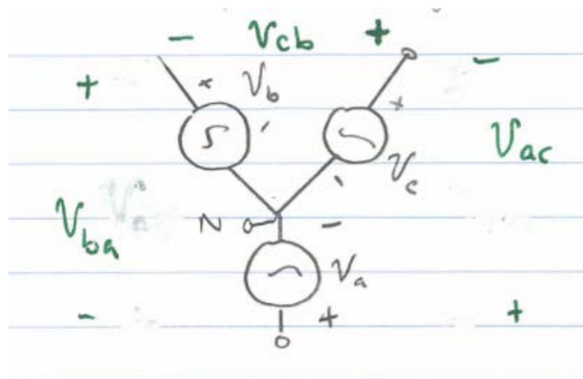
6.622 Power Electronics *Prof. David Perreault*

Lecture 22 - 3Φ Systems 2

1 Review

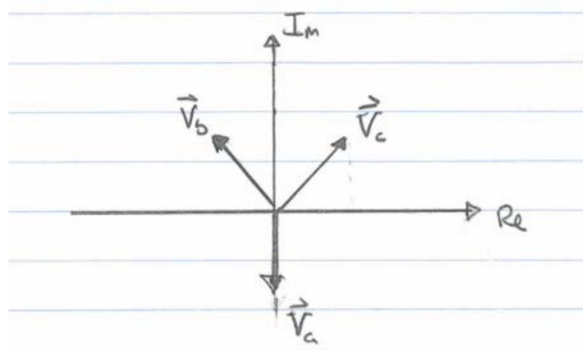
Three-phase set separated by 120°

$$v_a = V_s sin(\omega t)$$
$$v_b = V_s sin(\omega t - \frac{2\pi}{3})$$
$$v_c = V_s sin(\omega t + \frac{2\pi}{3})$$

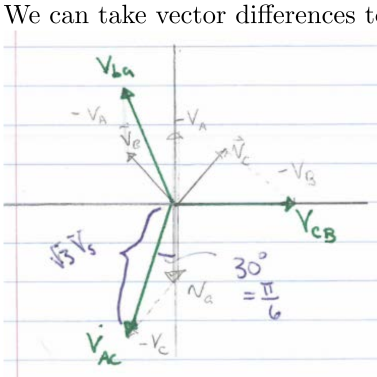


Phasor notation:

$$v_x(t) = Re\left[\vec{V_x} e^{j\omega t}\right]$$



We can take vector differences to get line-line waveforms



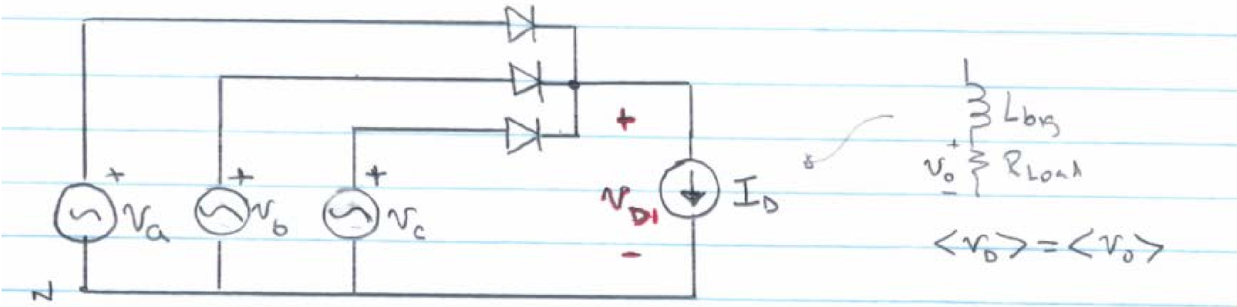
- $\sqrt{3}$ increase in magnitude for l-l
- 30° phase shift for l-l

  So 120 V_{rms} l-n ↔ 208$V_{rms} l.l.$ ⇒ Distribute 3Φ 208 l-l and break off l-n taps for differenct 1Φ branches

