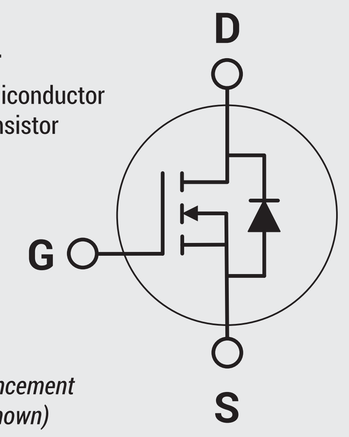
Power Conversion – The Basics

POWER SEMICONDUCTOR DEVICES

Power Semiconductor Device Types

Power MOSFET
Metal Oxide Semiconductor Field- Effect Transistor

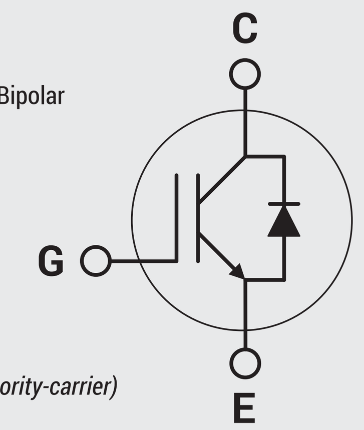
- Gate (G)
- Drain (D)
- Source (S)



(N-channel Enhancement Mode MOSFET shown)

IGBT
Insulated Gate Bipolar Transistor

- Gate (G)
- Collector (C)
- Emitter (E)

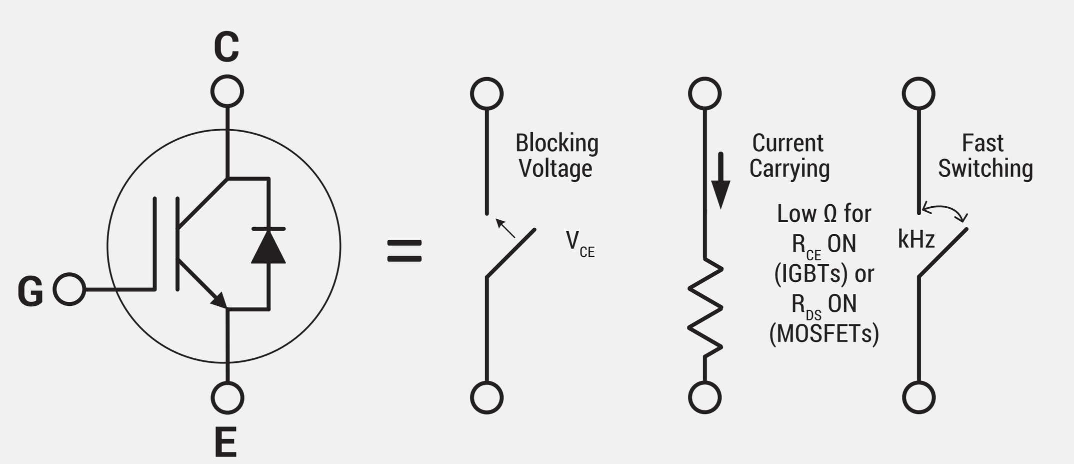


(P-channel (minority-carrier) IGBT shown)

