

Variable Frequency Drives

Basic VFD Theory



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ABB AC VARIABLE SPEED DRIVES

DC VARIABLE SPEED DRIVES

SOFT STARTERS

POWER QUALITY PRODUCTS

What is a VFD (Variable Frequency Drive)

- ❖ Electrical / electronic piece of equipment that varies the speed of a 3 phase or AC motor.

- ❖ Also called
- ❖ VSD (Variable speed drive)
- ❖ ASD (Adjustable speed drive)
- ❖ AFD (Adjustable frequency drive)
- ❖ Inverter



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Basic VFD Operation

- ❖ Convert AC power to DC power.
- ❖ Filter DC power.
- ❖ Invert DC power to variable voltage and variable frequency AC power.



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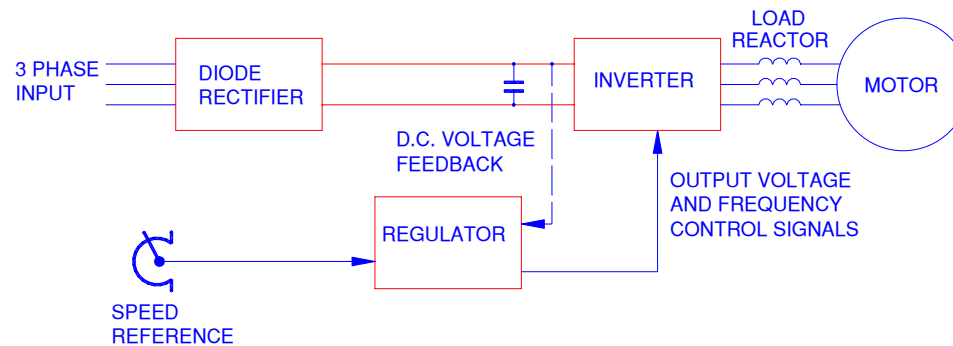
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Voltage Source VFD

PWM BLOCK DIAGRAM



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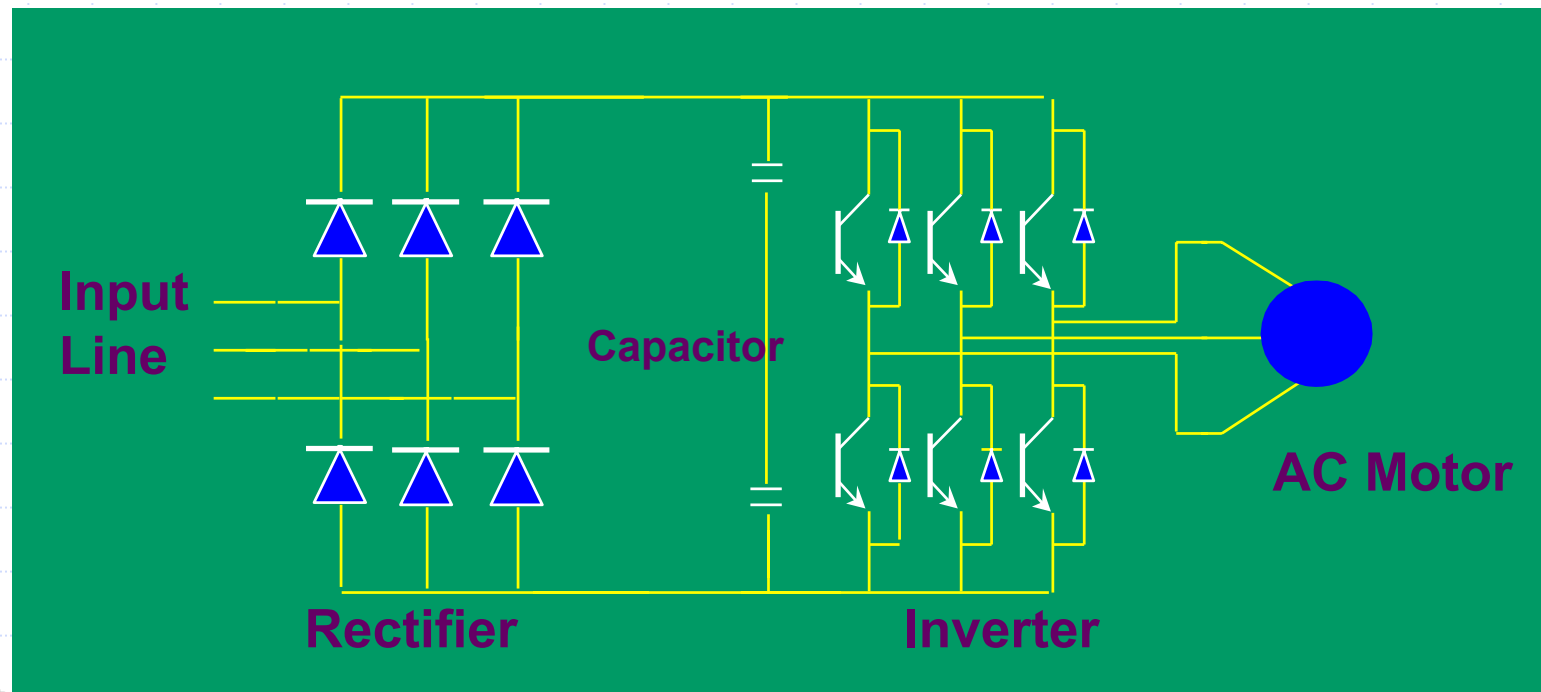
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PWM Power Diagram



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Convert AC Input Power to DC

AC input power is rectified to DC through a six pulse diode bridge

DC voltage is equal to AC input voltage * 1.414 (root 2)

$$\blacklozenge 230 * 1.414 = 325$$

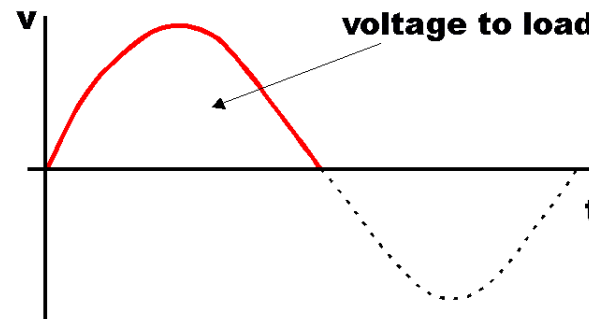
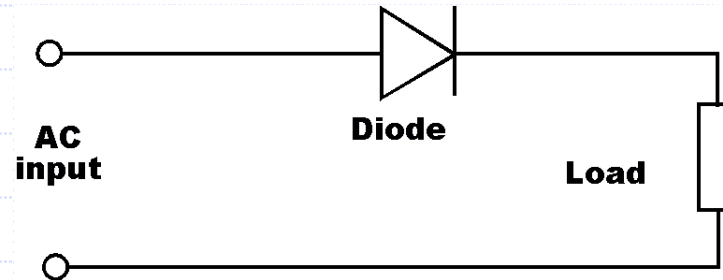
$$\blacklozenge 460 * 1.414 = 650$$

