OCTOBER 2020

Wire-to-Air Efficiency

SynRM^2 motor technology – optimize system design and performance

Mark Gmitro, Global Product Manager – Variable Speed AC Motors

EC Titanium

Beyond EC Efficiency and Performance

WEBINAR #7

“Wire-to-air efficiency: SynRM² motor technology to optimize system design and performance”

Mark Gmitro, Global Product Manager,
Variable Speed AC Motors, ABB Motors and Generators

Agenda

BALDOR · RELIANCE
EC-Titanium™

- Industry Trends why efficiency is important
- Technology Discussion SynRM^2 Motors (Synchronous Reluctance - Ferrite Assisted)
- Comparison motor technology and efficiency
- IEC Design considerations for SynRM^2 motors
- Lab testing data, partial load efficiency focus
- Fan design impact on wire to air efficiency

Energy efficiencies

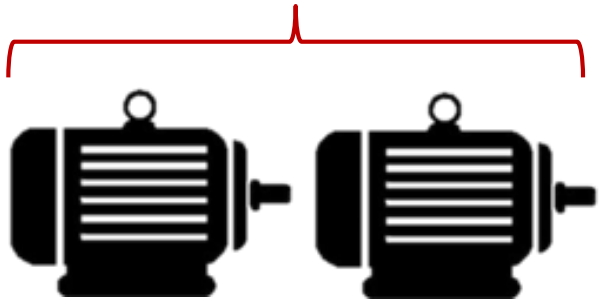
… Did you know?

Motors consume a lot of energy…

Motors consumes about 1/3 of the world's electricity

And it's going to increase..

That number is expected to **double** by 2040



A lot…

…equivalent to adding an electricity market the size of

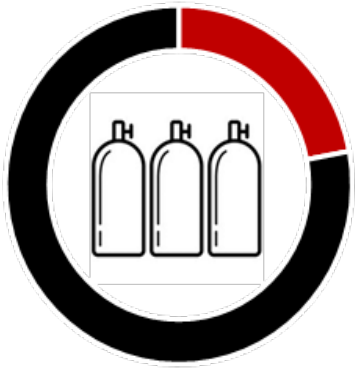
If this is a concern your customers have, we have a new product that will interest you

Energy efficiencies

Who are the biggest users?

In the U.S., **PUMP SYSTEMS** account for **40%** of the total industrial motor systems electricity consumption

In the U.S., **FAN SYSTEMS** account for **20%** of the total industrial motor systems electricity consumption



In the U.S., **COMPRESSED AIR SYSTEMS** account for **22%** of the total industrial motor systems electricity consumption

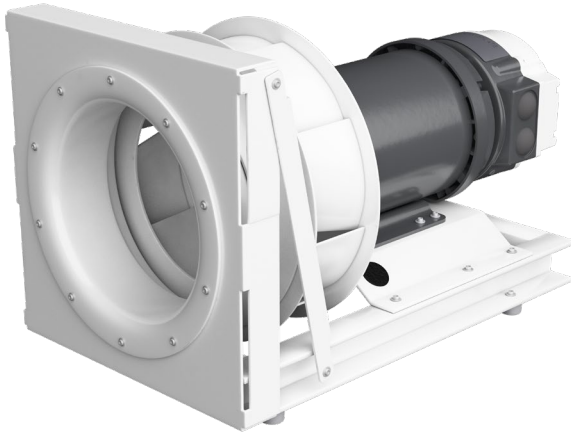
How can I make my operation more efficient?

Motor efficiency

What is the best motor design to optimize efficiency?

- In HVAC efficiency is the top design consideration.
- EC fans have been gaining favorability for high efficient systems.
- Systems using EC technology tend to be limited in design around the motor best operation point, do they results in the highest wire-to-air efficiency?
- EC motors in most cases are brushless DC also known as PM motors, equal to IE4, but the control is not necessarily efficient, causing poor part load conditions.
- More recent designs are tackling these challenges withSynRM^2 (Synchronous Reluctance – Ferrite Assisted Motor technology)
- The SynRM^2 designs provide a broader peak efficiency island (operating range), allowing greater flexibility in matching the motor directly to the Fan or Pumps best efficiency region.

- Real efficiency has to be evaluated based on wire to air efficiency
- Using the right type of motor allows manufacturers to select the best efficiency point for operation of the fan or pump.



