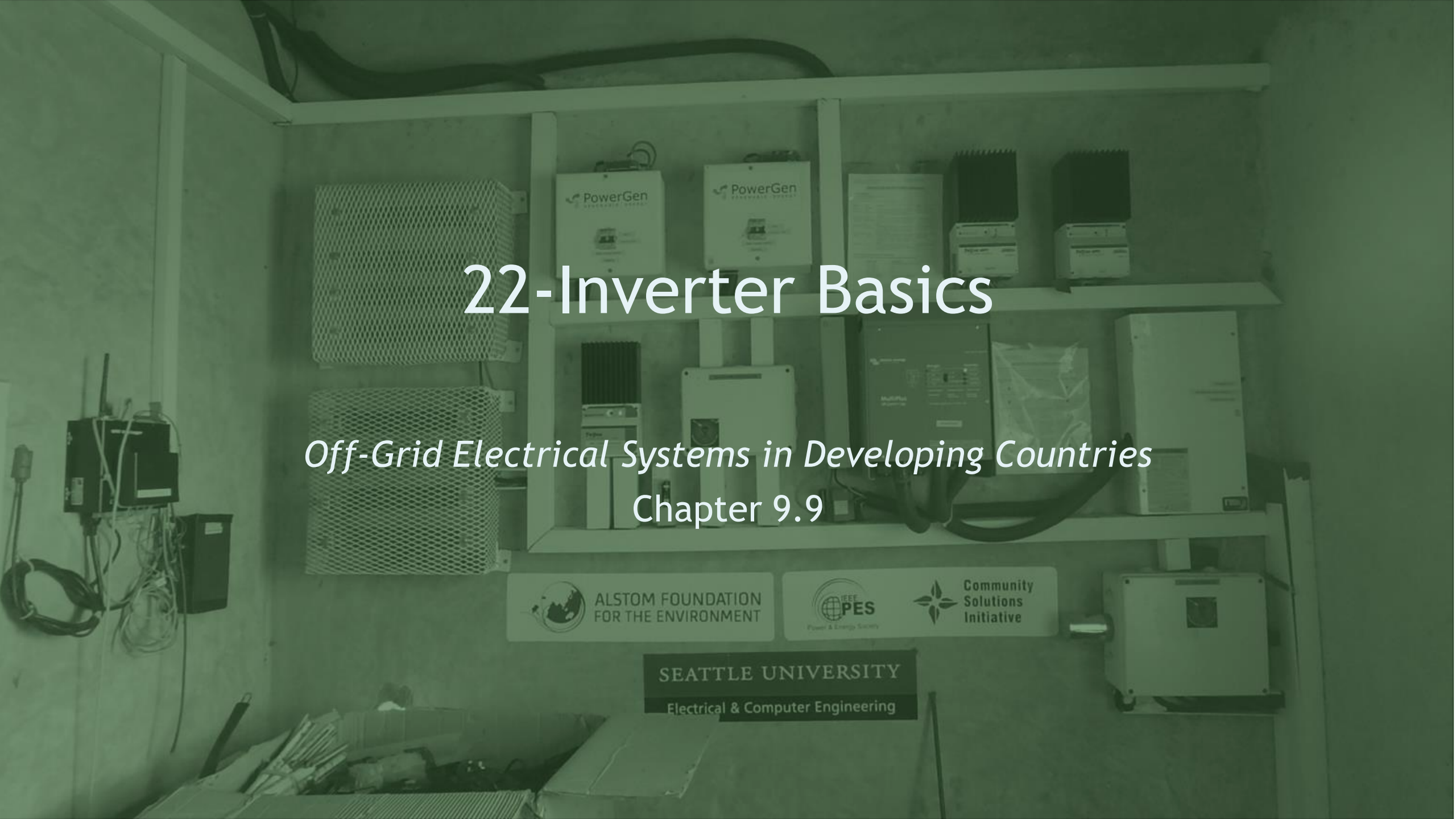

22-Inverter Basics

Off-Grid Electrical Systems in Developing Countries

Chapter 9.9

Learning Outcomes

At the end of this lecture, you will be able to:

- ✓draw and understand the basic operational principles of inverters
- ✓describe the differences in squarewave and sinusoidal inverters
- ✓determine the power output supplied by an inverter

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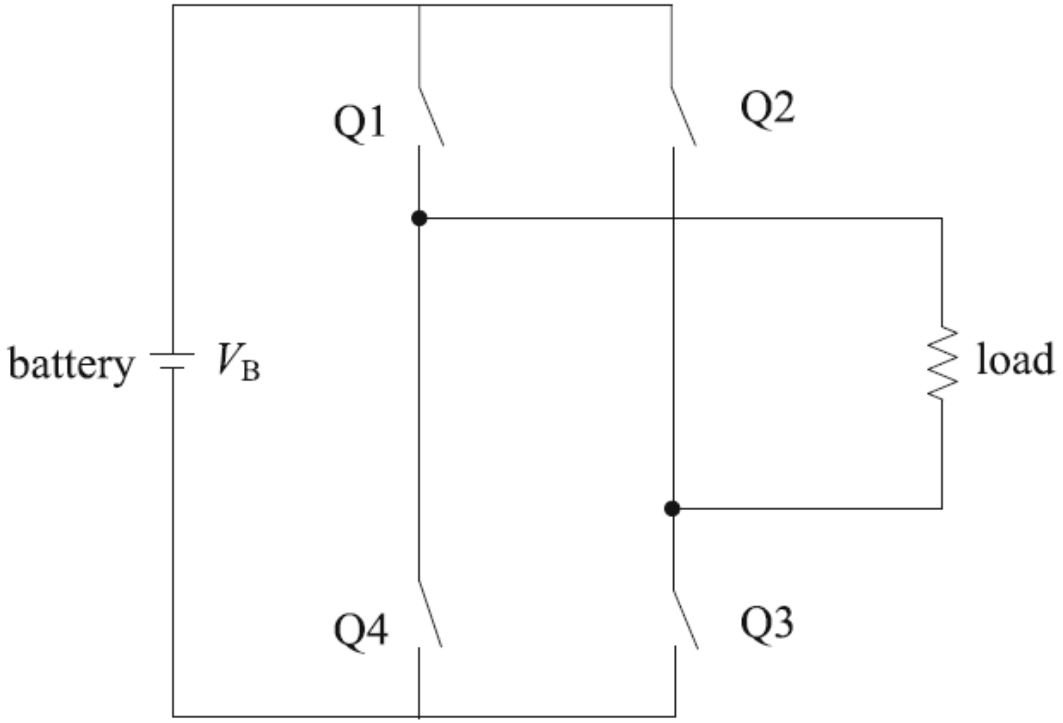
Inverters: Basic Circuit

- Use solid-state switching to alternate polarity of voltage applied to a load
- Switch in pairs
  - Q1, Q3 open and close at same time
  - Q2, Q4 open and close at the same time
- Voltage output can be increased via DC—DC converter at the input or transformer at the output (or both)