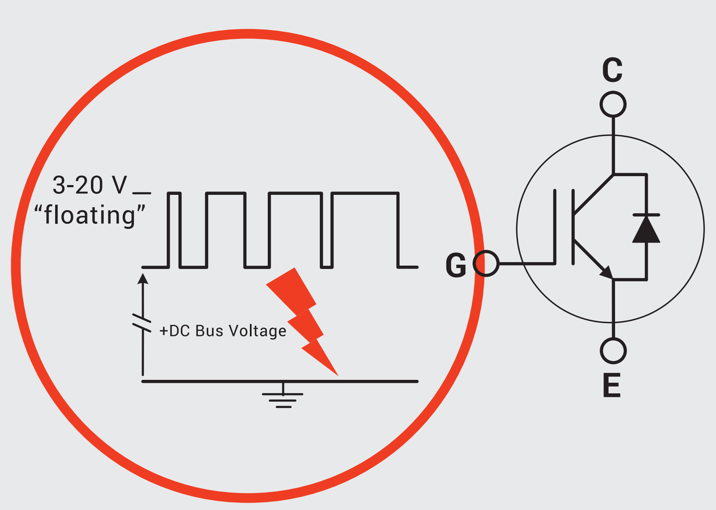
Characteristics (Power MOSFET)
- 500 V blocking voltage (typical)
- 10s of amperes
- 20 to 500 kHz switching frequencies
- Widely deployed in ≤240 VAC Class and low voltage DC applications

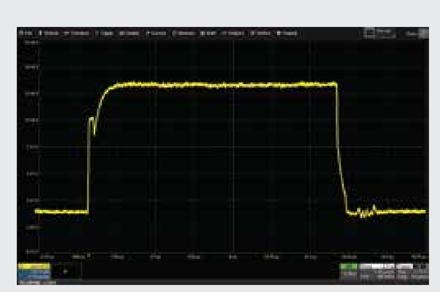
Characteristics (IGBT)
- 1200 V blocking voltage (typical)
- Hundreds of amperes
- 1 to 40 kHz switching frequencies
- Widely deployed in ≤600 VAC Class and high voltage DC applications

Power Semiconductor Device Operation



Upper-side Gate Drive





HVFO High Voltage Fiber Optic Probe

Applications

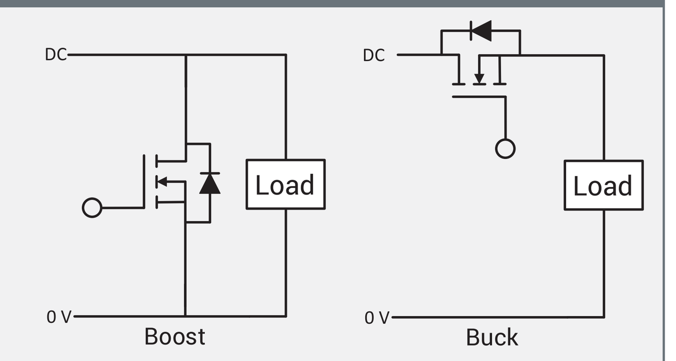
Power MOSFET
- DC-DC converters
- 120/240 VAC switch-mode power supplies
- Lighting ballasts and LED drivers
- Class D audio amplifiers
- Motor drives
- Solar PV inverters
- Uninterruptible power supplies (UPS)
- Battery chargers

IGBT
- DC-DC converters
- Grid-tied solar PV inverters
- Industrial automation
- Motor drives
- Vehicle propulsion drives
- Energy storage systems (ESS)
- Welding equipment

INVERTER SUBSECTIONS

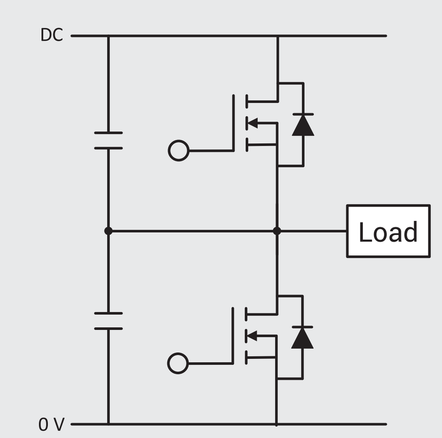
Single Device

Boost or Buck (typical)
MOSFET-based applications
- CFL lighting ballast
- LED driver
- 12 V input DC-DC converter