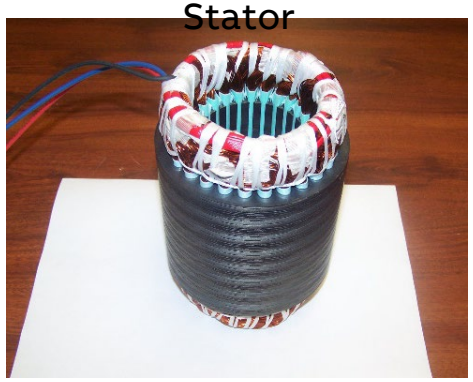
SynRM² Motor Design

SynRM² Motors

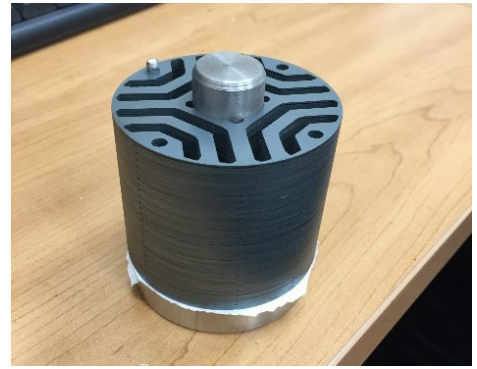
Synchronous Reluctance - Ferrite Assisted Rotor Design

- SynRM² Motors operate on the same principle as induction motors for rotation
- Utilizes a standard induction motor stator winding
- SynRM rotors have flux barriers (air gaps in rotor)
  - Flux gaps direct the flow of current in the rotor
  - Eliminates losses normally associated with induction solid rotors
  - No Loss Rotor = higher efficiency (only losses in stator)
  - Power factor is low in the 70% range
- SynRM² adds Ferrites to Rotor
  - Ferrite materials add to torque generation and field strength
    - No current required ferrites = no losses and added field strength further improves overall efficiency (less losses)
    - Less work stator = lower losses overall = higher efficiency
    - Stator just supplies “torque on demand” beyond ferrite field strength allows optimization of current and partial loads
  - Improves PF to at least 92% and up to 98% range