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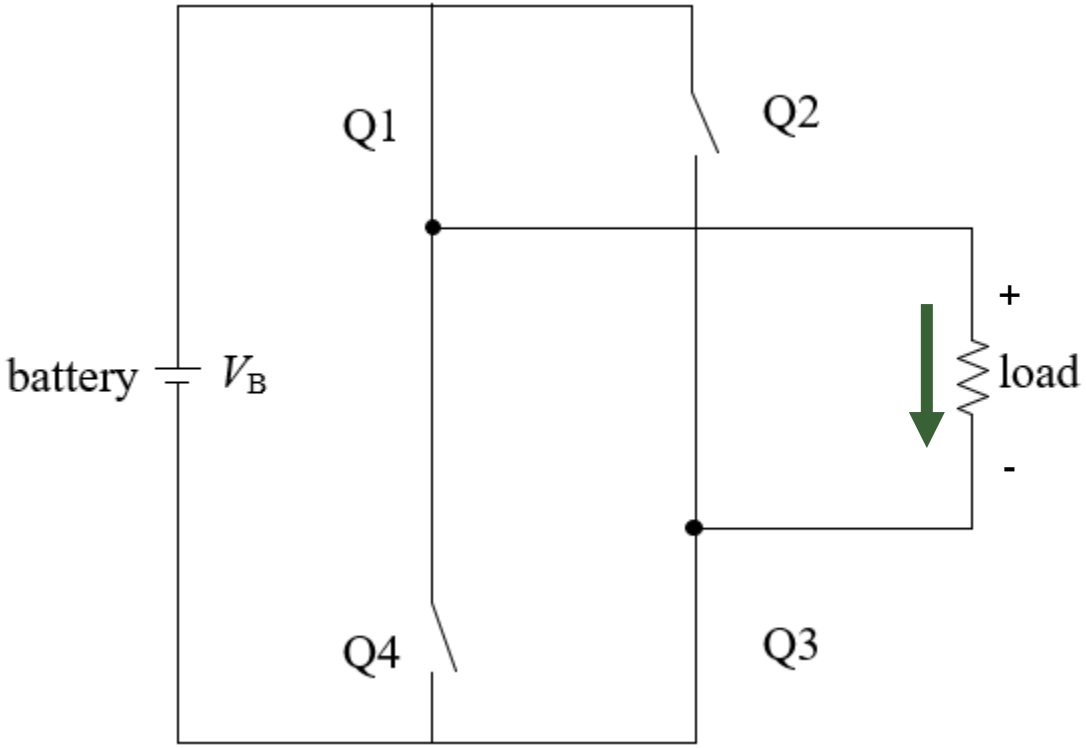
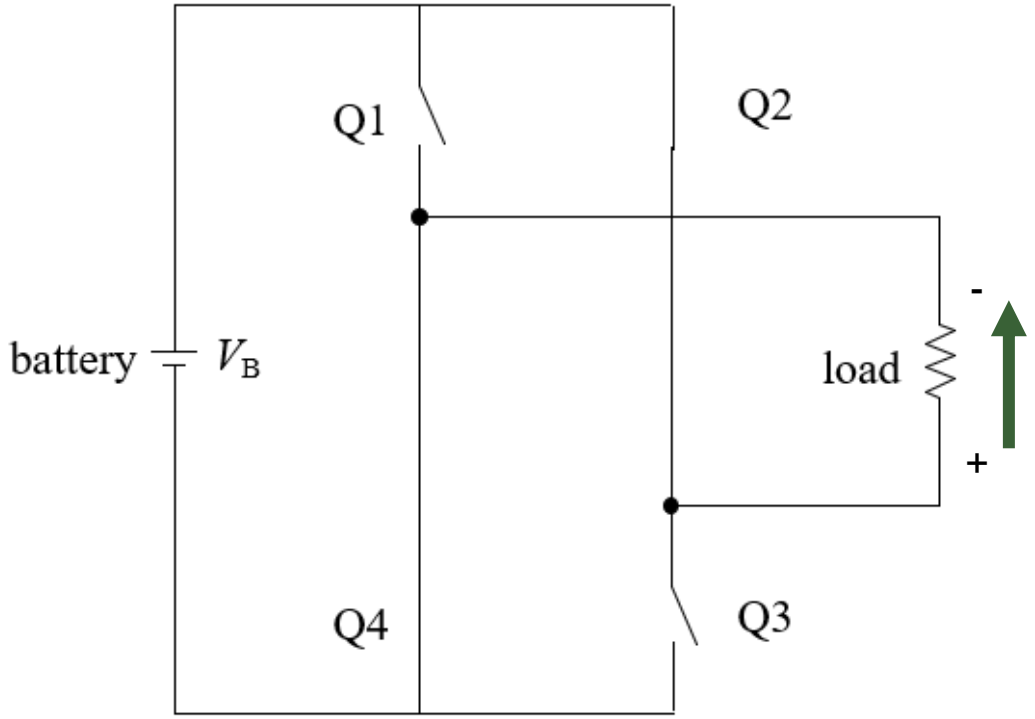
Inverters: Basic Circuit





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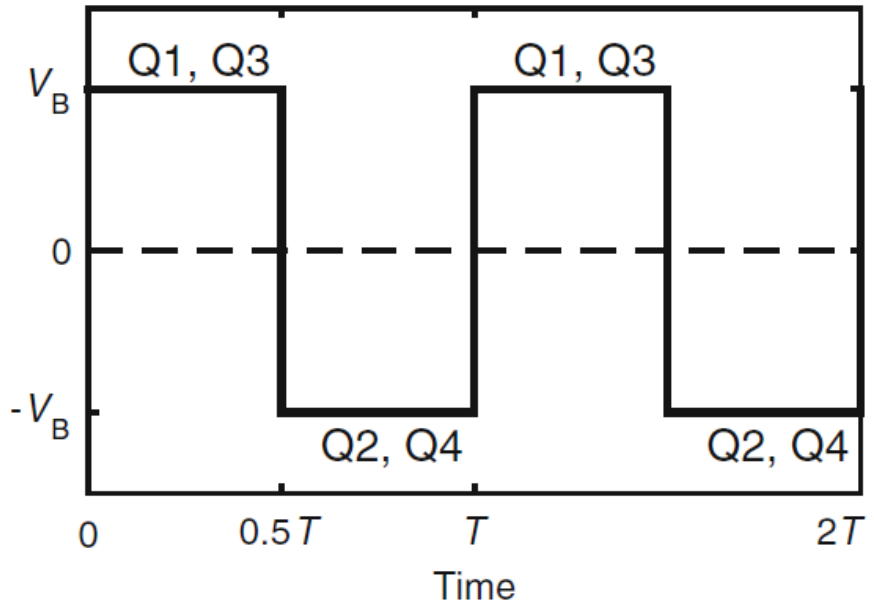
Output Signal

- Waveform is square
- Centered at zero



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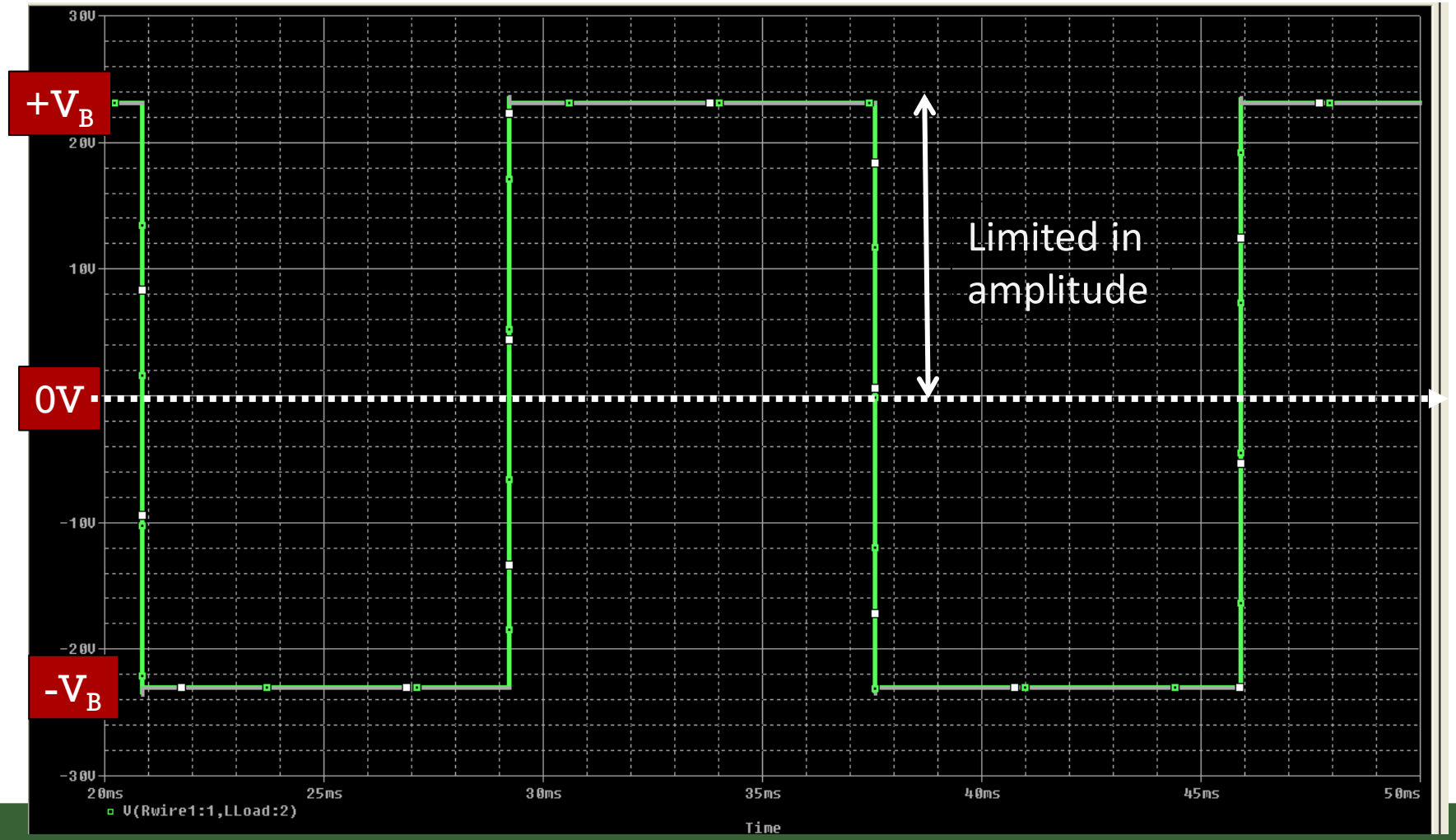
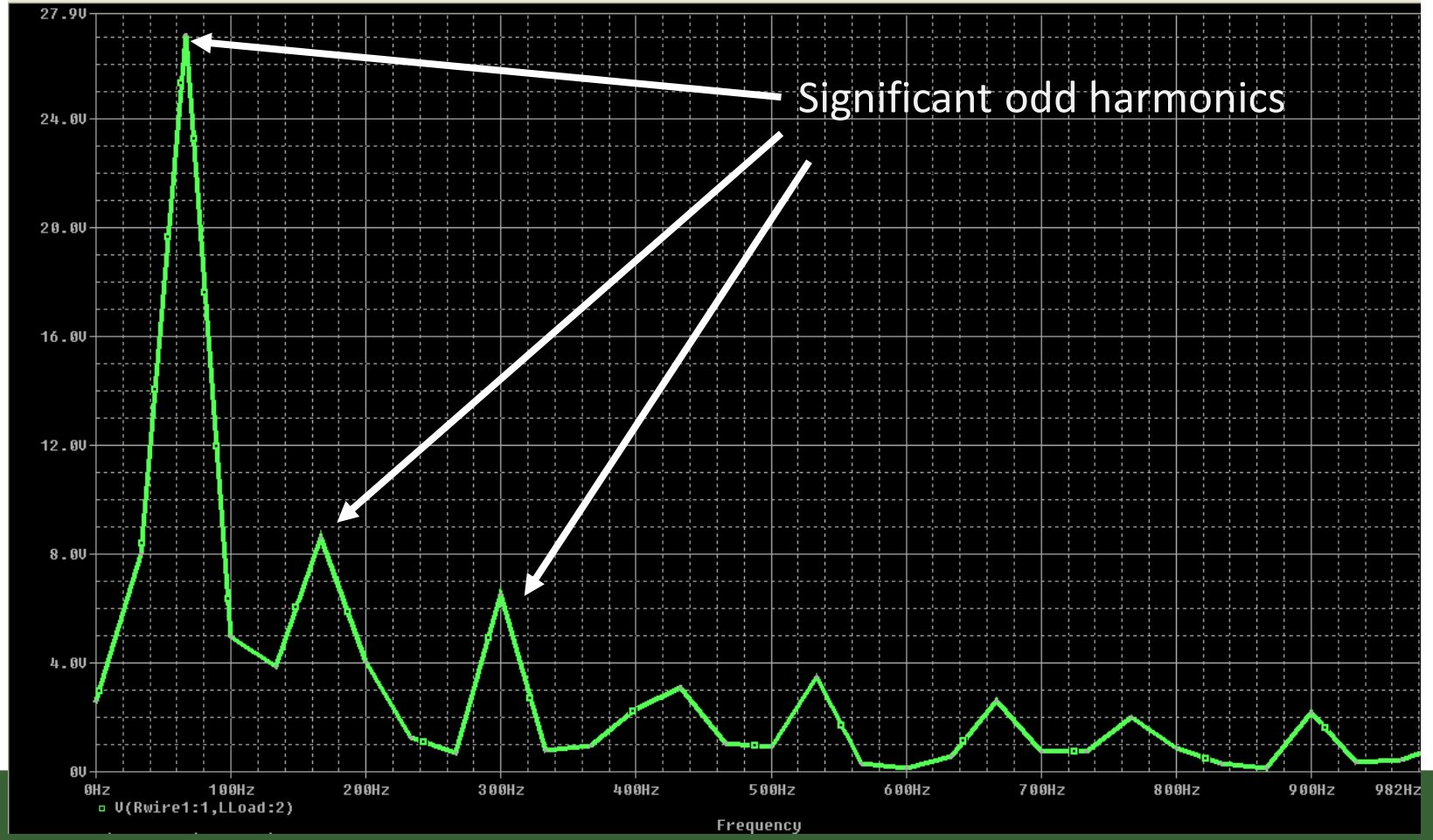
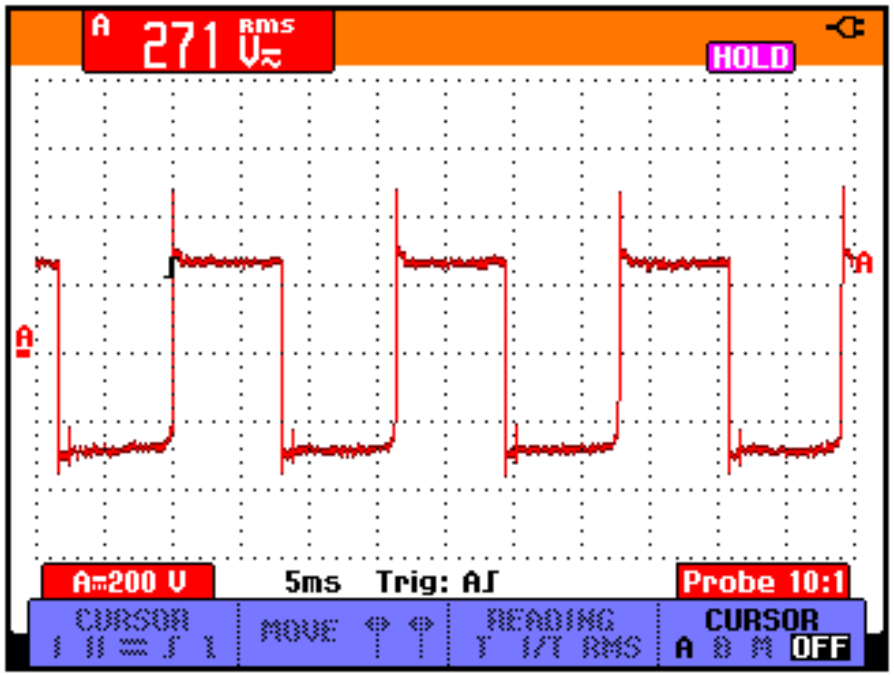