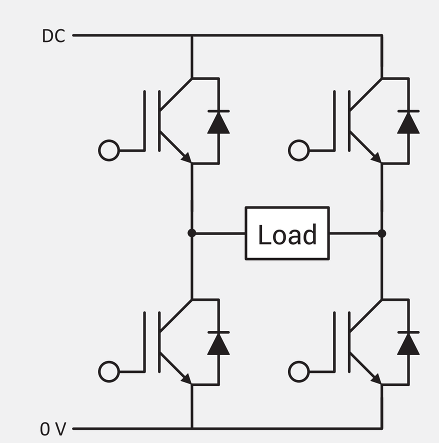
Half Bridge

MOSFET-based applications
- Switch-mode power supply (SMPS)
- Battery charging



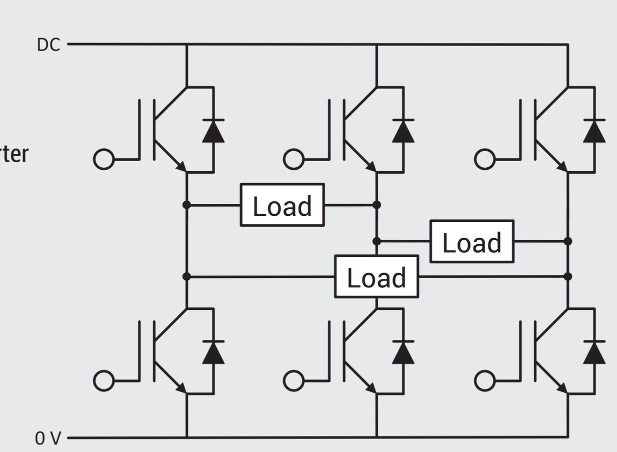
Full Bridge or H-Bridge

MOSFET- or IGBT-based applications
- Single-phase grid-tied solar PV inverter
- Stepper motor drive
- Class D audio amplifier
- Uninterruptible power supply (UPS)
- High power DC-DC converter
- Welding equipment



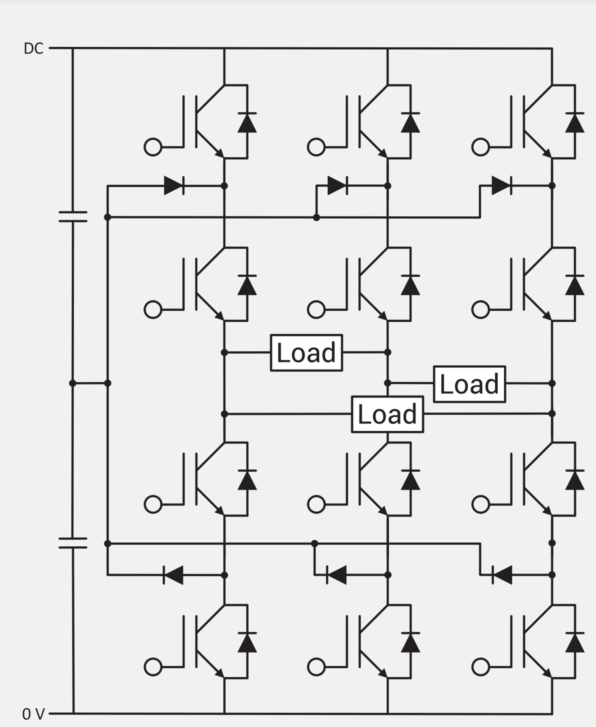
Cascaded H-Bridge

MOSFET- or IGBT-based applications
- Three-phase grid-tied solar PV inverter
- Motor drives
- Vehicle propulsion drives
- Energy Storage Systems (ESS)