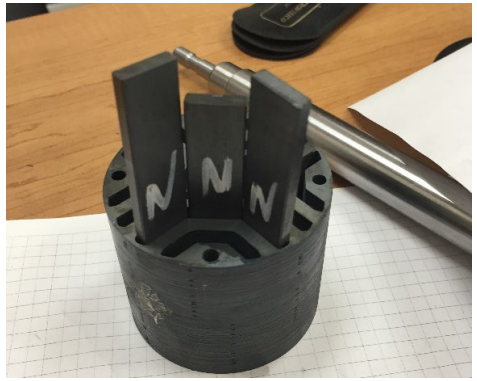
Standard Induction Stator



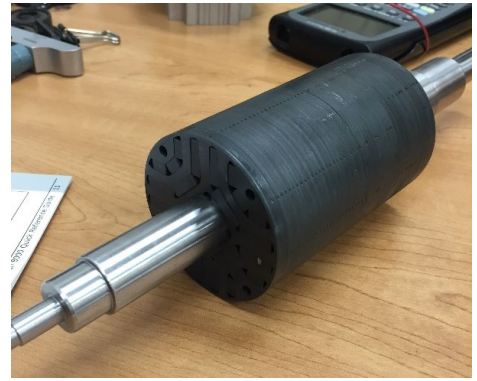
SynRM Rotor



Ferrite Material Added



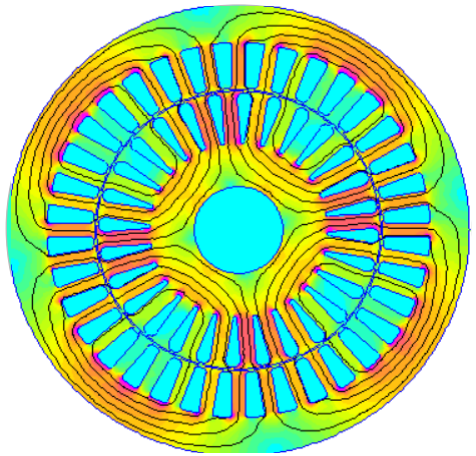
SynRM² Rotor



Energy efficiency bands

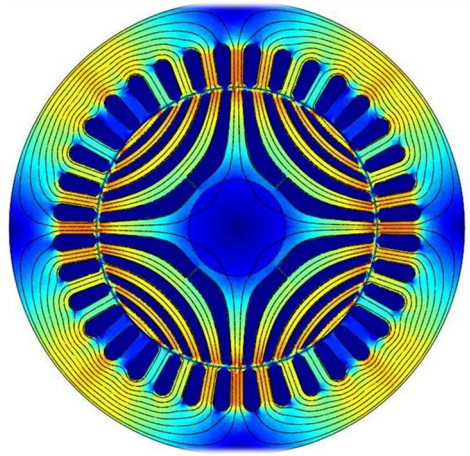
Each band of efficiency = 10% less losses in motor

Induction Motor IE3

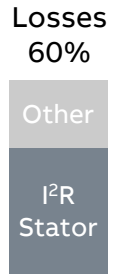


- Slip losses in rotor (I^2R)
- Heats up bearings and motor
- Lower efficiency adds to heat

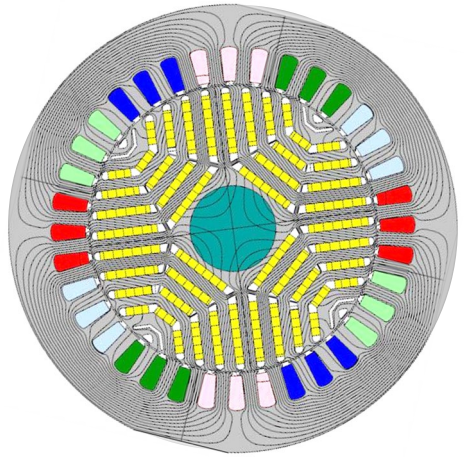
Synchronous Reluctance IE4



- Air gaps rotor direct magnet field lines
- Eliminates circulating currents
- Synchronous, no slip losses in rotor
- High efficiency and low motor temperature



SynRM² - Ferrite Assisted IE5



- Same SynRM rotor benefits with the addition of ferrite material in rotor
- Increases field strength (more lines of flux) less work required stator
- Less overall losses, lower current draw and lower motor temperatures

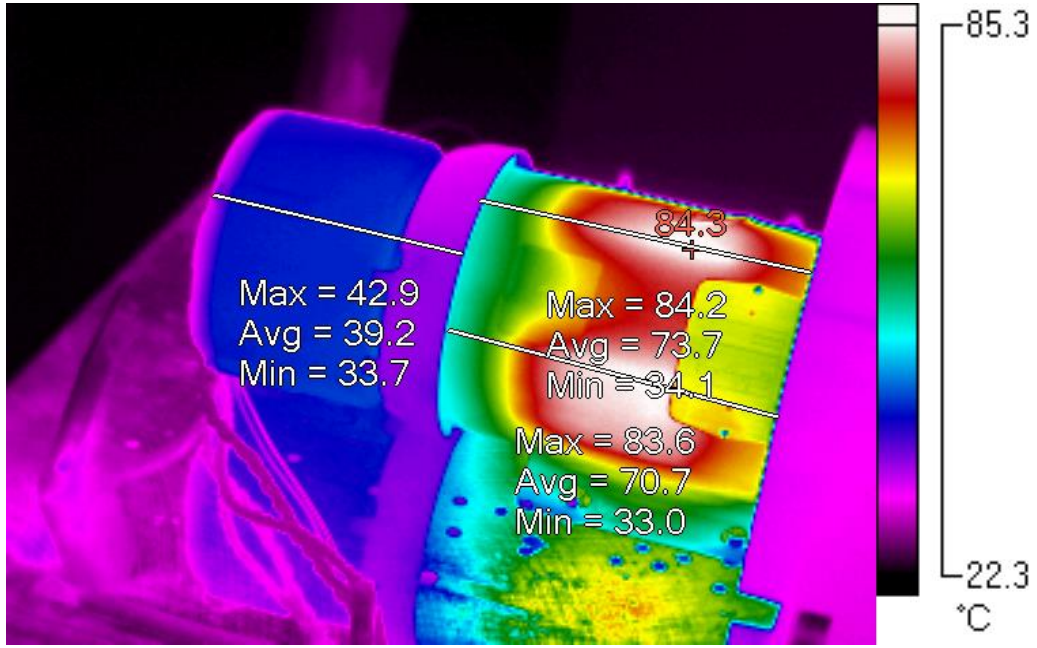
Increasing density magnetic lines of flux (torque per amp)

