EE-464 STATIC POWER CONVERSION-II

Three Phase Inverters

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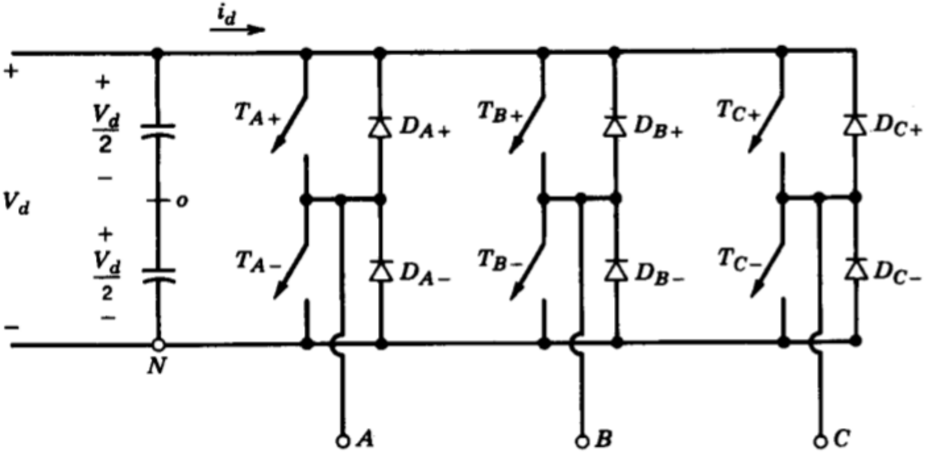
Three Phase Inverters

Different Sized Variable Frequency Drives (VFD)

Three Phase Inverters

Three Phase Voltage-Source Inverters



Three inverter legs are connected in parallel

Three Phase Voltage-Source Inverters

- Do not close top and bottom switches at the same time
- Point (o) is not needed put shown for simplicity in calculations
- Current can flow through the switch or anti-parallel diodes.

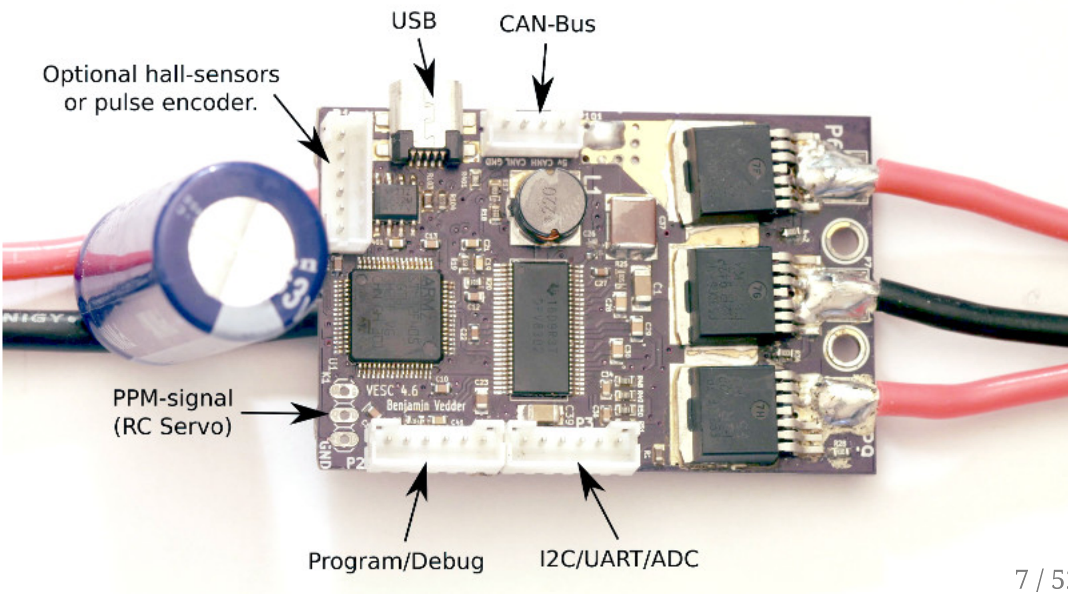
PWM Techniques

There are many different PWM techniques that will be covered:

- Square-wave (Six-step) PWM
- Sinusoidal PWM (SPWM)
- Hysteresis (Bang-Bang) Control
- Space-Vector PWM (SVPWM)
- Third harmonic injection

