Electric Motors: Best Practices

Improving Efficiency, Drive Issues & Preventive Maintenance

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SES SUSTAINABLE ENERGY SERVICES
Real • Objective • Results

What We Will Cover Today

- Motor Management – Why Bother?
- Motor Basics
- VFD Basics
- VFD + Motor Together
- Issues with VFD + Motor
- Design Considerations
- Troubleshooting
- Motor Management
- Preventive Maintenance
- Rebates

Why Bother?

- Motors consume 65% of industrial power and 30% to 50% of commercial power
  - That's 23% of power generation in U.S.
- It costs about $90 Billion each year to run motor driven systems
- Motors cause U.S. businesses $ Billions each year in wasted energy
- Running a motor can cost more than 10 times its purchase price each year
- Over life of typical motor, 98%+ of cost of ownership is operating cost

If owning a car was like owning a motor

- Purchase price = $30,000
- Annual operating cost = $500,000
- Operating cost over life of car = $4,000,000

What would You be willing to do
to make your car run more efficiently?

How important is purchase price now?

What it costs to run a motor

- Rating = 100HP
- Hours of Operation = 7,400
- Cost per kWh = $0.09
- Demand kW = $7
- Purchase Price = $4,200
- Load Factor = 90%
- Motor Eff. = 94%

$$Annual\ Cost = \overbrace{\frac{100\ x\ .746\ x\ 7400\ x\ .9\ x\ .09}{.94}}^{\text{kWh}} + \overbrace{\frac{100\ x\ .746\ x\ .9\ x\ 7\ x\ 12}{.94}}^{\text{kW}}$$

Annual Energy Costs = $47,569 + $6,000 = $53,569

Purchase Price = $4,200

Then must add maintenance costs!

... AND THIS IS A NEMA PREMIUM EFFICIENT MOTOR!

Changing a Standard Efficiency Motor to Premium Efficiency

$$kWSaved = \frac{HP\ x\ 0.746\ x\ LF}{Eff_{std}} - \frac{HP\ x\ 0.746\ x\ LF}{Eff_{EE}}$$

$$kWh\ Saved = kW\ x\ Oper.Hours$$

$$\$\ Saved = kWh\ x\ cost/kWh + kW\ x\ cost/kW\ x\ 12$$

Changing a Standard Efficiency Motor to Premium Efficiency

- Rating = 100HP
- Hours of Operation = 7400
- Cost per kWh = $0.09
- Demand kW = $7
- Purchase Price = $4,200
- Load Factor = 90%

$$kW = \frac{100\ x\ .746\ x\ .9}{.83} - \frac{100\ x\ .746\ x\ .9}{.94} = 9.6\ kW$$

$$kWh = 9.6\ kW\ x\ 7400 = 71{,}040\ kWh$$

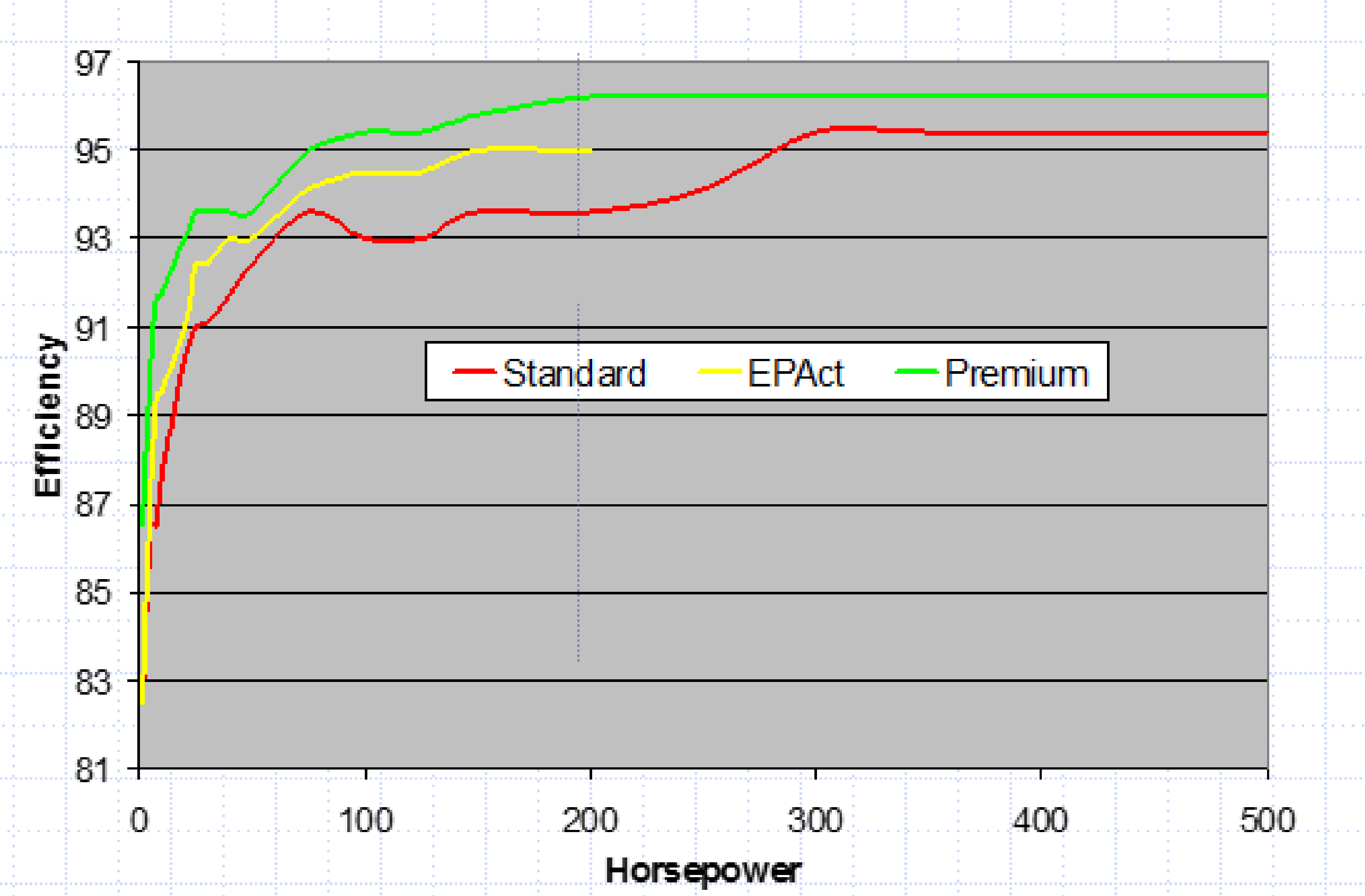
$$Cost\ Savings = (71{,}040\ x\ .09) + (9.6\ x\ 7\ x\ 12) = \$7{,}200/year$$

MOTOR BASICS

Motor Basics

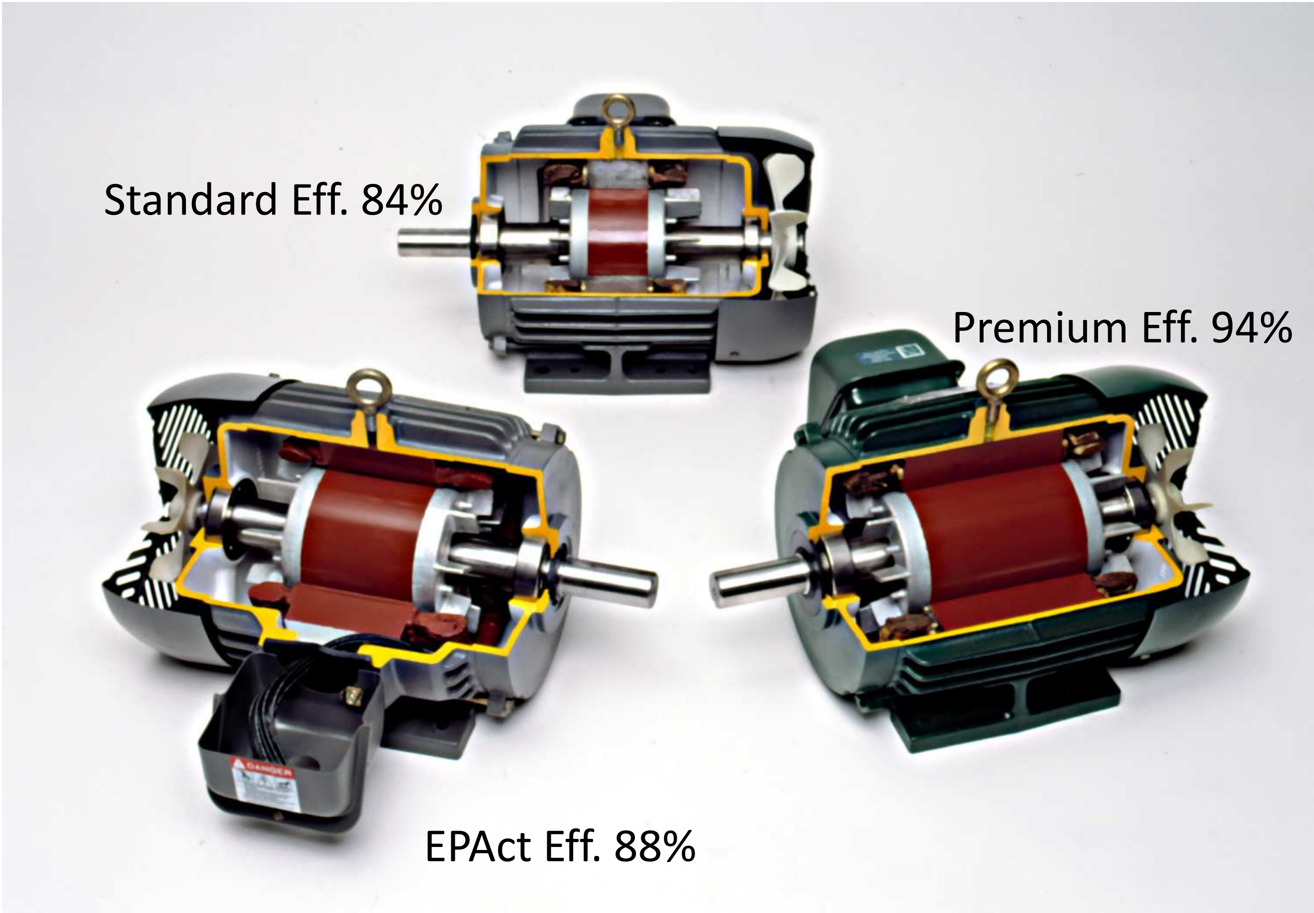
- Standard Efficiency
  - Most motors today where installed before 1997
  - Typical efficiency is 83% to 90%
- EPAct Motors
  - Energy Policy Act of 1992
  - Effective October 1997
  - Typical efficiency is 87% to 92%
- NEMA Premium Motors
  - Energy Independence and Security Act 2007
  - Effective December 2010
  - Typical efficiency is 91% to 95%
- DOE Extending Range for Premium Efficiency Motors with Effectivity June 2016
  - New rule adds NEMA - A, B, C and IEC - N, H plus specials in 1HP to 500HP
  - Applies to 5 million units vs 1.6 – 2 million units currently
  - Current rule affects 18 million connected HP; new rule affects 50 million HP