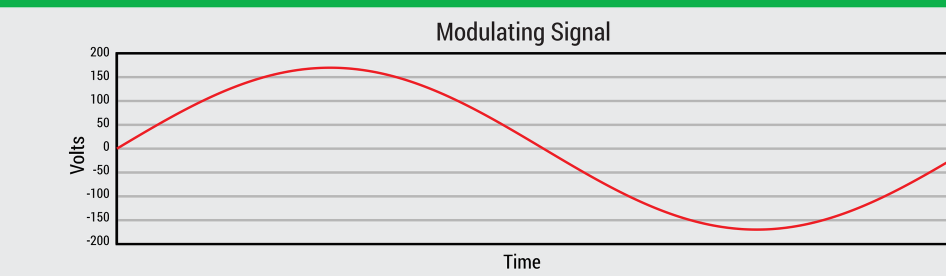
Neutral Point Clamped (NPC)

IGBT-based applications
- Motor drives
- Medium voltage (5 kV) applications

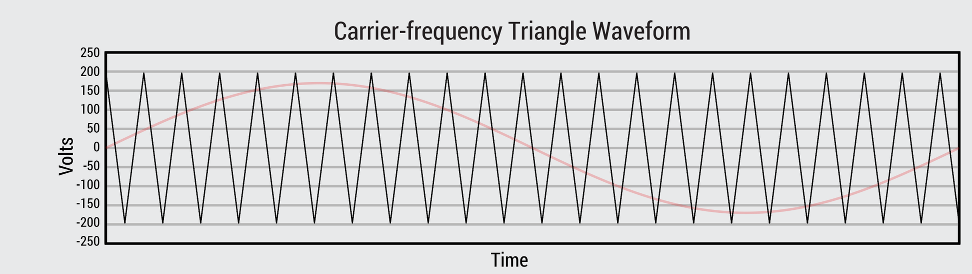


PULSE-WIDTH MODULATION (PWM)

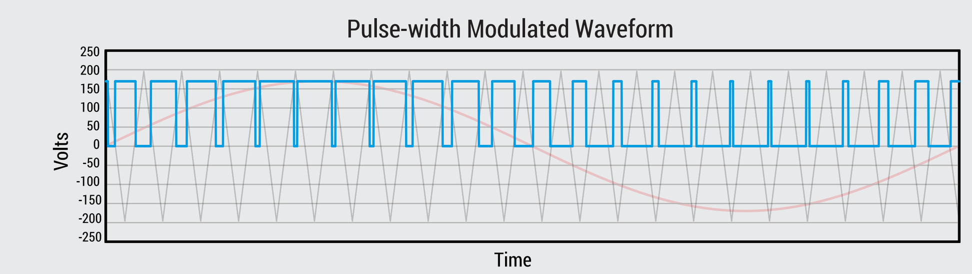
A modulating waveform defines the desired output voltage and frequency



A high-frequency (1 to 500 kHz) carrier waveform is generated
- The carrier waveform is usually a triangle waveform
- It is shown here as <<1 kHz to make it easy to see in relation to the lower frequency modulating waveform



The pulse width is defined by the intersection of the carrier waveform and modulating waveform
- This is a simple example for a single-device circuit

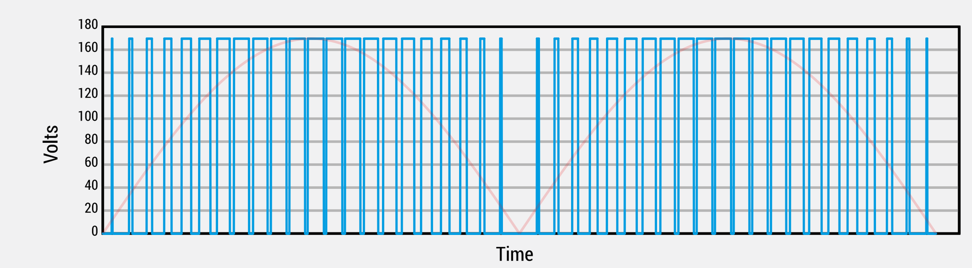


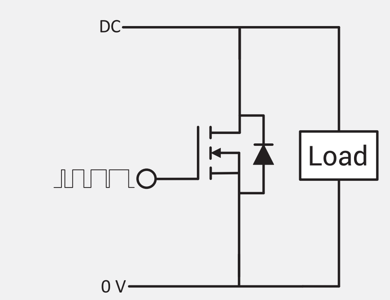
Single Device Implementation

Single gate-drive signal switches the single power semiconductor

Gate-drive PWM signal creates high voltage PWM signal at load
- "1" level = 170 Vdc (this example)
- "0" level = 0 Vdc

Fundamental frequency of PWM signal on load is the modulating waveform frequency, rectified.





