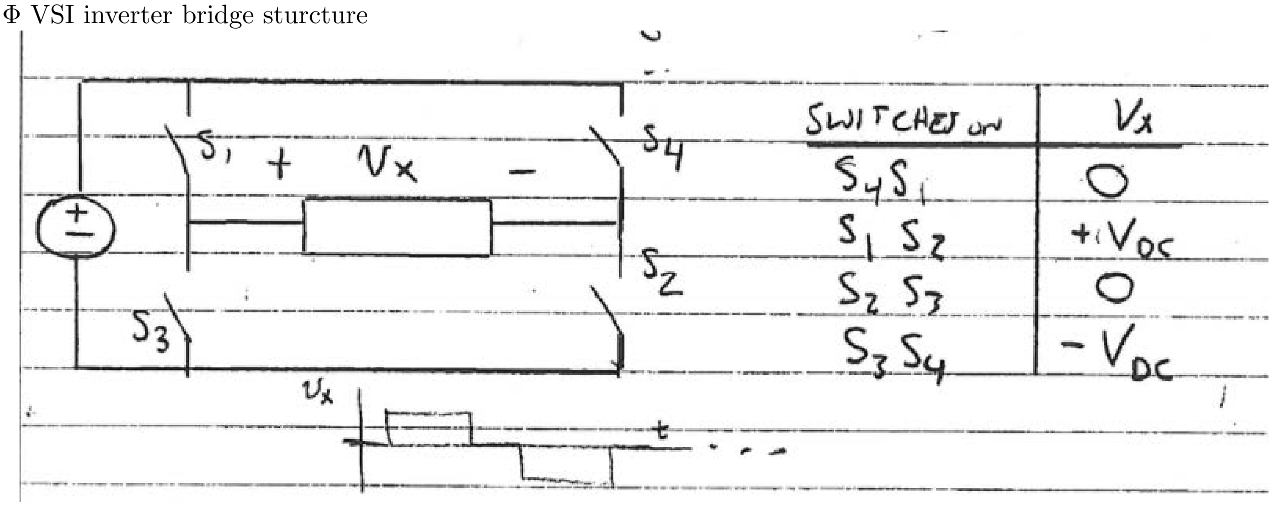
6.622 Power Electronics *Prof. David Perreault*

Lecture 18 - Inverters 2

From last time:
1 Φ VSI inverter bridge sturcture



1. We can synthesize pulsing voltages +, 0, - over time
2. Filter to get desired output waveform (e.g. sinusoid)
3. Switching frequency limitations are often a practical constraint

$\Rightarrow$ Show inverter module from a toyota prius as example

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To reduce filtering requirements, we often use waveform symmetrics to reduce unwanted content.

$$f(t) = \frac{b_0}{2} + \Sigma_{n=1}^{a} a_n sin(n\omega_0 t) + b_n cos(n\omega_0 t)$$

$$a_n = \frac{2}{T}\int_{<T>} f(t)sin(n\omega_0 t)dt, b_n = \frac{2}{T}\int_{<T>} f(t)cos(n\omega_0 t)dt$$

- For odd/even waves, synthesize odd/even patterns
- for half-wave symmetric outputs f(t) = $-f(t-\frac{T}{2})$ synthesize half-wave symmetric pulse patterns (a_{2k}, b_{2k} harmonics do not exist!)

$$f_{hws}(t) = \frac{f(t) - f(t-\frac{T}{2})}{2}; f_{hwr}(t) = \frac{f(t) + f(t-\frac{T}{2})}{2}; f(t) = f_{hws} + f_{hwr}$$

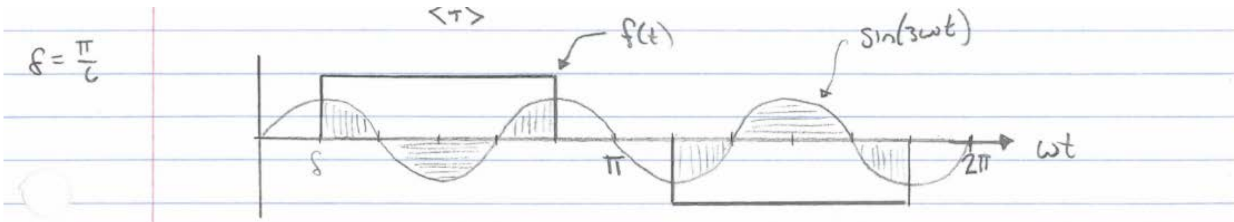
We have seen that by control of the width of one pulse per half cycle (and each device switching on/off once per full cycle) we can

- Maintain half-wave symmetry (no even harmonics)
- eliminate triple-n harmonics (especially 3rd harmonic)

- keep odd symmetry (no cosine components)

Why? With only odd components, nth harmonic amplitude is:

$$V_n = \frac{2}{T}\int_{<T>} f(t)sin(n\omega_0 t)dt$$



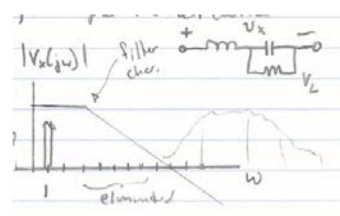
Positive area of $f(t)sin(2\omega t)$ cancels negative area $\therefore$ integral = 0!

