Permanent Magnet Motors for Higher Efficiencies

Steve Bistak
sbistak@novatorque.com
• What are the efficiency regulations in place for motors?
• What are the options for better efficiency?
• PMAC Motor Performance Advantages
• Real World Savings
• Motor Models, Labeling, VFD Compatibility
United States

EPAct
The Energy Policy Act of 1992, Starting in October 1997, required most general-purpose polyphase squirrel cage induction motors manufactured for sale in the United States in sizes between 1 and 200 horsepower to meet minimum efficiency standards.

EISA
The Energy Independence and Security Act ("EISA"), which was signed into law in 2007, became effective on December 19, 2010. This law expands the mandated energy efficiency standards from the Energy Policy Act of 1992 (EPAct) for a wider range industrial motors 1-500 HP which are manufactured for sale in the United States.

EISA Enhancements June 2016
8 pole motors covered

Not covered by US efficiency regulations
Air Over motors
Motors that can only be used on VFD’s
Europe

European Standards IE2 and IE3 are basically equivalent to EPAct and EISA. IE2 by June 16, 2011

IE3 by January 1, 2015 (for motors >=7.5 to 375 kW) and IE2 only in combination with an adjustable speed drive

IE3 for all motors by January 1, 2017, (for motors from 0.75 to 375 kW) and IE2 only in combination with an adjustable speed drive.

IE4 Standards established but not yet required (2020?), (for motors from 0.75 to 375 kW)

IE5 Standards in discussion stage.

Each of the EU Regulatory changes was / is on average a 2 Band improvement of efficiencies over the previous regulation, based on NEMA efficiency bands
What are the options for increased efficiency?

Some US manufacturers have introduced “Super Premium” product.

- ACIM with
  - longer core length
  - higher grade of electrical steel
  - more copper in the windings
  - redesigned fans and fan shrouds

These typically have design “A” starting characteristics and may not be suitable for retrofit applications without using a soft start or VFD (0 – 60% higher than Design “B”).

Copper Die Cast Rotor (in place of Aluminum Die Cast)

Have been discussed for a number of years but have not yet overcome manufacturing issues due to higher temperatures and pressures required. Articles read suggest 4% more efficient than ACIM. Typically design “A” starting characteristics.

Hybrid Induction motors with permanent magnets imbedded in cast aluminum rotor.

Some manufacturers have introduced Permanent magnet motors

- Require a VFD with PM capability for operation
- NO sine wave bypass capability
- frame sizes may be smaller than NEMA ACIM standards
Further Efficiency Gains Will Require New Motor Technology

- Permanent magnet motors the most likely candidates.
  Available today and offer an immediate efficiency boost due to the use of permanent magnets.

PM motors require a VFD for operation. Most new HVAC applications incorporate a VFD for speed control for energy savings to meet coming Federal regulations.

As Induction motors are designed for higher efficiencies they tend to become “design A” electrical types with very high amp draw on start up. This usually necessitates the use of a softstart or VFD to manage this excessive electrical draw.

PM Motors provide the highest levels of efficiency since no electrical energy is required to “induce” a magnetic field in the rotor.

Note: There is NO sine wave bypass possible with PM motors.
The relationship between frequency and motor speed is usually different than an induction motor.
Permanent Magnet Motors – Environmental Motivation

Annual Reduction 2,822 kWh
(1) 10hp

- Pounds of coal burned: 2,090
- Miles driven by an average passenger vehicle: 4,633
- Incandescent lamps switched to CFLs: 50.9
- Barrels of oil consumed: 4.5
- Gallons of gasoline consumed: 219
Permanent Magnet Motors – Key Benefits

• Higher full & variable speed efficiency

• Flatter efficiency curve

• Cooler operating temperatures

• Full torque at low speeds

• Increased power density
  • Some ratings available in smaller frames, providing lighter weight
Permanent Magnet Motors – Issues to consider

PM motors require an individual VFD per motor, NO sine wave bypass is available.

- Points to ponder
  - In a fan array there is usually built in redundancy eliminating the need for bypass
  - VFD’s are much more reliable today than they were in the ‘80s when bypass began to be implemented.
  - PM motors are much more efficient that ACIMs
    - This may allow the use of a smaller VFD than the ACIM would require
    - Always size VFD by motor FLA (not HP)
    - In facilities with a large number of motors this may allow smaller conductors and a smaller power feed and associated control.