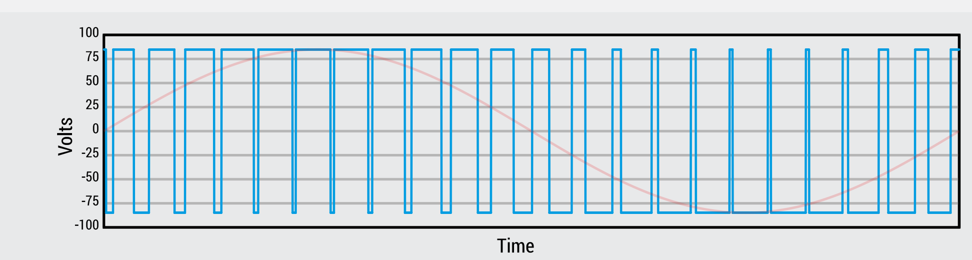
Half-Bridge Implementation

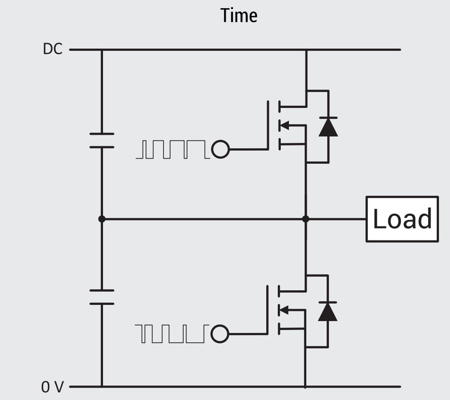
Load is connected at midpoint of circuit and could be terminated at either:
- The upper rail (DC)
- The lower rail (0 V) (as shown)

Complementary PWM signals are applied at the Upper Device and Lower Device gates
- Both devices cannot be "on" (conducting) at the same time

Upper and Lower Devices both:
- "1" level = 85 Vdc
- "0" level = 0 Vdc

Upper-Lower Device = Load
- +85 Vpk to -85 Vpk
- 50% PWM duty cycle = 0 V





Full-Bridge (H-Bridge) Implementation

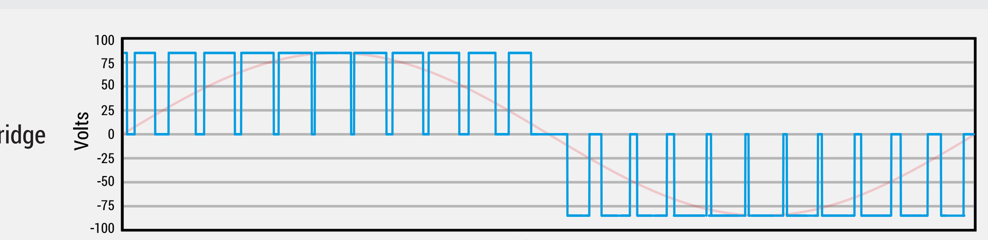
Load is connected at midpoint of each half-bridge