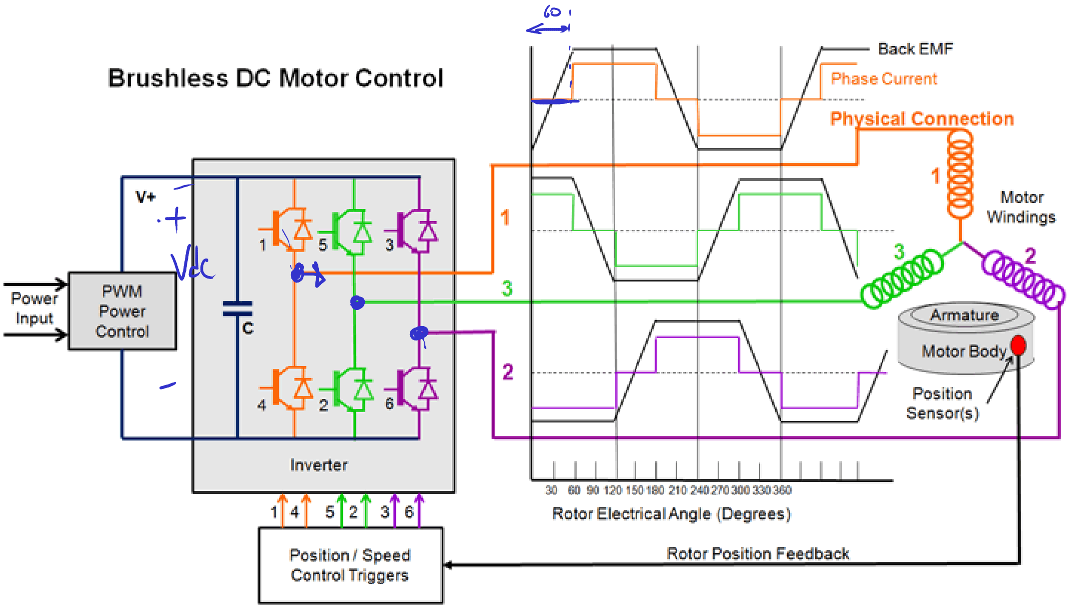
Six-Step Inverter

Commonly used in BLDC motor Drives



Six-Step Inverter

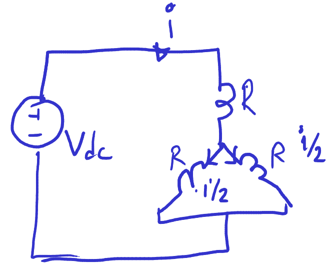
Commonly used in BLDC motor Drives

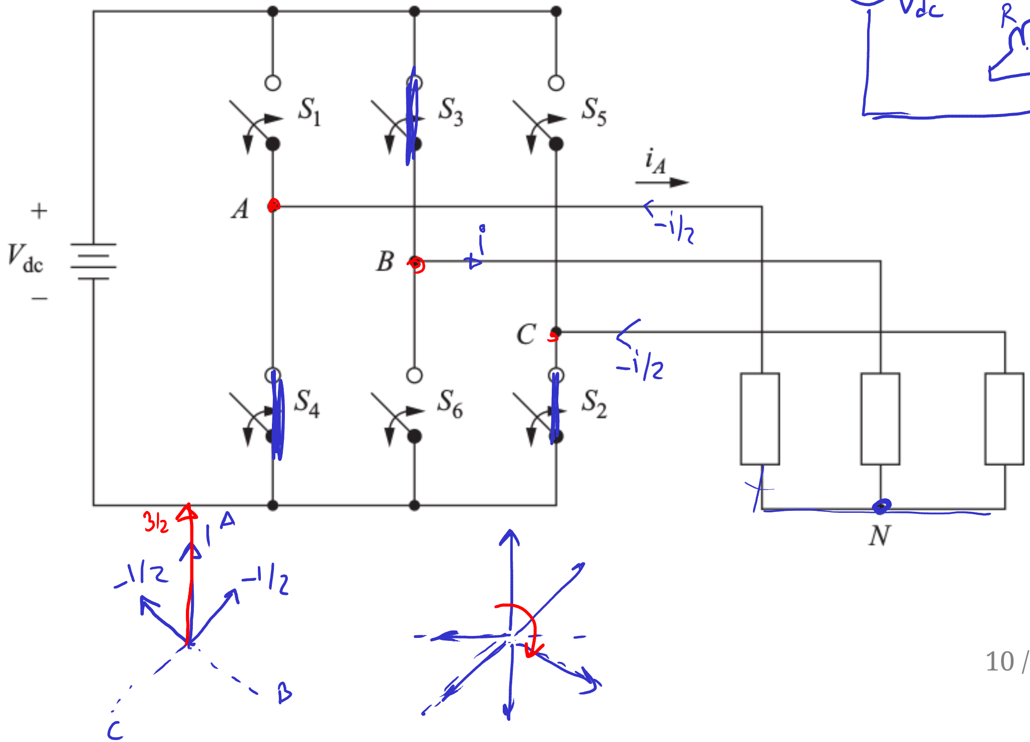


