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Fundamentals of Electricity



What you will Learn in this Lesson

- Definitions
- Ohms Law
- Power
- AC vs. DC current
- Single vs. 3 phase power
- Power factor
- Motor theory
- VFDs
- Harmonics

Definitions

- **Voltage (E)** – Practical unit of electrical pressure
 - Measured in Volts (V)
 - Pressure that will produce 1 amp of current flow against a 1 ohm resistance
 - It is the equivalent of the height of a water fall
- **Current (I)** – Movement of electrons through a conductor
 - Measured in Amperes (amps)
 - It is the equivalent of the amount of water flow over a water fall
- **Watt (W)** – Unit of real electric power
 - $1 \text{ Watt} = 1\text{V} \times 1\text{A}$
 - It is the equivalent of the work a river can do as the flow of water goes over a water fall
- **Resistance (R)** – Restriction of the flow of electrons through a conductor
 - Measured in Ohms (Ω)

Ohms Law

$$E = RI$$

$$E = W/I$$

$$E = (WR)^{1/2}$$

$$W = I^2R$$

$$W = E^2/R$$

- Basic relationship between volts, amps and resistance
- When considering electric circuits, ANY path from the path from the supply to the return will have the SAME voltage drop
- If one path as lower resistance, then more current WILL flow through that path until the voltage drop is the same for all paths

Power

$$W = EI \quad W = I^2R$$

$$W = E^2/R$$

- (Single Phase) power is the product of Volts x Amps
- Using Ohms Law, resistance can be substituted
- Watts can be converted to brake horse power by:

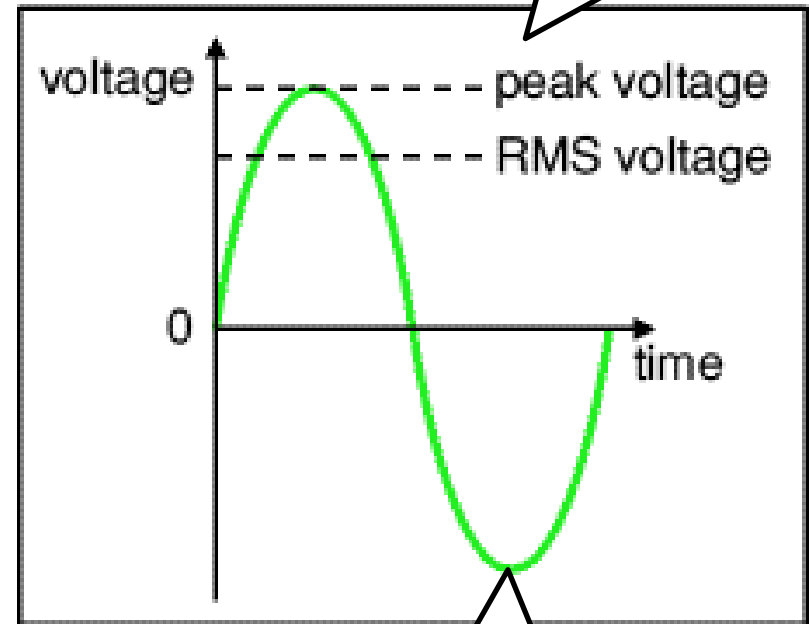
$$1 \text{ BHP} = 746 \text{ Watts}$$

Direct vs. Alternating Current

- Direct current (DC) flows in one direction through the circuit
 - Your car
- Alternating current (AC) flows first in one direction and then the other in a circuit
 - Pretty much everything in a building!
- It is easy to change alternating current and voltage up and down using a transformer which is why the building grid uses alternating current

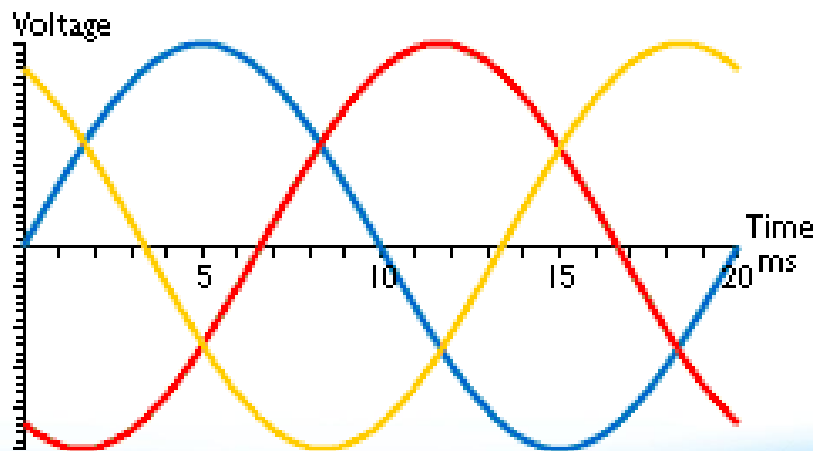
Alternating Current

- North America operates on a 60 Hz grid
- Most of the rest of the world operates on 50 Hz grid
- RMS (Root Mean Squared) is the “average voltage” or what the voltage would be if it were DC
- Note, as the voltage reverses, so does the current



Single vs. Three Phase AC Current

- **Single Phase** – A single continuous alternating current cycle
 - Typically used under 2 HP
- **Three Phase** - A continuous series of three overlapping AC cycles off set by 120 degrees
 - Typically used over 2 HP



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3 Phase (ϕ) Current

- It is possible to operate a motor with 3 “Hot” wires and no neutral!
- A motor will keep running on just 2 legs
 - Won't start
 - The current draw on the remaining 2 legs will have to increase to meet the load
- One leg of 460 volt 3 phase power is 265 volts
 - You will see 460 volts measured lead to lead
 - You will see 265 volts measured lead to neutral
 - You will see some single phase equipment design to operate on 265 volt such as WSHPs, fluorescent lighting, etc.