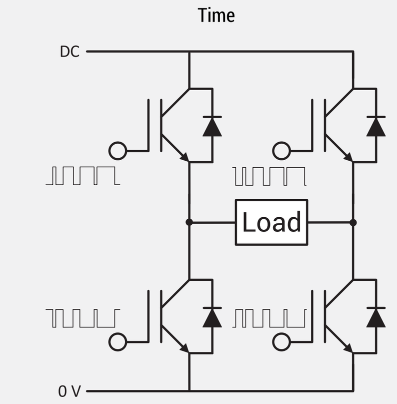
Complementary PWM signals are applied at the Upper Device and Lower Device gates
- Both devices cannot be "on" (conducting) at the same time

Upper Device:
- "1" level = 85 Vdc
- "0" level = 0 Vdc

Lower Device:
- "1" level = 0 Vdc
- "0" level = -85 Vdc

Upper-Lower Device = Load
- +85 Vpk to -85 Vpk
- 50% PWM duty cycle = 50% Output Voltage

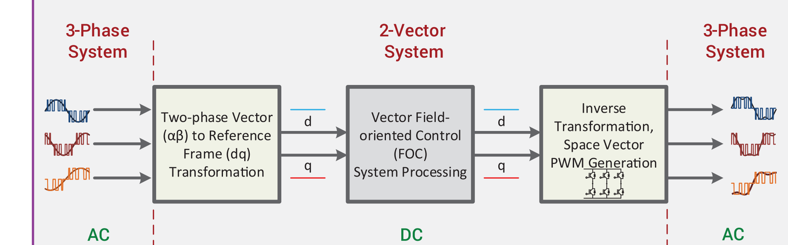




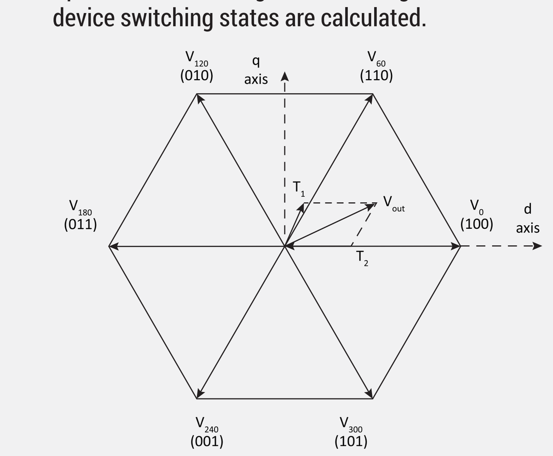
THREE-PHASE CONTROL METHODS

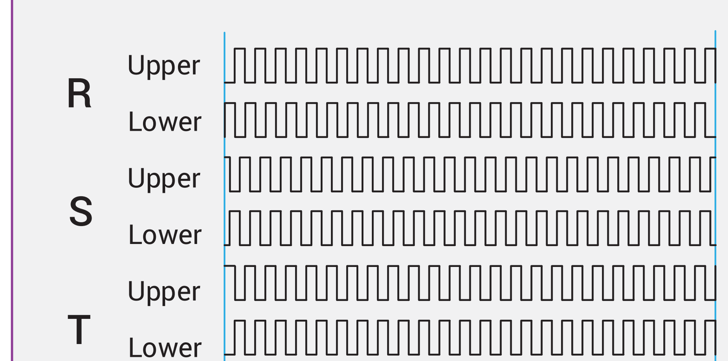
Sinusoidal

Two primary methods are used in the sinusoidal method
- Carrier-frequency (as previously described)
- Space Vector Modulation (SVM or SVPWM)
  - Three stator voltage vectors are transformed to a single rotating ("space") vector in a dq0 system.

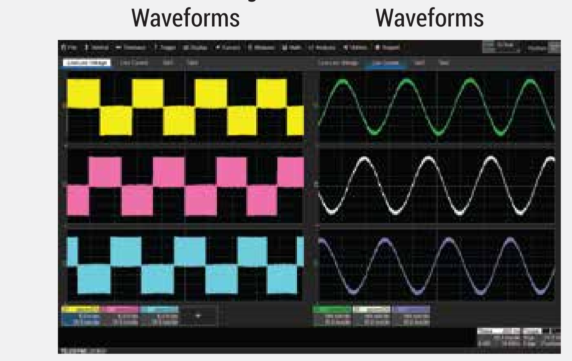


- Space vector has magnitude and angle, from which the device switching states are calculated.