Six-Step Inverter

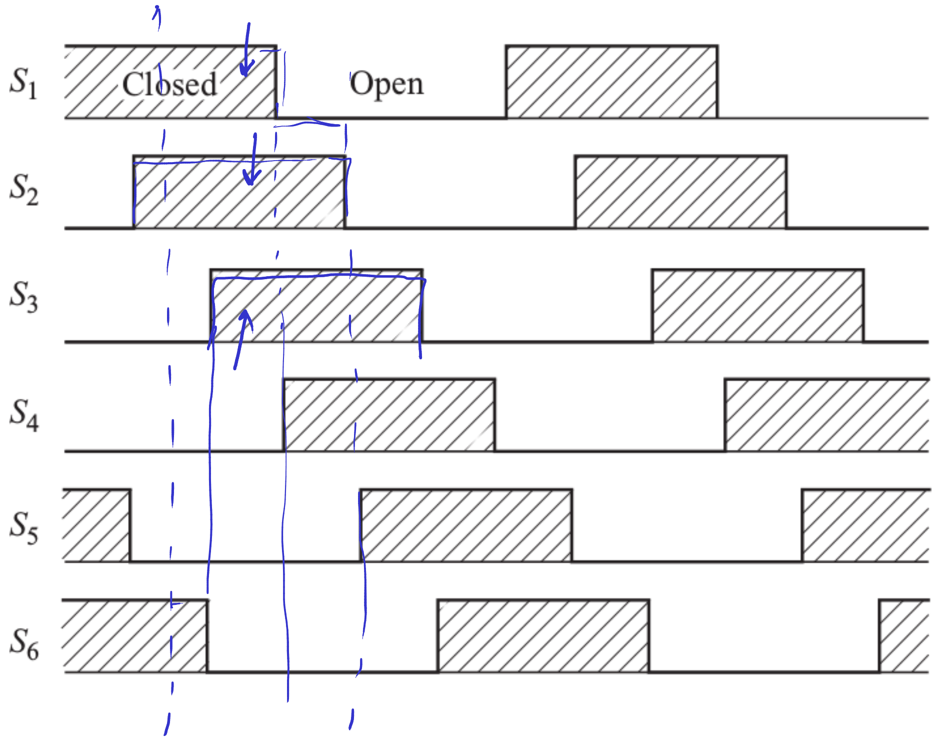
- Each switch has 50% duty ratio.
- Each leg has a phase difference of 120 degrees
- One switching action takes place at every 60 degrees

