2

STATES





<u>34</u>(S3 and S4 conduct)

$V_{ab} = -V_{dc}$

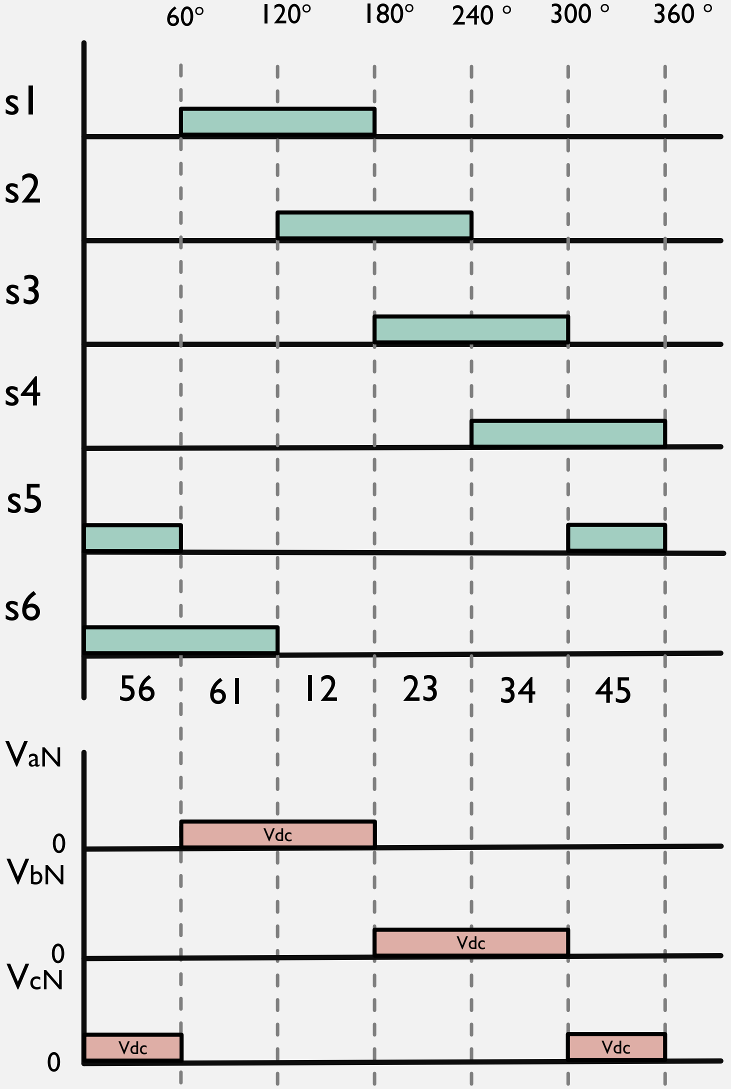
$V_{ca} = V_{bc} = V_{dc}/2$

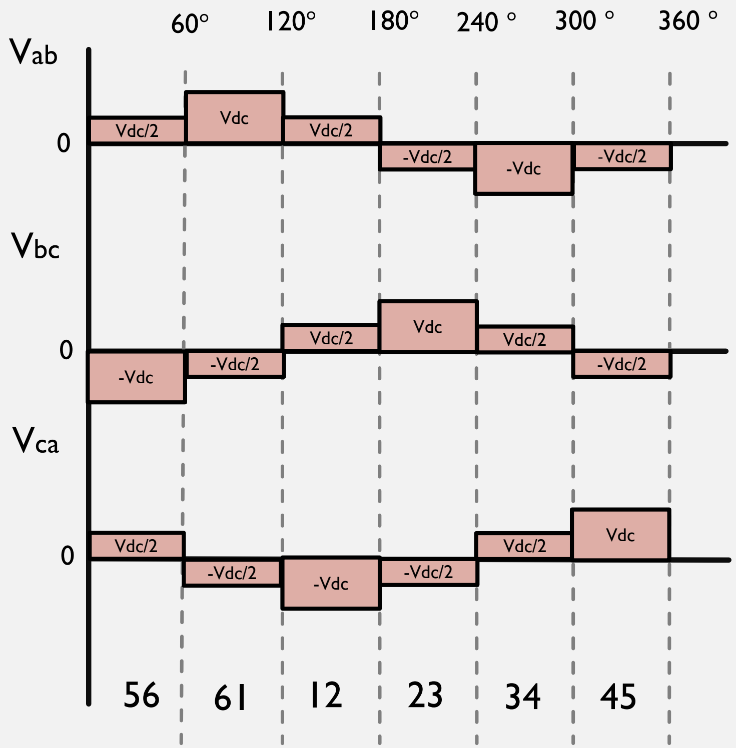
<u>45</u>(S4 and S5 conduct)