$$\blacklozenge 600 * 1.414 = 850$$

DC power is filtered and stored through a capacitor bank called the DC bus



Diode Rectifier



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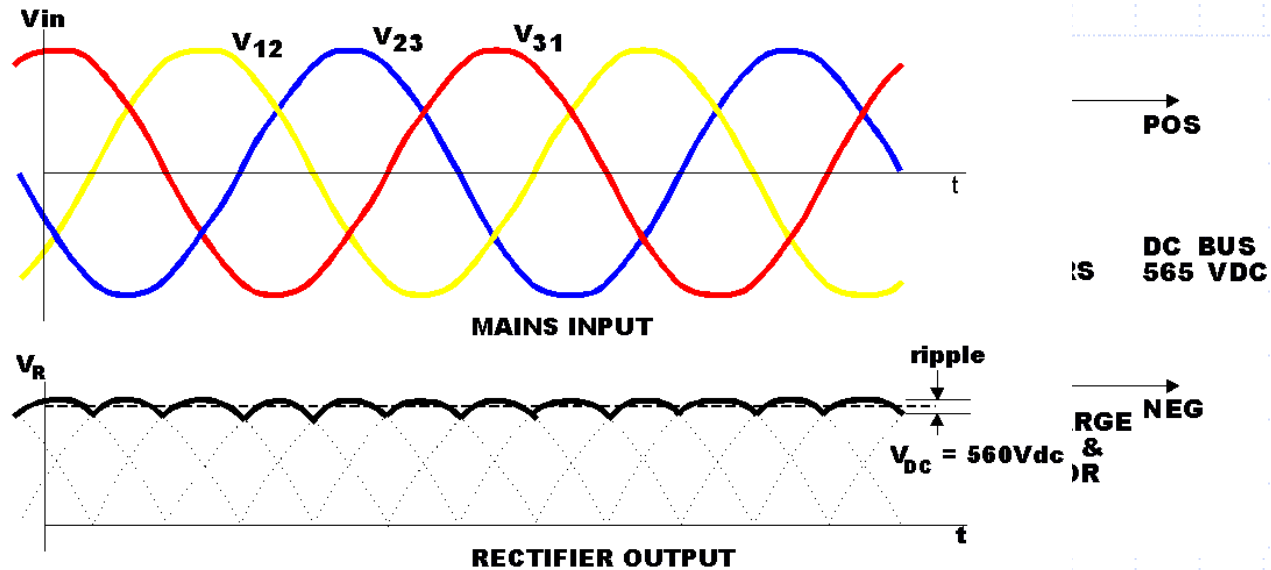
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Rectifier and Filter



4501-112 Rev A



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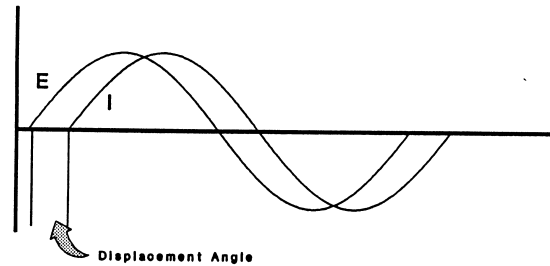
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Power Factor

POWER FACTOR

For Simple Applications:
Cosine of the Displacement Angle Between Voltage and Current



However: When one of the waveforms is non-sinusoidal
(such as PWM Current)

$$\text{True Power Factor} = \frac{\text{Real Power}}{\text{Apparent Power}}$$

Which includes both the Fundamental and Harmonic Waveforms



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Invert DC Power to Variable Voltage and Frequency AC Power

- ❖ 2 IGBT's per output phase switch the positive and negative sides of the DC Bus utilising pulse width modulation
- ❖ IGBT's will have a characteristic rise time depending on its generation and current rating
- ❖ Rise time is the time it takes the IGBT pulse when switched on to reach DC bus voltage level



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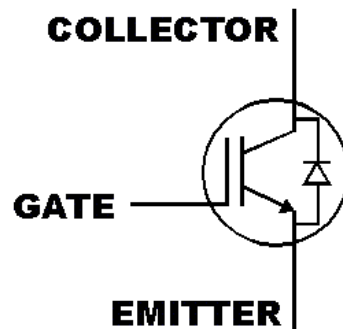
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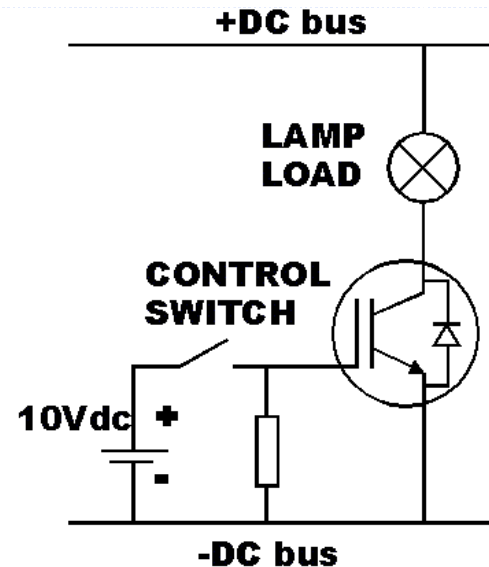
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Insulated Gate Bipolar Transistors