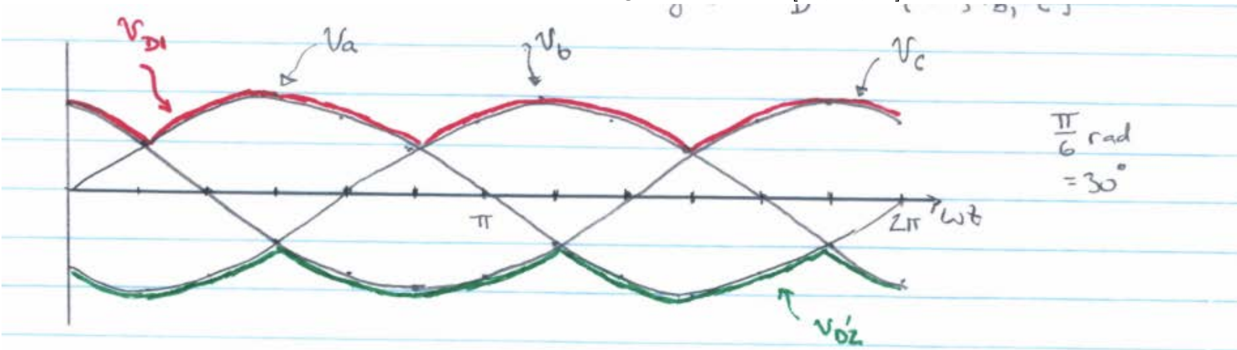
We can create sinusoids of any magnitude + phase by using transformers to select + add up parts of different l-n voltages! (as simple as vector addition...)

2 Consider diode rectification of 3-phase

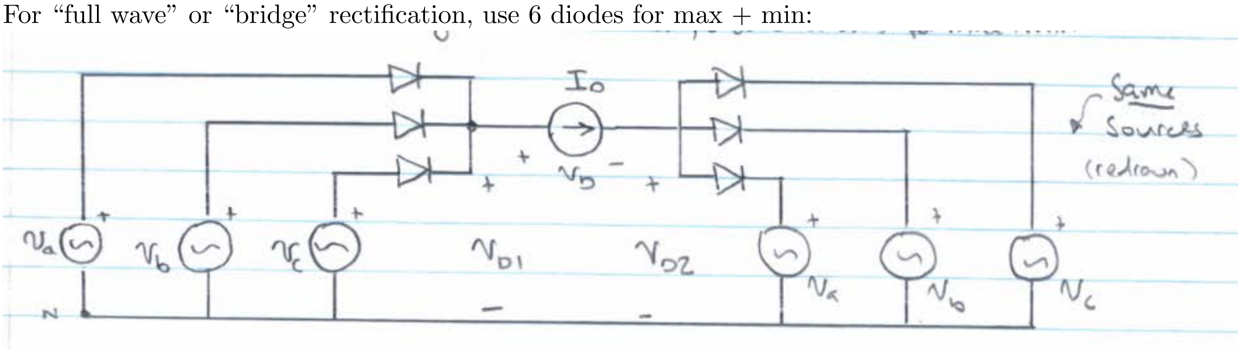
The equivalent "half-wave" rectification is:



v_D is the diode "or" of the three line-to-neutral voltages $v_D = max\,[v_a, v_b, v_c]$