- With a single VFD and multiple motors each “branch” should have
  - Short circuit protection
  - Motor Overload protection
  - A disconnecting means
  - If bypass is required it is generally provided by a parallel large VFD
- When all the above is considered the cost generally runs from about the same to lower for an individual VFD solution.
### Efficiency Comparison ACIM vs. PM

PM motor efficiencies on VFD power. ACIM on Sine wave. ACIM motors lose 0.5 – 1.5 points of efficiency when run on VFD.

<table>
<thead>
<tr>
<th>NEMA Efficiency Band</th>
<th>HP @ 1800 RPM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>96.2</td>
<td></td>
</tr>
<tr>
<td>95.8</td>
<td></td>
</tr>
<tr>
<td>95.4</td>
<td></td>
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<tr>
<td>95.0</td>
<td></td>
</tr>
<tr>
<td>94.5</td>
<td></td>
</tr>
<tr>
<td>94.1</td>
<td></td>
</tr>
<tr>
<td>93.6</td>
<td></td>
</tr>
<tr>
<td>93.0</td>
<td></td>
</tr>
<tr>
<td>92.4</td>
<td></td>
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<tr>
<td>91.7</td>
<td></td>
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<tr>
<td>91.0</td>
<td></td>
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<td>90.5</td>
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<td>89.5</td>
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<td>88.5</td>
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<td>87.5</td>
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<td>86.5</td>
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<td>85.5</td>
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<tr>
<td>85.0</td>
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</tr>
<tr>
<td>84.0</td>
<td></td>
</tr>
<tr>
<td>82.5</td>
<td></td>
</tr>
</tbody>
</table>

**General range of efficiencies for Permanent Magnet Motors**

**General range of efficiencies for AC Induction Motors**

IE 5, Sup. Prem, NEMA Prem, EPAct.
Permanent Magnet Motors – Primary Advantage

PM Motor vs. Induction at Multiple Speeds

Motor Efficiency vs. Speed (rpm):
- 1800 rpm
- 1200 rpm
- 900 rpm

Permanent Magnet Motors
– Primary Advantage
#1 - Higher Full & Variable Speed Efficiency

Variable Speed Constant Torque Motor Performance
Efficiency vs Speed
5 HP, 184T PMAC vs NEMA Premium Induction

![Graph showing motor efficiency vs speed with comparison between PM Motor Eff and Ind Motor Eff.](image)

- PM Motor Eff:
  - 90.6% (387 watts loss)
- Ind Motor Eff:
  - 84.6% (679 watts loss)

Improvement:
- 43% improvement from 90.6% to 91.7% (338 watts loss)
- 23% improvement from 84.6% to 89.5% (438 watts loss)
NovaTorque Annual Saving vs. Induction Motor

**Annual Savings - PM Motor vs. Premium Induction**
**Multiple HP - 1800 RPM - 80% Duty Cycle**

<table>
<thead>
<tr>
<th>Electricity Cost (¢/kWh)</th>
<th>Total Annual Savings for 5 HP</th>
<th>Total Annual Savings for 3 HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>$69.91</td>
<td>$41.95</td>
</tr>
<tr>
<td>0.06</td>
<td>$83.89</td>
<td>$50.33</td>
</tr>
<tr>
<td>0.07</td>
<td>$97.87</td>
<td>$58.72</td>
</tr>
<tr>
<td>0.08</td>
<td>$111.85</td>
<td>$67.11</td>
</tr>
<tr>
<td>0.09</td>
<td>$125.84</td>
<td>$75.50</td>
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<tr>
<td>0.1</td>
<td>$139.82</td>
<td>$83.89</td>
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<tr>
<td>0.11</td>
<td>$153.80</td>
<td>$92.28</td>
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<td>0.12</td>
<td>$167.78</td>
<td>$100.67</td>
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<td>0.13</td>
<td>$181.76</td>
<td>$109.06</td>
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<tr>
<td>0.14</td>
<td>$195.75</td>
<td>$117.45</td>
</tr>
<tr>
<td>0.15</td>
<td>$209.73</td>
<td>$125.84</td>
</tr>
</tbody>
</table>

Note: Duty Cycle = 80% at full speed
Permanent Magnet Motors – Financial Motivation