3 Phase Power

$$W_{3\phi} = 1.732 \cdot E \cdot I \cdot PF$$

- 3 phase power is the sum of the 3 legs
 - Each leg is changing with time so the average is found by using “1.732”
- Amperage is what is measured in any given leg
- Voltage is measured “leg to leg”
- PF = Power Factor

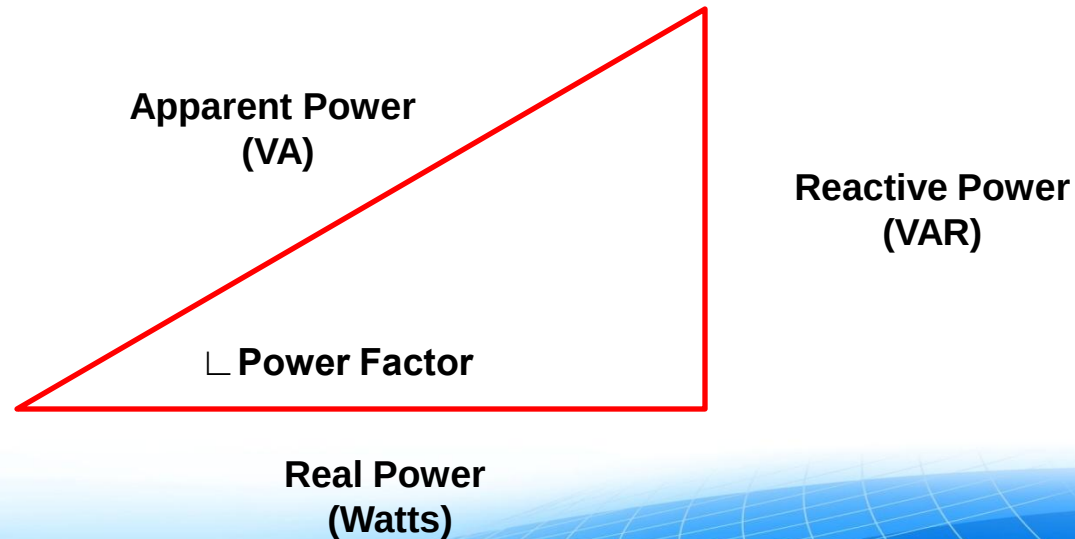
Power Factor

$$PF = W/VA$$

- **Power Factor (PF)** – The ratio of **Real Power (W)** to **Apparent Power (VA)**
 - Apparent power is calculated by volts times amps
 - Dimensionally same as watts
- If current and voltage are in phase
 - Apparent power = real power and $PF = 1$
 - No impact to 3 phase power
- However...

Power Factor

- Certain electrical devices will cause the current to **lead** or **lag** the voltage
 - Motors are an **inductive** load that causes current to lag
 - Some lighting ballasts are a **capacitive** load that causes current to lead voltage
 - The two wired in parallel can cancel each other out



Power Factor

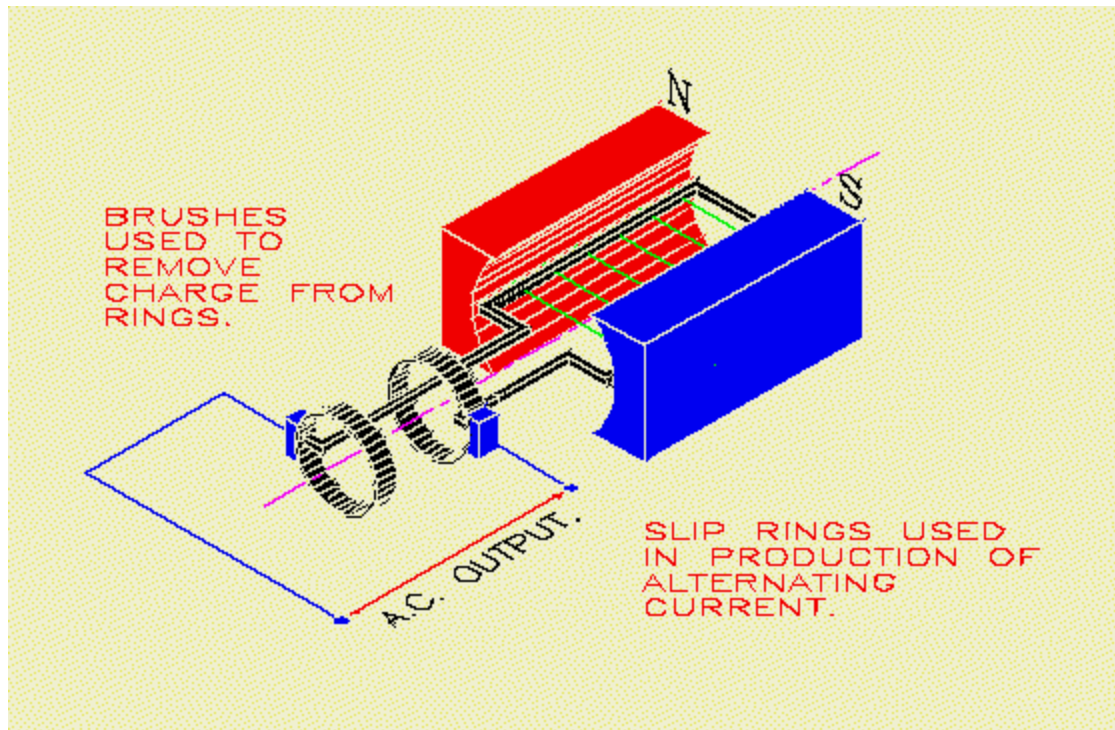
- Why do we care?
- Basically everything we sell has an inductive component to it
- The utility charges for the real power consumed (550 Watts)
- But the generating station and the transmission wires had to carry 647 VA of power to get the chiller to run
- This does not make the utility happy
- They get even by installing a power factor meter on the building and charging for a poor power factor