Motor Basics



Differences in Motor Construction

10 HP, 1200 RPM



Inverter Grade Motors

- NEMA Premium Efficiency features plus
- Beginning and ending of windings are separated
- Extra insulation to protect against voltage spikes
- Wound with inverter grade magnet wire (for voltage spikes)
- Designed to handle higher frequency components
- Either rated for higher temperatures or constant speed cooling fan on auxiliary power for low speeds
- Will provide full-rated torque at zero speed and well past base speed

Induction Motors

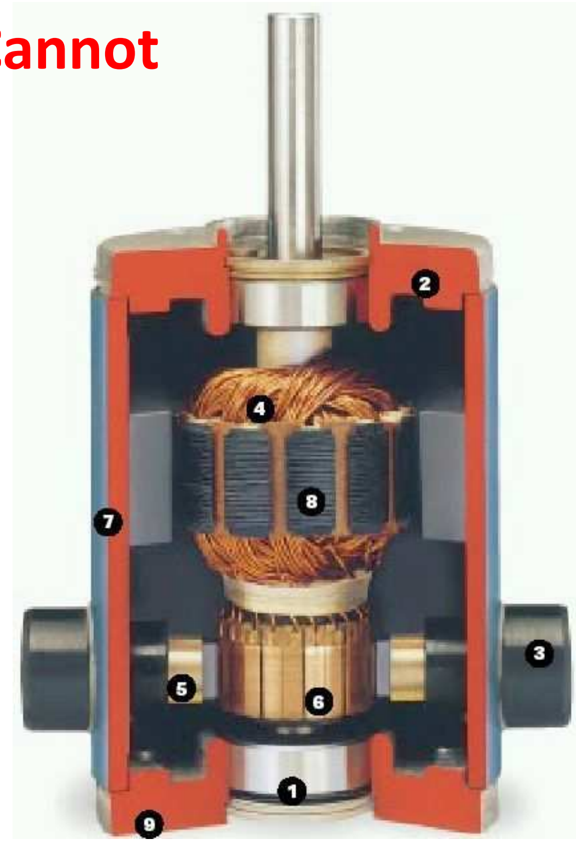
- Inexpensive
- Widely available
- No expensive permanent magnets
- Covers most applications
- Rotor slip losses

Permanent Magnet Motors

Requires VFD to Operate

- High efficiency
- High torque
- High speed
- Requires expensive permanent magnets
- Requires permanent excitation

Needs Redundant VFD Bypass – Cannot Run on 60Hz



Switched Reluctance Motors

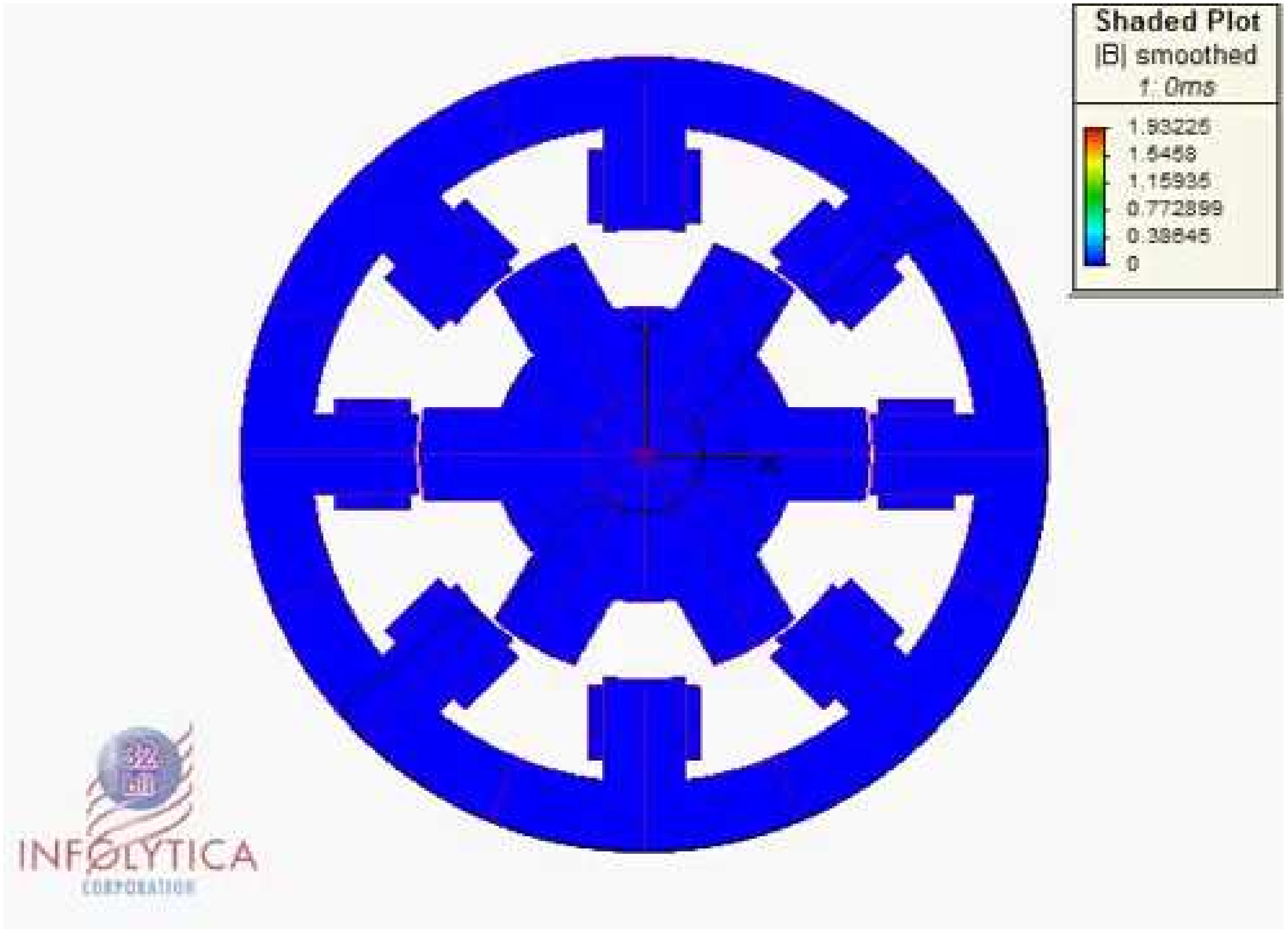
Requires VFD to Operate

Needs Redundant VFD Bypass – Cannot Run on 60Hz

- High efficiency
- High torque from zero to 100%+
- High speeds
- No expensive permanent magnets
- Noisy
- Higher torque ripple
- Rotor core loss
- High fundamental frequency
- Multi-lead connection

Switched Reluctance Motor

Requires VFD to Operate



Electrically Commutated Motor

- High efficiency
- Rotor losses almost zero
- Inherent variable speed
- Usually 1.0HP and less
- Expensive
- Permanent magnet
- Easy to control
- Favored in HVAC apps

True Load - Slip

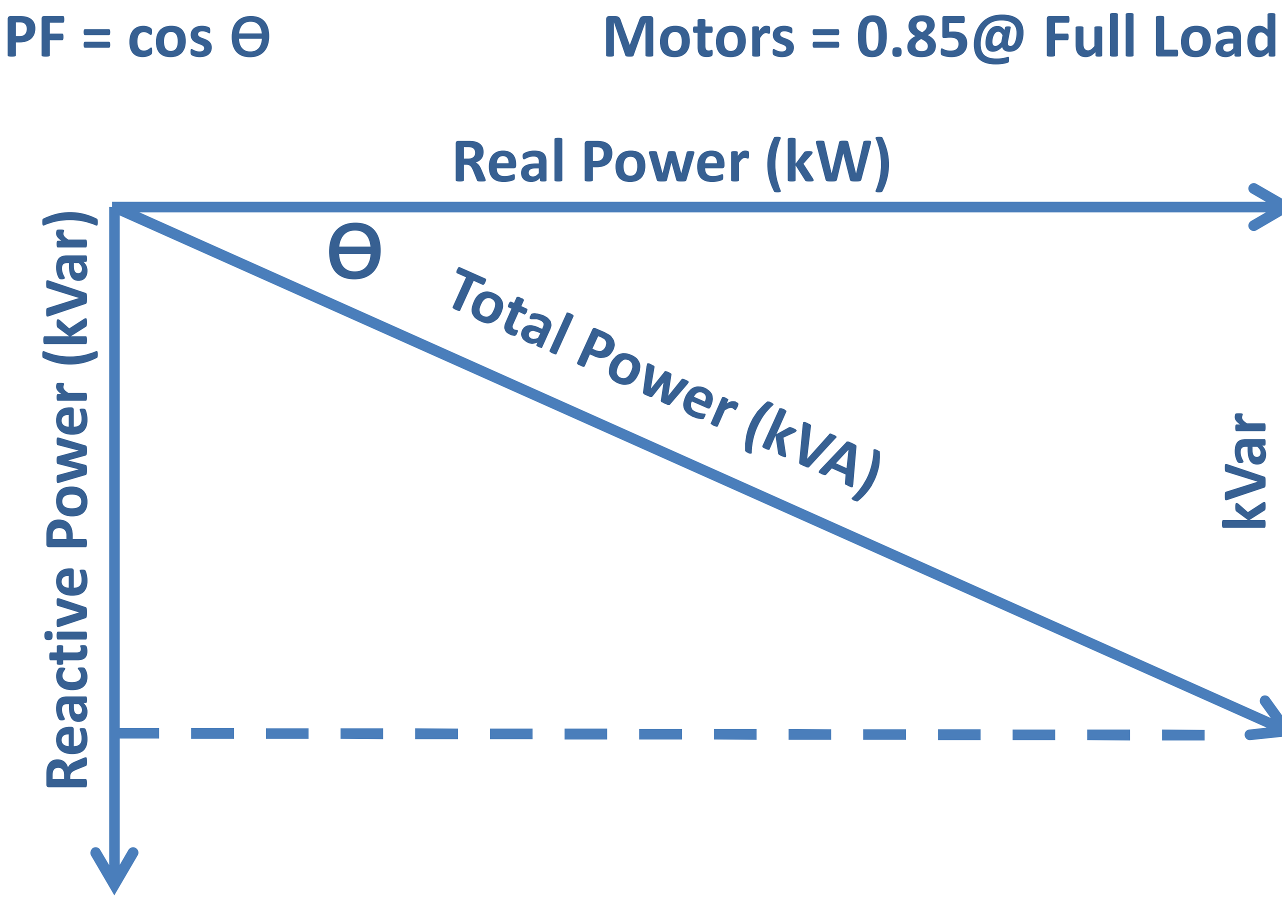
- Speed (RPM) = (60 Hz X 60 sec/min) / Number of pole pairs
- RPM = 3600, 1800, 1200, 900, 720..... no other choices
- NLRPM = No Load RPM = 3600, 1800, 1200, 900, 720....
- FLRPM = Full Load RPM (this is on nameplate)
- Measured RPM (use tach or meas. current -> motor curve)
- Design Slip = NLRPM – FLRPM
- True Slip = NLRPM – Measured RPM
- % Load = True Slip / Design Slip
- True Load = % Load X nameplate HP