Six-Step Inverter



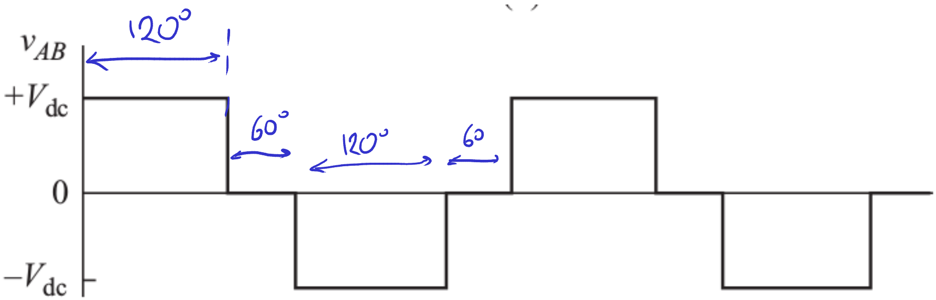


Six-Step Inverter

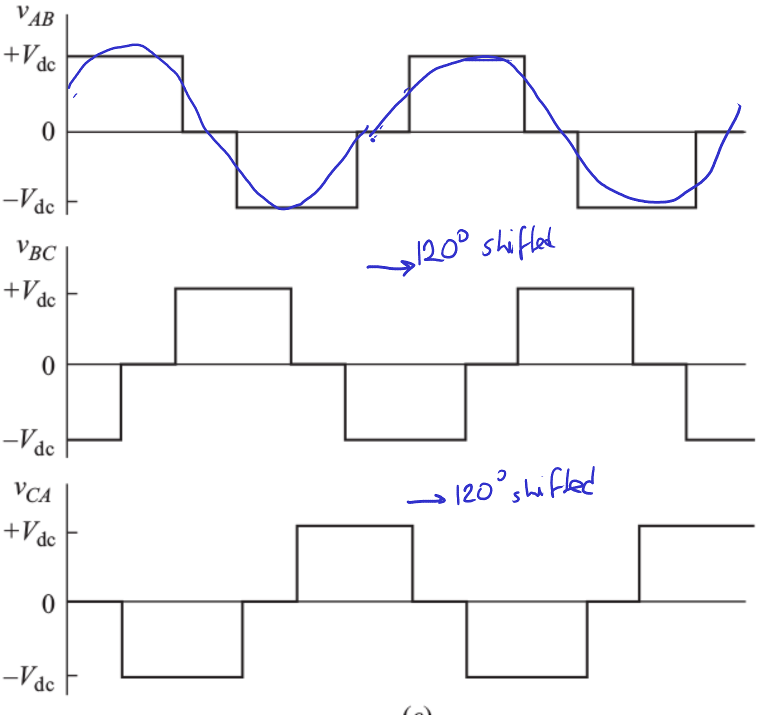


Six-Step Inverter

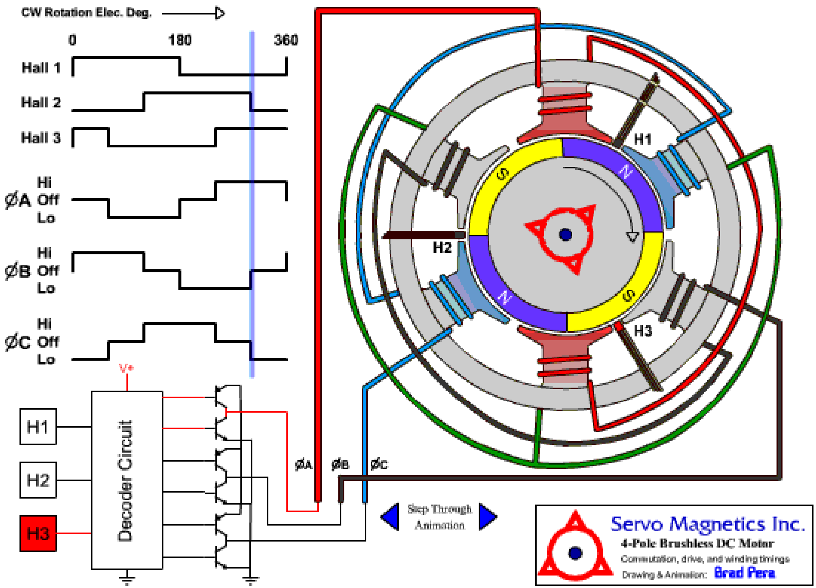
Line-to-line voltage: $V_{AB} = V_{A0} - V_{B0}$



Line-to-line voltages:

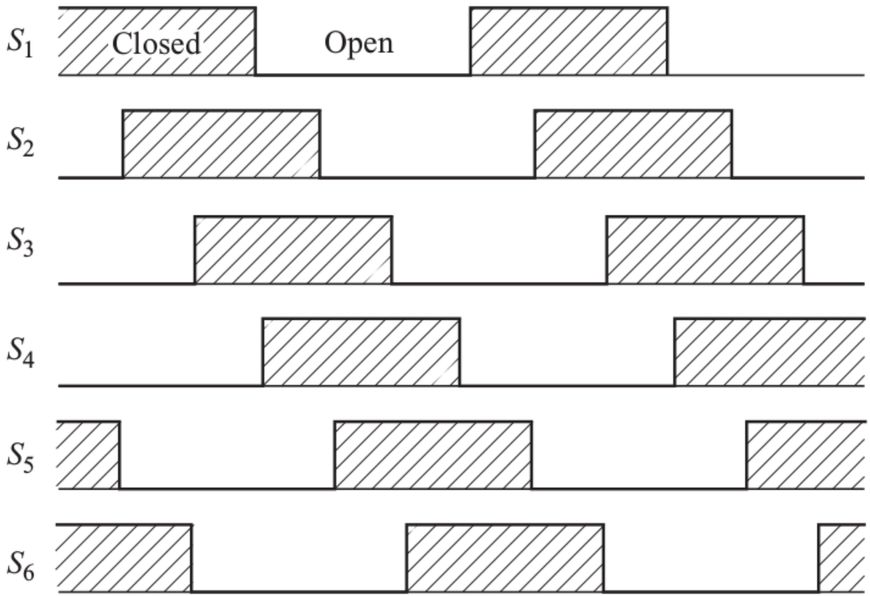


Square Wave Operation

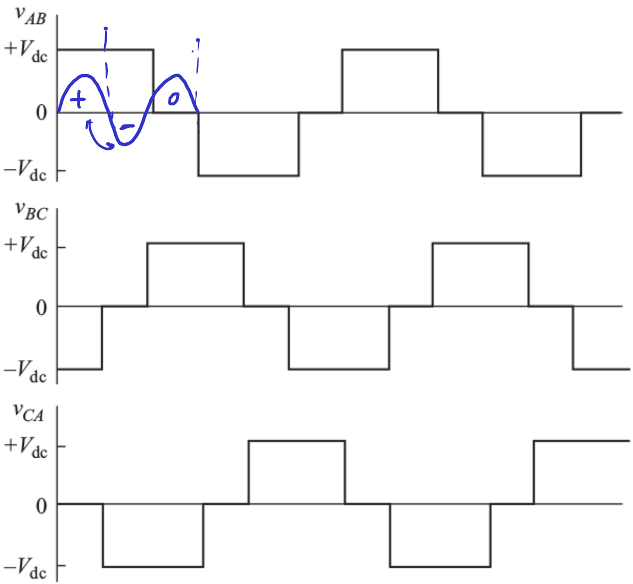


[BLDC Drive with square wave]

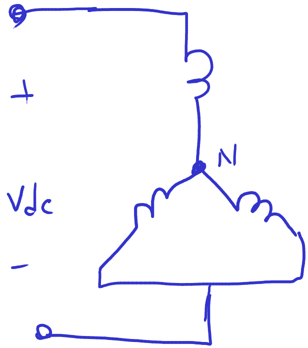
Switching Sequence



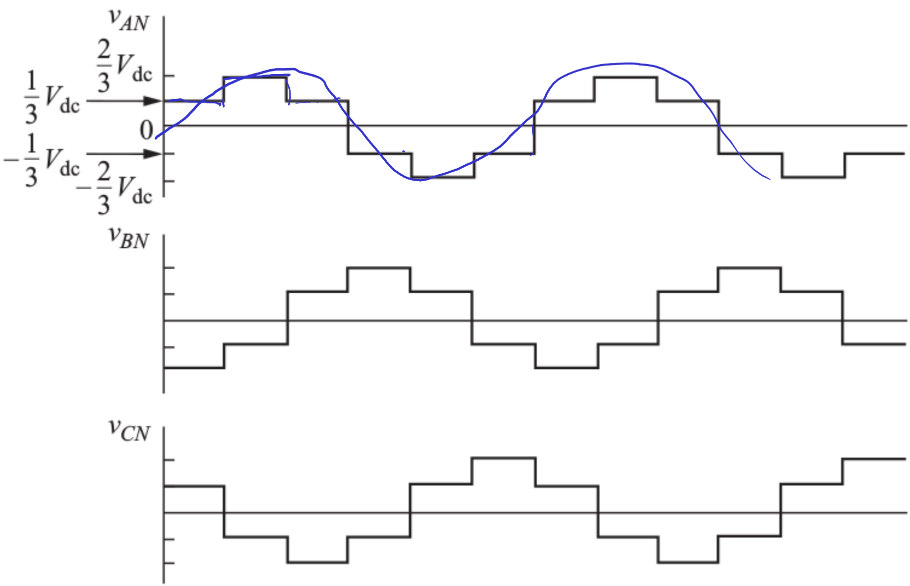
Line-to-Line Voltages



(c)



Equivalent Phase Voltages



Line-to-Line Harmonics

Fourier Coefficients

$$\hat{V}_{n,l-l} = \frac{1}{n}\frac{4}{\pi}V_{dc}cos(n\frac{\pi}{6})$$

For: $n = 6k \pm 1 = 1, 5, 7, 11, 13...$

- No even harmonics
- No third order harmonics

Line-to-Line Harmonics

RMS of the fundamental component?

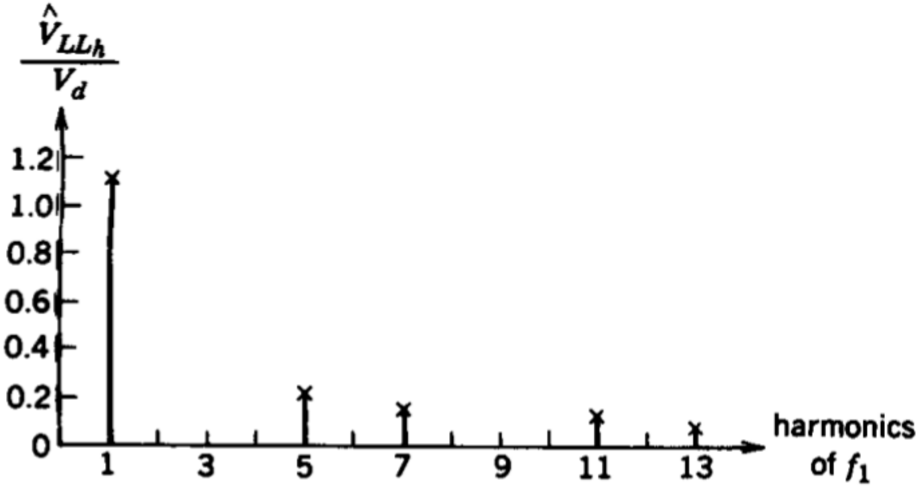
$$V_{1,l-l,rms} = \frac{1}{\sqrt{2}}\frac{4}{\pi}V_{dc}\frac{\sqrt{3}}{2} = 0.78V_{dc}$$