$V_{ca} = V_{dc}$

$V_{bc} = V_{ab} = - V_{dc}/2$

Delta 120° from the start





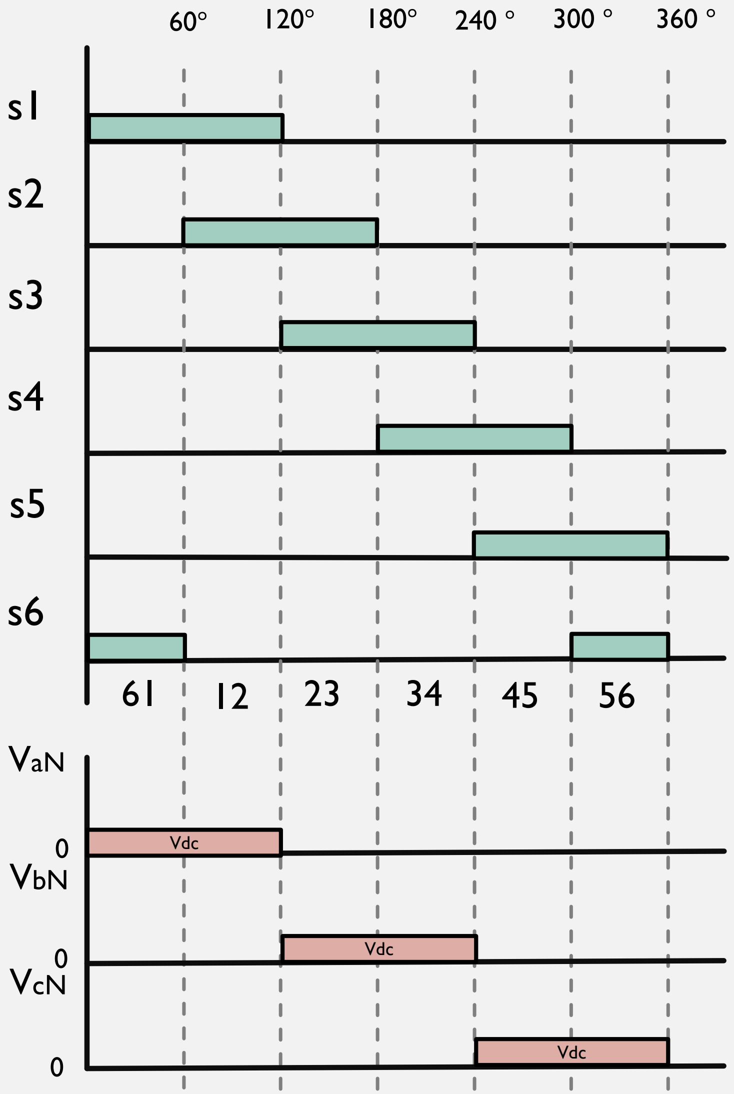
Delta-connection:

$V_{phase}=V_{line}$

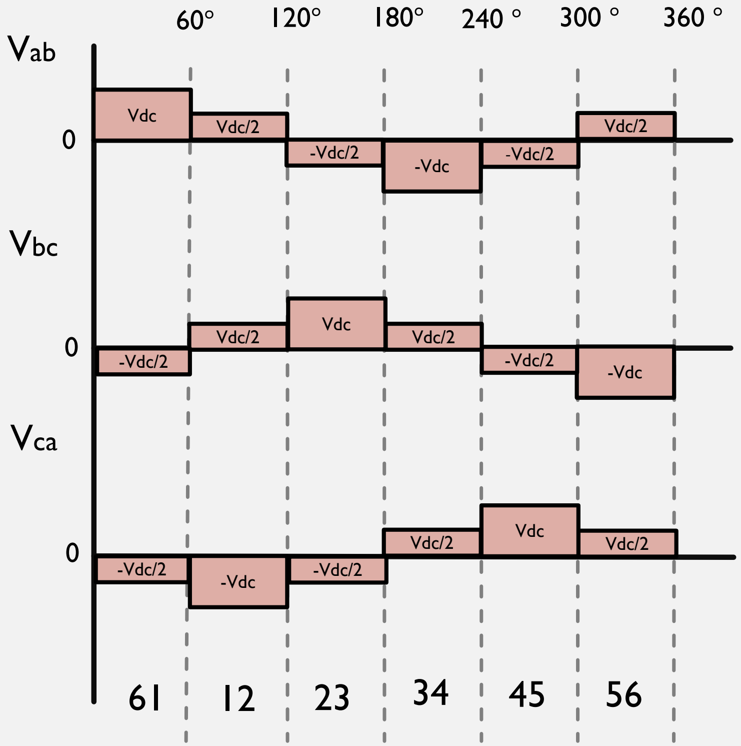
$V_{an} = V_{ab}$

$V_{bn}=V_{bc}$

$V_{cn}=V_{ca}$



Delta 120° from the end



Delta-connection:

Vphase=Vline

Van = Vab

Vbn=Vbc

Vcn=Vca

HARMONIC ANALYSIS

➢ <u>Delta 120° from the start</u>

$T_o = T\ , \omega_o = {}^{2\pi}/_{T}\ , \omega_n = n\omega_o$ with Vab odd function

Because of the odd symmetry
=> a_n=0

$$b_n = \frac{2}{T_o}\int_0^{T_o} V_{ab(t)}\sin(\omega_n t)\,dt = \frac{4}{T}\int_0^{\frac{T}{2}} V_{ab(t)}\sin(\omega_n t)\,dt$$

$$= \frac{4}{T}\left[\int_0^{\frac{T}{6}} \frac{V_d}{2}\sin(\omega_n t)\,dt + \int_{\frac{T}{6}}^{\frac{T}{3}} V_d\sin(\omega_n t)\,dt + \int_{\frac{T}{3}}^{\frac{T}{2}} \frac{V_d}{2}\sin(\omega_n t)\,dt\right]$$

$$= \frac{4}{T}\left\{\frac{V_d}{2}\left[\frac{-\cos(\omega_n t)}{\omega_n}\right]_0^{\frac{T}{6}} + V_d\left[\frac{-\cos(\omega_n t)}{\omega_n}\right]_{\frac{T}{6}}^{\frac{T}{3}} + \frac{V_d}{2}\left[\frac{-\cos(\omega_n t)}{\omega_n}\right]_{\frac{T}{3}}^{\frac{T}{2}}\right\}$$

$$= \frac{4V_d}{T\omega_n}\left\{\frac{1}{2}[-\cos(\omega_n t)]_0^{\frac{T}{6}} + [-\cos(\omega_n t)]_{\frac{T}{6}}^{\frac{T}{3}} + \frac{1}{2}[-\cos(\omega_n t)]_{\frac{T}{3}}^{\frac{T}{2}}\right\}$$

1.	0	S1	S1	0	0	0
2.	0	0	S2	S2	0	0
3.	0	0	0	S3	S3	0
4.	0	0	0	0	S4	S4
5.	S5	0	0	0	0	S5
6.	S6	S6	0	0	0	0
	0-60º	60º-120º	120º-180º	180º-240º	240º-300º	300º-360º
V_{ab}	$V_d/2$	V_d	$V_d/2$	$-V_d/2$	$-V_d$	$-V_d/2$
V_{bc}	$-V_d$	$-V_d/2$	$V_d/2$	V_d	$V_d/2$	$-V_d/2$
V_{ca}	$V_d/2$	$-V_d/2$	$-V_d$	$-V_d/2$	$V_d/2$	V_d

HARMONIC ANALYSIS

$$= \frac{2V_d}{n\pi}\left\{\frac{1}{2}\left[-\cos\left(\frac{2n\pi}{T}\frac{T}{6}\right)+1\right]+\left[-\cos\left(\frac{2n\pi}{T}\frac{T}{3}\right)+\cos\left(\frac{2n\pi}{T}\frac{T}{6}\right)\right]+\frac{1}{2}\left[-\cos\left(\frac{2n\pi}{T}\frac{T}{2}\right)+\cos\left(\frac{2n\pi}{T}\frac{T}{3}\right)\right]\right\}$$

$$= \frac{2V_d}{n\pi}\left\{\frac{1}{2}\left[-\cos\left(\frac{n\pi}{3}\right)+1\right]+\left[-\cos\left(\frac{2n\pi}{3}\right)+\cos\left(\frac{n\pi}{3}\right)\right]+\frac{1}{2}\left[-\cos(n\pi)+\cos\left(\frac{2n\pi}{3}\right)\right]\right\}$$

$$= \frac{2V_d}{n\pi}\left(-\frac{1}{2}\cos\left(\frac{n\pi}{3}\right)+\cos\left(\frac{n\pi}{3}\right)-\cos\left(\frac{2n\pi}{3}\right)+\frac{1}{2}\cos\left(\frac{2n\pi}{3}\right)+\frac{1}{2}-\frac{1}{2}\cos(n\pi)\right)$$

$$= \frac{2V_d}{n\pi}\left(\frac{1}{2}\cos\left(\frac{n\pi}{3}\right)-\frac{1}{2}\cos\left(\frac{2n\pi}{3}\right)+\frac{1}{2}-\frac{1}{2}\cos(n\pi)\right)$$

$$= \frac{V_d}{n\pi}\left(\cos\left(\frac{n\pi}{3}\right)-\cos\left(\frac{2n\pi}{3}\right)+1-\cos(n\pi)\right)$$