$\Rightarrow$ we can introduce more nothces in each half cycle (for more switching transitions in each cycle) so that higher harmonics (e.g. 5th are cancelled) while not disturbing the nullling of the 3rd. (see one example, next page)

In general: Harmonic elimination / programmed PWM

- Can eliminate one odd harmonic for each pulse per half cycle (and each switching transition per ac cycle)
- More harmonics eliminated, the higher the net device switching frequency
- Precise timing measured (μP)

$\rightarrow$ As more lower-order harmonics are eliminated, high-order harmonics actually increase, but these are more easily filtered!



Note: see classic papers for more on this area:

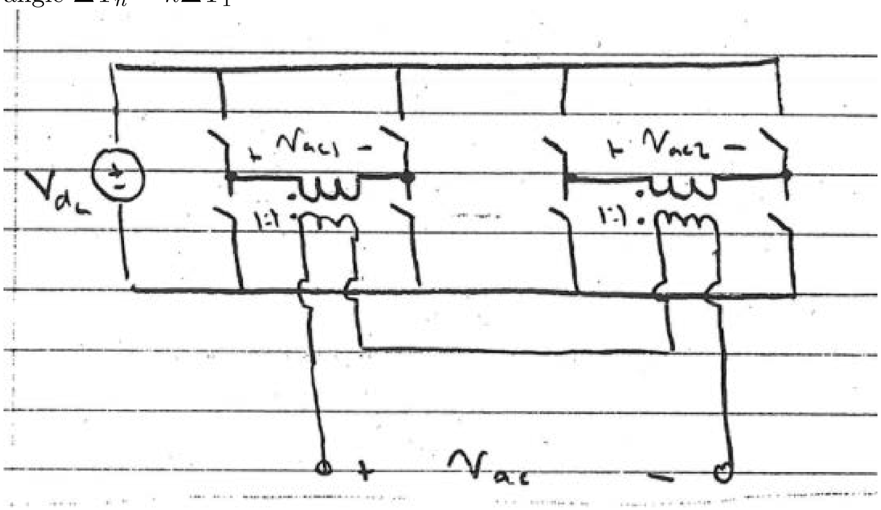
- H. S. Patel and R. G. Hoft "Generalized Techniques of Harmonic Elimination and Voltage Control in Thyristor Inverters: Part I — Harmonic Elimination Techniques"
- H. S. Patel and R. G. Hoft "Generalized Techniques of Harmonic Elimination and Voltage Control in Thyristor Inverters: Part II — Voltage Control Techniques"

1 Harmonic Cancellation

Add up time-shifted waveforms to cancel desired harmonic component(s)