+V_B
0V
-V_B
Limited in amplitude
30V
20V
10V
-10V
-20V
-30V
20ms
25ms
30ms
35ms
40ms
45ms
50ms
V(Rwire1:1,LLoad:2)
Time

Inverter

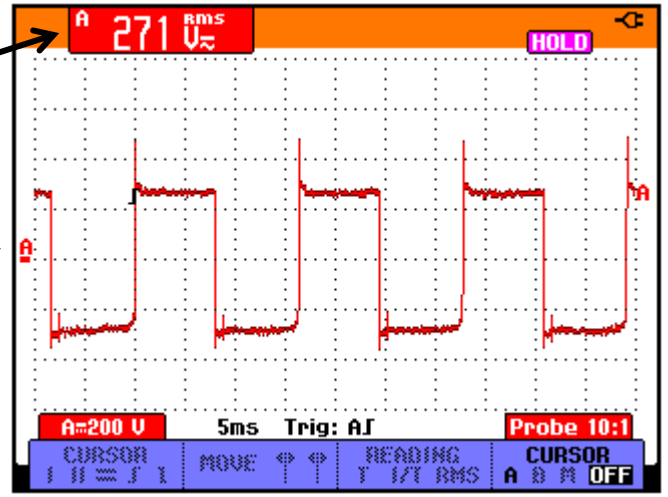

Significant odd harmonics
27.9V
24.0V
20.0V
16.0V
12.0V
8.0V
4.0V
0V
0Hz
100Hz
200Hz
300Hz
400Hz
500Hz
600Hz
700Hz
800Hz
900Hz
982Hz
V(Rwire1:1,LLoad:2)
Frequency

Squarewave Inverter

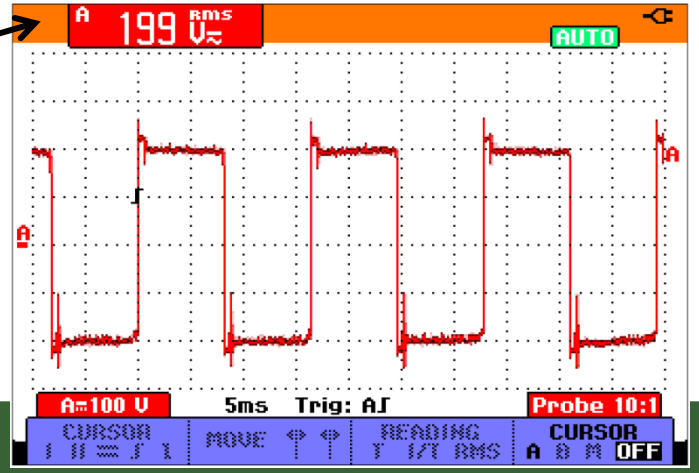


Squarewave Inverter

V_B = 12.4 V

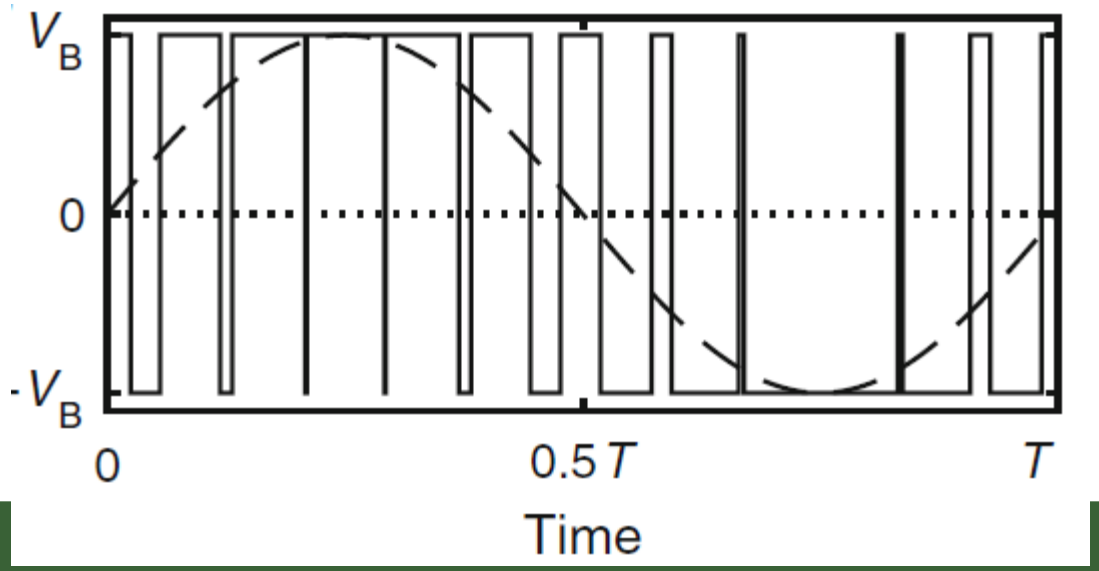


V_B = 9 V



PWM Inverters

- Distortion in output can be reduced using PWM
- Vary duty cycle over the course of the output