True Load Example - Slip

- Nameplate
  - FLRPM = 3555
  - HP = 75
- NLRPM = 3600 (obviously!)
- Measured RPM = 3576
- Design Slip = 3600 – 3555 = 45
- True Slip = 3600 – 3576 = 24
- % Load = 24 / 45 = 53.3%
- True Load = 53.3% X 75 = 40 HP

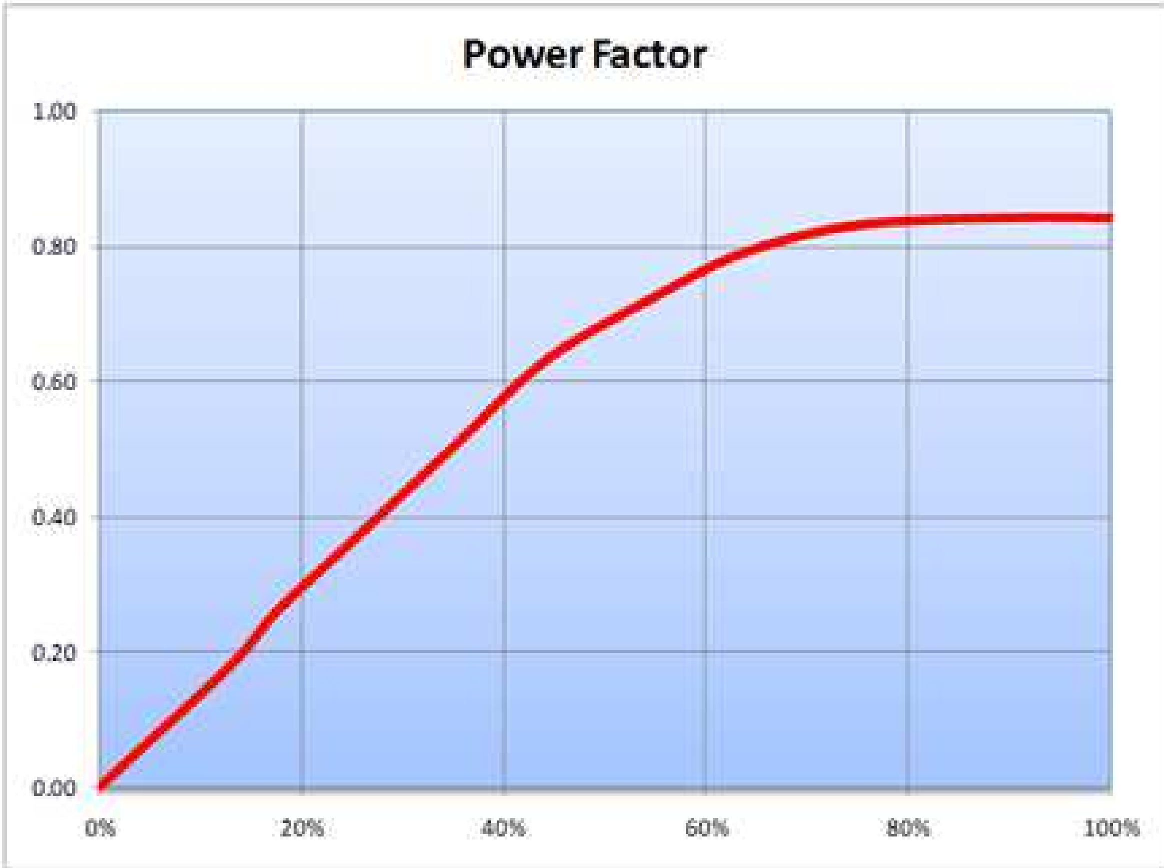
Motor Efficiency vs. Load

Power Factor



Power Factor vs. Load

PF



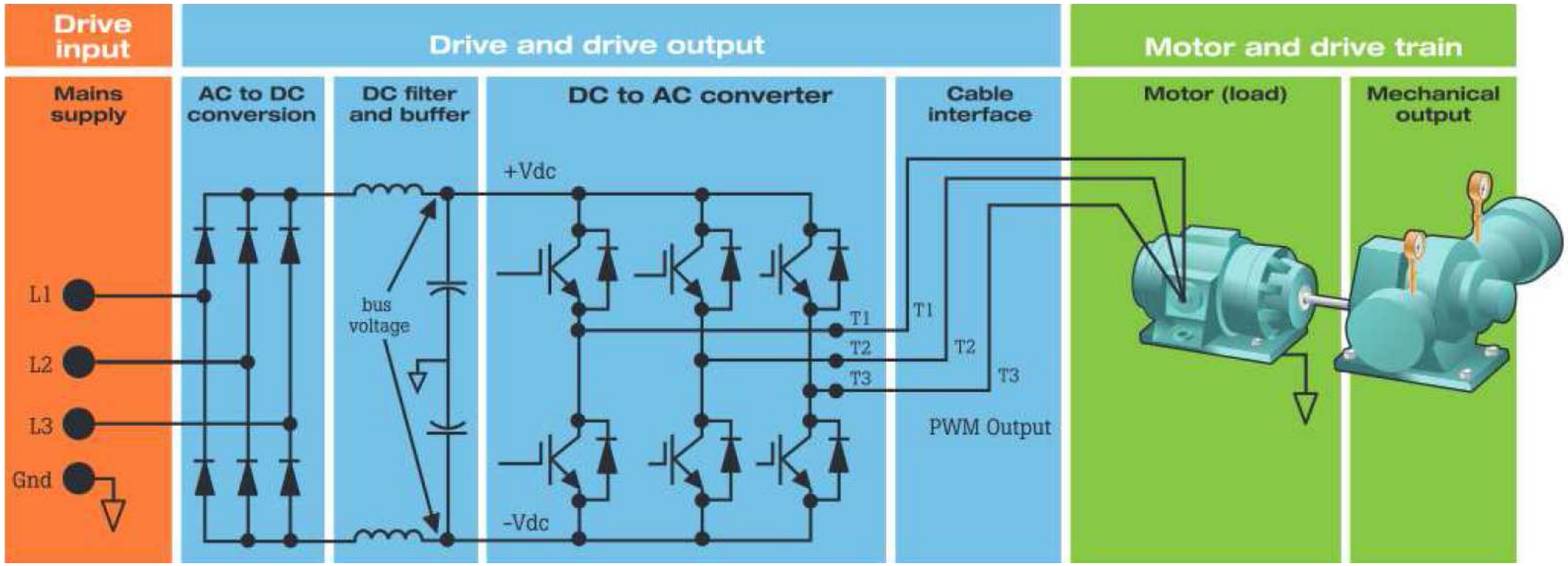
Load

VFD BASICS

Variable Frequency Drives

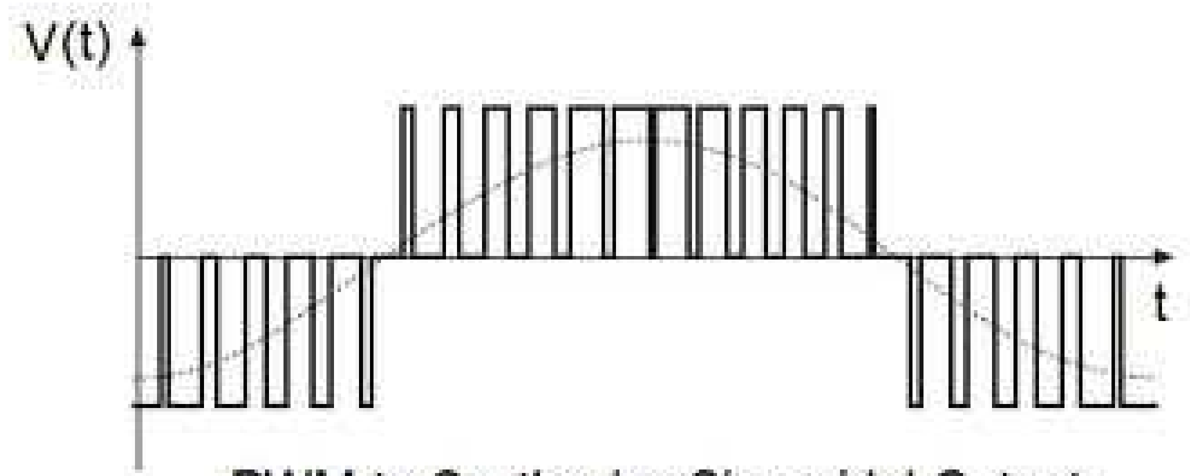
- Ideal for variable load/variable speed application
- Less ideal for constant load/speed applications
- Inherent soft start (extends motor life)
- Unity Power Factor at all loads
- Same variable speed & fast torque of DC motors, but less expensive and much more reliable
- Drive adds heat and stress to motor so inverter grade motors are best
- Drive makes motor less efficient at or near full load when compared to running motor without VFD

Motor/VFD – Envision as 3 Segments



This helps to clarify what measurements
and troubleshooting steps need to be taken

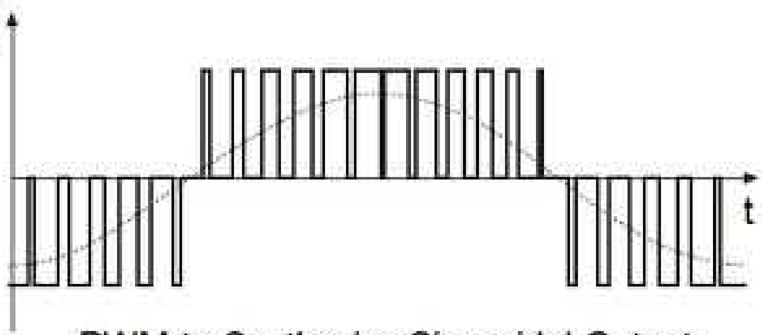
VFD Output Voltage – PWM



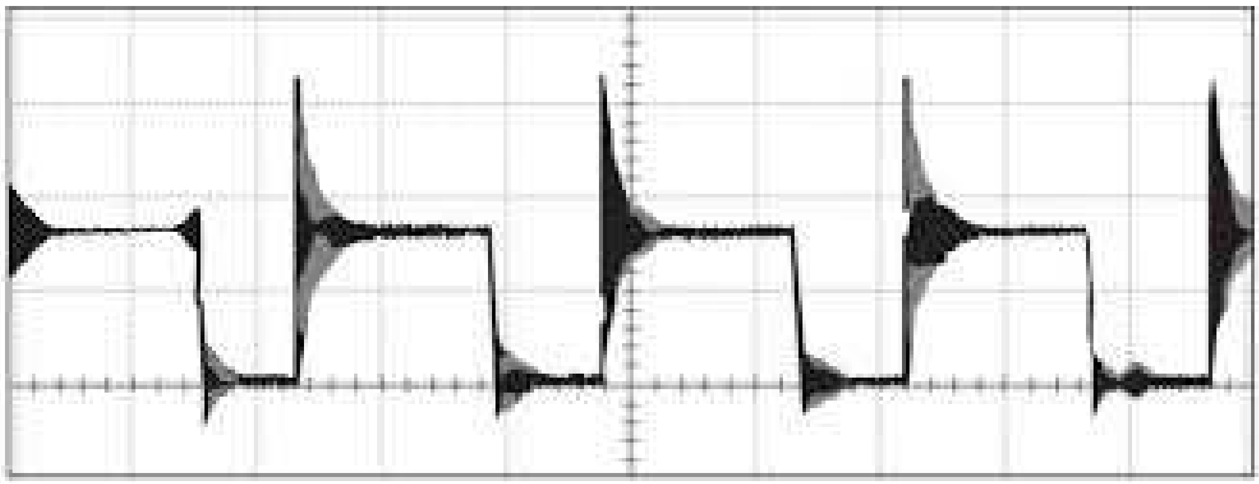
PWM to Synthesize Sinusoidal Output

VFD & MOTOR TOGETHER

VFD Output Voltage – Reflected Wave



PWM to Synthesize Sinusoidal Output



Rapid dV/dT !!!