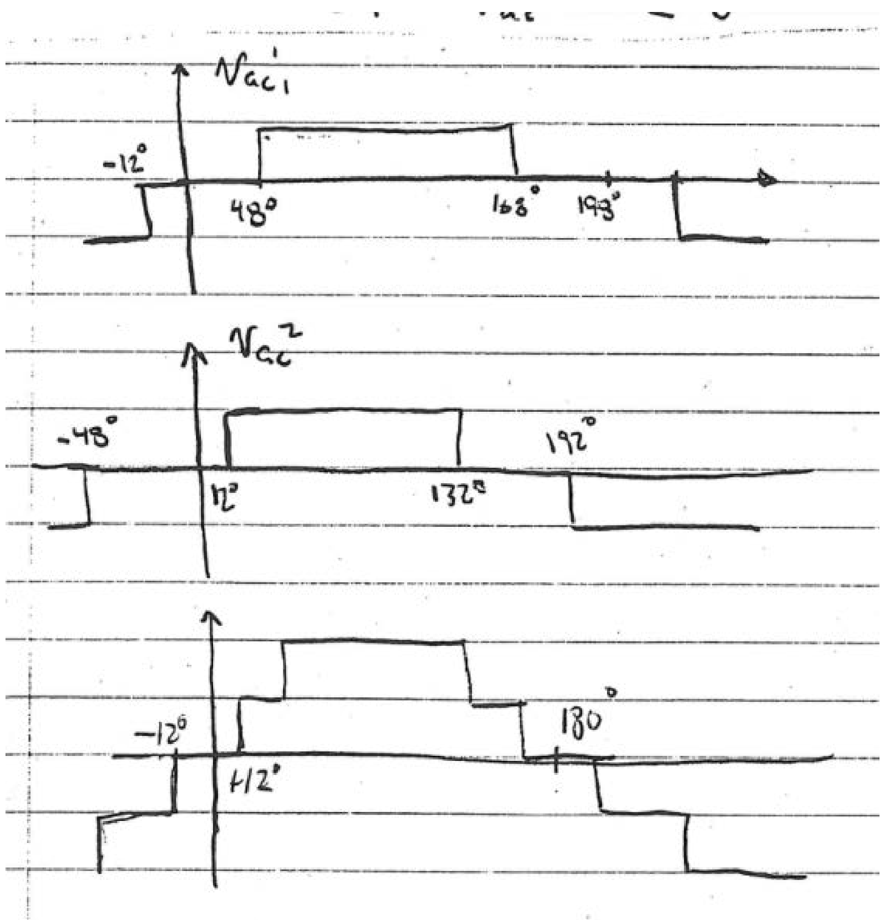
If x(t) $= \Sigma A_n sin(n\omega_0 t + \Phi_n)$
$\therefore x(t - t_1) = \Sigma A_n sin(n\omega_0(t - t_1) + \Phi_n)$
$= \Sigma A_n sin(n\omega_0 t + \Phi_n - n\omega_0 t_1)$ $(\Phi_n - n\omega_0 t_1 = \Phi'_n)$

If we time-shift to change the fundamental by an angle $\Delta\Theta_T = -\omega_0 t_1$, we shift the nth harmonic by an angle $\Delta\Phi_n = n\Delta\Phi_1$



Sum 2 waveforms

- Shift fundamentals by 36° (±18°)
- Shifts 5th harmonic by 180° (±90°)

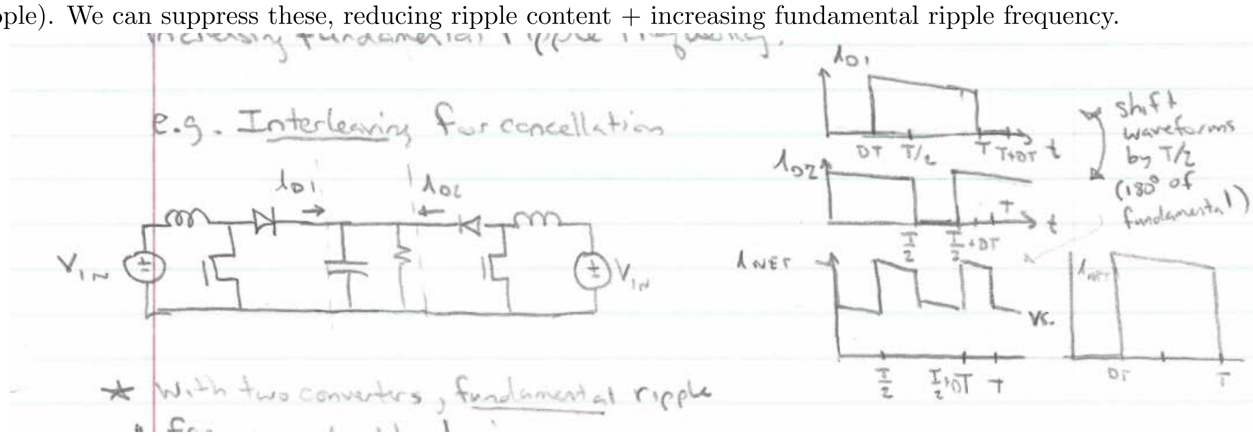


First harmonic → shifted by +18°
Summed wave has no 5th harmonic
Final image has no third or 5th harmonic

By adding waveforms time shifted so that their 5th harmonics are 180° out of phase, the 5th harmonic is cancelled in the summed waveform!

Harmonic cancellation and harmonic elimination can also be applied in other forms of power converters.

For example, in dc-dc conversion, we have a desired frequency (dc) and undesired components (all ac ripple). We can suppress these, reducing ripple content + increasing fundamental ripple frequency.



With 2 converters, fundamental ripple

1. Frequency doubles!
2. Also, p-p current ripple (net) is half that of a single high-power unit.

We can interleave N identical converters by phase-shifting them by $\Delta t = \frac{T}{N} (\omega_1 = \frac{2\pi}{N})$. The net ripple freuquency in the input and output waveforms will ideally be at N times the individual switching frequency!

→ This trick is very widely used, including in the converters for most PC power supplies feeding the final low voltage to the microprocessor