Harmonics RMS:

$$V_{n,l-l,rms} = \frac{1}{n}0.78V_{dc}$$

For: $n = 6k \pm 1 = 1, 5, 7, 11, 13...$

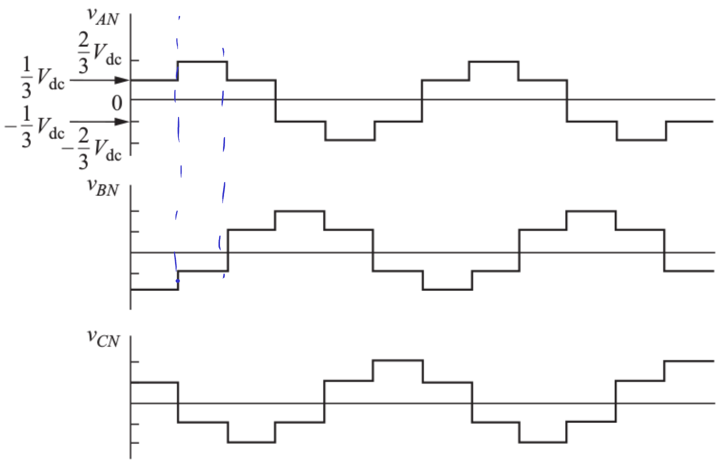
Line-to-Line Harmonics



(c)

Line-to-Neutral voltages:

Neutral point is floating



Voltage level changes every 60 degrees (that's why it's a six-step inverter!)

Line-to-Neutral Harmonics

Fourier Coefficients

$$\hat{V}_{n,l-N} = \frac{1}{n}\frac{2}{3\pi}V_{dc}(2 + cos(\frac{\pi n}{3}) - cos(\frac{2\pi n}{3}))$$