4501-113 Rev A



(a) IGBT Symbol and Terminals



(b) IGBT as a Power Switch



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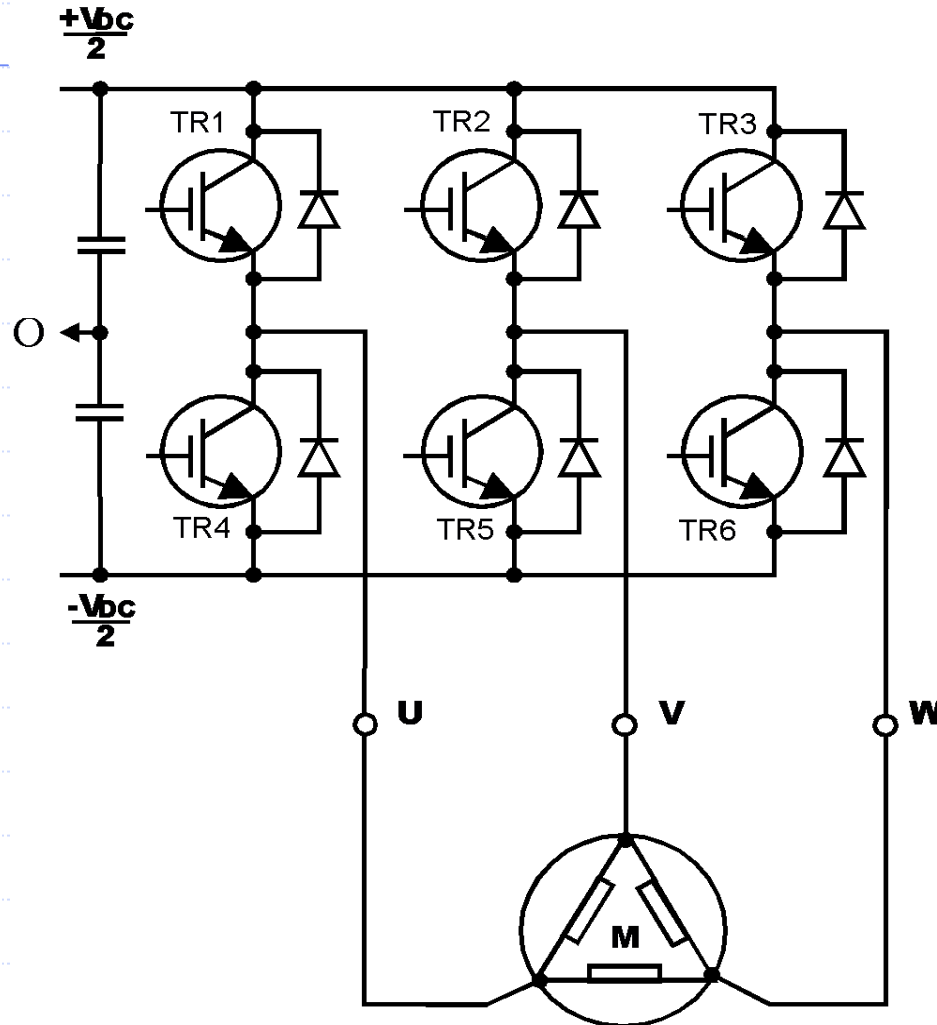
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Inverter



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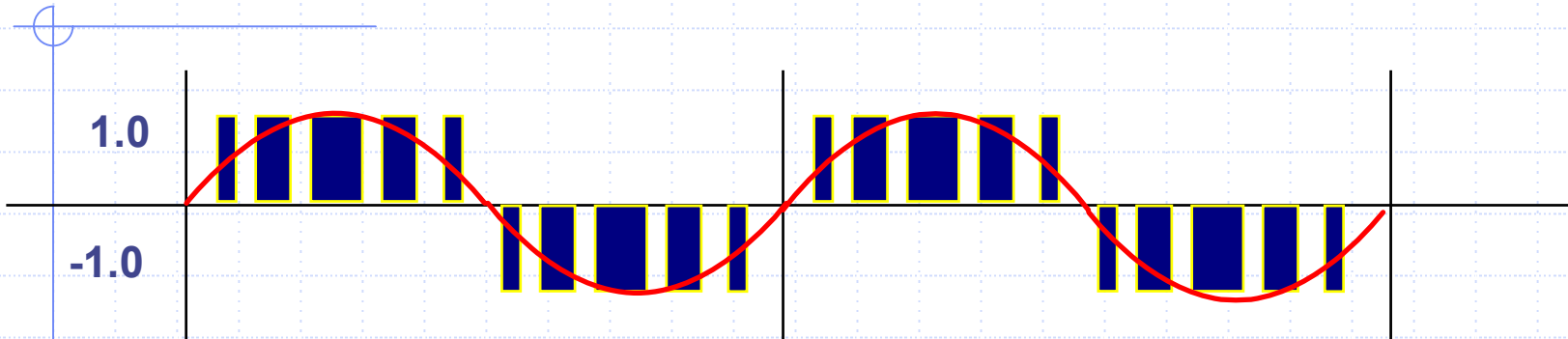
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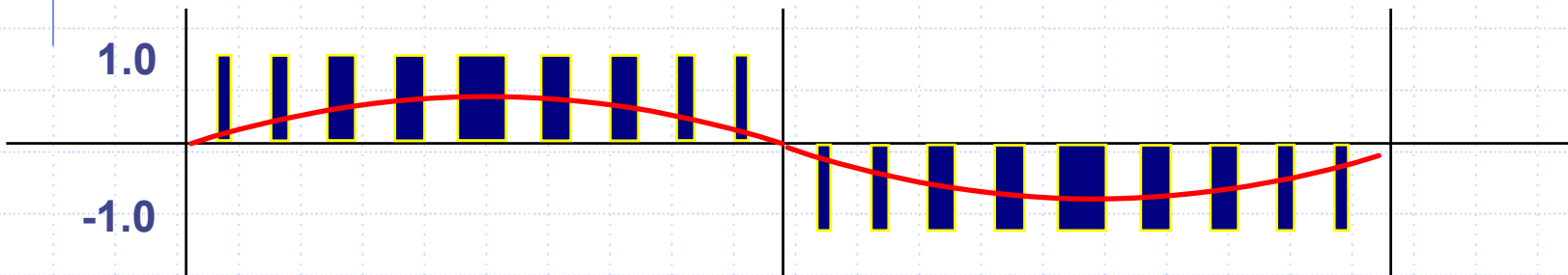
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PWM Waveform