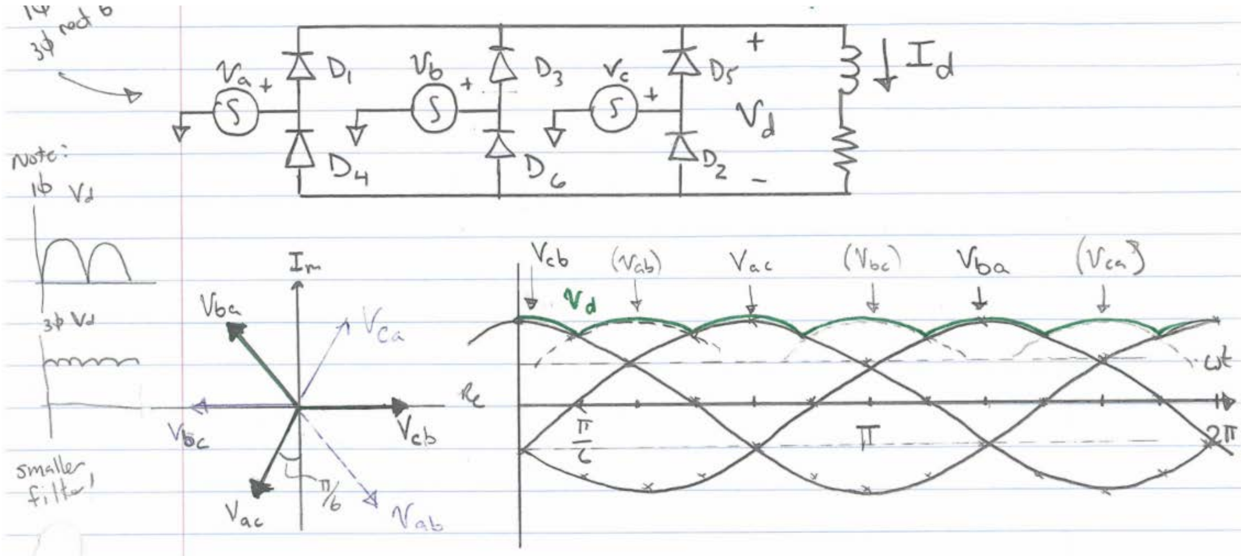
If we had <u>reversed</u> the diodes, we'd get $v_{DZ} = min\,[v_a, v_b, v_c]$
For "full wave" or "bridge" rectification, use 6 diodes for max + min:



$$v_d = v_{D1} - v_{D2} = max\,[v_a, v_b, v_c] - min\,[v_a, v_b, v_c]$$

* this is the same as $v_d = max\,[v_{ab}, v_{ac}, v_{bc}, v_{ba}, v_{ca}, v_{cb}]$

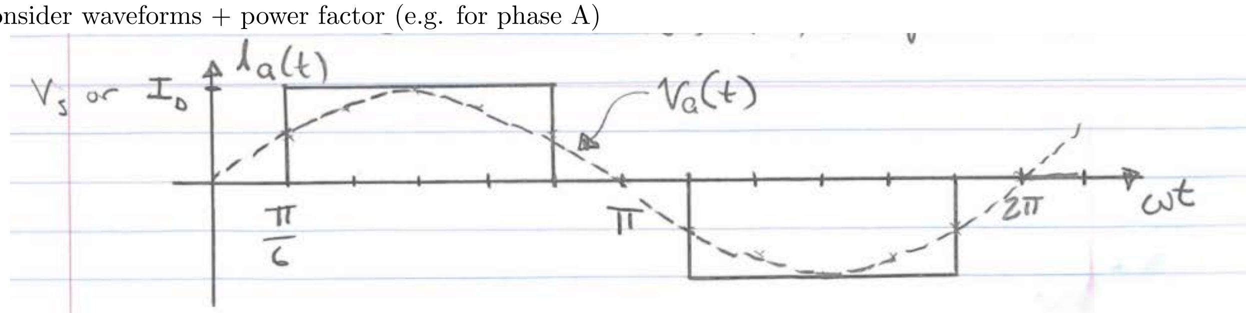
The 3Φ full-bridge rectifier can be drawn as follows:
Note: 1Φ red 4 diodes, 3Φ red 6 diodes!



- v_d is $max\,[v_{ab}, v_{ac}, v_{bc}, v_{ba}, v_{ca}, v_{cb}]$
- Phases named such that successive l-n maxima are $v_a, v_b, v_c, v_a, v_b, v_c$... so l-l max goes $v_{ab}, v_{ac}, v_{bc}, v_{ba}, v_{ca}, v_{cb}$...
- Diodes numbered such that conduction sequence is: $\frac{D_6}{D_1}, \frac{D_1}{D_2}, \frac{D_2}{D_3}, \frac{D_3}{D_4}, \frac{D_4}{D_5}, \frac{D_5}{D_6}, \frac{D_6}{D_1}$...

To simplify tracking behavior.