Annual Savings - PM Motor vs. Premium Induction
Multiple HP - 1800 RPM - 100% Duty Cycle

Note: Duty Cycle = 100% at full speed
Electronically Commutated Motors
All in One System - Unitary

All in one solution
VFD / EC motor / Fan all in one unit

Pros

All in one
reduced wiring
reduced assembly

Cons

One piece breaks and it all goes out for repair
More limited in what you can get
  Fan selection
  Motor ratings
  VFD features
EC Motor with integral VFD + Fan

Two Components
EC motor / VFD, Fan

Pros
- More Fan Choices
- Reduced Installation
- Reliable and the default choice
- Easy maintenance and replacements

Cons
- Limited Motor HP range and speeds available
- Motor or VFD failure and both go for repair
- More limited in what you can get
  - Motor ratings
  - VFD features
Individual components
EC motor, VFD, Fan

Pros
More Fan Choices
More Motor Choices
More VFD Choices
Pick the best product for your application from each category
Pick the highest efficiency product in each category.
easier / faster repair / replacement. Only replace the failed item.

Cons
More thought required to match the proper items
More assembly time
Permanent Magnet Motors - Configurations

External Rotor
Used primarily with VFD/EC motor/fan - unitary product
Permanent Magnet Motors - Configurations

EC Motor/VFD
Permanent Magnet Motors - Configurations

Single Stator & Rotor
Traditional configuration
Permanent Magnet Motors - Configurations

Single Stator & Dual Rotor
PMAC vs. NEMA Premium Motor

Typical Efficiency Comparison on Variable Torque load.
Motor Base Speed on ECPM motors **not tied to number of poles!**

Comparison of Motor Efficiency on Typical 10HP, 2700RPM Fan Application

- **PMAC 10HP @ 2400 Base Speed**
- **NEMA Premium 10HP ACIM 1800 RPM Base Speed**
- **NEMA Premium 15HP ACIM 3600 RPM Base Speed**
Same as an AC Induction Motor

- Follow the VFD manufacturer’s wiring instructions.
- Mount and align as you would an ACIM.
- Consider protection against shaft currents.
When comparing PMAC to ACIM Remember

• ALL published data on AC Induction Motors is based on operation on sine wave power.
  Efficiency – per NEMA Standards
  Service Factor - Typically 1.15 – 1.25
  Temperature Rise - B

• When an ACIM is operated on VFD power
  Efficiency – drops by approximately .5 – 1 ½ points or more
  Service Factor - 1.0
  Temperature Rise - F

Since PMAC motors can only be run on a VFD, their published information is generally based on performance while on the VFD.
#3 – Generally Cooler Operation

PM Motors Operate at Lower Temperatures

Electricity / Power in → Heat to atmosphere - losses → Rotation / work out

Higher Efficiency = Lower Heat Losses
Improved efficiency positive effect on costs to cool

IF you are mounting your AHU motors in the airstream a more efficient motor with have a positive effect in reducing your cooling costs because the put less heat, due to reduced losses, into the airstream.

<table>
<thead>
<tr>
<th>Watt/HP</th>
<th>HP</th>
<th>Watts</th>
<th>% Eff</th>
<th>% Loss</th>
<th>Watts Lost</th>
<th>Time Proportion</th>
<th>Watt Loss x Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induction Motor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>745.7</td>
<td>5.00</td>
<td>3,728.50</td>
<td>89.14%</td>
<td>10.86%</td>
<td>404.92</td>
<td>0.1</td>
<td>40.49</td>
</tr>
<tr>
<td>745.7</td>
<td>1.48</td>
<td>1,105.87</td>
<td>86.77%</td>
<td>13.23%</td>
<td>146.31</td>
<td>0.8</td>
<td>117.05</td>
</tr>
<tr>
<td>745.7</td>
<td>0.63</td>
<td>466.06</td>
<td>80.44%</td>
<td>19.56%</td>
<td>91.16</td>
<td>0.1</td>
<td>9.12</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>166.65</td>
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<tr>
<td>PM Motor</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>745.7</td>
<td>5.00</td>
<td>3,728.50</td>
<td>94.40%</td>
<td>5.60%</td>
<td>208.80</td>
<td>0.1</td>
<td>20.88</td>
</tr>
<tr>
<td>745.7</td>
<td>1.48</td>
<td>1,105.87</td>
<td>92.33%</td>
<td>7.67%</td>
<td>84.82</td>
<td>0.8</td>
<td>67.86</td>
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<tr>
<td>745.7</td>
<td>0.63</td>
<td>466.06</td>
<td>88.71%</td>
<td>11.29%</td>
<td>52.62</td>
<td>0.1</td>
<td>5.26</td>
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<td></td>
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<tr>
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<td></td>
<td>Heat introduced into the airstream has been reduced by 44%</td>
</tr>
</tbody>
</table>
Test conducted from Oct 2013 through Feb 2014