Full Voltage, 60 Hz PWM Waveform



Half Voltage, 30 Hz PWM Waveform



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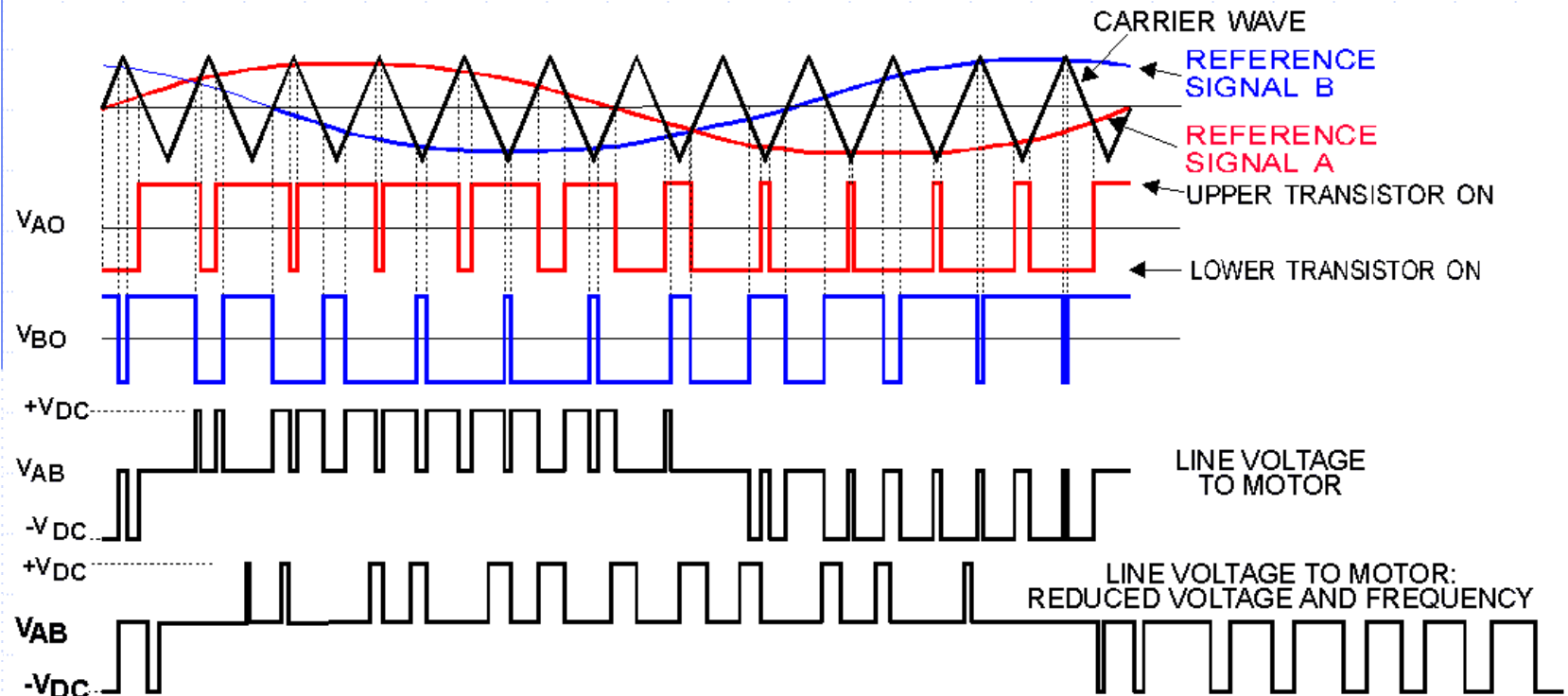
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Pulse Width Modulation