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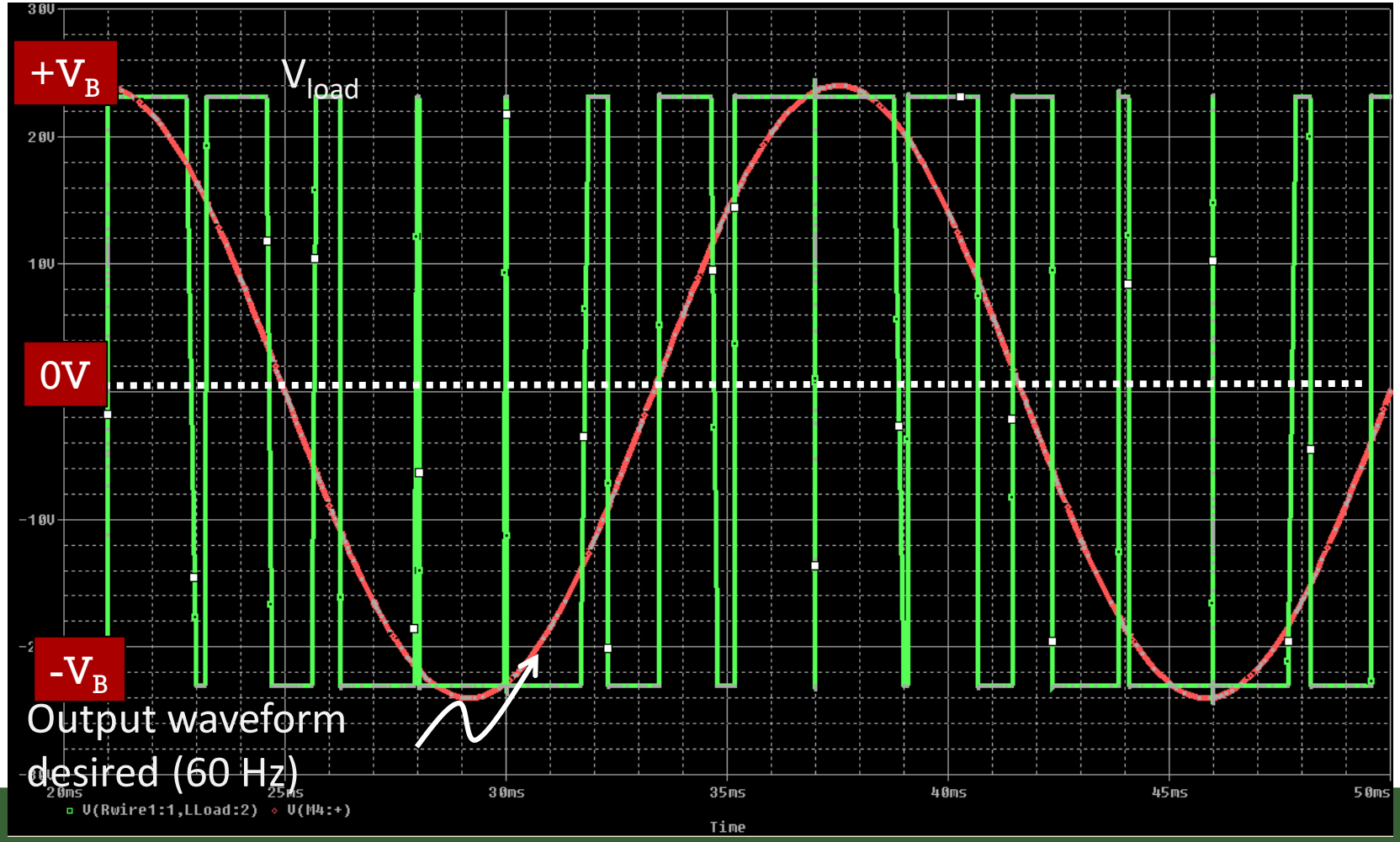
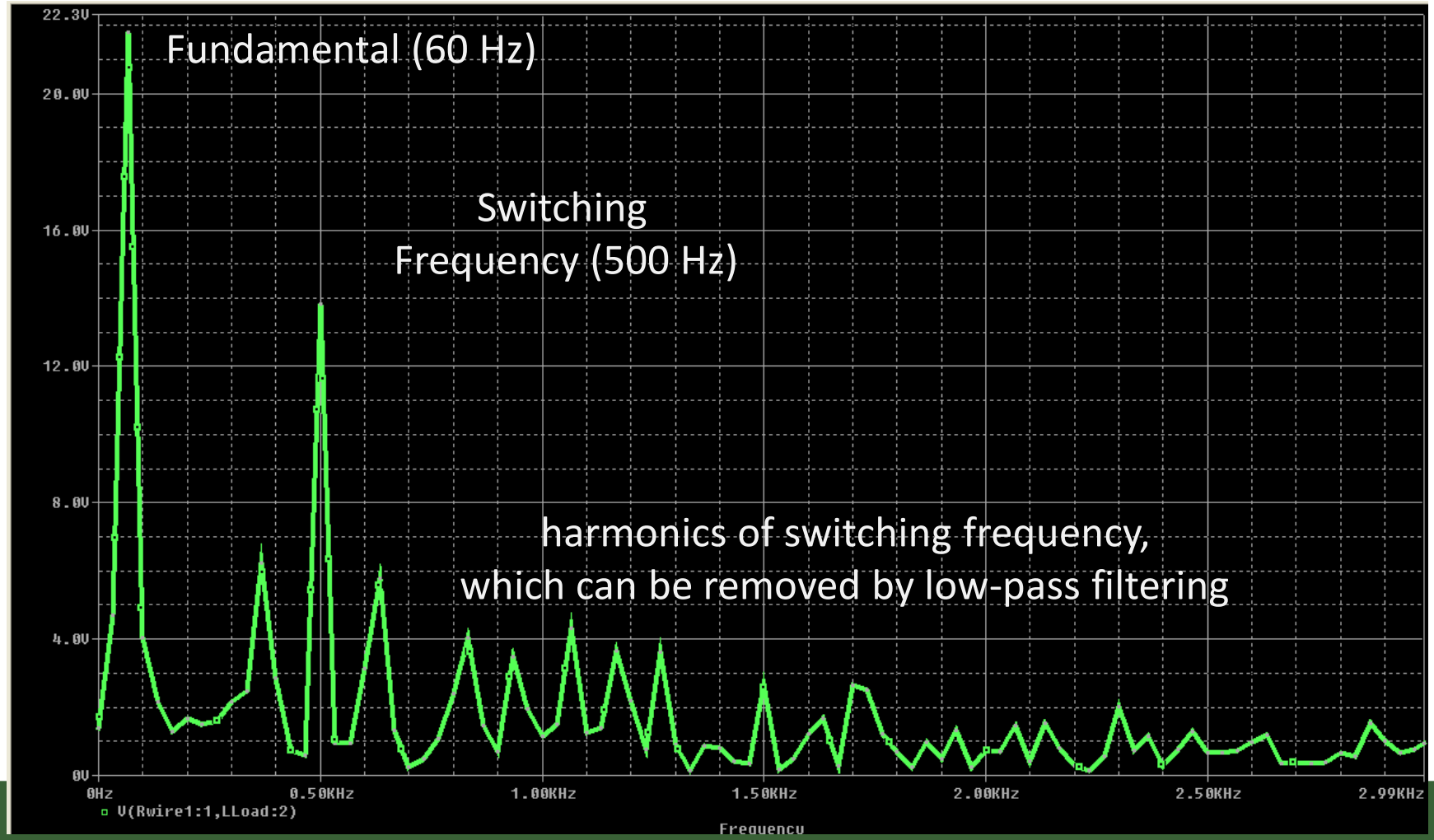
PWM Inverter