VFD Output Voltage – Corona Inception Voltage (CIV)

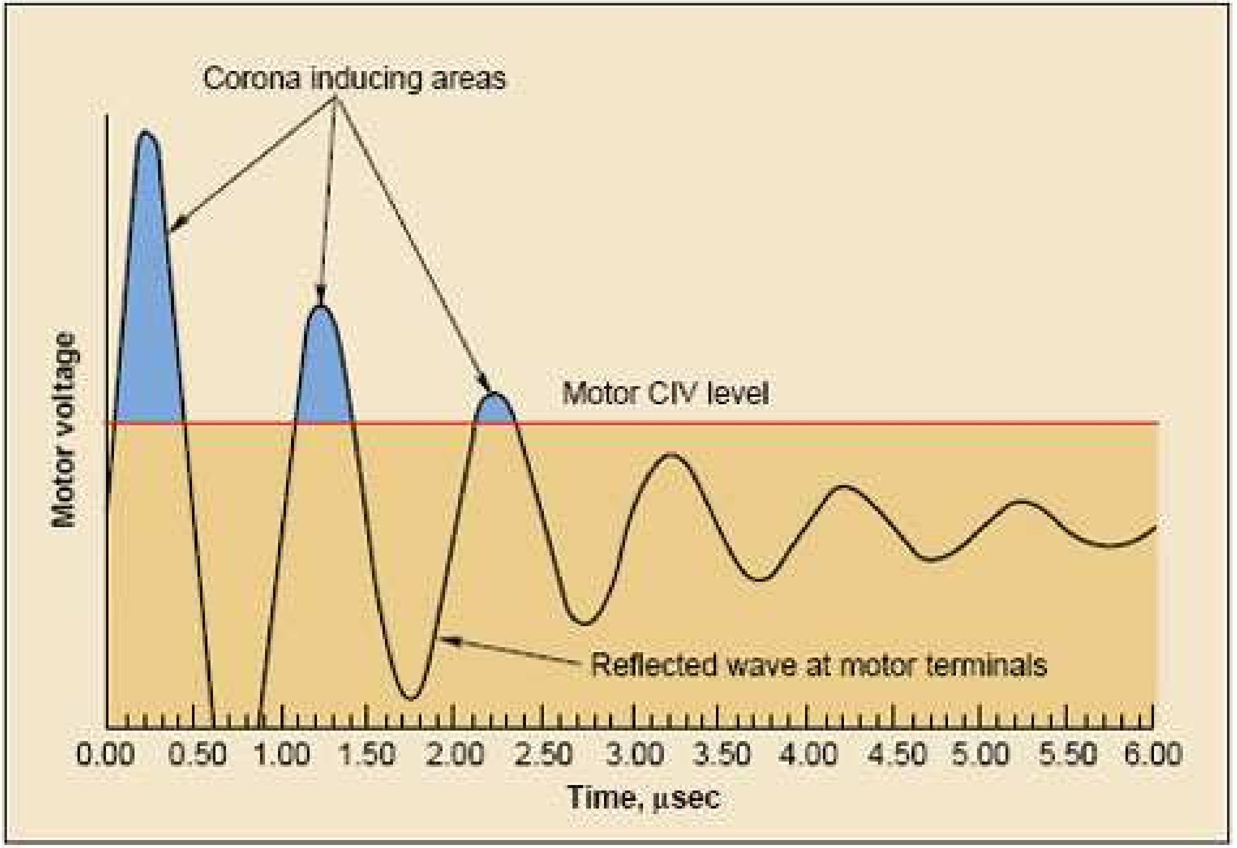
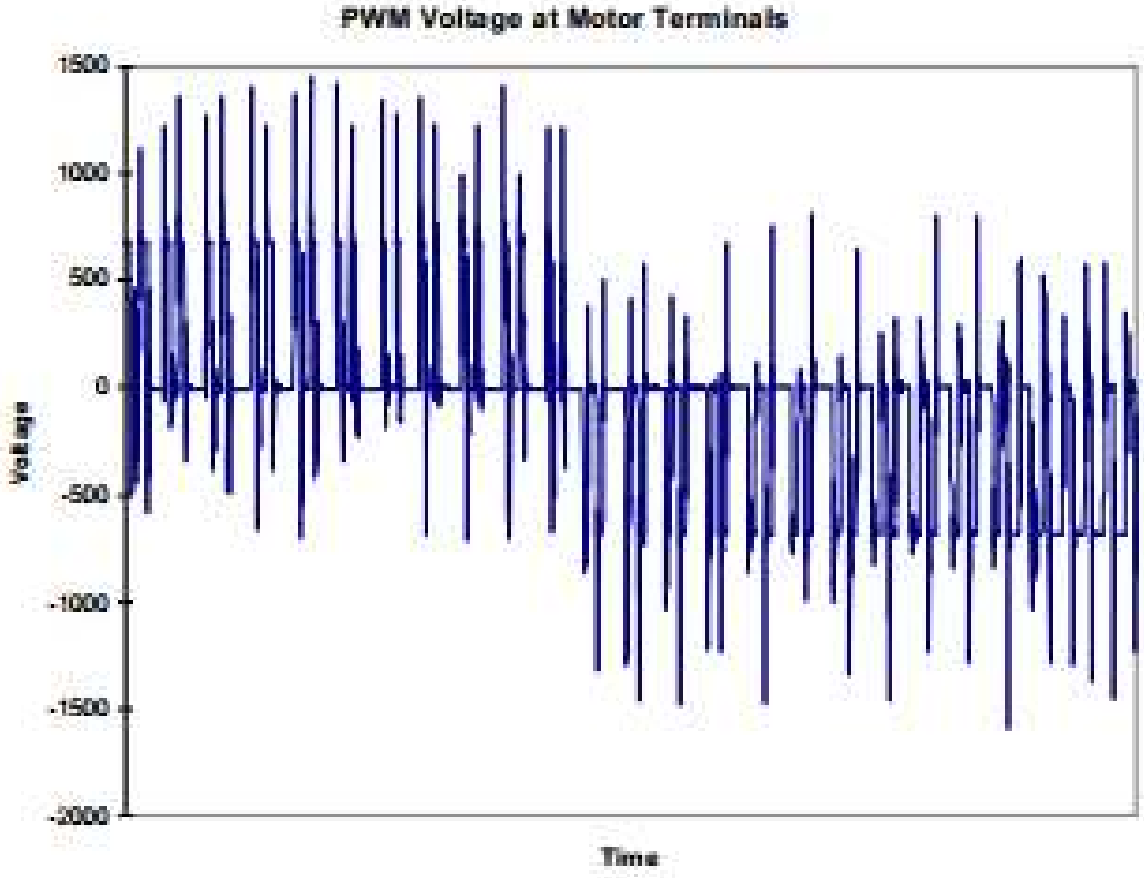


Figure 2 — The peak voltage can exceed the CIV value more than once during a single pulse. For example, any voltage over 1,600 V in a 480-V system will trigger a series of waves over the CIV level.