4501-035 Rev D

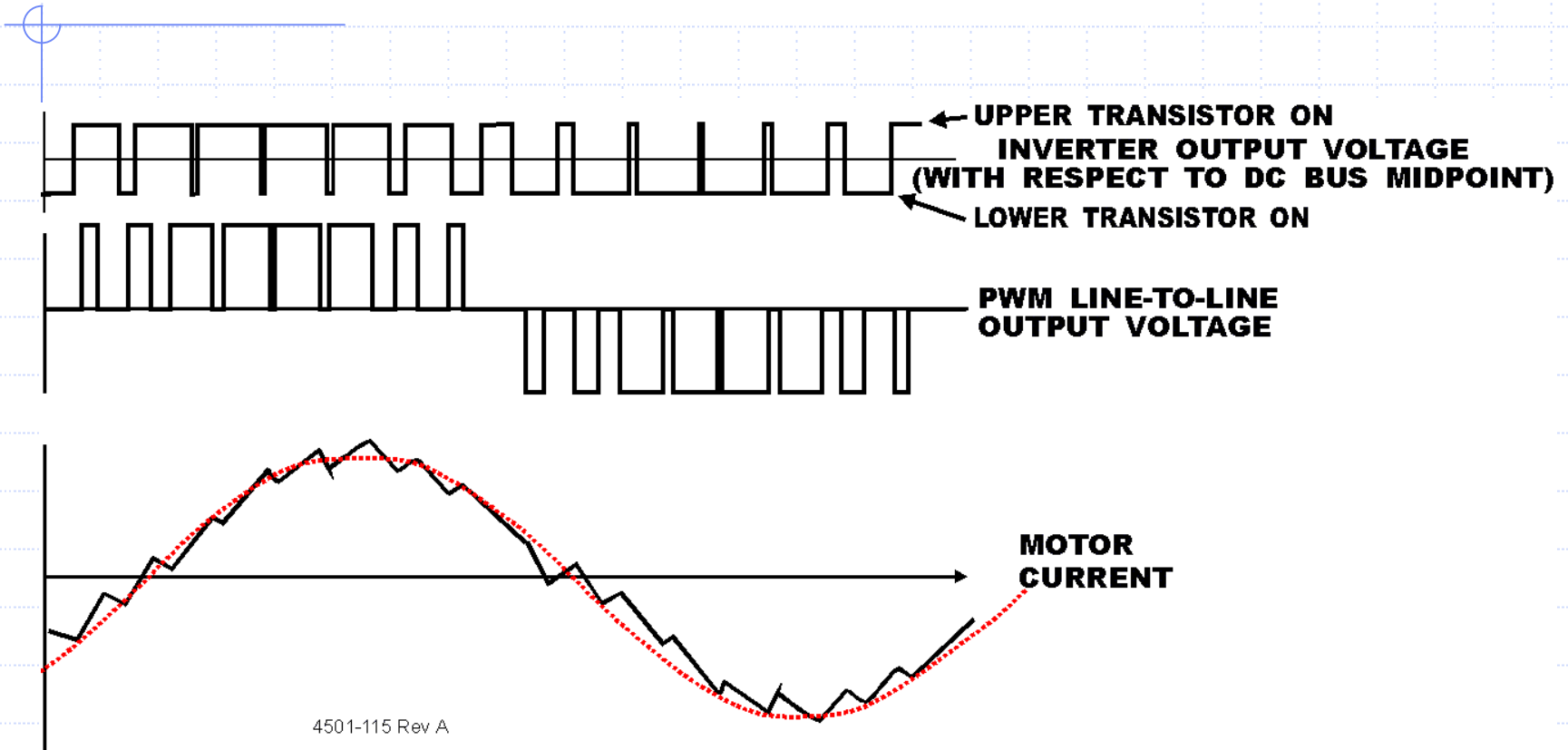


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Modulation of Waveform



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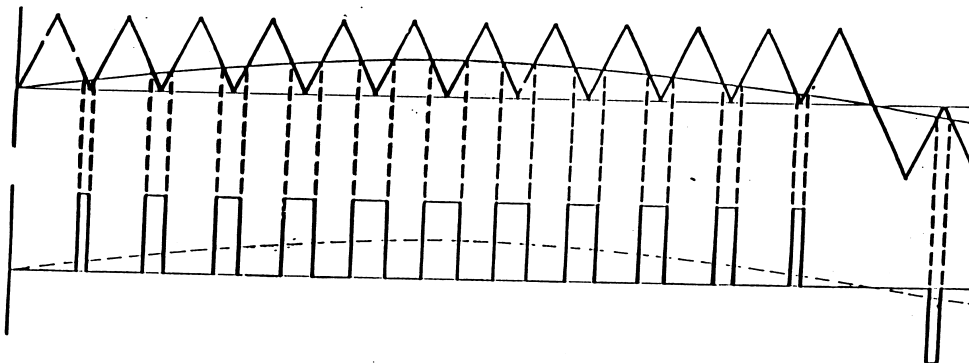
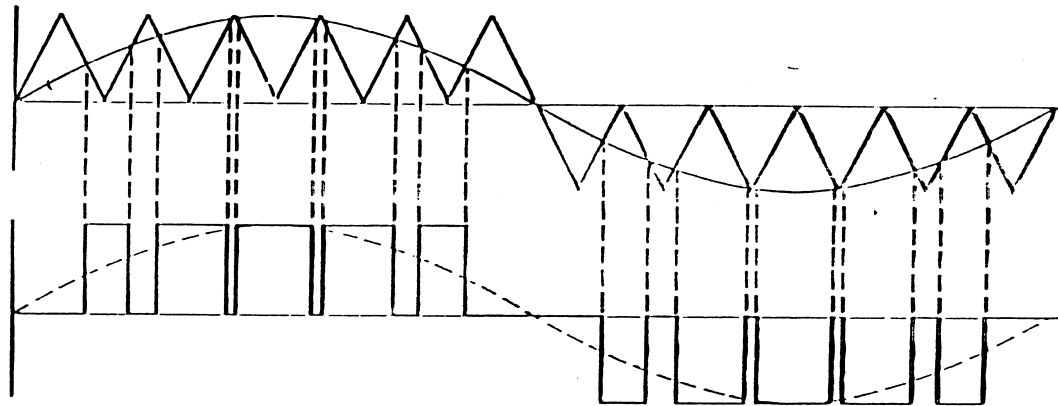
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PWM Carrier Frequency



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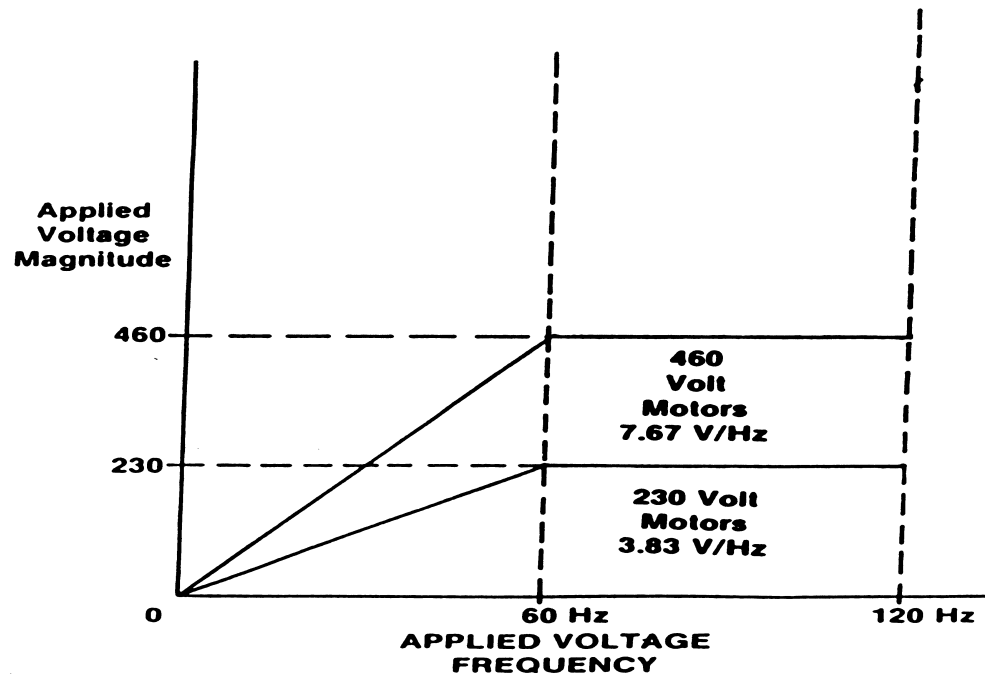
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Volts / Hz Ratio