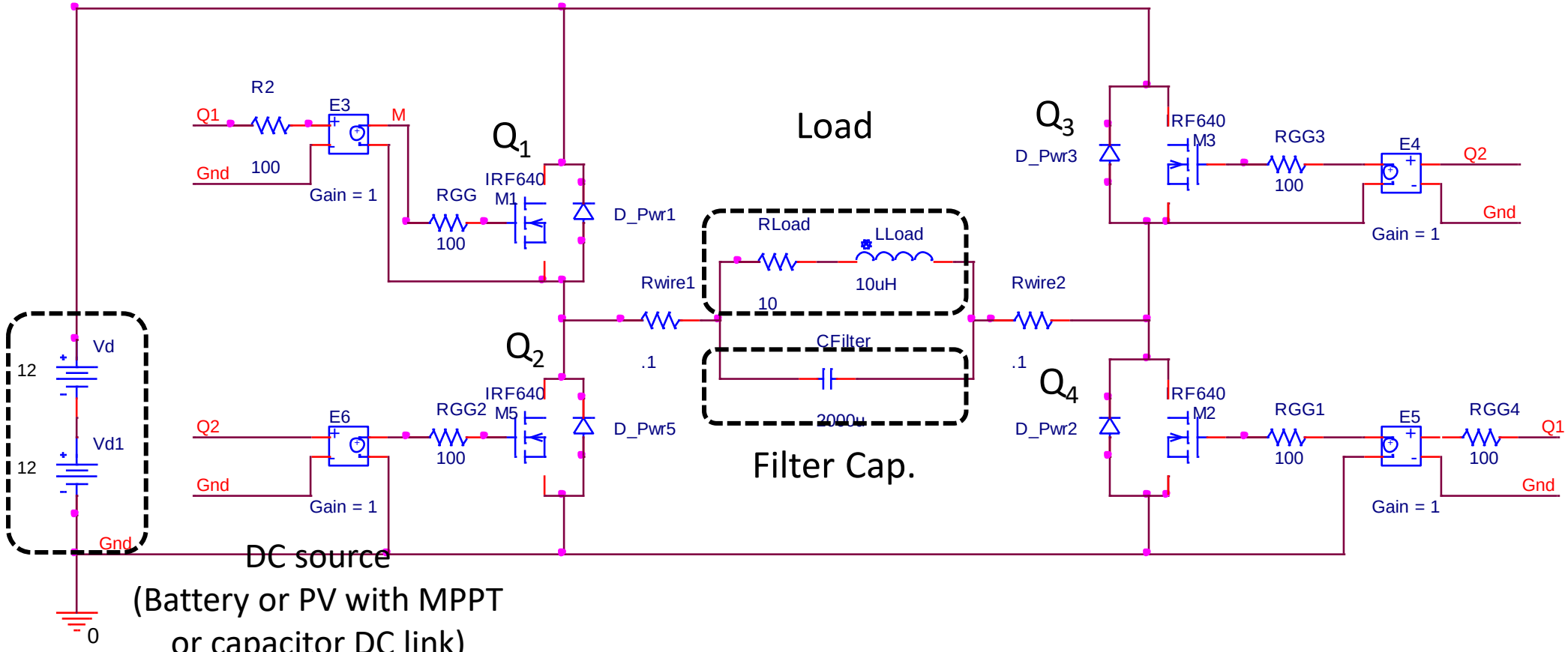
- Switching frequency should be much greater (4kHz - 10kHz) than fundamental frequency (60 Hz or 50 Hz)

- Basic idea: vary the duty ratios within each switching period to replicate a sine wave

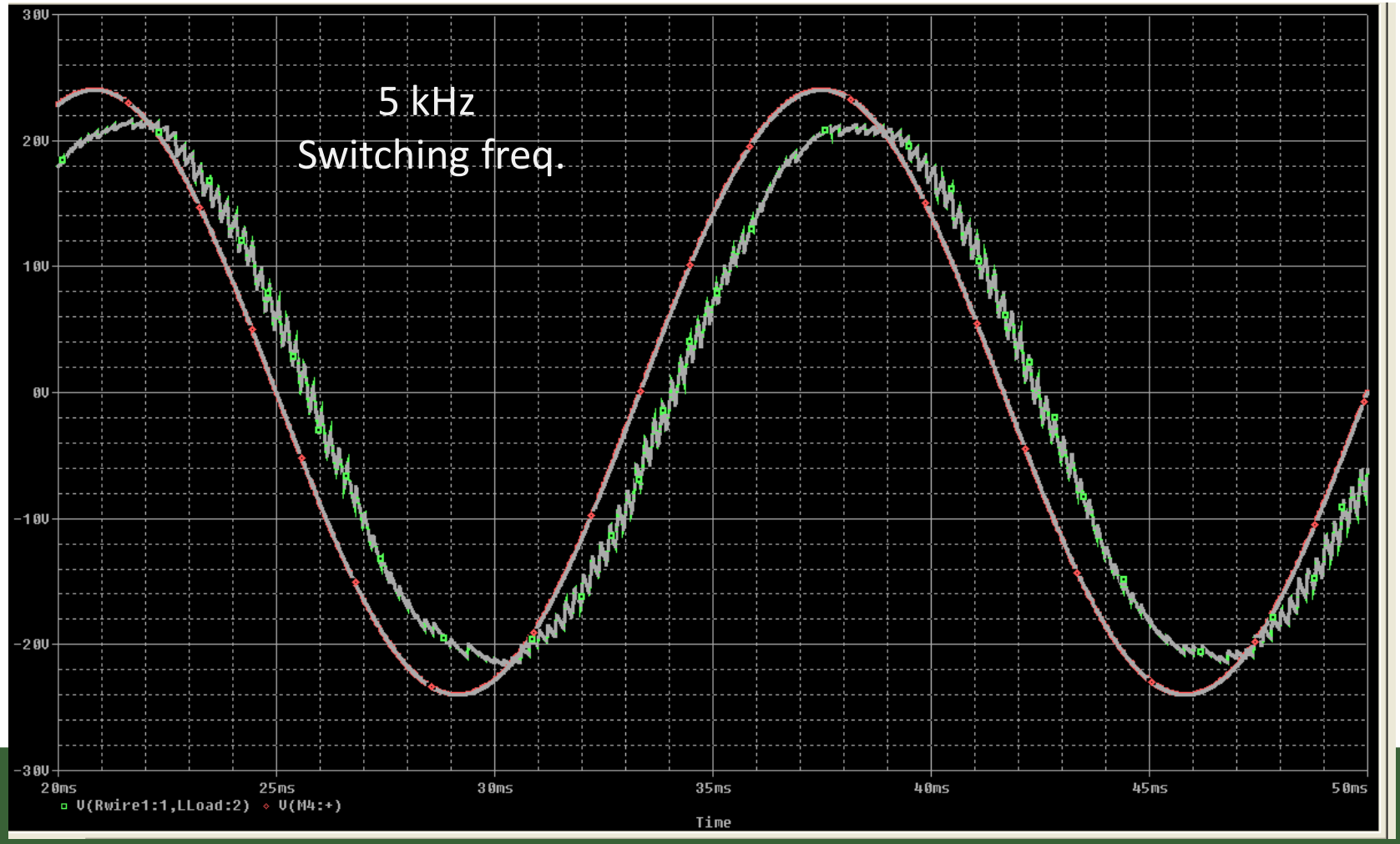

+V_B
V_load
0V
-V_B
Output waveform
desired (60 Hz)
30V
20V
10V
-10V
20ms
25ms
30ms
35ms
40ms
45ms
50ms
V(Rwire1:1,LLoad:2)
V(M4:+)
Time


Fundamental (60 Hz)
Switching
Frequency (500 Hz)
harmonics of switching frequency,
which can be removed by low-pass filtering
22.3V
20.0V
16.0V
12.0V
8.0V
4.0V
0V
0Hz
0.50KHz
1.00KHz
1.50KHz
2.00KHz
2.50KHz
2.99KHz
V(Rwire1:1,LLoad:2)
Frequency