Resulting Voltage at Motor Terminals



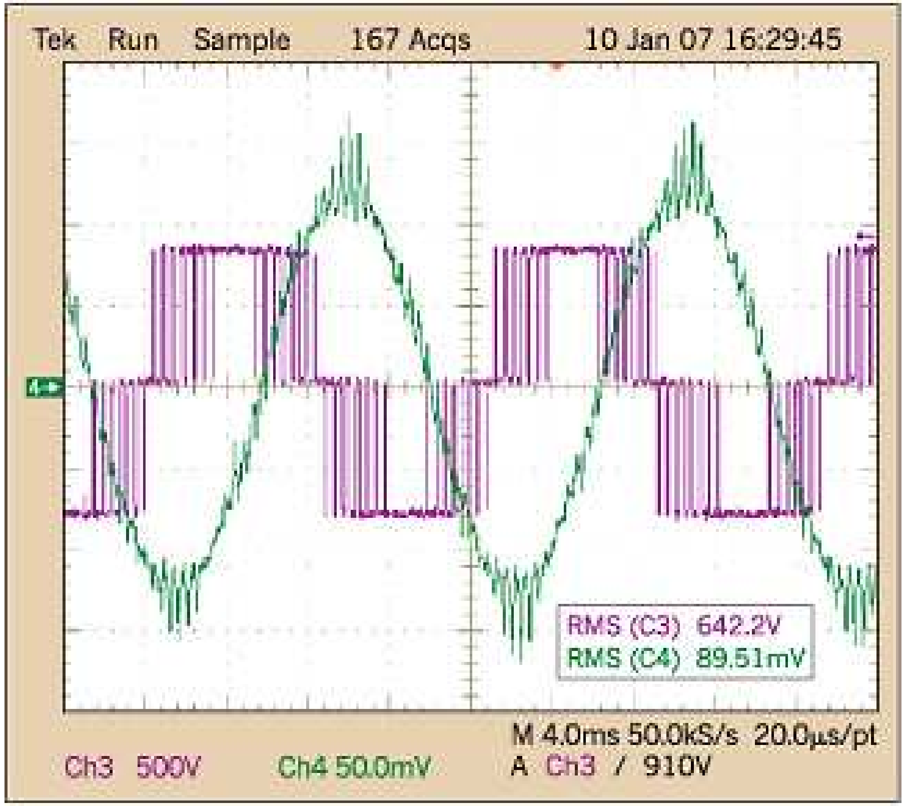
VFD Output Voltage – Insulation Failure

APPLICATION CONSIDERATIONS

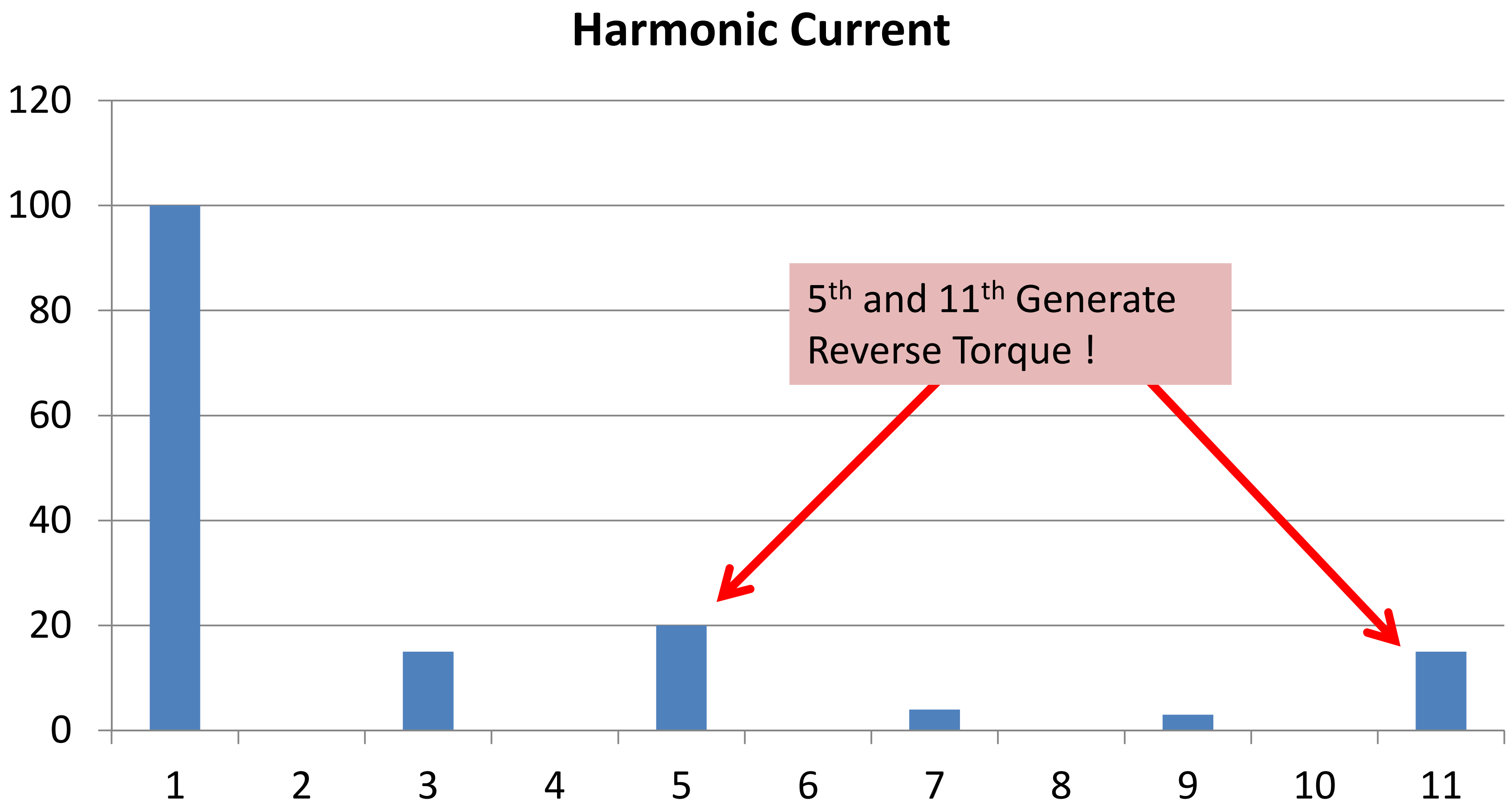
More on Reflected Waves

- Caused by dV/dT rise time and length of motor cable
- Motor cable has different impedances at each end, so…
- Some portion of the signal is reflected back to the source
- Under 50 feet of cable – No problem!
- Over 50 feet: $Fr = 1/(2*\pi*\sqrt{(L * C)})$
- Above 50 feet, Fr = 2 to 5 MHz
- Above 250 feet, Fr = 500kHz to 1.5 MHz
- These frequencies are at or below high frequency components of PWM voltage waveform
- When self-resonant frequencies in cable match waveform frequency, cable goes into resonance – causing a signal gain
- This can cause voltage spikes to reach 2 to 3 the DC voltage source of the VFD inverter

VFD Output Voltage – Harmonics



Negative Sequencing



Other Considerations

- Be careful with EE motor retrofits (i.e., centrifugal loads, screw compressors…)
- VFD’s require IEEE 519 Powerline Filter!
- An Isolation Transformer is a good idea!
- Faster Speeds
  - Increase work volume
  - Reduces torque
  - Requires more power (RPM^3)
  - Plan for increased LRA -> fuses, breakers

TROUBLESHOOTING AND MAINTENANCE

You Need Really Good Tools!

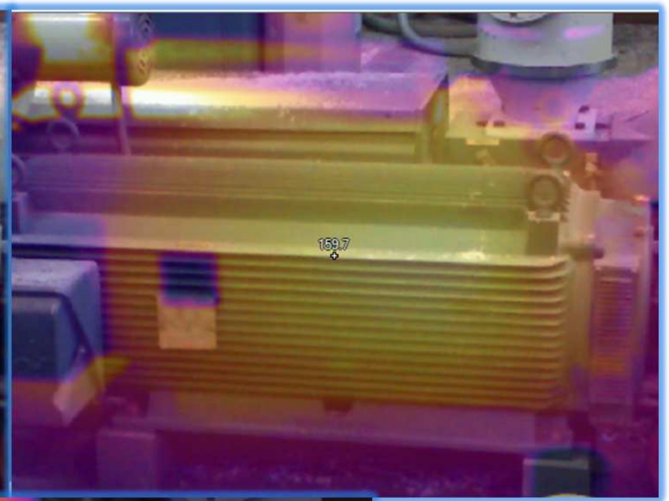
Fluke 810

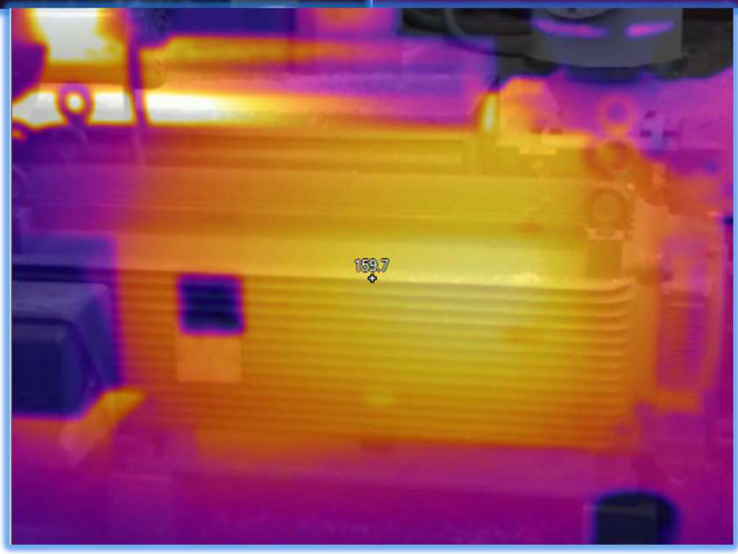
Fluke 435-II

Fluke Ti29

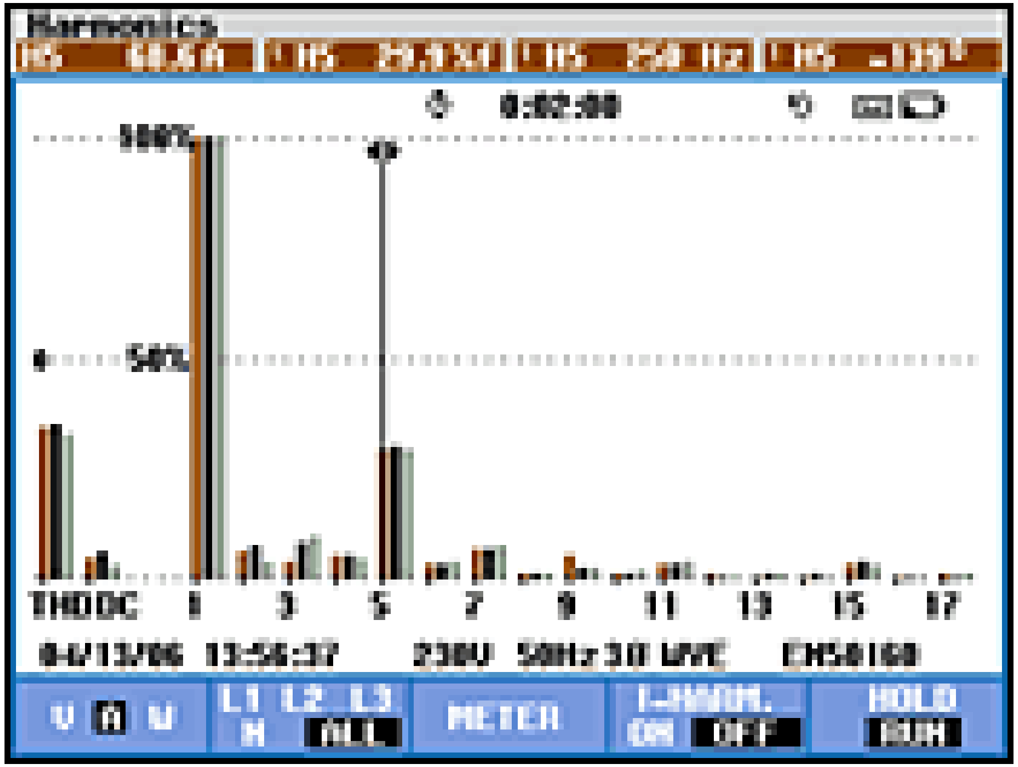
UE Systems

Fluke Ti29 – IR Fusion Imaging





Fluke 435-II – Complete Range of Power Analysis, including Harmonics



Fluke 810 – Vibration Analysis
Most Critical for Good PM

Causes of Vibration

- Bearing Wear
- Looseness (bearings or mounting)
- Imbalance
- Shaft misalignment

UE Systems – When You Need to Listen

Factors that Influence Efficiency

- Design for both *Power Losses* and *Power Consumption*
- Increase gear unit efficiency
- Increase motor efficiency
- Eliminate unnecessary functions
- Use/recycle released energy by direct utilization, regeneration of braking energy & energy storage
- Size components for demand
- Reduce/control output speeds
- Reduce load torque through rigid transmission components, counterweights & minimizing friction
- Use of energy-saving modes
- Turn off