**CONSTANT VOLTS/Hz CHARACTERISTIC
OF AC MOTORS**



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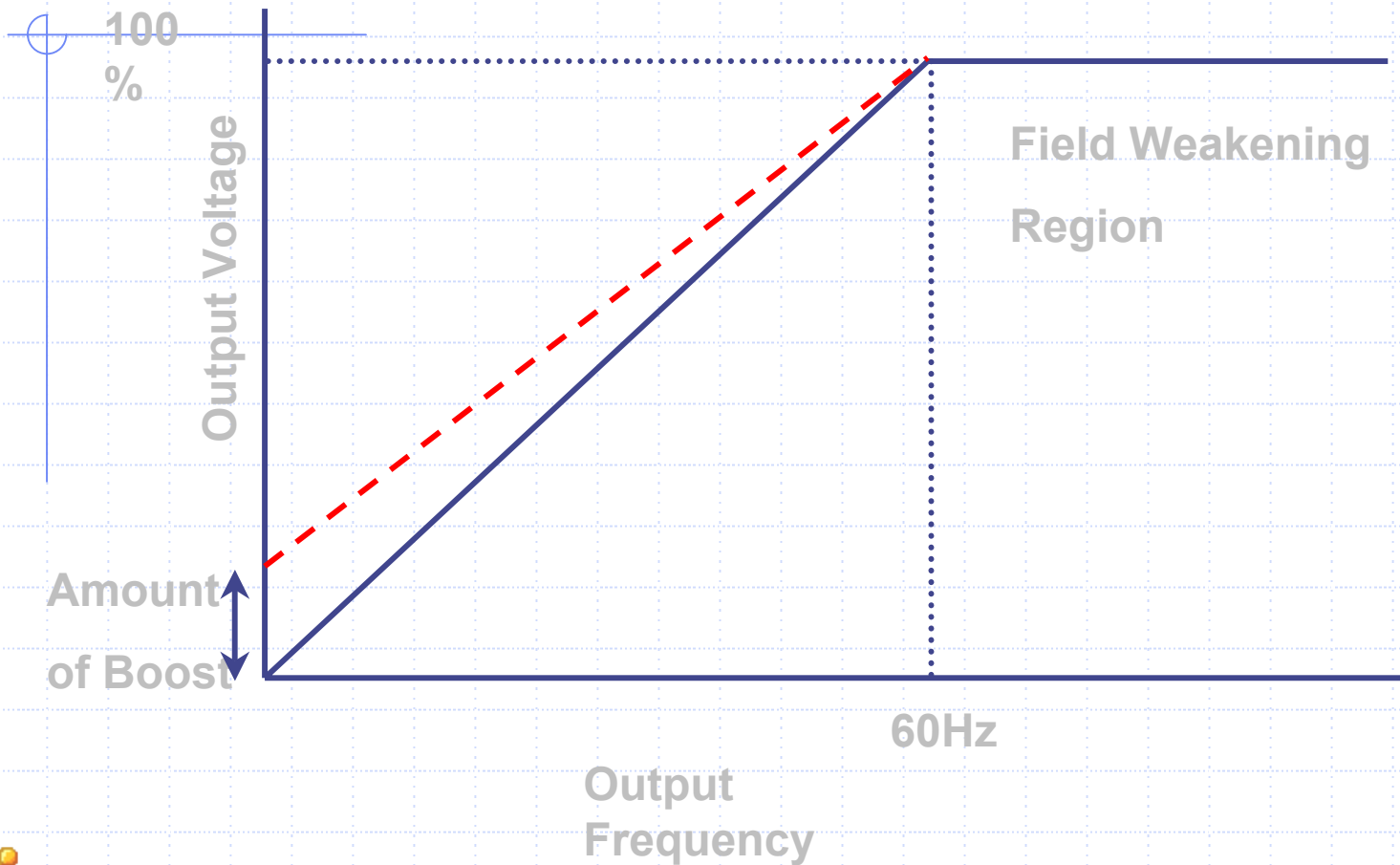
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Variable Voltage Variable Frequency



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VFD Summary

- ❖ VFD Varies the speed of an AC Motor
- ❖ Maximum output voltage = input voltage
- ❖ V/Hz ratio is controlled throughout the range up to 60 Hz.
- ❖ Torque decreases after 60Hz.
- ❖ Output wave form is Pulse Width Modulated (PWM) .



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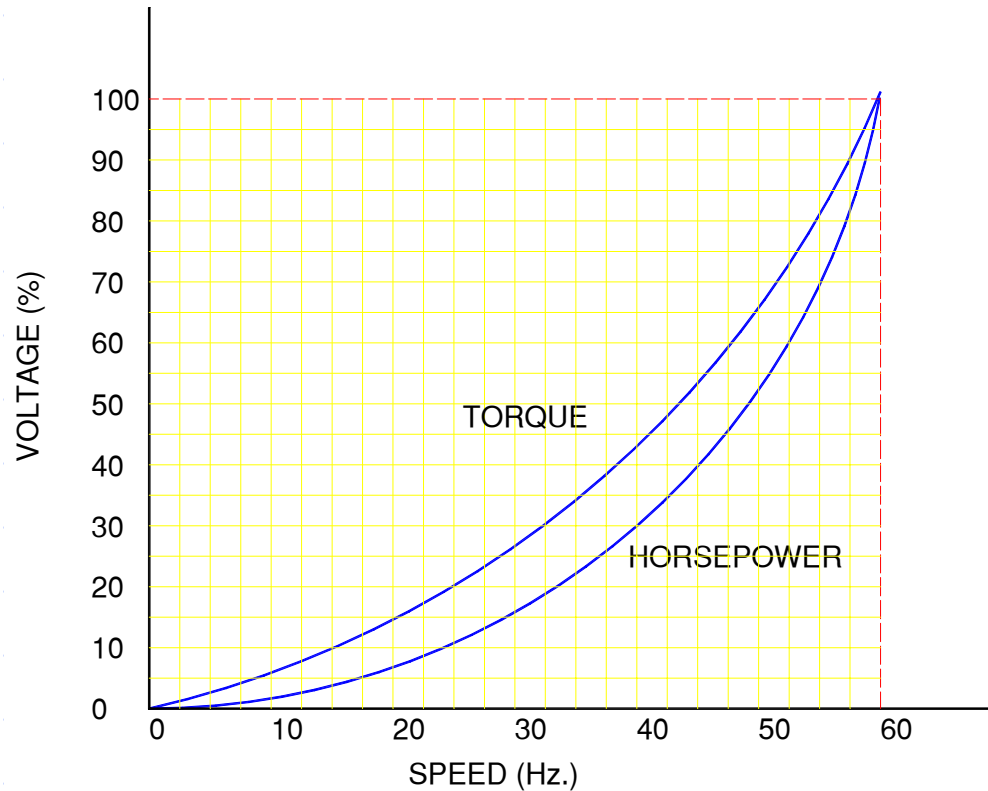
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Application Types

- ❖ Variable Torque
- ❖ Constant Torque
- ❖ Constant Horsepower



Variable Torque Curve



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Variable Torque

Affinity Laws:

- ❖ Flow is proportional to speed.

$$(\text{Flow}_1 / \text{Flow}_2) = (\text{RPM}_1) / (\text{RPM}_2)$$

- ❖ Pressure is proportional to the square of the speed.