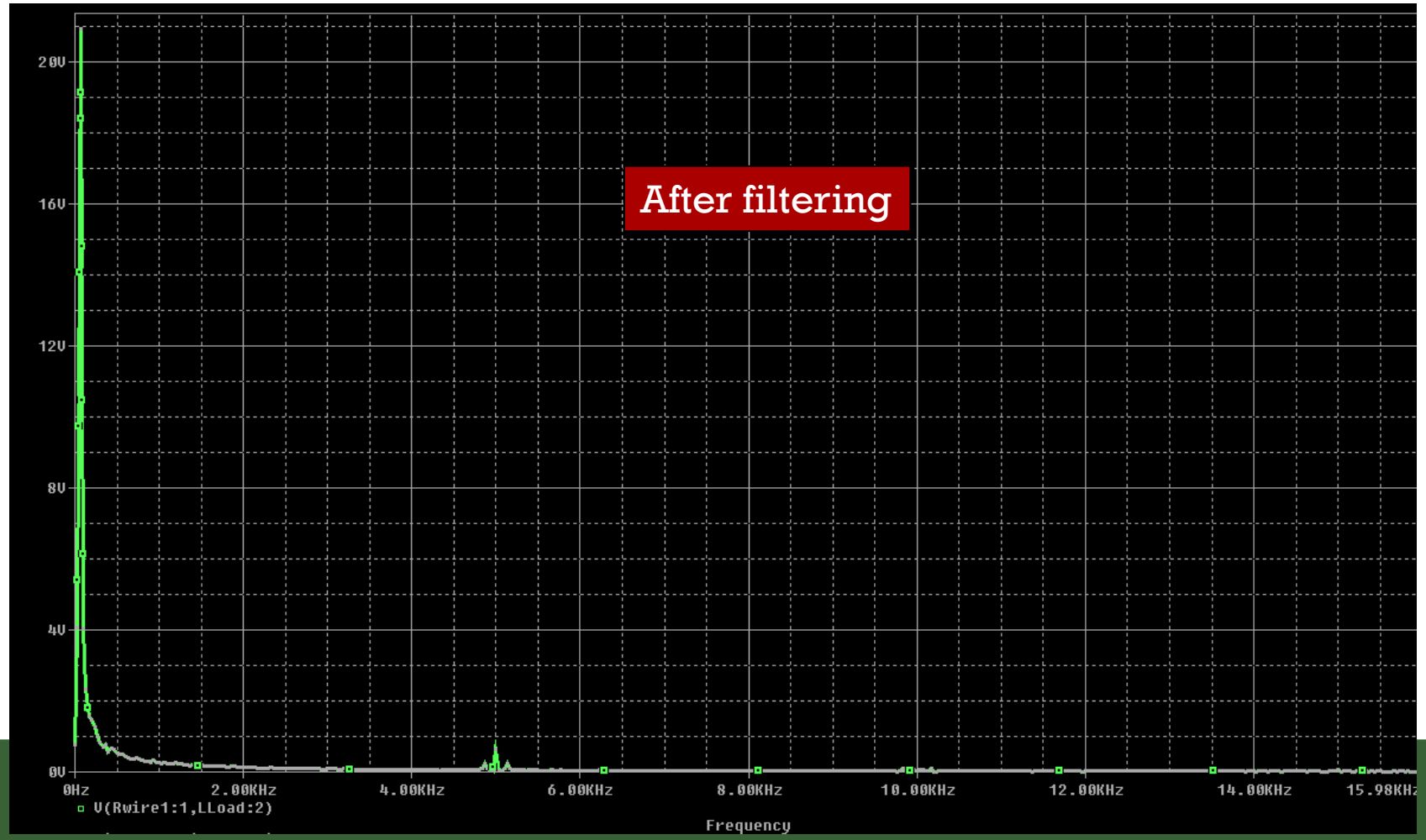
PWM Inverter



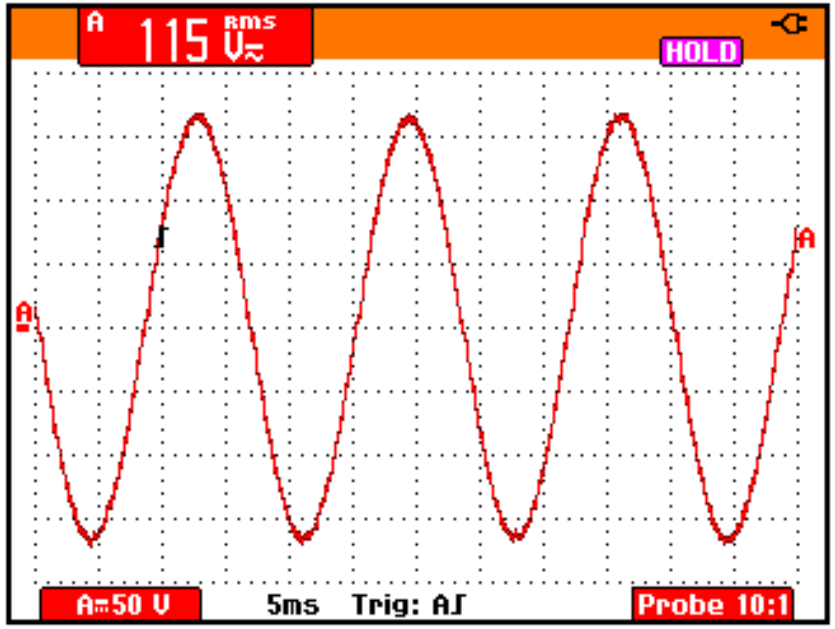
PWM Inverter



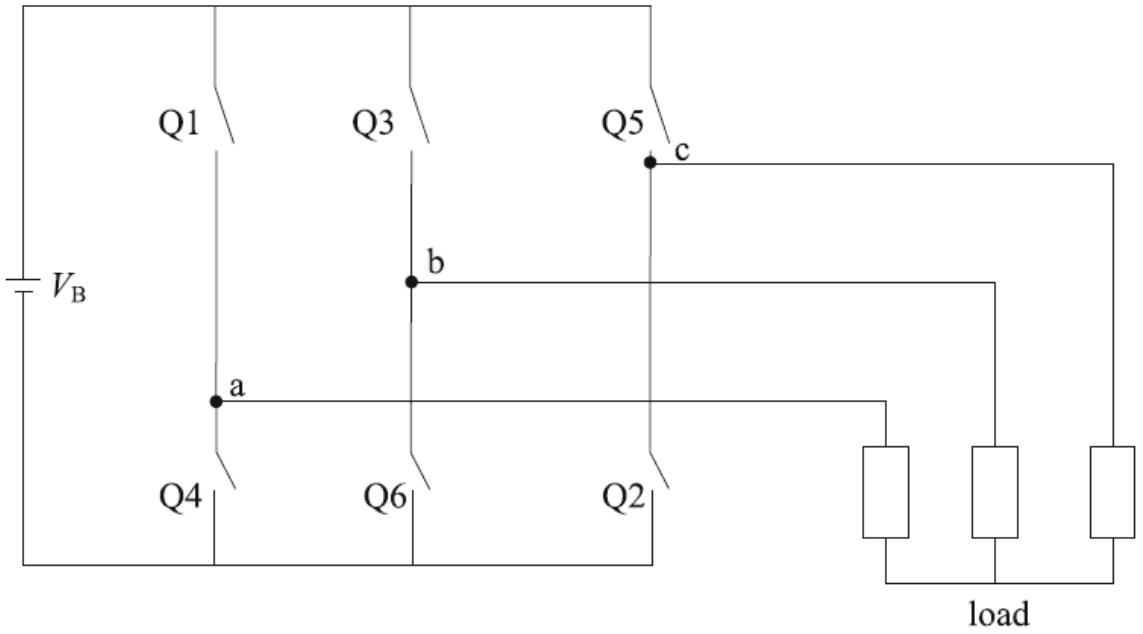
PWM Inverter

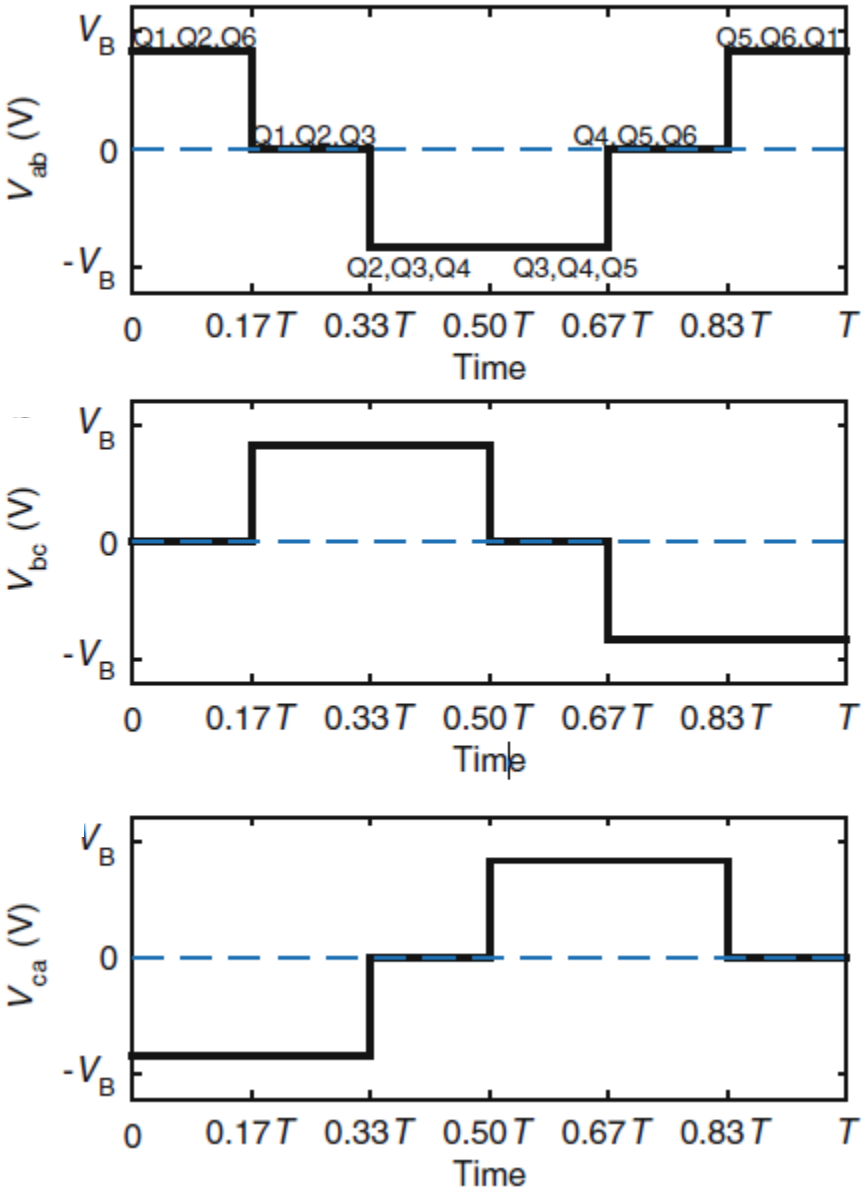


PWM Inverter



Three-Phase Inverters





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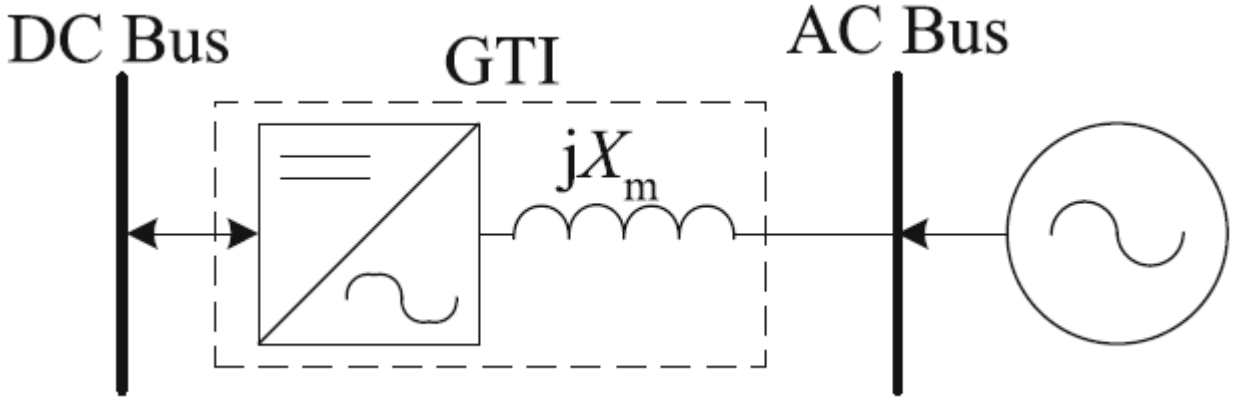
Grid Tied Inverters (GTI)

