Power Converter Systems

Graduate Course EE8407

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Topic 6

Multilevel Cascaded H-Bride (CHB) Inverters



CHB Inverter Fed Drive Source: Toshiba - General Electric

Multilevel CHB Inverters

Lecture Topics

- H-Bridge Inverter
- CHB Inverter Topologies
- Phase Shifted PWM
- Level Shifted PWM
- PWM Scheme Comparison



Multilevel CHB Inverters

Why Use Multilevel Inverters?

- To increase inverter operating voltage without devices in series
- To minimize THD with low switching frequencies f
- To reduce EMI due to lower voltage steps

Switching frequency for high power converters: $f_{sw} = 60$ Hz ~ 1000Hz

Multilevel Inverter Topologies

• Per-Phase Diagram



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H-Bridge Inverter

• H-bridge Power Cell



H-Bridge Inverter

Typical Industrial Applications



Five-level CHB inverter

H-bridge Power Cell

H-Bridge Inverter

Bipolar Modulation



H-Bridge Inverter

• **Bipolar Modulation (FFT)**



H-Bridge Inverter

• Unipolar Modulation (1)





• Two modulation waves

$$\mathbf{v}_m$$
 and \mathbf{v}_{m} -

- One carrier wave V_{cr}
- Unipolar PWM:

$$V_{AB}$$
 from 0 to + V_d
or from 0 to - V_d

H-Bridge Inverter

• Unipolar Modulation (2)



• Two carrier waves:

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CHB Inverter Topologies

• Five-Level CHB Inverter



Complementary Switch pairs: S_{11} and S_{41} ; S_{31} and S_{21} ; S_{12} and S_{42} ;



Converters in cascade, but no switching devices in series.

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CHB Inverter Topologies

• Output Voltage and Switching Status (five-level)

Output Voltage	Switching State						
v_{AN}	<i>S</i> ₁₁	S ₃₁	S ₁₂	S ₃₂	v_{H1}	v_{H2}	$\land \land $
2 <i>E</i>	1	0	1	0	E	E	$S_{11} + S_{31} + S_{31}$
- E	1	0	1	1	E	0	
	1	0	0	0	E	0	$E = V_{max}$
	1	1	1	0	0	E	
	0	0	1	0	0	E	$\begin{bmatrix} S_{41} \\ \vdots \\ $
0	0	0	0	0	0	0	
	0	0	1	1	0	0	+ 🗆
	1	1	0	0	0	0	
	1	1	1	1	0	0	$ \begin{vmatrix} S_{12} \\ \downarrow \\ \downarrow \\ S_{32} \\ \downarrow \\ \downarrow \\ \end{vmatrix} $
	1	0	0	1	E	- <i>E</i>	
	0	1	1	0	- <i>E</i>	E	$E = V_{H2}$
- <i>E</i>	0	1	1	1	- <i>E</i>	0	
	0	1	0	0	- <i>E</i>	0	
	1	1	0	1	0	- <i>E</i>	
	0	0	0	1	0	- <i>E</i>	$+\Box$
-2E	0	1	0	1	- <i>E</i>	- <i>E</i>	

Waveform of V_{AN} is composed of five voltage levels: 2E, E, 0, -E, and -2E

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CHB Inverter Topologies

• Seven- and Nine-Level Inverters (Per phase diagram)





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CHB Inverter Topologies

Unequal dc Bus Voltages



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CHB Inverter Topologies

• Unequal dc Bus Voltages (Two-cell seven-level topology)

Output Voltage		Switchi	17	IZ		
V_{AN}	S_{11}	S_{31}	S_{12}	S ₃₂	V _{H1}	V _{H2}
3 E	1	0	1	0	E	2E
2 <i>E</i>	1	1	1	0	0	2E
	0	0	1	0	0	2E
E	1	0	1	1	E	0
	1	0	0	0	E	0
	0	1	1	0	- <i>E</i>	2E
	0	0	0	0	0	0
0	0	0	1	1	0	0
0	1	1	0	0	0	0
	1	1	1	1	0	0
	1	0	0	1	E	-2E
- <i>E</i>	0	1	1	1	- <i>E</i>	0
	0	1	0	0	- <i>E</i>	0
25	1	1	0	1	0	-2E
	0	0	0	1	0	-2E
- 3 E	0	1	0	1	- <i>E</i>	-2E



Phase Shifted PWM

• Carrier Based PWM – Phase Shifted



- # of voltage levels: m = 7
- # of carriers: *m_c* = *m* 1 = 6

Carriers for *H1* bridge: *v*_{cr1} and *v*_{cr1}.

Carriers for H2 bridge: v_{cr2} and v_{cr2} -

Carriers for H3 bridge: v_{cr3} and v_{cr3-}

m = 7

Phase Shifted PWM

• Inverter Waveforms (7-level, phase shifted)



Phase Shifted PWM

• FFT (7-level, phase shifted)



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Phase Shifted PWM

• Harmonic Content (7-level, phase shifted)



Textbook: Bin Wu, 'High-Power Converters and AC Drives', Wiley - IEEE Press, 2006

Level Shifted PWM



Level Shifted PWM

• Gating Arrangement (7-level)



- # of voltage levels:
 m = 7
- # of carriers: m_c = m - 1 = 6
- **f** sw(device):
 - not equal to f_{cr} , and
 - not the same for all switches.
- Device conduction angle:
 - not equal.
- Necessary to swap switching pattern.

Level Shifted PWM

• Inverter Output Voltages (seven-level)



• *m* = 7

 Switching occurs at different times

- *V*_{AB} close to a sinusoid
- Low THD, low EMI

•
$$f_{sw(inv)} = f_c = 3600 \text{Hz}$$

Textbook: Bin Wu, 'High-Power Converters and AC Drives', Wiley - IEEE Press, 2006

Level Shifted PWM



Level Shifted PWM

• Measured Waveforms (IPD, 7-level)



PWM Scheme Comparison



PWM Scheme Comparison

• Total Harmonic Distortion (THD)



PWM Scheme Comparison

Summary

Comparison	Phase-shifted Modulation	Level-shifted Modulation (IPD)		
Device Switching Frequency	Same for all devices	Different		
Device Conduction Period	Same for all devices	Different		
Rotating of switching patterns	No required	Required		
THD of inverter output line-to-line voltage	Good	Better		
Low Order Harmonics	No	Yes (Very low amplitude)		

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Thanks