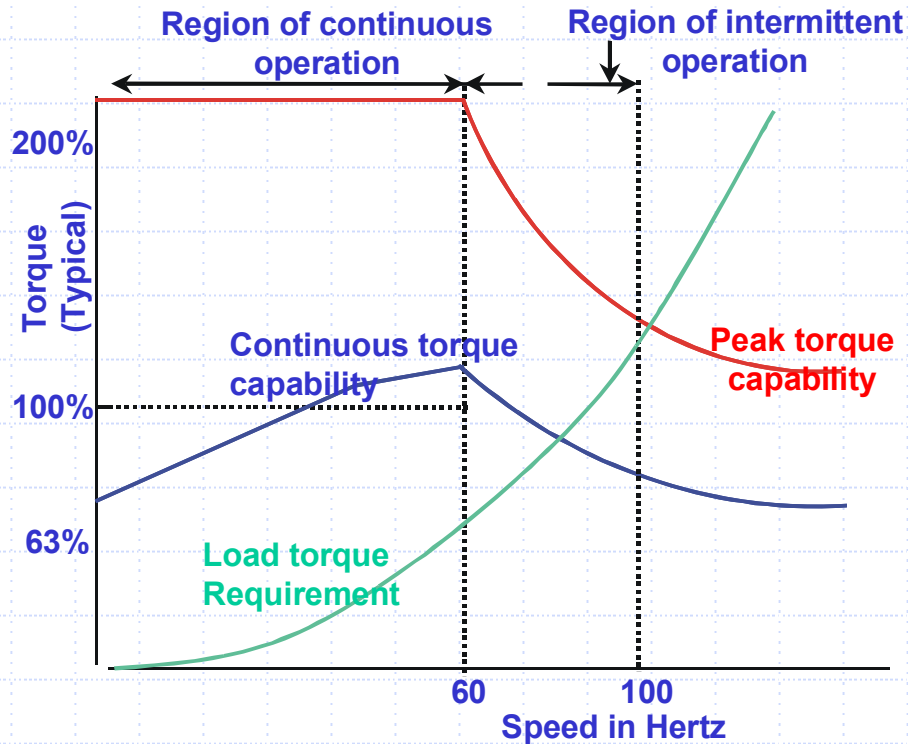
$$(\text{Press}_1 / \text{Press}_2) = (\text{RPM}_1)^2 / (\text{RPM}_2)^2$$

- ❖ HP is proportional to the cube of the speed.

$$(\text{HP}_1 / \text{HP}_2) = (\text{RPM}_1)^3 / (\text{RPM}_2)^3$$



Load Torque Proportional To The Square of Speed



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Variable Torque - Flow

Flow is proportional to speed.

$$(\text{Flow}_1 / \text{Flow}_2) = (\text{RPM}_1) / (\text{RPM}_2)$$

Flow Gallons/min	RPM		Second RPM		Second Flow
10000	1800		900		5000.00



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Variable Torque - Pressure

Pressure is proportional to the square of the speed.

$$(\text{Press}_1 / \text{Press}_2) = (\text{RPM}_1)^2 / (\text{RPM}_2)^2$$

Pressure Lb/sq. in	RPM		Second RPM		Second Pressure (lb/sq. in)
1000	1800		3600		4000



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Variable Torque – Horsepower

HP is proportional to the cube of the speed.

$$(HP_1 / HP_2) = (RPM_1)^3 / (RPM_2)^3$$

Horsepower	RPM	Second RPM	Second Horsepower
10	3450	3000	6.58



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Variable Torque Applications

Irrigation Water Pumps
Down-hole Water Pumps
Submersible Water Pumps
Domestic Water Pumps
Centrifugal Sewage
Treatment Pumps

Centrifugal Fans
Blowers
Air Handling Units
Chillers



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Constant Torque

- ❖ Torque remains constant up to the motor base speed.
- ❖ HP is proportional to the speed.



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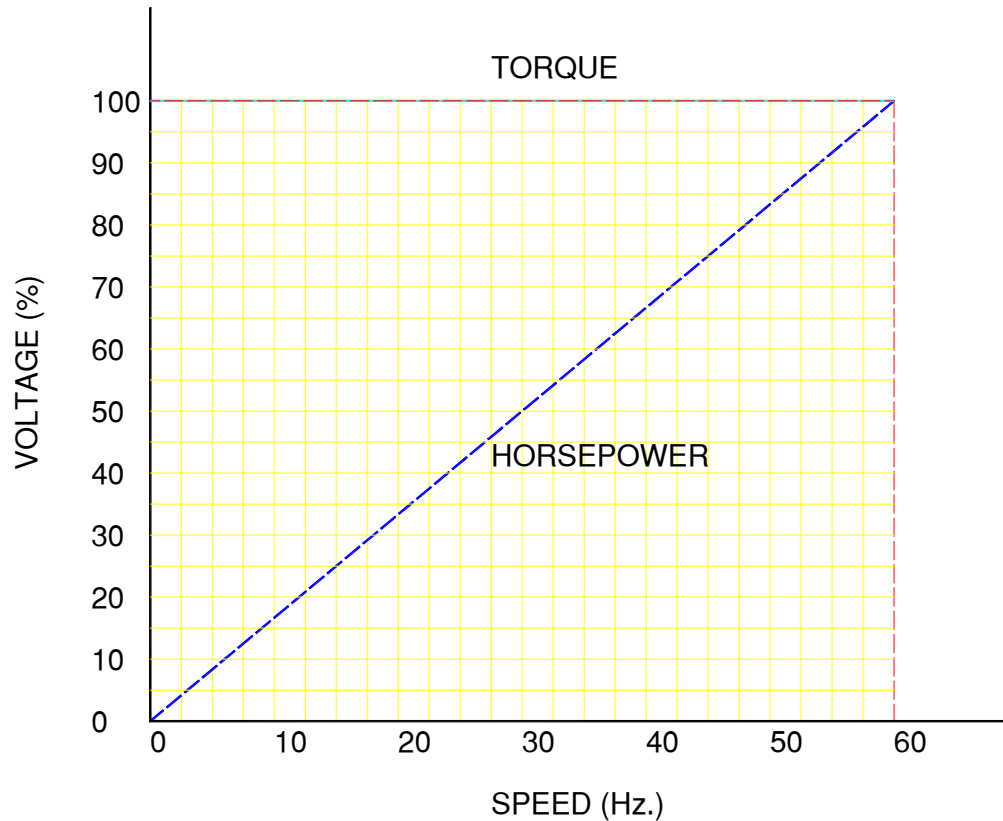
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Constant Torque Curve



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Constant Torque Applications

Conveyors
Compressors
Positive Displacement Pumps
Crushers
Mixers
Elevators
Escalators
Etc.