Troubleshooting When VFD Present

- Check Phase Imbalance

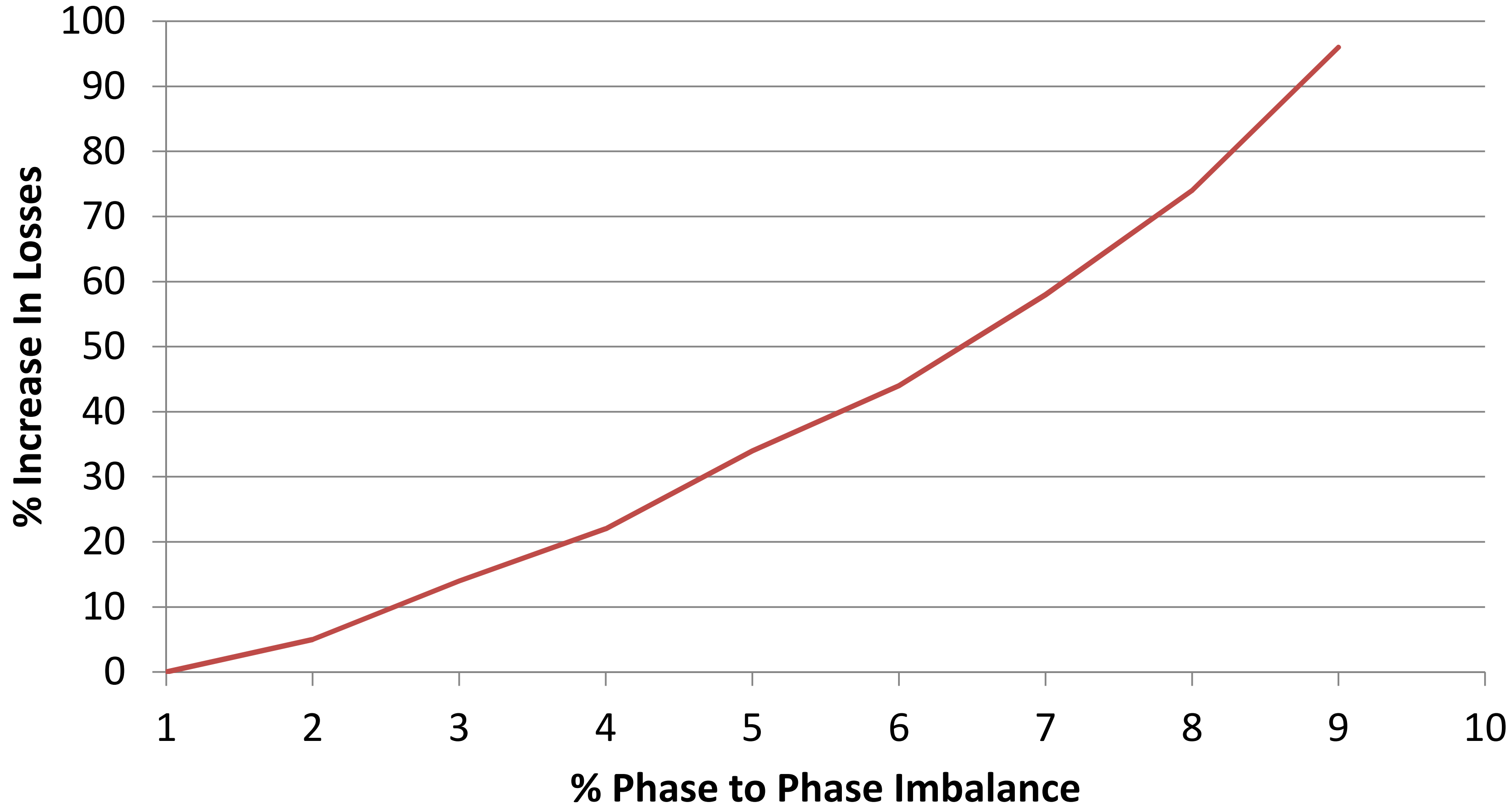
Example:

1. Measure phase current: A = 149; B = 162; C = 153
2. Find average: (149+162+153)/3 = 154.7
3. Find greatest deviation: 154.7 – 162 = 7.3
4. Find imbalance: 7.3/154.7 x 100% = 4.7% **Less that 10% = OK**

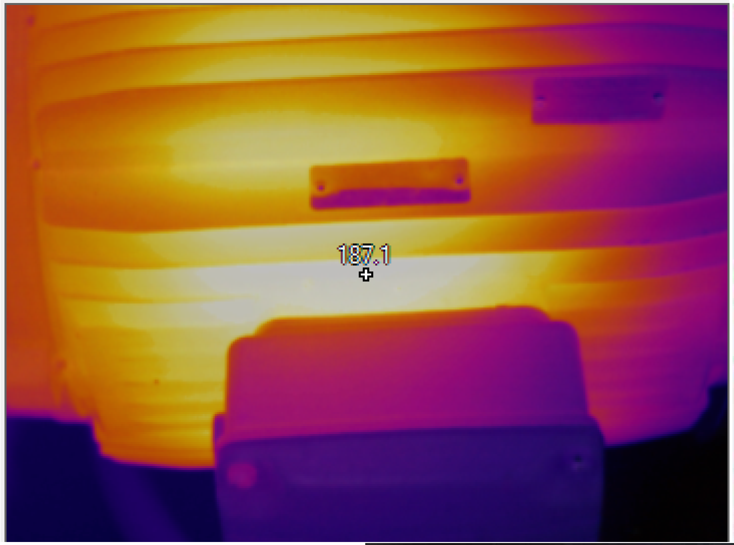
Problems could be voltage imbalance, stator insulation deterioration, VFD problem, loose connections, or?

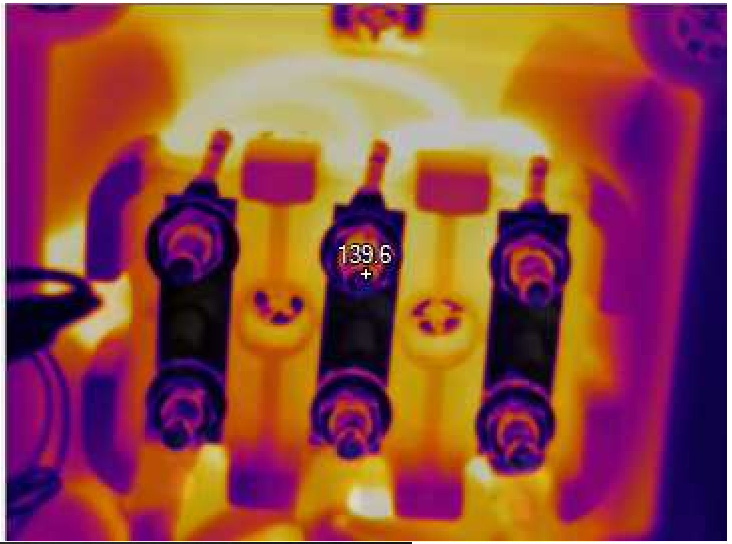
Voltage imbalance (same calc) but should be **less than 3%.**

Impact of Voltage Imbalance

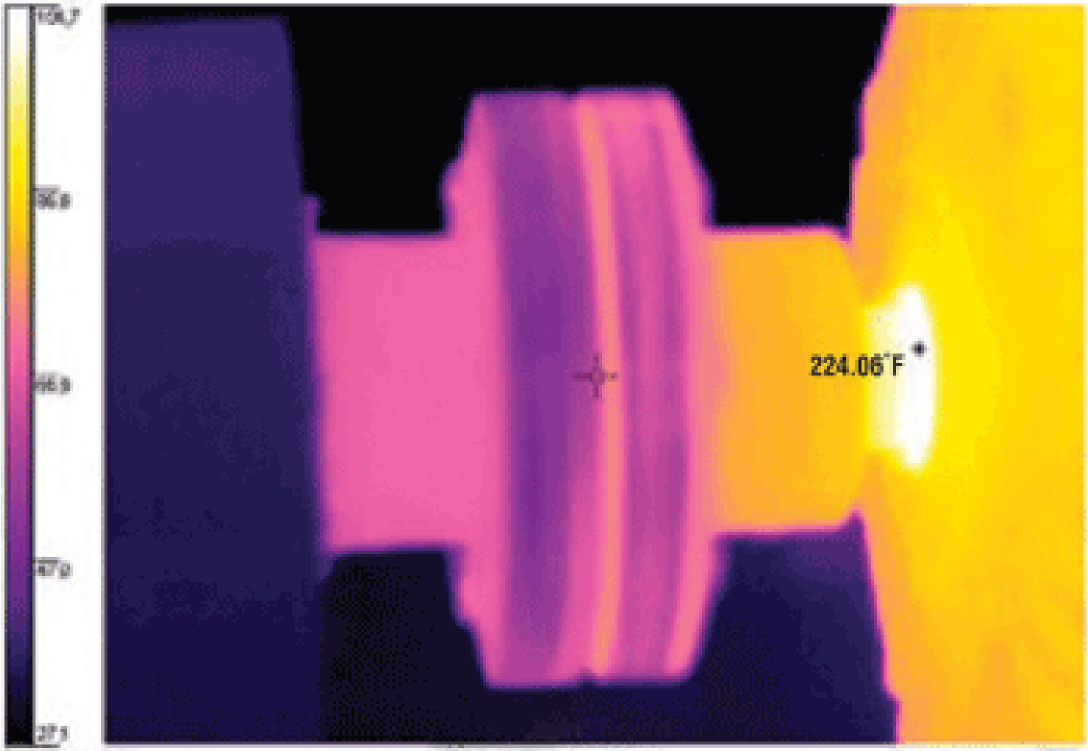


IR Imaging - Extremely Helpful!