Power Factor Correction

- It is common for large motors (chillers typically) to have a spec requirement for “*unit shall have a minimum power factor of 0.90...*”
- Manufacturers can tell you what the PF of the equipment is
 - You need to check this
 - If it does not meet spec, you will need PF correction
 - This is done by adding capacitors
- Capacitor manufacturers have selection process to size capacitors based on what your current full load PF is and where you need to be.
- Some equipment manufacturers include PF correction as an option

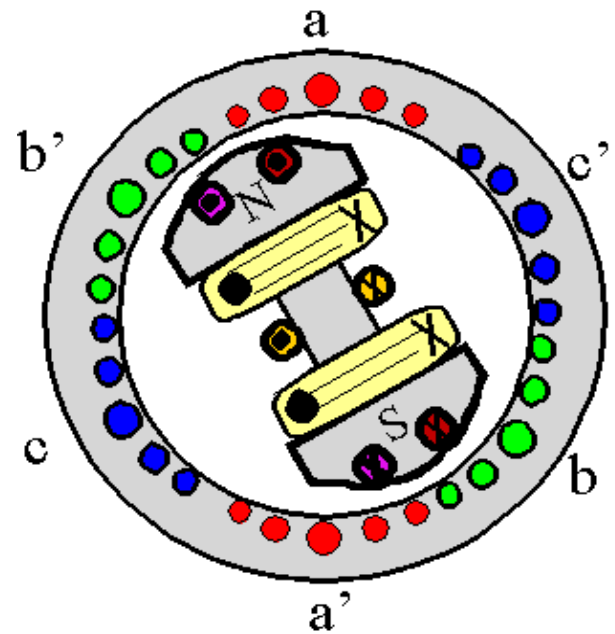
Motor Theory

- Motors are based on electromagnetism
- As current alternates direction, the magnetic poles reverse and the rotor is attracted to the next stator magnet



Induction Motor

- Industry work horse motor
- 3 phase
- Can be 90+ efficient at full load
- Nominal rpm based on frequency and number of poles
- Asynchronous
 - As load increases, motor rpm “slips”
 - Slippage provides the torque



Induction Motors

$$\text{Synchronous Speed (srpm)} = (120 \cdot f) / p$$

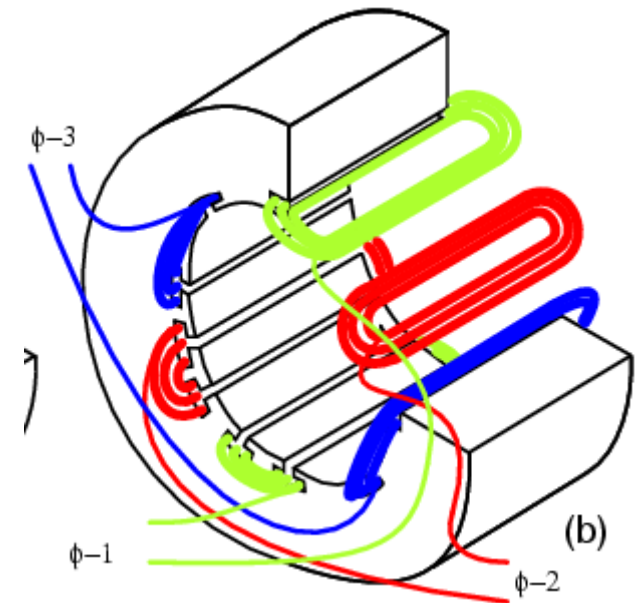
Where

f = frequency (60 Hz in North America)

p = Number of poles typically 2, 4, 6 or 8

Induction Motor Operation - Stator

- Image is a 2 pole, 3 phase induction stator
- As alternating current is introduced to stator windings
- A rotating magnetic field is created
- In the space where the rotor is, the magnetic field flux is constantly changing

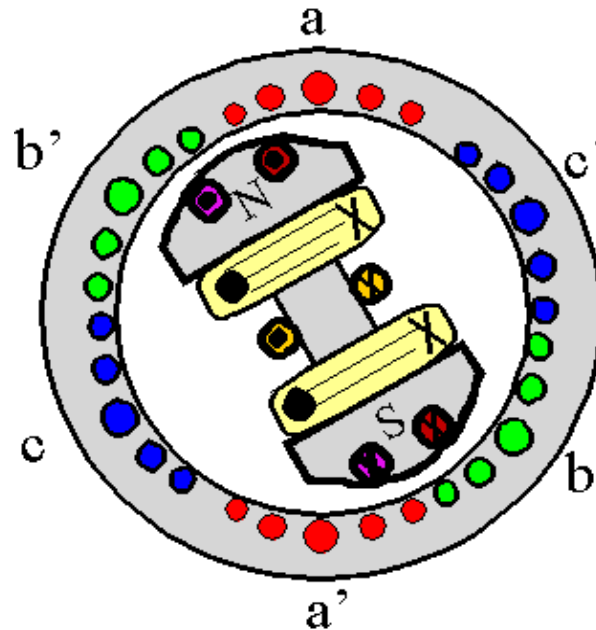


Induction Motor Operation - Rotor

- Rotor has steel bars running parallel to shaft
- As stator magnetic field cuts through steel bars
 - Current starts to flow back and forth along bars
 - Current then creates its own magnetic field