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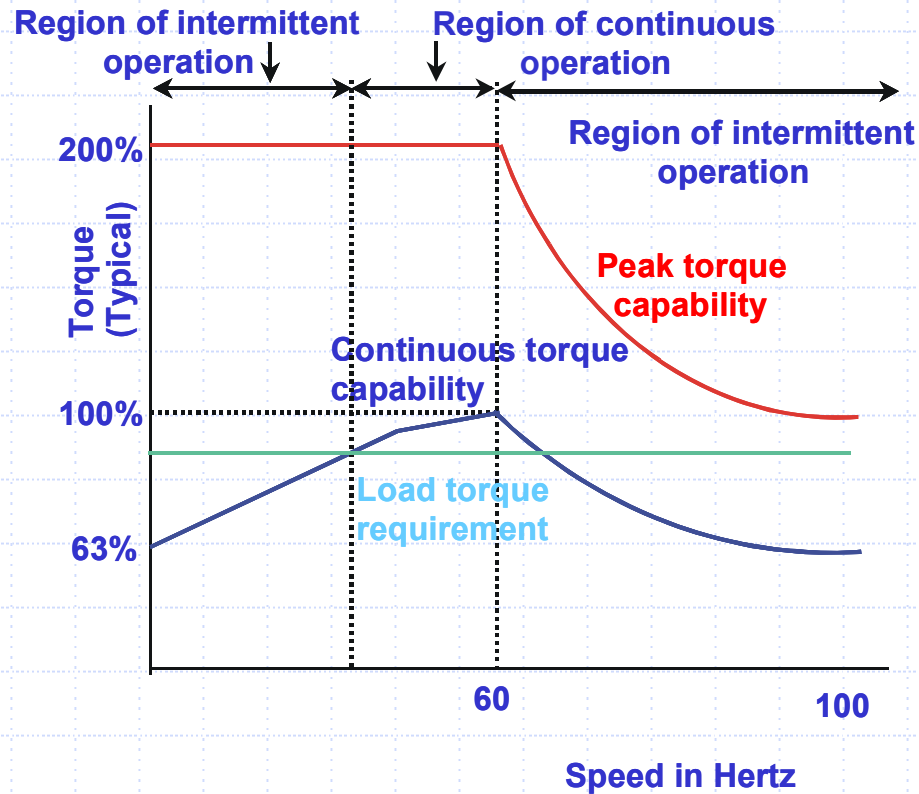
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Constant Torque Load



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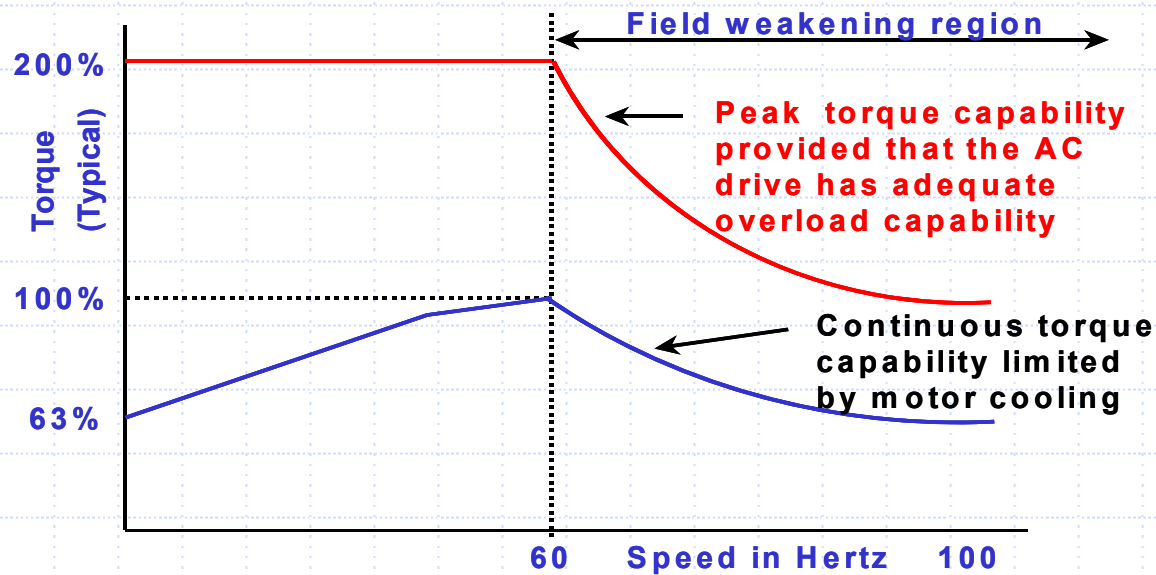
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Torque De-rating Due to Motor Cooling



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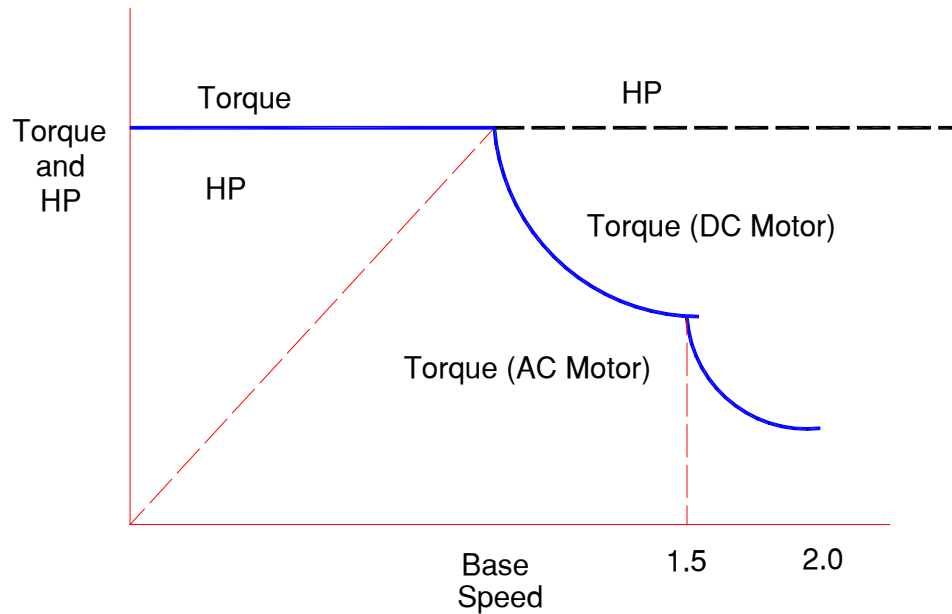
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Torque Curve Below & Above 60 Hz, Constant Torque V/F Ratio



Constant Torque Mode of Operation



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