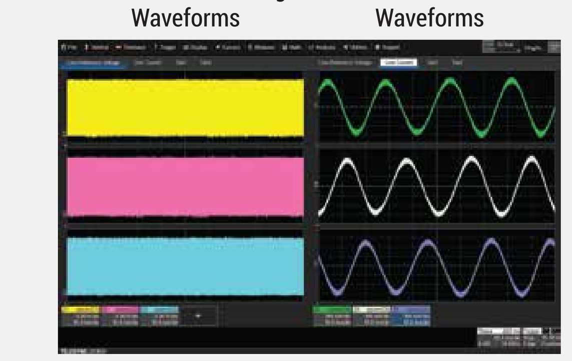




Line-Line Voltage Waveforms | Line Current Waveforms



Line-Reference Voltage Waveforms | Line Current Waveforms

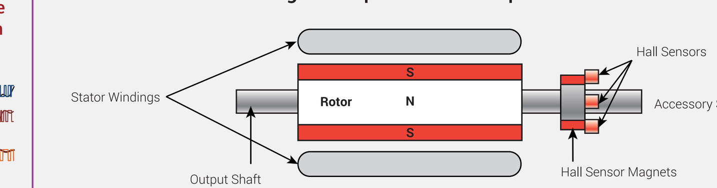


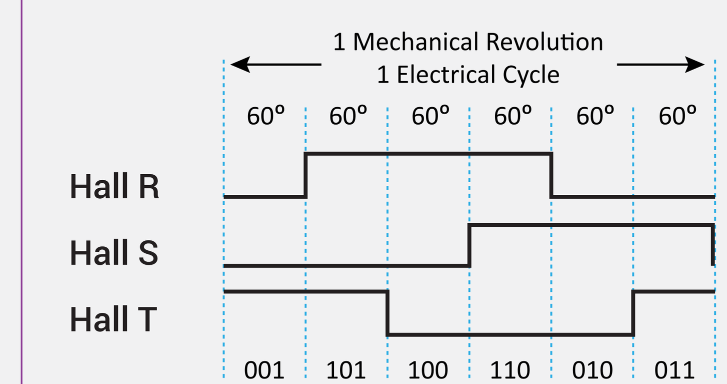
Trapezoidal (Six-Step Commutated)

Three Hall sensors define a 3-bit binary pattern that describes six line-reference stator voltage operating states.

Only two phases are energized at any given time.

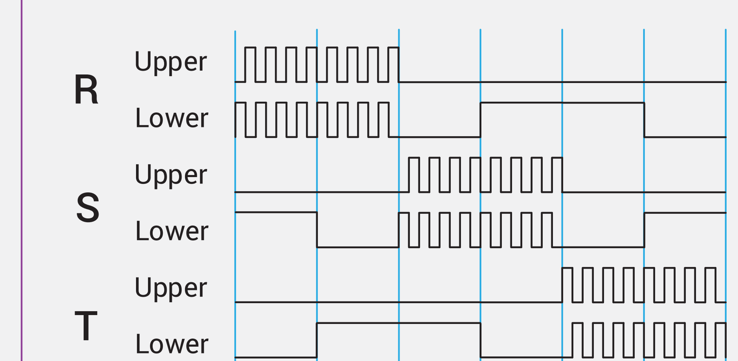
Back EMF of the voltage is trapezoidal in shape.