Induction Motor Operation

- Once there is a magnetic force created in rotor, the rotor “chases” the rotating field in the stator



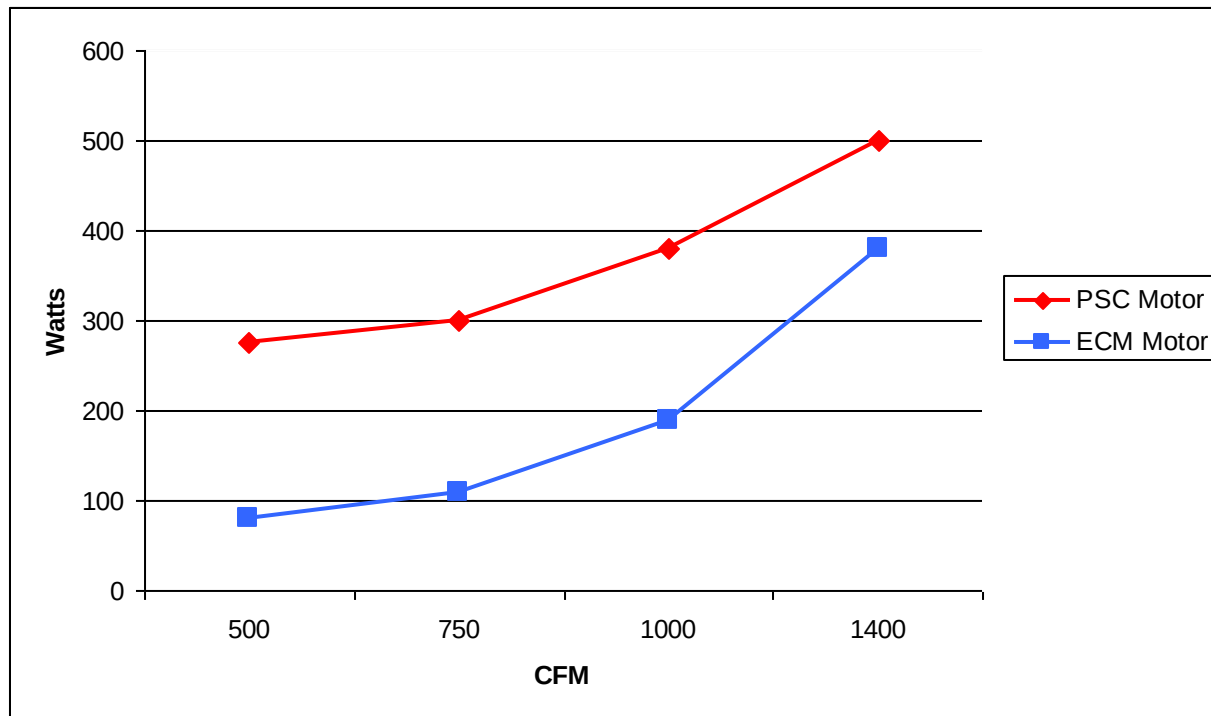
Other Motor Types

- Single phase inductions motors can be
 - Shaded pole
 - Permanent Split Capacitor (PSC) type
- Permanent Magnet Synchronous motors (PMSM)
 - Replace rotor with permanent magnet
 - Synchronous (no slippage)
 - Very efficient over full operating range
- Electronically Commutated Motor (ECM)
 - Single phase PMSM type

What is an Electronically Commutated Motor?

- Made popular by GE
 - GE sold (2004) to Regal Beloit
 - Licensed to sell under GE brand
 - Started rebranding as Genteq (2009)
- Many manufacturers build ECM motors
 - Emerson, Panasonic etc
- Typically replace Permanent Split Capacitor motors
- Brushless DC Motor Technology
- Typically Fractional HP, single phase

Advantage 1 - Efficiency



Advantage 1 - Efficiency

PSC Motor

- 55-65% Max efficiency
- Can drop to 15-20% @ minimum rpm
- Can use as much energy at part load as at full load!
- Minimum speed ~ 600 rpm

ECM Motor

- 80%+ efficiency
- 60%+ efficiency down to 400 rpm @ 10% load
- Minimum speed ~ 200 rpm

