DC-to-AC rectangular wave converter

• The 4-quadrant converter with $D=0.5$ is able to transform a DC voltage $E_H$ into a rectangular AC voltage $\pm E_H$, which contains a fundamental sinusoidal component having an amplitude of $1.27E_H$ and an effective value of $1.27E_H/\sqrt{2}=0.90E_H$

• It is bidirectional (DC-to-AC and AC-to-DC) and frequency-variable

• The output has a fixed amplitude and large 3$^{rd}$, 5$^{th}$ and 7$^{th}$ harmonics.

$$E_{LL} = \frac{400}{\pi} \left[ \sin(2\pi ft) + \frac{1}{3}\sin(6\pi ft) + \frac{1}{5}\sin(10\pi ft) + \ldots \right]$$
PWM (pulse width modulation)

- 4-quadrant DC-to-DC converter using a carrier frequency $f_c$ and different values of $D$

\[ E_{LL} = (2D-1)E_H \]

- To obtain $E_{LL}(t) = E_m \sin(2\pi ft + \theta)$,

\[ D(t) = \frac{E_m}{2E_H} \sin(2\pi ft + \theta) + \frac{1}{2} \]
DC-to-AC non-sine wave converters with PWM

- With $D$ varying periodically between 0.8 and 0.2 at a frequency $f < 0.1 f_c$
- Although $f_c$ is fixed, the ON/OFF pulse widths change continually with $D$.
- That is why this type of switching is called \textit{pulse width modulation} or PWM
DC-to-AC sine wave converter with PMW

- To obtain $E_{LL}(t)=E_m \sin(2\pi ft + \theta)$

\[ D(t) = \frac{E_m}{2E_H} \sin(2\pi ft + \theta) + \frac{1}{2} \]

Amplitude modulation ratio $m=E_m/E_H$
Frequency modulation ratio $m_f=f_c/f=T/T_c$

- Create a 83.33Hz sine voltage wave with peak value $E_m=100V$ using a DC-to-AC converter with $E_H=200V$ and $f_c=1000Hz$:

$T=1/83.33=0.012s=12000\mu s$

$T_c=1/1000=1000\mu s$

$m_f=T/T_c=12$, so each $T_c$ covers $360/12=30^o$

Calculate $D$ for $\phi(t)=2\pi ft + \theta=0^o, 30^o, 60^o, \ldots$, which correspond to $E_{LL}=100\sin \phi (V)$

In each carrier period $T_c$, Q1&Q4 are ON for $DT_c = 1000D(\mu s)$ and then Q2&Q3 are ON for the remaining $(1-D)T_c = 1000(1-D) (\mu s)$

**Table 21E** Generating A Sine Wave

<table>
<thead>
<tr>
<th>angle $[\text{deg}]$</th>
<th>$E_{LL} [\text{V}]$</th>
<th>$D$</th>
<th>$Q1, Q4 \text{on} [\mu s]$</th>
<th>$Q2, Q3 \text{on} [\mu s]$</th>
<th>interval</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.5</td>
<td>500</td>
<td>500</td>
<td>A</td>
</tr>
<tr>
<td>30</td>
<td>50</td>
<td>0.625</td>
<td>625</td>
<td>375</td>
<td>B</td>
</tr>
<tr>
<td>60</td>
<td>86.6</td>
<td>0.716</td>
<td>716</td>
<td>284</td>
<td>C</td>
</tr>
<tr>
<td>90</td>
<td>100</td>
<td>0.75</td>
<td>750</td>
<td>250</td>
<td>D</td>
</tr>
<tr>
<td>120</td>
<td>86.6</td>
<td>0.716</td>
<td>716</td>
<td>284</td>
<td>E</td>
</tr>
<tr>
<td>150</td>
<td>50</td>
<td>0.625</td>
<td>625</td>
<td>375</td>
<td>F</td>
</tr>
<tr>
<td>180</td>
<td>0</td>
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<td>500</td>
<td>500</td>
<td>G</td>
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<tr>
<td>210</td>
<td>-50</td>
<td>0.375</td>
<td>375</td>
<td>625</td>
<td>H</td>
</tr>
<tr>
<td>240</td>
<td>-86.6</td>
<td>0.284</td>
<td>284</td>
<td>716</td>
<td>I</td>
</tr>
<tr>
<td>270</td>
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<td>750</td>
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<tr>
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<td>375</td>
<td>625</td>
<td>L</td>
</tr>
<tr>
<td>360</td>
<td>0</td>
<td>0.5</td>
<td>500</td>
<td>500</td>
<td>M</td>
</tr>
</tbody>
</table>

**Figure 21.82** Positive half-cycle of the fundamental 83.33 Hz voltage comprises six carrier periods of 1 ms each.
Bipolar PWM and Unipolar PWM

- Once the carrier frequency is filtered out, the resulting voltage will be sinusoidal.
- A higher carrier frequency would yield a better sinusoidal waveform but would increase the power losses of the electronic switches, e.g. IGBTs.
3-phase, 6-pulse thyristor rectifier (AC-to-DC converter)

- Control the DC output voltage $E_d$ by the delay angle $\alpha$ of triggering pulses

$$E_d = 1.35E \cos \alpha$$
Homework Assignment #8

• Read Chapter 21
• Questions:
  – 21-25, 21-26, 21-33, 21-34, 21-35
• Due date:
  – hand in your solution to GTA Wenyun at MK 207 directly or by email before the end of 11/29 (Tuesday)