- Certain inverters can be coupled to AC Bus's with other AC coupled sources

Note that "grid tied" does not necessarily mean the national grid is on site



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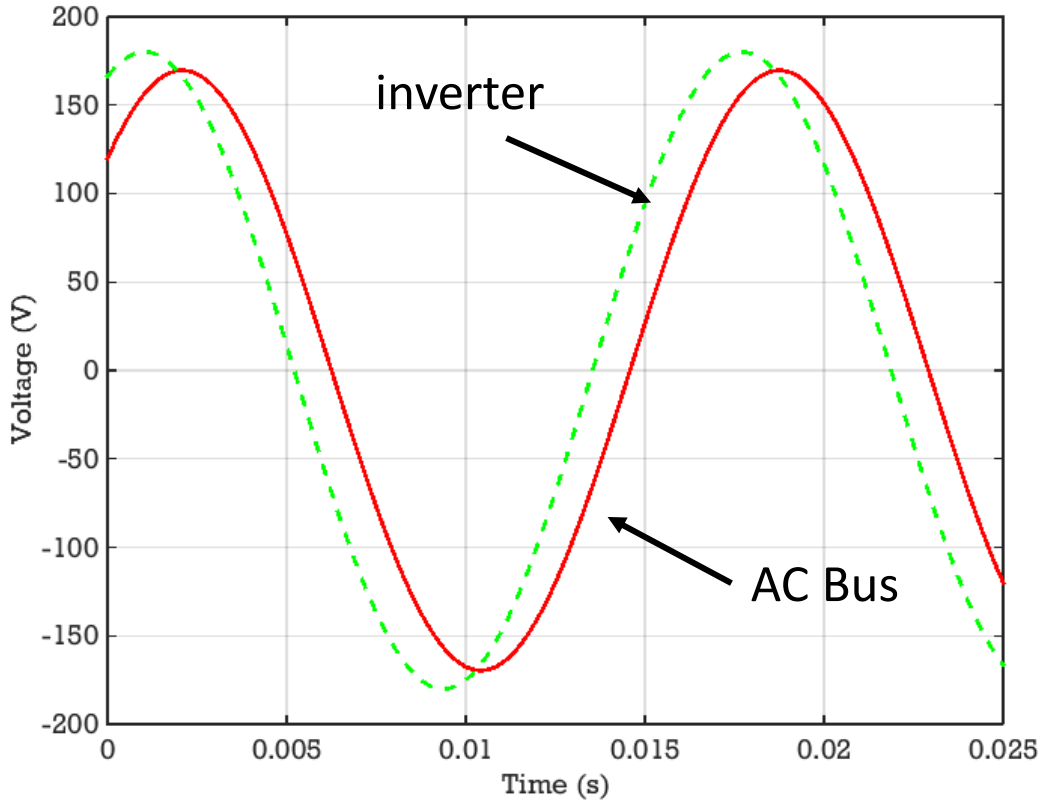
AC Bus Connection

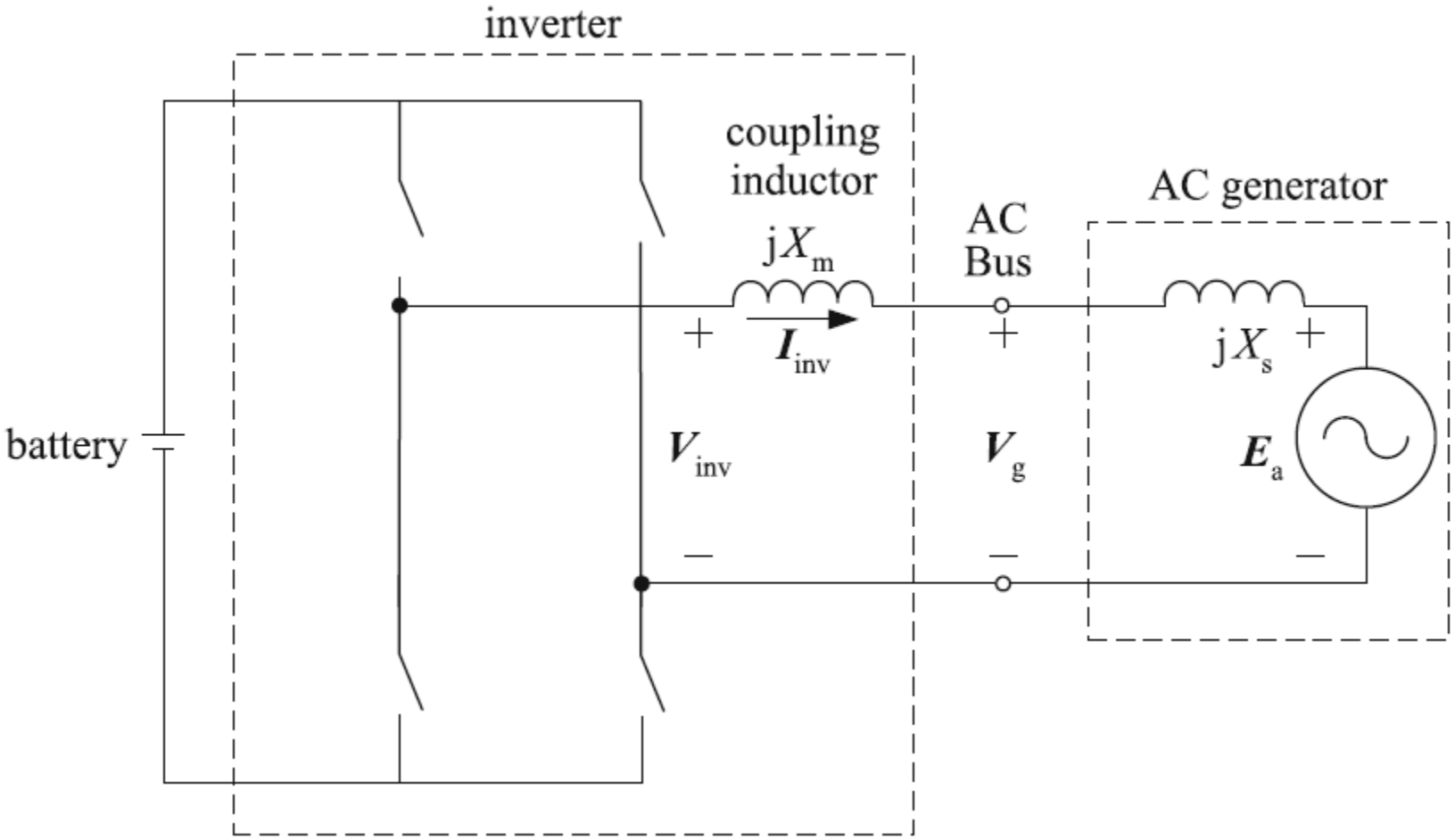


By adjusting the timing (phase) of the inverter switching, it is possible to make inverter voltage
lead or lag grid voltage, as well
as make the magnitude larger or smaller.

GTI

- Inverters have large coupling inductors
- Inverter current:

$$I_{inv} = \frac{V_{inv} - V_g}{jX_m}$$



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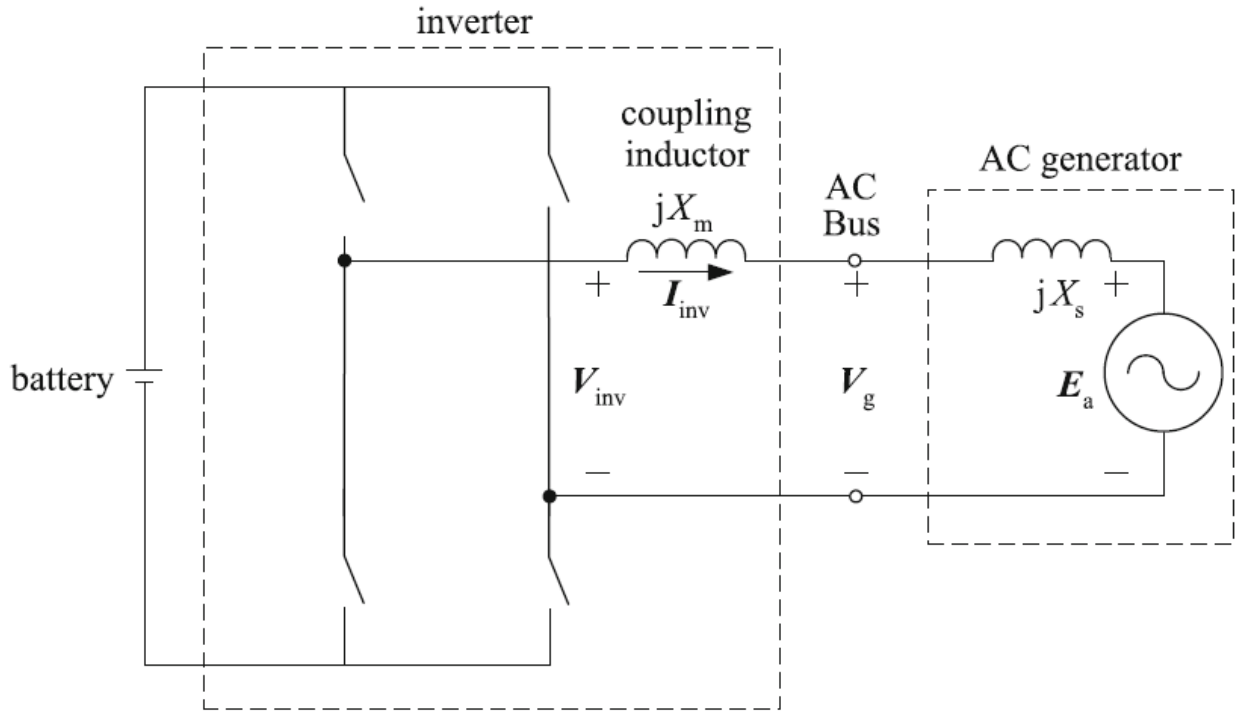
Inverter Power