Consider waveforms + power factor (e.g. for phase A)



$$V_{a,rms} = \frac{V_s}{\sqrt{2}}; i_{a,rms} = \sqrt{\frac{2}{3}I_d^2} = \frac{2}{3}I_d$$

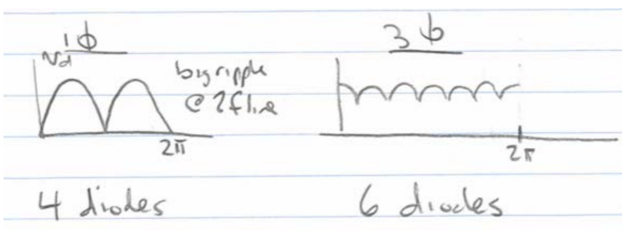
$$< P >= \frac{1}{\pi}\int_{\frac{\pi}{6}}^{\frac{5\pi}{6}} I_d V_s sin(\psi) d\psi = \frac{V_s I_d}{\pi} \cdot [cos(\frac{\pi}{6}) - cos(\frac{5\pi}{6})]$$

$$< P >= \frac{V_s I_d \sqrt{3}}{\pi}$$

$$\Rightarrow K_p = \frac{< P >}{V_{RMS} I_{RMS}} = \frac{V_s I_d \sqrt{3}}{\pi} \cdot \frac{\sqrt{2}}{V_s} \frac{\sqrt{3}}{I_d} \frac{1}{\sqrt{2}} = \frac{3}{\pi} \approx 0.96$$

This compares favorably to a single-phase bridge rect ($K_p \approx 0.91$)
Why better? : No triple harmonics!

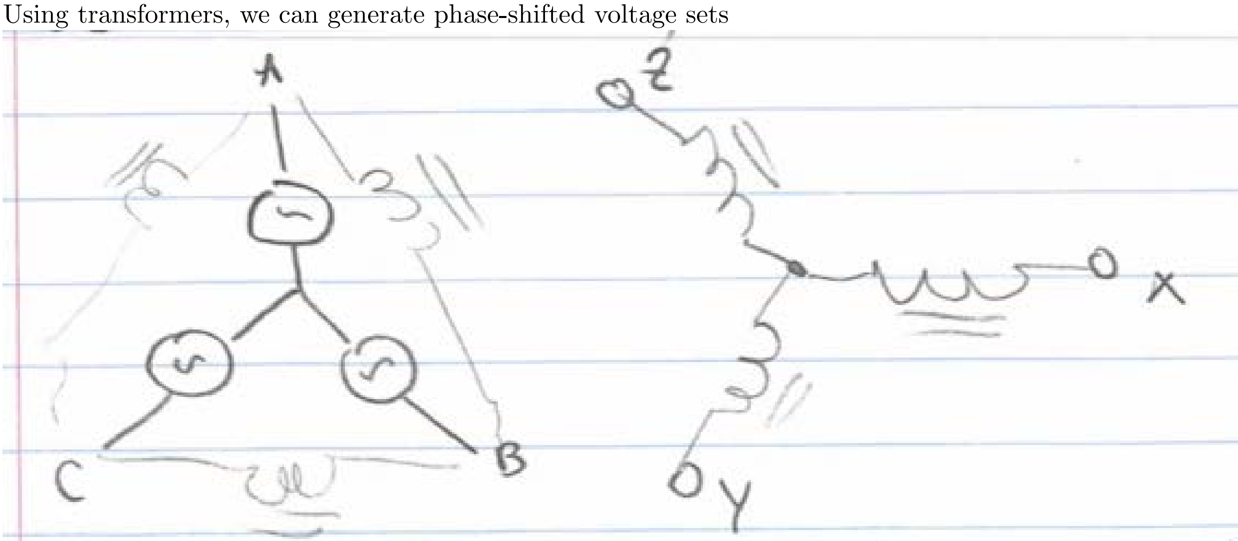
Also:



small ripple @ $6 f_{line}$

⇒ 3Φ wins!