HARMONIC ANALYSIS

$b_1 = \frac{3V_d}{\pi} = 0,9549V_d$

$b_2 = b_3 = b_4 = 0$

$b_5 = \frac{3V_d}{5\pi} = 0,19099V_d$

$b_6 = 0$

$b_7 = \frac{3V_d}{7\pi} = 0,13642V_d$

…

$b_{11} = \frac{3V_d}{11\pi} = 0,0868V_d$

…

$b_n = \sum_{n=6k\pm1}^{\infty} \frac{3V_d}{n\pi} \quad k = 0,1,2,\ldots$

$$Vab = \sum_{n=6k\pm1}^{\infty} \frac{3\mathrm{V_d}}{\mathrm{n\pi}} \sin(n\omega_o t)$$

$$Vbc = \sum_{n=6k\pm1}^{\infty} \frac{3\mathrm{V_d}}{\mathrm{n\pi}} \sin\left(n\omega_o t + \frac{2\pi}{3}\right)$$

$$Vca = \sum_{n=6k\pm1}^{\infty} \frac{3\mathrm{V_d}}{\mathrm{n\pi}} \sin\left(n\omega_o t - \frac{2\pi}{3}\right)$$

- ✓ Because of the 90◦ symmetry the even components will be equal to zero.
- ✓ In addition, there is no neutral connection, so the ac line currents contain no dc or triplen harmonics

HARMONIC ANALYSIS

- Delta 120° from the end

$$Vab = \sum_{n=6k\pm1}^{\infty} \frac{3V_d}{n\pi} \sin\left(n\omega_o t + \frac{n\pi}{3}\right)$$

- RMS Value for Vab with 120º pulses

$$V_{ab(rms)} = \sqrt{\frac{1}{T}\int_0^T V_{ab}{}^2\, dt} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} V_{ab}{}^2\, d\theta} = \sqrt{\frac{2}{2\pi}\int_0^{\pi} V_{ab}{}^2\, d\theta} = \sqrt{\frac{1}{\pi}\int_0^{\pi} V_{ab}{}^2\, d\theta}$$

$$= \sqrt{\frac{1}{\pi}\left[\int_0^{\frac{\pi}{3}} \frac{V_d{}^2}{4}\, d\theta + \int_{\frac{\pi}{3}}^{\frac{2\pi}{3}} V_d\, d\theta + \int_{\frac{2\pi}{3}}^{\pi} \frac{V_d{}^2}{4}\, d\theta\right]} = \sqrt{\frac{1}{\pi}\left(\frac{V_d{}^2}{4}\left[\frac{\pi}{3} - 0\right] + V_d{}^2\left[\frac{2\pi}{3} - \frac{\pi}{3}\right] + \frac{V_d{}^2}{4}\left[\pi - \frac{2\pi}{3}\right]\right)}$$

$$= \sqrt{\frac{1}{\pi}\left(\frac{V_d{}^2}{4}\frac{\pi}{3} + V_d\frac{\pi}{3} + \frac{V_d{}^2}{4}\frac{\pi}{3}\right)} = \sqrt{\frac{1}{\pi}\left(\frac{6\pi V_d{}^2}{12}\right)} = \frac{V_d}{\sqrt{2}}$$

1.	S1	S1	0	0	0	0
2.	0	S2	S2	0	0	0
3.	0	0	S3	S3	0	0
4.	0	0	0	S4	S4	0
5.	0	0	0	0	S5	S5
6.	S6	0	0	0	0	S6
	0-60º	60º-120º	120º-180º	180º-240º	240º-300º	300º-360º
V_{ab}	V_d	$V_d/2$	$-V_d/2$	$-V_d$	$-V_d/2$	$V_d/2$
V_{bc}	$-V_d/2$	$V_d/2$	V_d	$V_d/2$	$-V_d/2$	$-V_d$
V_{ca}	$-V_d/2$	$-V_d$	$-V_d/2$	$V_d/2$	V_d	$V_d/2$

HARMONIC ANALYSIS

- <u>THDv</u>

$$V_{ab,1,rms} = \frac{3V_{dc}}{\sqrt{2}\pi}$$

$$\mathrm{THD}_v = \frac{\sqrt{V_{ab,rms} - V_{ab,1,rms}}}{V_{ab,1,rms}} = \frac{\sqrt{\frac{{V_{dc}}^2}{2} - \frac{9{V_{dc}}^2}{2\pi^2}}}{\frac{3V_{dc}}{\sqrt{2}\pi}} = \frac{\sqrt{\frac{{V_{dc}}^2}{2}(1 - \frac{9}{\pi^2})}}{\frac{3V_{dc}}{\sqrt{2}\pi}} = \frac{\sqrt{(1 - \frac{9}{\pi^2})}}{\frac{3}{\pi}} = 0.31 \text{ ή } 31\%$$

Thank you!