For: $n = 6k \pm 1 = 1, 5, 7, 11, 13...$

Simpler Form

$$\hat{V}_{n,l-N} = \frac{1}{n}\frac{2}{\pi}V_{dc}$$

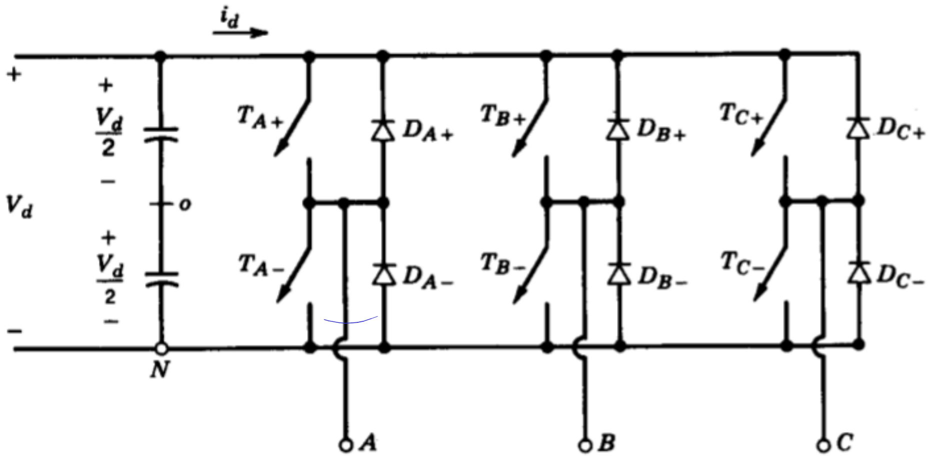
Line-to-Neutral Harmonics

$$\hat{V}_{n,l-N} = \frac{1}{n}\frac{2}{\pi}V_{dc}$$

For: $n = 6k \pm 1 = 1, 5, 7, 11, 13...$

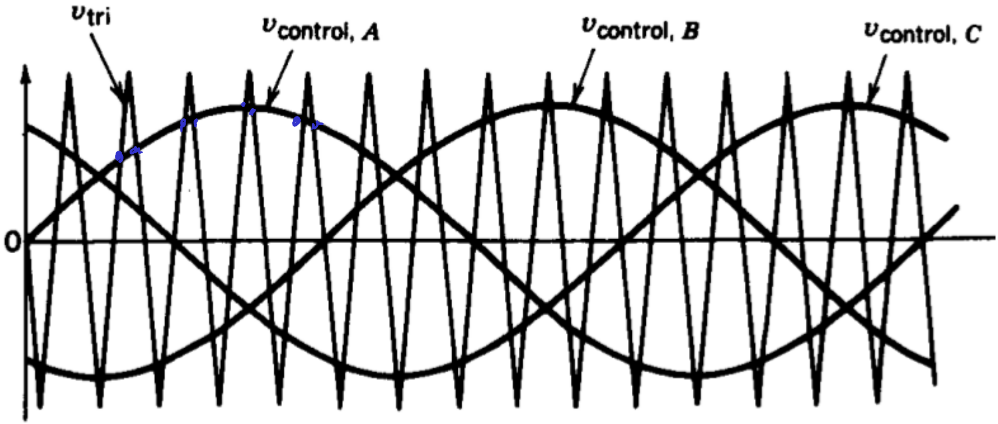
- No even harmonics
- No third order harmonics

Three Phase Voltage-Source Inverter



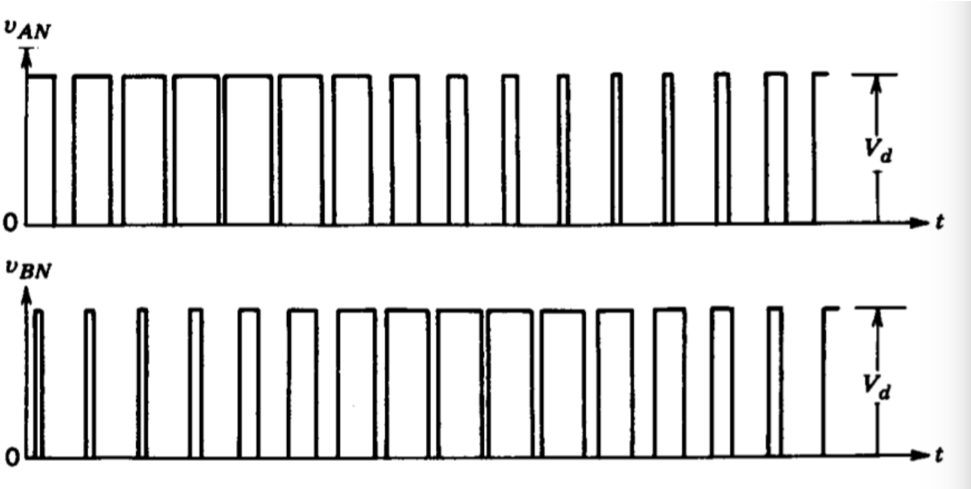
Sinusoidal PWM (SPWM)

A triangular carrier wave is generated and compared with each phase.



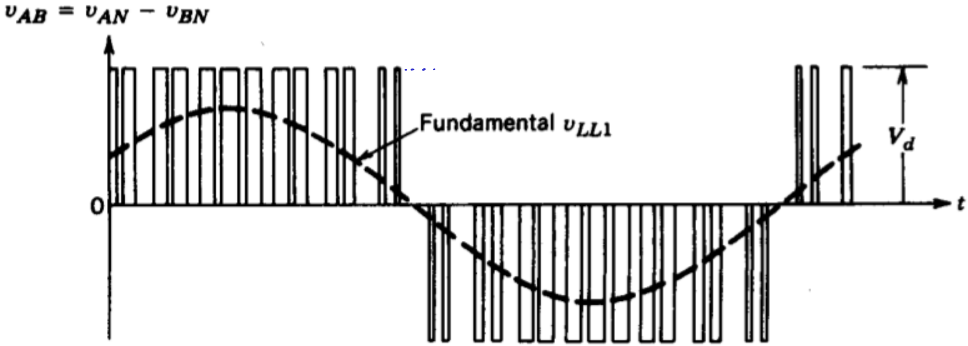
Sinusoidal PWM (SPWM)

Vd or 0 voltage is generated at V_{AN} depending on the comparison.