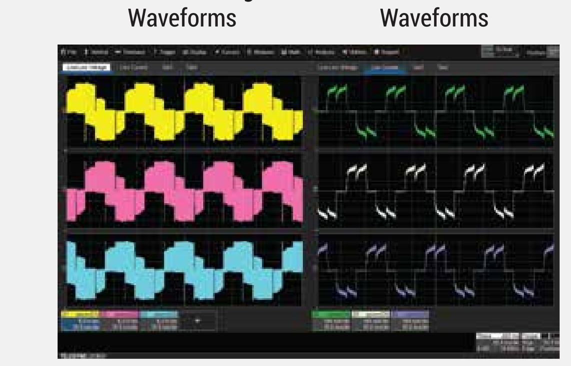


Three Hall effect sensors, 120° apart, one rotor pole-pair

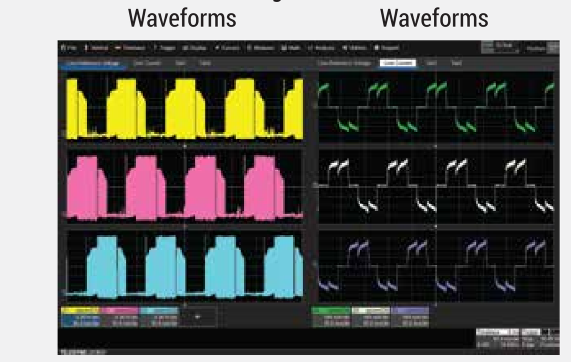
May also be designed to operate "sensorless" (without Hall sensors).

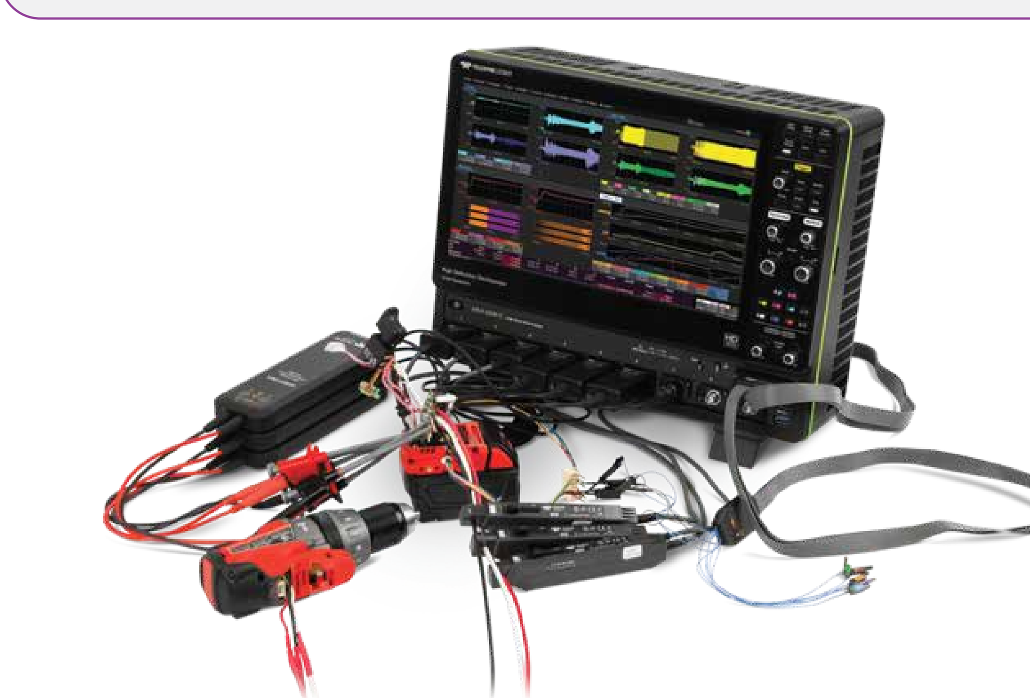


Line-Line Voltage Waveforms | Line Current Waveforms



Line-Reference Voltage Waveforms | Line Current Waveforms





HD 4096

MDA 8000HD Motor Drive Analyzers 8 channels, 12 bits, 2 GHz

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