Advantage 2 - ECM Motor Characteristics

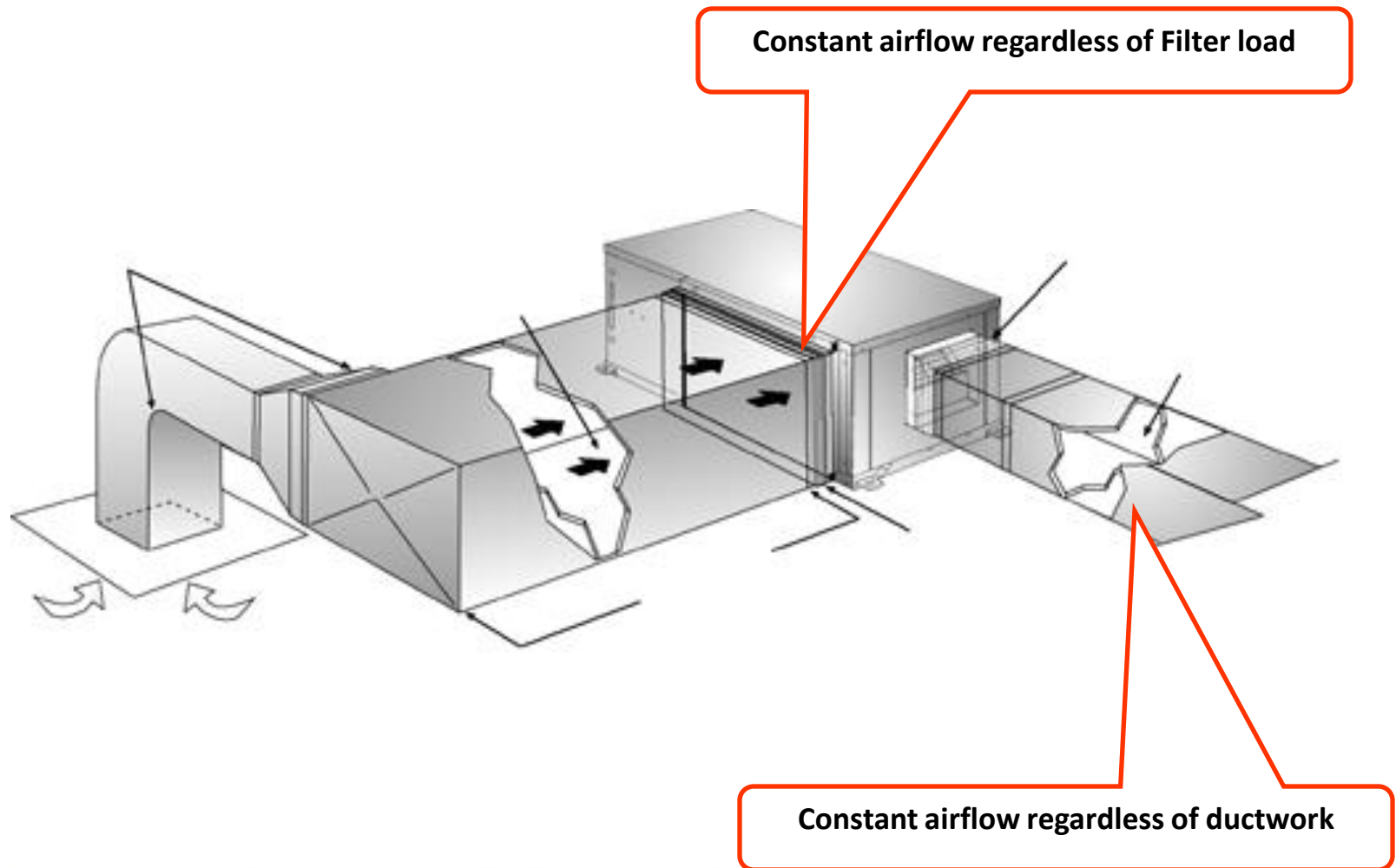
Programmable Characteristics

- Rotation direction
- Start/stop ramp rates
- On/off blower delays
- Speed (rpm)
 - Multiple settings, preprogrammed by OEM
- Torque

Advantage 2 - ECM Motor and Static Pressure

- It is possible to program multiple ***airflow*** settings regardless of static pressure!
 - Don't need any other sensors
 - Works up to about 1 in. W.C.
 - Done by OEM
 - 5% airflow
- Can use FC controller to deliver different CFMs

Advantage 2 - ECM Motor and Static Pressure



A Few Things About Motors...

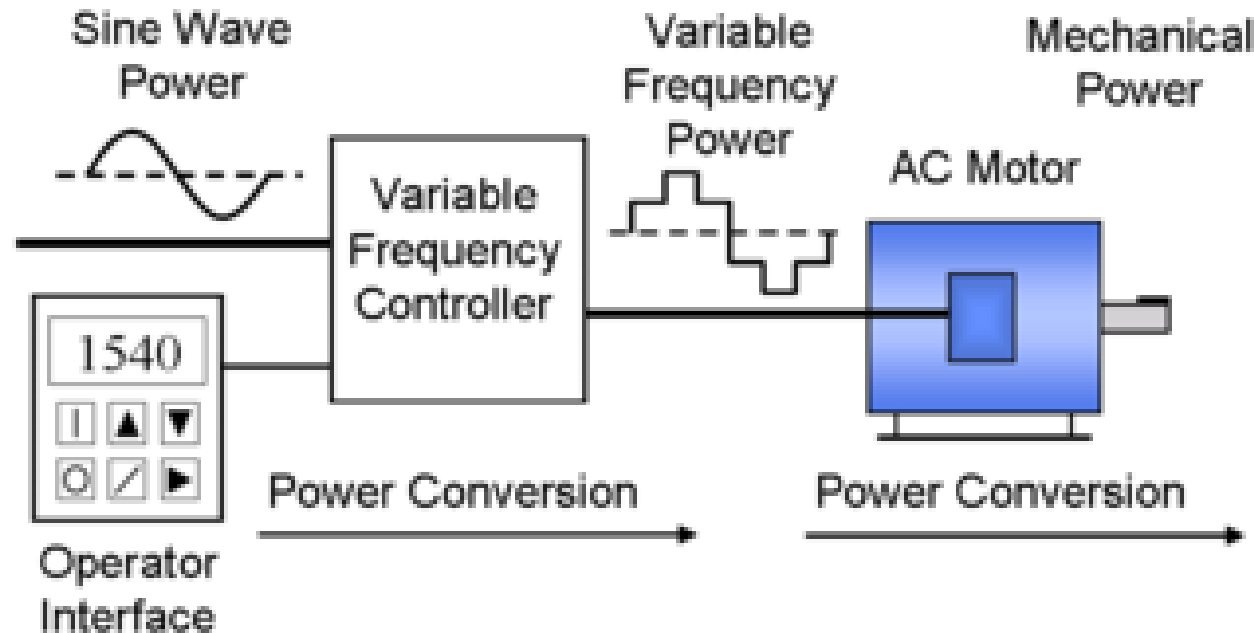
- A “10 HP” motor does not do 10 HP of work
 - It does whatever you ask of it
 - If there is a 5 hp load, it will do 5 hp and draw the current required to do the work
 - However, if there is 12 hp load, it will (try) and do the work and will draw the current required to do the work
 - This will end badly for the motor so protection is used (Circuit Breakers and thermal overloads)
- Motor efficiencies are given at full load
 - They drop off at part load
 - Using a 20 hp motor for a 4 hp load is worse than using a 5 hp motor for a 4 hp load