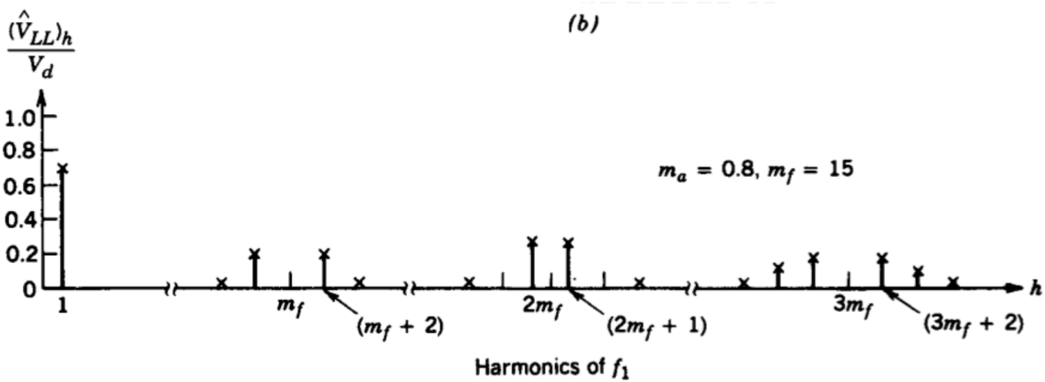
Sinusoidal PWM (SPWM)

Line to line voltage ($V_{AB} = V_{AN} - V_{BN}$)



Sinusoidal PWM (SPWM)

Harmonics in the line voltage

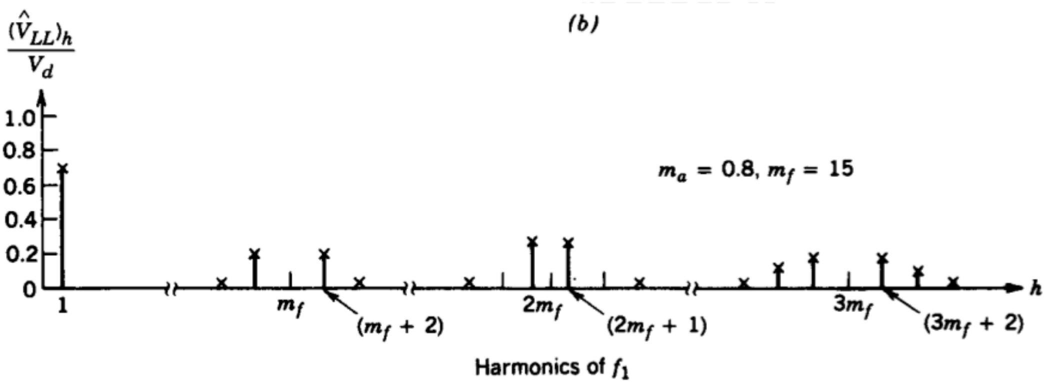


Harmonics at the side bands,

Like the unipolar but starts at mf.

Sinusoidal PWM (SPWM)

Harmonics in the line voltage



If mf is small, it is better to use synchronized PWM, and mf should be an odd interger, preferably multiple of 3 to reduce harmonics.

Sinusoidal PWM (SPWM)

Harmonics in the line voltage

Table 8-2 Generalized Harmonics of v_{LL} for a Large and Odd m_f That Is a Multiple of 3.

h \ m_a	0.2	0.4	0.6	0.8	1.0
1	0.122	0.245	0.367	0.490	0.612
$m_f \pm 2$	0.010	0.037	0.080	0.135	0.195
$m_f \pm 4$				0.005	0.011
$2m_f \pm 1$	0.116	0.200	0.227	0.192	0.111
$2m_f \pm 5$				0.008	0.020
$3m_f \pm 2$	0.027	0.085	0.124	0.108	0.038
$3m_f \pm 4$		0.007	0.029	0.064	0.096
$4m_f \pm 1$	0.100	0.096	0.005	0.064	0.042
$4m_f \pm 5$			0.021	0.051	0.073
$4m_f \pm 7$				0.010	0.030

Voltage Levels?

Linear Region ($m_a < 1$)

$$\hat{V}_{AN1} = m_a \frac{V_d}{2}$$

$$V_{l-l,rms} = \frac{\sqrt{3}}{\sqrt{2}} m_a \frac{V_d}{2}$$

$$V_{l-l,rms} = 0.612 V_d$$ (max in linear region)

Voltage Levels?

Overmodulation ($m_a > 1$)

Square-Wave Operation?

$$V_{l-l,rms} = \frac{\sqrt{3}}{\sqrt{2}}\frac{4}{\pi}m_a\frac{V_d}{2}$$

$$V_{l-l,rms} = 0.78V_d$$

$$V_{l-l,rms,h} = \frac{0.78}{h}V_d \text{ for } h = 6n \pm 1$$

Voltage Levels?