Comparison of a 5 HP (Premium Efficiency, IE3) induction motor with a 5 HP PMAC
- Both equipped with variable frequency drive (VFD)
- Parallel operation in an air handling exhaust application with power monitoring through the Building Management System
- Test conducted for 1 month, then motor positions swapped and the test continued another month

PMAC motor consumed 8.5% less power for the same air flow!
Barclay’s Bank Air Handler Retrofit

Replaced 40 HP motor & fan with 4x2 array of 4.5 HP PMAC motors & fans

7 of 8 motors running with variable speed. 8th motor for redundancy

25% energy saving predicted; 35% energy savings measured

- Estimate 8 to 12% of savings from PMAC compared to NEMA Premium motor efficiency

Line current reduced

- Before retrofit: 47.5 amps
- After retrofit: 30.2 amps
Major HVAC OEM – Data Center Case Study

- PMAC 900rpm rated motors were comparatively tested against AC Induction 6-pole motors for use in an Oregon data center application.

- Test results showed a 16%-18% energy reduction over 6-pole AC Induction motors for the application operating points.

<table>
<thead>
<tr>
<th>Blower Speed</th>
<th>350 rpm</th>
<th>500 rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFM</td>
<td>16,400</td>
<td>23,720</td>
</tr>
<tr>
<td>AC Induction (kW)</td>
<td>0.980</td>
<td>2.792</td>
</tr>
<tr>
<td>NovaTorque (kW)</td>
<td>0.817</td>
<td>2.286</td>
</tr>
<tr>
<td>Power Reduction</td>
<td><strong>16.6%</strong></td>
<td><strong>18.1%</strong></td>
</tr>
</tbody>
</table>
Permanent Magnet Motors - Example

Retrofit on Existing Air Handlers

- 2 motors per floor (17 floors)
- Added VFDs for controls
- Units run 12-14 daily 5 days a week

Initial Findings

- 43.7% reduction in power usage
- Expected project payback < 2 years
  (motors + VFDs + labor)
ALL ECPM motors require a VFD for operation. Not all VFDs are capable of running ECPM motors. The VFD must have the proper algorithm as part of it’s firmware.

Most major VFD manufacturers have at least one product capable of running ECPM motors.
Savings Calculator – Most motor manufacturers have a savings calculator

Typical data input requirements

**Savings Calculator**

**Fan Operating Points**
- MAX OUTPUT POWER (BHP): 10
- MAX SPEED (RPM): 2250
- SPEED 2 (RPM): 1950
- SPEED 3 (RPM): 1125

**Duty Cycle**
- DUTY CYCLE SELECTION: 24 hours, 7 days
- PERCENT TIME AT MAX SPEED: 30%
- PERCENT TIME AT SPEED 2: 50%
- PERCENT TIME AT SPEED 3: 20%

**Motors / Power Cost**
- MOTOR VOLTAGE CLASS: 460 VAC, 3-Phase
- NUMBER OF MOTORS: 1
- POWER COST ($/KW-HR): 0.16
- TIME INTERVAL (MONTHS): 12

**SAVINGS**
- PM MOTOR:
- AC INDUCTION MOTOR:
- ENERGY SAVINGS (KW-HR):
- COST SAVINGS (DOLLARS):

**NUMBER OF SPEEDS**
- 3 Operating Points

[Calculate Savings]
### Savings Calculator

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#### SAVINGS
- **AC INDUCTION MOTOR:** 10HP, 1800rpm 4-Pole
- **ENERGY SAVINGS (KW-HR):** 2070.7
- **COST SAVINGS (DOLLARS):** $331
Efficiencies generally provided at the data points and along any point on graph.
Thank You !!!!

Steve Bistak
sbistak@novatorque.com