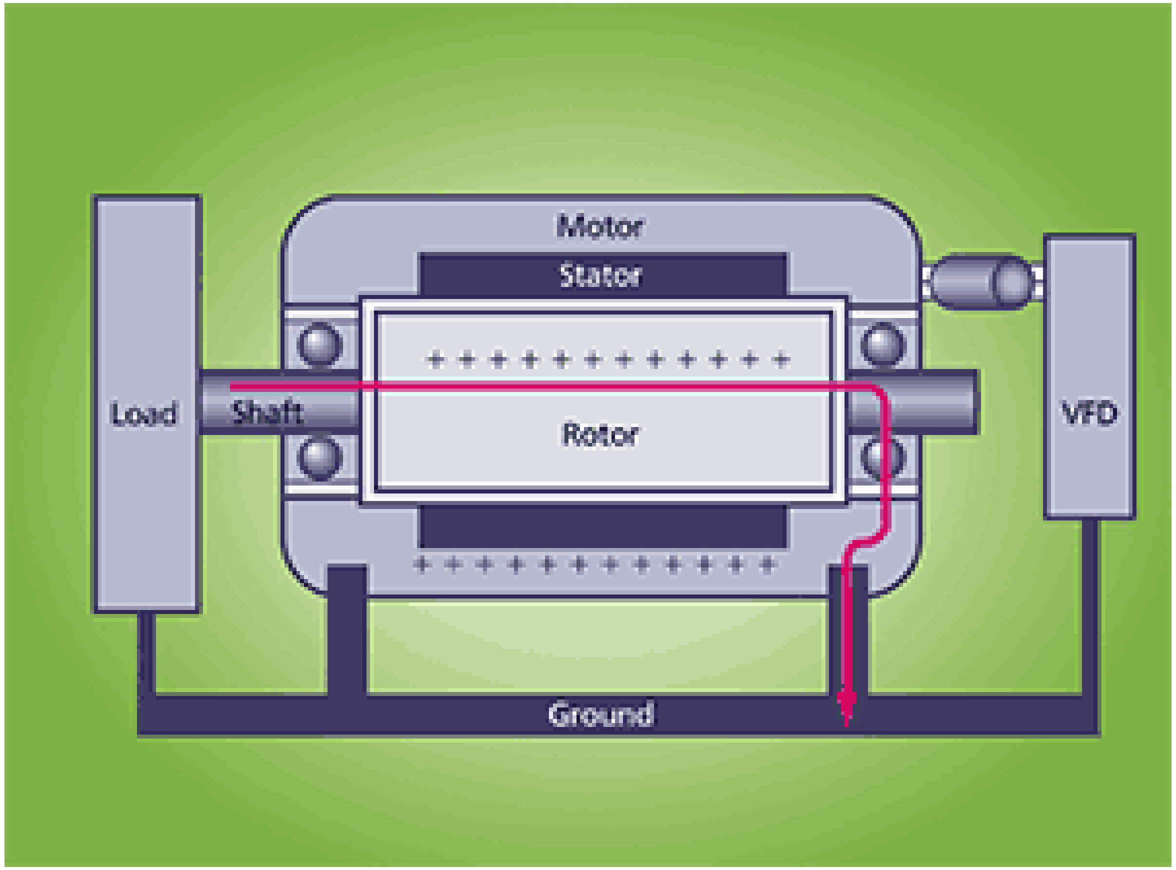




What Bearing Wear Looks Like

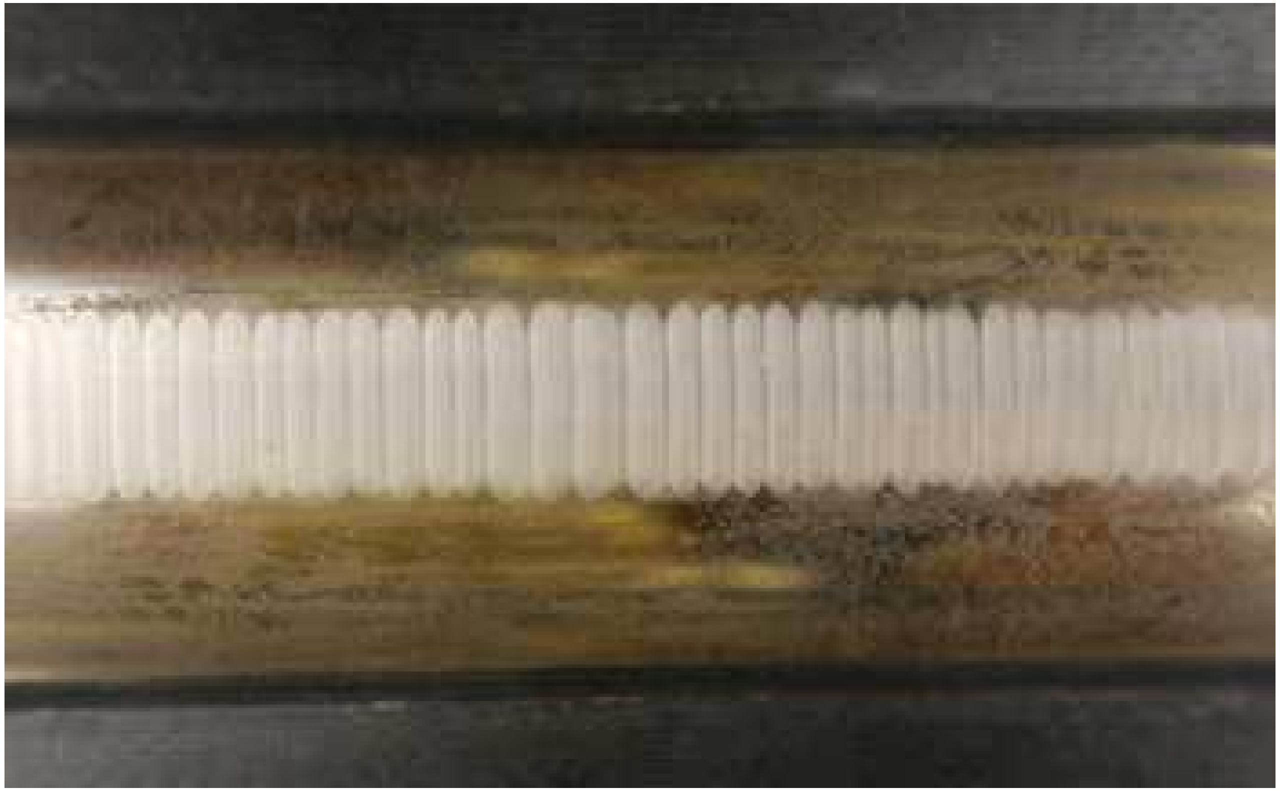


VFD Caused Bearing Wear



- Capacitive coupled leakage current
- Static electricity from load

Fluting



A Closer Look

MOTOR MANAGEMENT AND PREVENTIVE MAINTENANCE

Motor Management, Preventive Maintenance

- Well planned PM is key to dependable, long-life operation of motors, pumps and generators
- Unscheduled production stoppage and long repairs are intolerable
- Management often sees value of PM but resists investment for proper tools and training
- PM often needs to be pitched as a business case
- Case studies of prior breakdowns and resulting costs will help
- Once budget approved, develop a plan for each motor category

Motor Efficiency Improvement Program

- Survey your Motors. Gather nameplate information (HP, RPM, enclosure, voltage, amps)
- Initially focus on motors that exceed minimum size and operating hours
- 10HP and above
- 2,000 hours/year of operation
- Collect info re Standard, EPAct and NEMA Prem. Eff.
- Constant load (not intermittent, cycle or fluctuating)
- Older or rewound Standard Efficiency Motor
- Easy access

Motor Efficiency Improvement Program

- Conduct Motor Replacement Analysis by the following three categories:
- Motors Offering Rapid Payback through Energy Savings. Motors that run continuously (8,000 or more hours/year.
- Improved Reliability - Oversized Motors
- Utility Rebate Program - utility pays end-user to replace older inefficient motor with new NEMA Premium Motor.

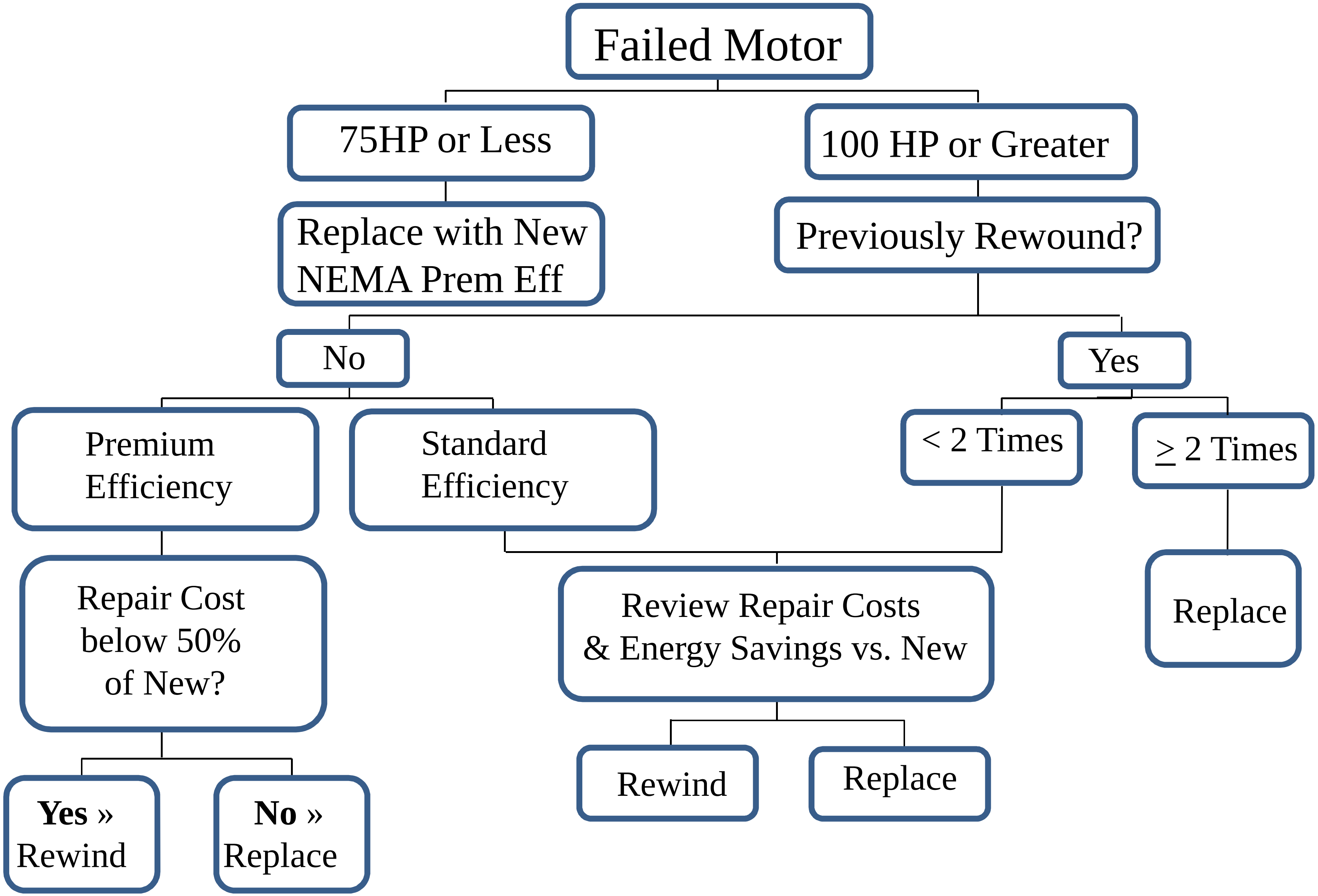
Motor Efficiency Improvement Program

- Replace Motor at time of Failure – Motors with Intermediate Payback, when these motors fail, you will want to replace them a NEMA Premium Motor. Plan this decision out with End-User. Motor must be available from stock.
- Leave Present Situation as is – Motors with Extended Payback. These motors are used less than 2,000 hours each year. They can be replaced with an EPAct Motor.