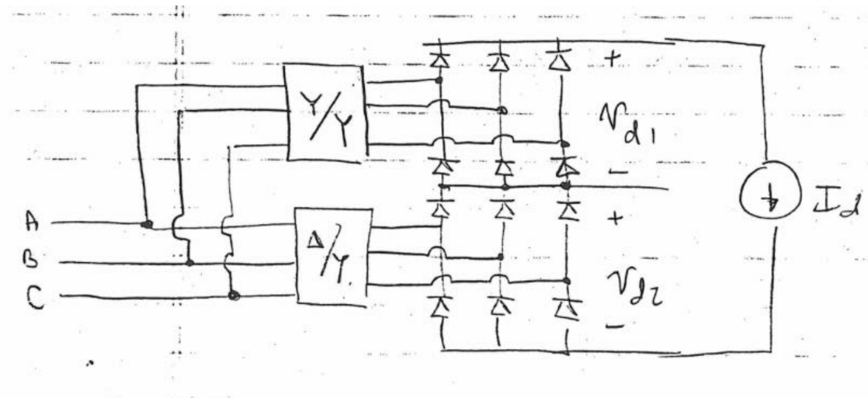
We can do even better (in terms of harmonics/ P.F.) with higher order rectifiers
Using transformers, we can generate phase-shifted voltage sets



"Δ-Y" set ⇒ can create 30° phase shift ABC→XYZ

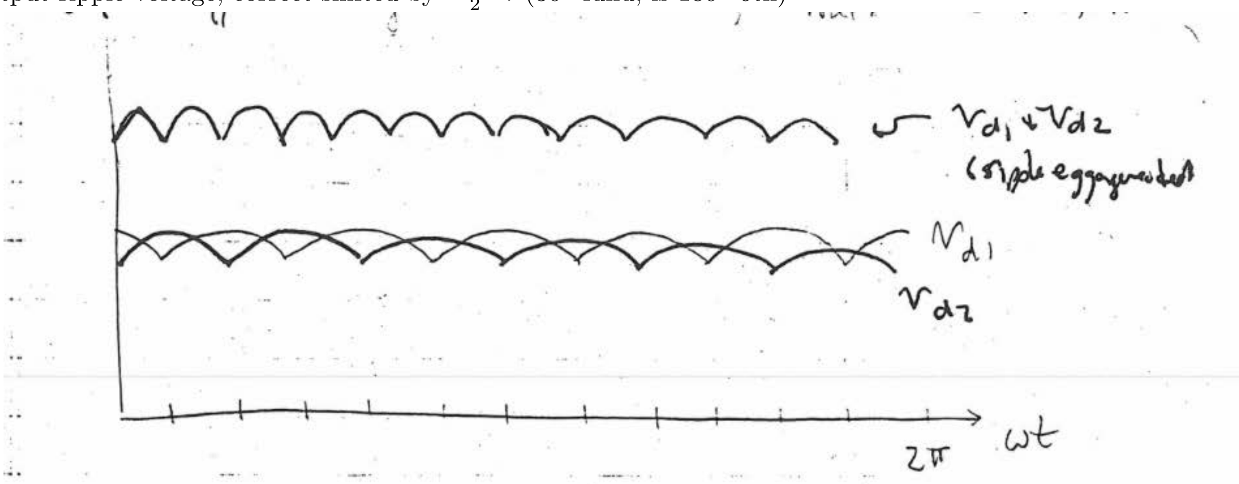
3 Higher-order rectifier

Suppose we use two phase-shifted transformer sets on series-stacked six-pulse bridges



The $\frac{Y}{Y_1}, \frac{\Delta}{Y}$ transformer sets generate equal voltage magnitudes, with a 30° phase difference between their 3Φ outputs

Since all voltages are isolated, constant current in the bridges → the two six pulse bridges act independently. Since input waveforms shifted by 30° ($\frac{T}{12}$) and output ripple is at 6 x input frequency ($T_{V_{out}} = \frac{T}{6}$) Output ripple voltage, correct shifted by $\frac{T_{V_{out}}}{2}$. (30° fund; is 180° 6th)