Variable Frequency Drives (VFDs)

$$\text{Synchronous Speed (srpm)} = (120 \cdot f) / p$$

- Motors cannot change speed
- HVAC loads are constantly changing so speed control is critical to good operation
- A VFD can change the ***frequency*** so the motor will operate at different speeds

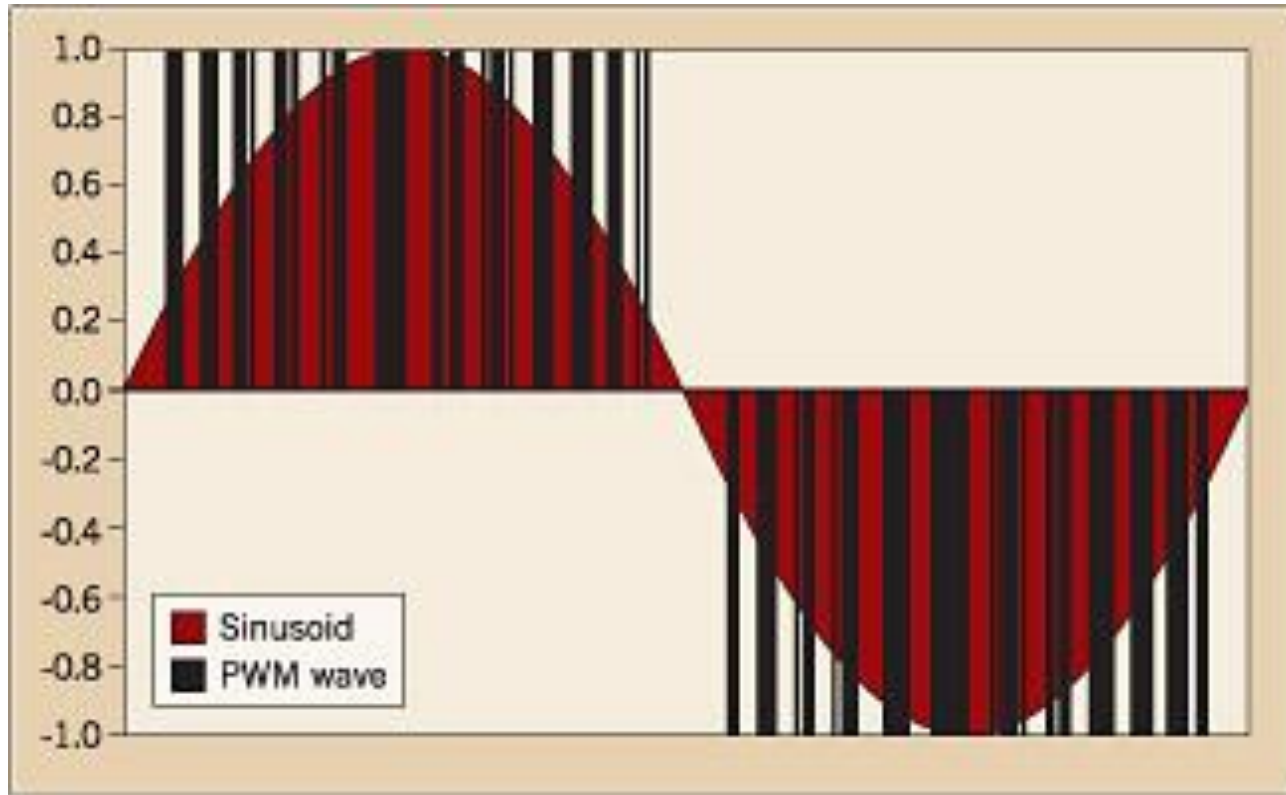
Variable Frequency Drives



- VFDs convert AC power to DC (Rectifier)
- Use Pulse Width Modulation (PWM) to create a square shaped wave at the desired frequency
- Use Insulated Gate Bipolar Transistor (IGBT)