Motor Efficiency Improvement Program

- If motor is NEMA Prem go ahead and rewind
- If failed ODP motor not EE, scap for copper and replace with NEMA Prem
- If failed TEFC motor is not EE, scrap for copper and replace with NEMA Prem, unless 50+HP, then rewind
- If rewind, use good shop that uses DOE specs, inspect periodically
- Reference: *Horse Power*, DOE Publication

Repair / Replace Decision Tree



Areas to Cover for Good PM Program

- Thermal imaging
  - Over-heating (insulation class, impact on life)
  - Overloads
  - Imbalances
- Vibration analysis
  - Included load on shaft (gear box, etc.)
- Load analysis
  - Tachometer and slip equations
- Power analysis
  - Phase imbalance
  - Overload
  - Harmonics
  - Power Factor
  - Power Quality

Create a Record for Each Motor

M-13

Motors

General Information

Site Name	[redacted]
Motor ID/ Tag	
Location/Service	
Year Built	2011

Motor Data

	Nameplate
Manufacturer	Marathon
Model Number	EVD 256TTFNA6001
Serial Number	AE R140
Motor Type	TEFC AC Prem Eff.
Motor Efficiency	92.4%
Full-Load HP	20
Frame Size	
Frame Style	256T
Full-Load RPM	~~33~~ 3537
Synch RPM	3600
Volts	460
Phase	3
Full-Load Amps	23.4
Power Demand (kW)	15
Connection Type	

Design/Operating Conditions

	Design	Measured
Ambient Temp	129 F	136 F
Load on shaft	Blower	

Measurments

Voltage A	476.1
Voltage B	472.4
Voltage C	474.6
Current A	21.7
Current B	22.9
Current C	22.4
Shaft RPM	3541
Frame Temp Range	class H
Hotspot Temp	164.2 F

Motor Control

ON/OFF	Yes
VFD	NO
Soft-start	No
Multiple Speed Settings	No

Operating Schedule

Time of Day Scheduling	M-F 530A-10p Sat 7A-3p
Annual Oper. Hours	4654

Covert Collected Data into Database

	ID	Location	Make and Model	HP	Photo	Vibration	IR	Power	Condition	Comments
3	M1	806 Erema Cutter/Compactor	WEG Lenze 06AG008	22.8	Yes	Yes	Yes	Yes		Excessive bearing wear, severe current unbalance
4	M2	806 Erema Extruder	WEG LENZE TEO1FOXOXOX000091180	22.8	Yes	Yes	Yes	Yes		Severe bearing wear, excessive heating at power connection, overloaded
5	M3	2 1/2 - Extruder	RELIANCE 01KL517389DFT1	150	Yes	Yes	Yes	Yes		Excessive bearing wear; severe 5th and 11th harmonic
6	M4	3 Layer 1 - Extruder C				No	No	No		Machine down
7	M5	3 Layer 1 - Extruder B				No	No	No		Machine down
8	M6	3 Layer 1 - Extruder A				No	No	No		Machine down
9	M7	5 Layer - Extruder D	CONTRAVES 2190B450B03	10	Yes	Yes	Yes	No		Moderate bearing wear; non-std
10	M8	5 Layer - Extruder E	CONTRAVES N058/0413-FN112	10	Yes	Yes	Yes	No		Excessive bearing wear
11	M9	5 Layer - Extruder C	BALDOR P28800450035000	25	Yes	Yes	Yes	No		Moderate bearing wear
12	M10	5 Layer - Extruder B	CONTRAVES 2190B450B02	10	Yes	Yes	Yes	No		Excessive bearing wear
13	M11	5 Layer - Extruder A	BALDOR 59084771-001001-JN	50	Yes	Yes	Yes	No		Moderate bearing wear; non-std
14	M12	2 1/2 - Grinder	LEESON M286TDB10B	30	Yes	Yes	Yes	No		
15	M13	9 Layer - IBC Exhaust Blower	MARATHON EVD 256TTFNA6001	20	Yes	Yes	Yes	No		
16	M14	3 Layer 2 - Air Ring Exhaust	MARATHON DUB 215TTFS6001GWR140	10	Yes	Yes	Yes	No		
17	M15	9 Layer - Air Ring Blower	MARATHON EVD286TSTFN6001BHR1401	30	Yes	Yes	Yes	No		
18	M16	9 Layer - IBC Supply	MARATHON EVD286TSTFN6001BHR1402	20	Yes	Yes	Yes	No		Slight looseness
19	M17	9 Layer - Extruder A	RELIANCE 73424318-00-DR-T1	60	Yes	Yes	Yes	No		
20	M18	9 Layer - Extruder B	RELIANCE 7350638-001-CK-T2	40	Yes	Yes	Yes	No		
21	M19	9 Layer - Extruder C	RELIANCE 7350638-001-CK-T3	40	Yes	Yes	Yes	No		
22	M20	9 Layer - Extruder D	RELIANCE 7350638-001-CK-T4	40	Yes	Yes	Yes	No		
23	M21	9 Layer - Extruder E	RELIANCE 7350638-001-CK-T5	40	Yes	Yes	Yes	No		
24	M22	9 Layer - Extruder F	RELIANCE 7350638-001-CK-T6	40	Yes	Yes	Yes	No		
25	M23	9 Layer - Extruder G	RELIANCE 7350638-001-CK-T7	40	Yes	Yes	Yes	No		
26	M24	9 Layer - Extruder H	RELIANCE 7350638-001-CK-T8	40	Yes	Yes	Yes	No		
27	M25	9 Layer - Extruder I	RELIANCE 7342431A-00-DKT1	60	Yes	Yes	Yes	No		
28	M26	3 Layer 2 - Extruder A	SAFTRONICS 5CD184TA096B017	60	Yes	Yes	Yes	No		
29	M27	3 Layer 2 - Extruder B	SAFTRONICS CD203PA097A151	50	Yes	Yes	Yes	No		
30	M28	3 Layer 2 - Extruder C	GE 5CD84TA096B032	60	Yes	Yes	Yes	No		
31	M29	605 Erema - Extruder	SIEMENS ILE10011DC434AB4Z	15	Yes	Yes	Yes	No		Moderate bearing looseness
32	M30	605 Erema - Cutter/Compactor	SIEMENS ILA91866	20	Yes	Yes	Yes	No		
33	M31	Macchi reclaim				No	No	No		motor not accessible
34	M32	3 Layer 1 - IBC Suply				No	No	No		Machine down
35	M33	2 /12 - Air Ring Supply	BALDOR M3314T	15	Yes	Yes	Yes	No		
36	M34	3 Layer 1 - IBC Exhaust				No	No	No		Machine down
37	M35	3 Layer 1 - Air Ring Supply				No	No	No		Machine down
38	M36	5 Layer - Air Ring Blower	TOSHIBA B0202OLF2UMH01	20	Yes	Yes	Yes	No		
39	M37	3 1/2 - Extruder	RELIANCE 7135052-001-DJT1	150	Yes	Yes	Yes	No		
40	M38	3 1/2 - IBC Suply Blower	MARATHON DVF 254TTFNA6001 AER1401	15	Yes	Yes	Yes	No		
41	M39	3 1/2 - IBC Exhaust	RELIANCE P21G3319H	10	Yes	Yes	Yes	No		Moderate bearing looseness
42	M40	6" Extruder	POWERTEC A32EYS1000100000	250	Yes	Yes	Yes	No		Bearings at both ends have moderate wear
43	M41	6" - Air Ring Supply	BALDOR M4107T	25	Yes	Yes	Yes	No		Moderate bearing wear and looseness
44	M42	2" Extruder	GE 50D363NA001A015	30	Yes	Yes	Yes	No		
45	M43	6" - Grinder	LEESON C324T17FB7D	30	Yes	Yes	Yes	No		
46	M44	6" - Grinder	DELCO 1V9716L1	40	Yes	Yes	Yes	No		
47	M45	3 1/2 - IBC Exhaust Blower	MARATHON DVA 215TTFS6001GWR1401	10	Yes	Yes	Yes	No		
48	M46	GD VS-40 Air Compressor	RELIANCE 89864009	54.4	Yes	Yes	Yes	No		
49	M47	3 Layer 2 - Air Ring Supply	MARATHON BVA254TTFNA6001AER140	15	Yes	Yes	Yes	No		Slight bearing wear

REBATES

Utility Rebates for Motors and VFD - AEP

NEMA Premium™ Efficiency Criteria Qualifying Motors Exceed NEMA Premium™ Efficiency							
Horse-power	3600 RPM		1800 RPM		1200 RPM		Incentive /Motor
	Open	Closed	Open	Closed	Open	Closed	
1	77.0%	77.0%	85.5%	85.5%	82.5%	82.5%	$8
1.5	84.0%	84.0%	86.5%	86.5%	86.5%	87.5%	$10
2	85.5%	85.5%	86.5%	86.5%	87.5%	88.5%	$13
3	85.5%	86.5%	89.5%	89.5%	88.5%	89.5%	$20
5	86.5%	88.5%	89.5%	89.5%	89.5%	89.5%	$25
7.5	88.5%	89.5%	91.0%	91.7%	90.2%	91.0%	$40
10	89.5%	90.2%	91.7%	91.7%	91.7%	91.0%	$45
15	90.2%	91.0%	93.0%	92.4%	91.7%	91.7%	$60
20	91.0%	91.0%	93.0%	93.0%	92.4%	91.7%	$75
25	91.7%	91.7%	93.6%	93.6%	93.0%	93.0%	$80
30	91.7%	91.7%	94.1%	93.6%	93.6%	93.0%	$90
40	92.4%	92.4%	94.1%	94.1%	94.1%	94.1%	$100
50	93.0%	93.0%	94.5%	94.5%	94.1%	94.1%	$120
60	93.6%	93.6%	95.0%	95.0%	94.5%	94.5%	$130
75	93.6%	93.6%	95.0%	95.4%	94.5%	94.5%	$140
100	93.6%	94.1%	95.4%	95.4%	95.0%	95.0%	$190
125	94.1%	95.0%	95.4%	95.4%	95.0%	95.0%	$238
150	94.1%	95.0%	95.8%	95.8%	95.4%	95.8%	$285
200	95.0%	95.4%	95.8%	96.2%	95.4%	95.8%	$380
250	95.0%	95.8%	95.8%	96.2%	95.4%	95.8%	$475

VFD Application	Incentive Amount
Supply/ Return Fan	$60/HP
Chilled Water Pump/ Condenser Water Pump	
Hot Water Pump	
Cooling Tower Fan	
Other HVAC Motor (Fan/ Pump)	
Process Fan and Pump Motor	

Pool Pump & Compressor Prescriptive Incentives

VFD Application	Size Requirements	Incentive Amount
Pool Pump	N/A	$100/HP
New Compressor	≤ 150 HP	$100/HP

Installing VFDs on Existing Equipment

Incentives qualify for new VFDs, not replacement VFDs.
Prescriptive Incentives for VFD applications ≤ 200 HP*
(For motors >100 HP custom analysis is completed, but prescriptive incentives are paid.)

Installing VFDs on New Equipment

Subject to ASHRAE 90.1-2007 standards. If a VFD is required it is not eligible for incentives.

The following are the most common applications not eligible for incentives:

VFD Application	Required by ASHRAE 90.1-2007	Notes
Variable Air Volume (VAV) Fan Control	Motor ≥ 10 HP	Supply/ return fans
Hydronic Variable Flow Systems	Motor > 50 HP & Pump Head > 100 ft	Variable fluid flow pumps
Heat Rejection Equipment, Fan Speed Control	Motor ≥ 7.5 HP	Cooling towers, condensing units, etc.

Utility Rebates for Motors and VFD's – FirstEnergy

- Motors and VFD's fall under their custom program and pay $0.08/kWh saved, caped at 50% of project cost.

Utility Rebates for Motors and VFD's – DP&L

Premium Motors

Measure	Rebate (per HP)
1.0 - 5.0 HP	$25.00
7.5 - 20.0 HP	$15.00
25.0 - 250.0 HP	$10.00

Variable Frequency Drives

Measure	Rebate (per HP)
1.0 - 250.0 HP	$40.00

Utility Rebates for Motors and VFD's – Duke Energy

VARIABLE FREQUENCY DRIVES

For all VFD operations >2000 hours per year applied to HVAC fans and pumps and process pumps

HP	INCENTIVE/HP
From 1.5 hp to 50 hp	Up to $100.00/hp

Visit www.duke-energy.com for required efficiency levels.

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