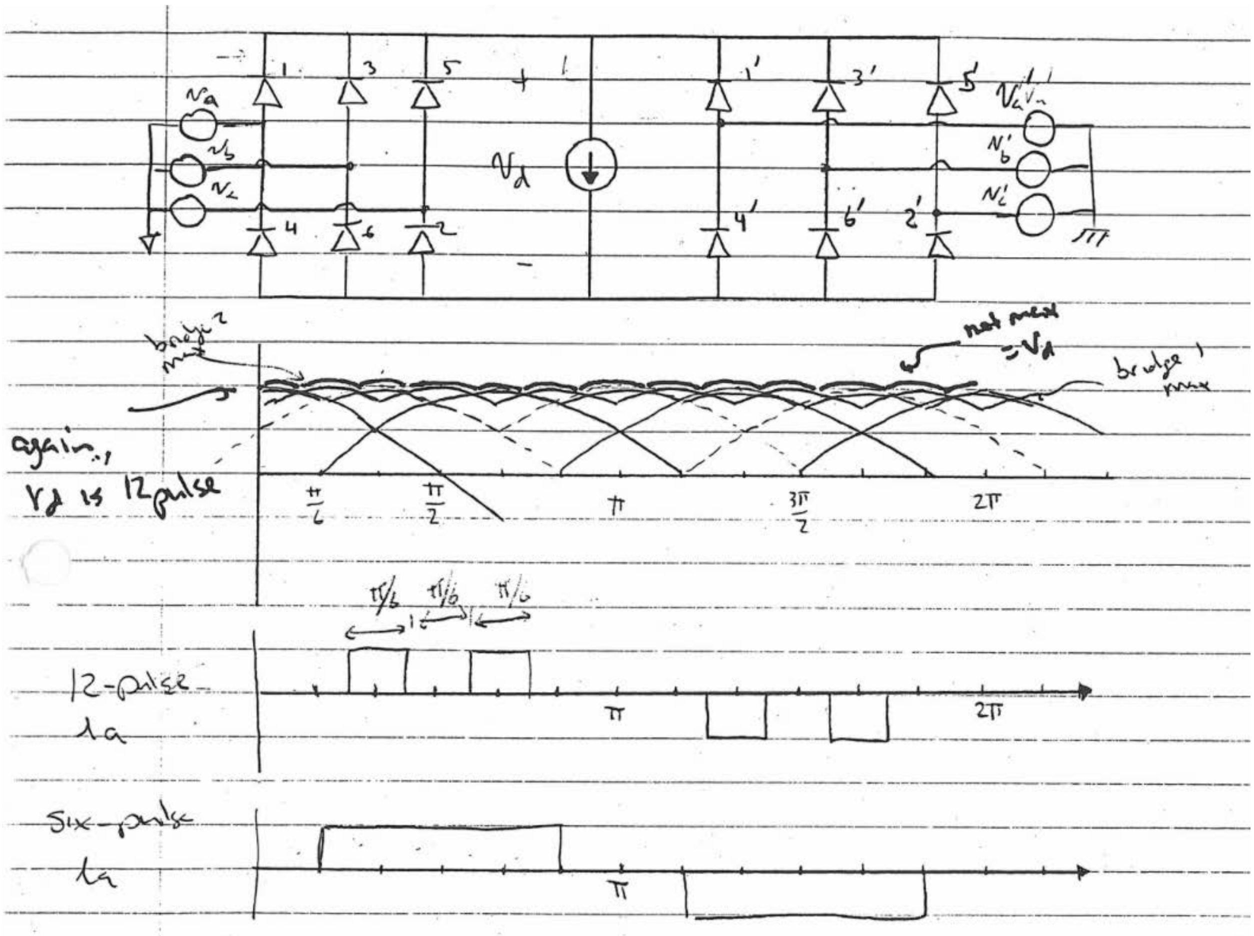
We have a 12-pulse rectifier:

- smaller ripple magnitude
- hiher ripple frequency

For easier output filger

Net input current + power factor also improves

Consider parallel case (direct connection)



12 pulse $I_{d1,rms} = \sqrt{\frac{2\pi}{6} \cdot \frac{1}{2\pi} \cdot I_d^2} = \frac{I_d}{\sqrt{6}}$

6 pulse $I_{d1,rms} = \sqrt{\frac{4\pi}{6} \cdot \frac{1}{2\pi} \cdot I_d^2} = \frac{I_d}{\sqrt{3}}$

So 12 pulse, $I_{rms} \downarrow$ by $\sqrt{2}$, but twice as many devices

→ Each device carries the full current for $\frac{1}{2}$ the time!

(ohmic loss in devices, transformers, lines depend on RMS!)