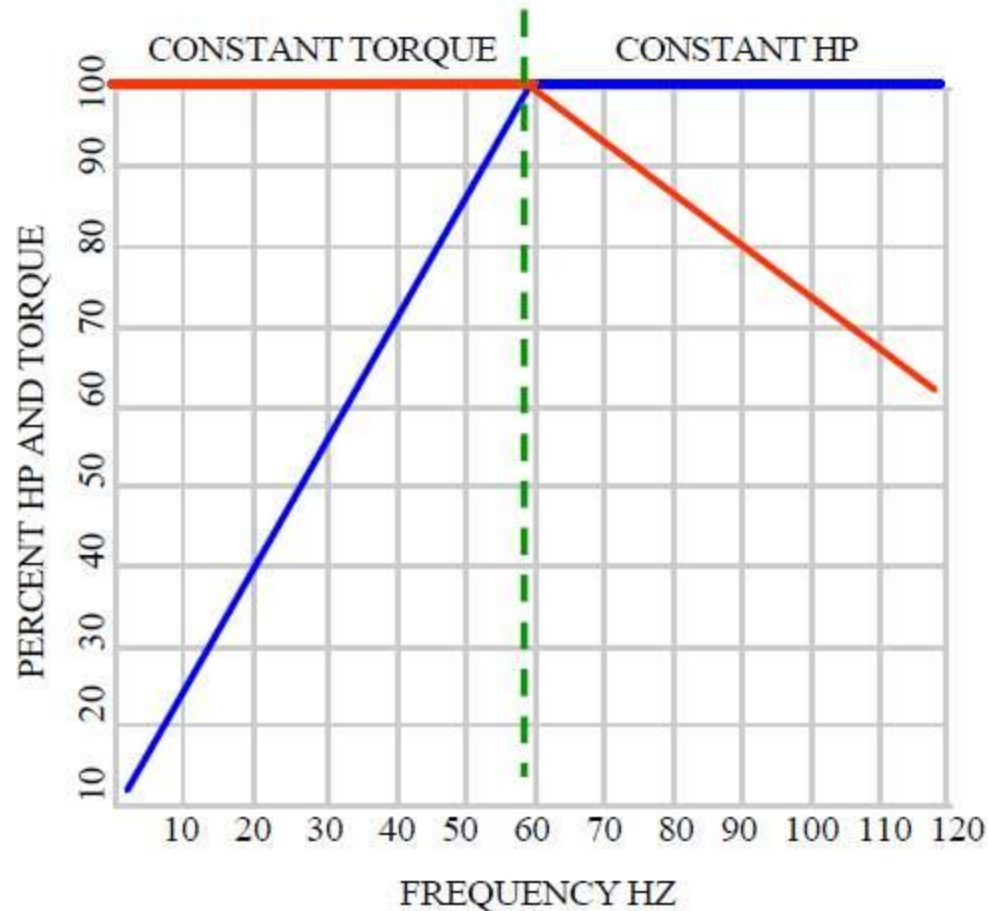
Variable Frequency Drives

Pulse Width Modulation - Theory



VFDs and Speed

- Typically the voltage to frequency ratio is constant
 - Voltage drops at low frequency
 - Torque remains constant
 - Power drops!
- Most HVAC loads drop as the speed is reduced
- Over-speeding a motors is possible but will not increase motor power rating



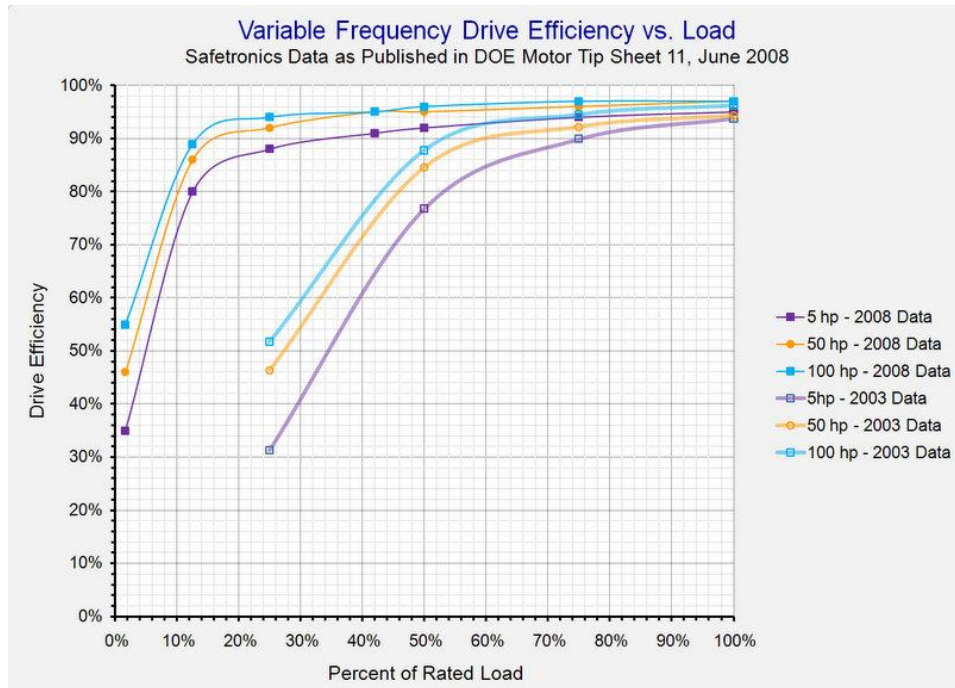
Red = Torque

Blue = HP

Green = Nominal Frequency

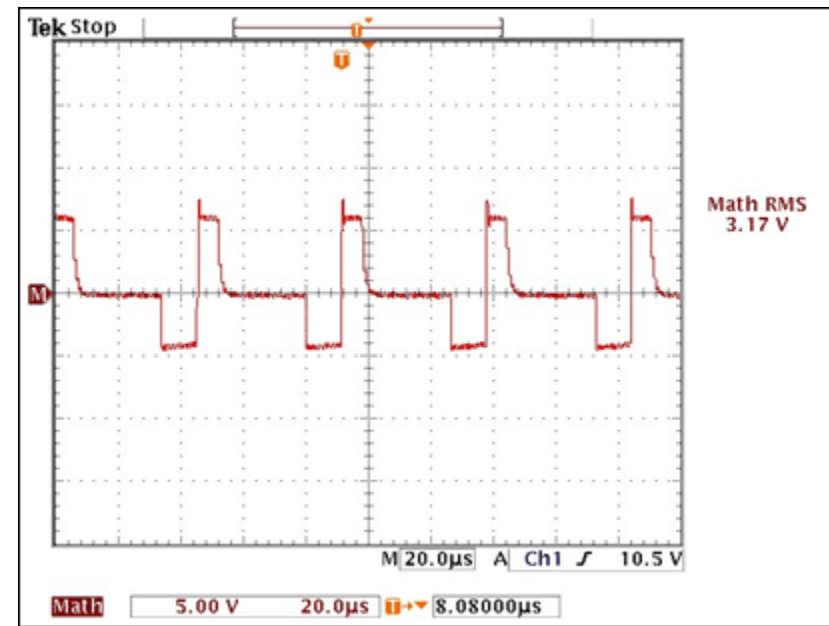
VFDs and Efficiency

- VFDs consume about 2% of rated power
- They lower the efficiency of the product they are used on at full load
- They maintain their efficiency for most of their operating range
- (Not so for an induction motor!)