$$P_{inv} = \mathrm{Re}\left\{\boldsymbol{V}_{inv}\boldsymbol{I}_m^*\right\} = \mathrm{Re}\left\{\boldsymbol{V}_{inv}\left(\frac{\boldsymbol{V}_{inv}-\boldsymbol{V}_g}{jX_m}\right)^*\right\}$$

$$P_{inv} = \mathrm{Re}\left\{\frac{|\boldsymbol{V}_{inv}|^2}{-jX_m} - \frac{\boldsymbol{V}_{inv}\boldsymbol{V}_g}{-jX_m}\right\}$$

$$P_{inv} = \mathrm{Re}\left\{\frac{|\boldsymbol{V}_{inv}|^2}{-jX_m} - \frac{|\boldsymbol{V}_{inv}||\boldsymbol{V}_g|\cos(\delta)+j|\boldsymbol{V}_m||\boldsymbol{V}_g|\sin(\delta)}{-jX_m}\right\}$$

$$P_{inv} = \frac{|\boldsymbol{V}_{inv}||\boldsymbol{V}_g|\sin(\delta)}{X_m}$$



Power supplied by the inverter can be controlled by adjusting the inverter's voltage magnitude and phase

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How Much Power can an Inverter Supply?

- Limiting factor is usually the safe internal operating temperature of the inverter
  - More current = higher temperature due to I^2R and eddy current losses
  - Higher temperature shortens lifespan of insulation, electrolytic capacitors, and other components
- Inverter will disconnect load if temperature becomes too high
- Spec sheets usually

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Specifications

- Rated continuous power depends on the ambient temperature
- Higher ambient temperature results in lower continuous power output (inverter overheats faster)
- Peak power is how much power the inverter can provide for a short period

MultiPlus-II 120V	12/3000/120-50	24/3000/70-50	48/3000/35-50
PowerControl & PowerAssist	Yes		
Transfer switch	50A		
Maximum AC input current	50A		
INVERTER			
DC Input voltage range	9,5–17 V	19–33 V	38 – 66 V
Output	Output voltage: 120 VAC ± 2%		
Cont. output power at 25°C (3)	3000 VA		
Cont. output power at 25°C	2400 W		
Cont. output power at 40°C	2200 W		
Cont. output power at 65°C	1700 W		
Maximum apparent feed-in power	2500 VA		
Peak power	5500 W		
Maximum efficiency	93%	94%	95%
Zero load power	13 W	13 W	11 W
Zero load power in AES mode	9 W	9 W	7 W
Zero load power in Search mode	3 W	3 W	2 W
CHARGER			
AC Input	Input voltage range: 90-140 VAC Input frequency: 45 – 65 Hz		
Charge voltage 'absorption'	14,4 V	28,8 V	57,6 V
Charge voltage 'float'	13,8 V	27,6 V	55,2 V
Storage mode	13,2 V	26,4 V	52,8 V
Maximum battery charge current (4)	120 A	70 A	35 A
Battery temperature sensor	Yes		

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Specifications

- Ensure inverter has Low Voltage Disconnect protection
  - Prevents battery from deep discharge by disconnecting the load

GENERAL			
Auxiliary output	Yes (32 A)		
External AC current sensor (optional)	100 A		
Programmable relay (5)	Yes		
Protection (2)	a – g		
VE.Bus communication port	For parallel, split phase and three phase operation, remote monitoring and system integration		
General purpose com. port	Yes, 2x		
Remote on-off	Yes		
Operating temperature range	-40 to +65°C (-40 – 150 °F) (fan assisted cooling)		
Humidity (non-condensing)	max 95%		
ENCLOSURE			
Material & Colour	Steel, blue RAL 5012		
Protection category	IP22		
Battery-connection	M8 bolts		
120 V AC-connection	Screw terminals 13 mm² (6 AWG)		
Weight	19 kg		
Dimensions (hxwxd) mm	578 x 277 x 148	536 x 277 x 147	536 x 275 x 147
STANDARDS			
Safety	EN-IEC 60335-1, EN-IEC 60335-2-29, UL458		
Emission, Immunity	EN 55014-1, EN 55014-2 EN-IEC 61000-3-2, EN-IEC 61000-3-3 IEC 61000-6-1, IEC 61000-6-2, IEC 61000-6-3		
Uninterruptible power supply	Please consult the certificates on our website.		

1) Can be adjusted to 50 Hz
2) Protection key:
   a) output short circuit
   b) overload
   c) battery voltage too high
   d) battery voltage too low
   e) temperature too high
   f) 120 VAC on inverter output
   g) input voltage ripple too high
3) Non-linear load, crest factor 3:1
4) Up to 75°F / 25°C ambient
5) Switches off when no external AC source available
6) Programmable relay which can be set for general alarm, DC under voltage or genset start/stop function. AC rating: 120V / 4A, DC rating: 4A up to 35VDC and 1A up to 60VDC
7) A.o. to communicate with a Lithium Ion battery

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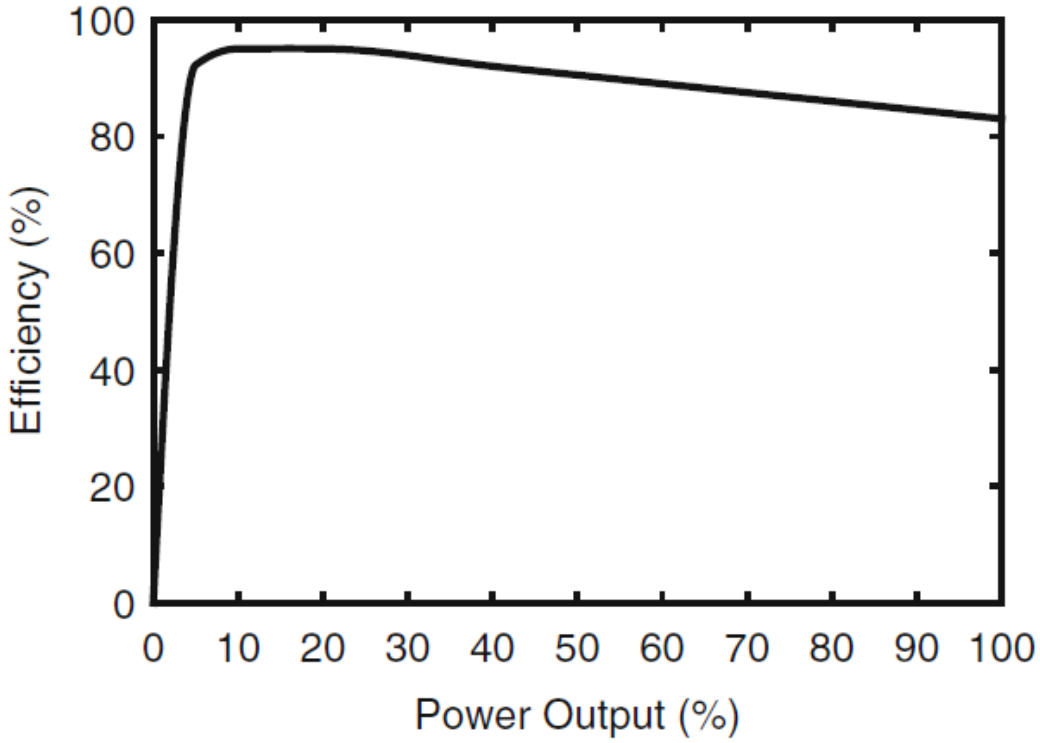
Inverter Efficiency

- Inverter efficiency is not constant, and is non-linear
- Low efficiency at low-loading
- Inverter efficiency is sometimes reported as the “European” efficiency, which considers different operating points

$$\eta_{inv} = 0.03\eta_{inv}(0.05) + 0.06\eta_{inv}(0.10) + 0.13\eta_{inv}(0.20) + 0.10\eta_{inv}(0.30) + 0.48\eta_{inv}(0.50) + 0.20\eta_{inv}(1.00)$$



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Practical Considerations

Higher-quality inverters feature:

- output sinusoidal voltage with little distortion and constant frequency and magnitude;
- good voltage regulation;
- high efficiency at low loading;
- insensitivity to changes in input voltage;
- short-term increased surge capacity;
- low-voltage disconnect capability;
- can be configured in the field;
- include data logging and diagnostic features

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