Voltage Spikes

- The voltage spikes as the IGBT closes are problematic
- They can cause a spark anywhere the motor insulation goes to ground (bearings) and cause pitting
- Long leads between the VFD and motor should be avoided to minimize this effect

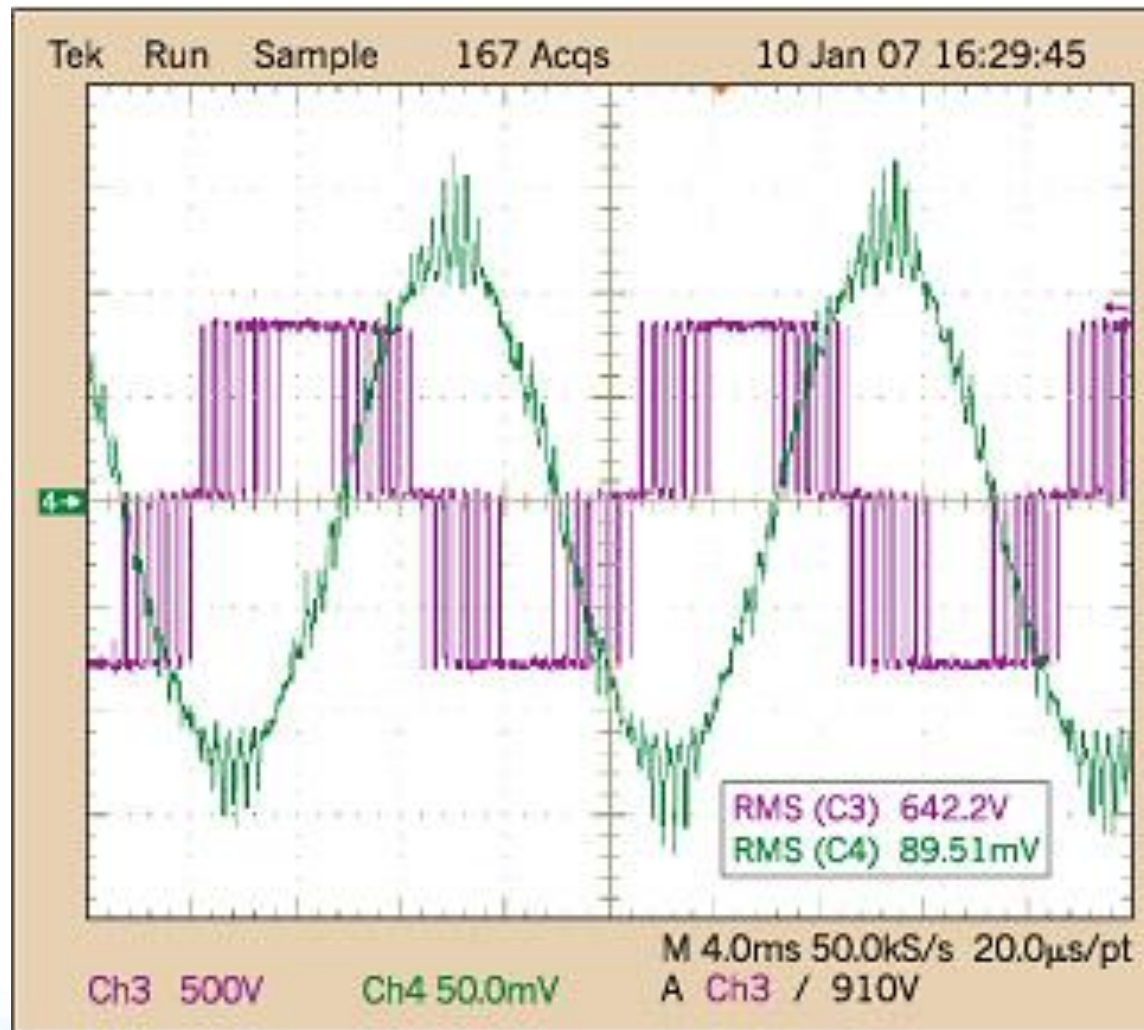


A Few Things about VFDs...

- They are common under 150 hp and 575 volts
- 4160 volts units are industrial and are just coming into our industry (big chillers)
- The control system will communicate with the VFD either digitally or by a common analog signal to set the speed
- VFDs have near unity power factor regardless of motor
- VFDs can be acoustically noisy at low frequencies
- VFDs cause ***harmonics***

Harmonics

Pulse Width Modulation - Real



Harmonics

- Harmonics are high frequency noise on the power distribution system
- Harmonics are caused by non linear loads or where current is drawn in abrupt short bursts (VFDs, UPS systems etc.)
- Harmonics can disrupt communications and affect electric grid performance
- Utility will hold building owner responsible to maintain harmonics at the connection point
 - IEEE 519
- Harmonics can be resolved by
 - Isolation transformer
 - Harmonic traps
 - Line reactors

End of Lesson

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