SynRM² Motor Temperature Rise

Less Losses = Cooler Running Motor

Induction Motor Max Temperature 84.3 °C

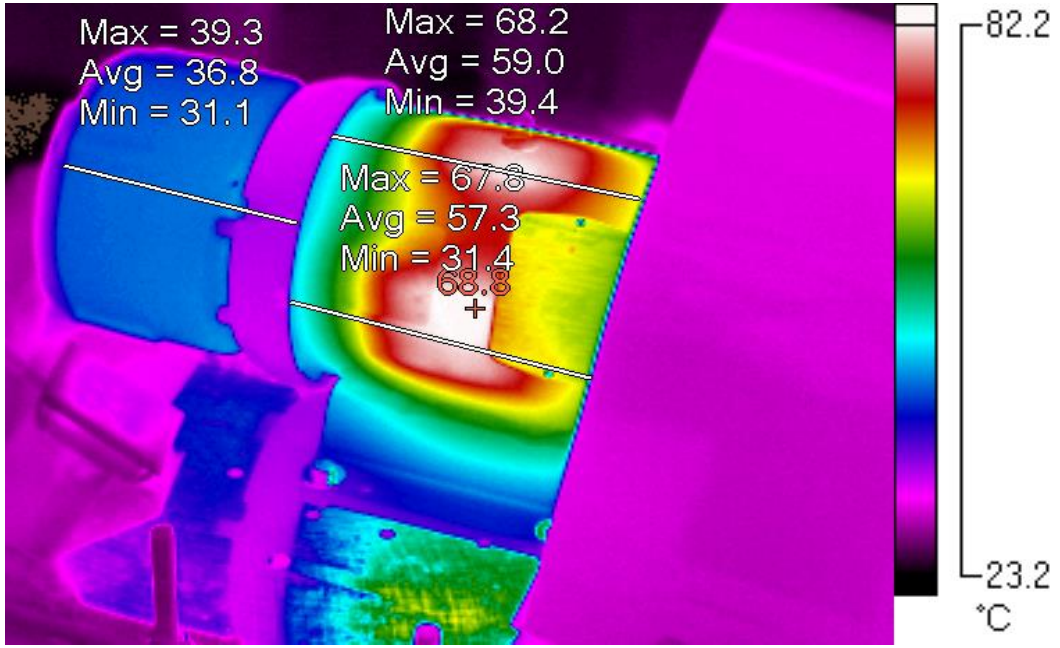
3 HP, TEFC, 1800 RPM Induction with ODE Drive



SynRM² Motor Max Temperature 68.2 °C

3 HP, TEFC, 1800 RPM SynRM² Motor with ODE Drive

16.2 °C lower temperature rise (20% cooler)



Motor Technology Comparison

Induction Motor (IE3)

Benefits

- Familiar and proven technology
- Starts Direct Across Line
- Easy to use and maintain

Limitations

- Speed accuracy difficult without sensors
- Slip losses in rotor (I^2R) adds heat to motor and bearings
- Lower efficiency at lower speed and partial loads
- Drive less efficient at lower loads due no load current

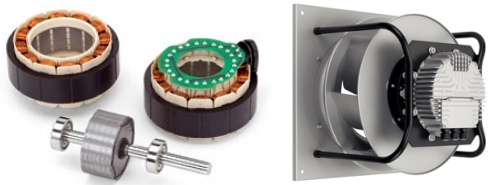
SynRM Motor (IE4)

Benefits

- High Efficiency IE4
- Synchronous Speed
- Low bearing / winding temp.
- High power density
- Magnet Free – No losses rotor
- Easy to use and maintain

Limitations

- Requires Drive (VFD)
- Higher current demand
- Low power factor (~70%)



ECM (IE4 to IE5)

Benefits

- High Efficiency IE4
- Easy to use and maintain
- Well recognized in market
- Compact / light / built in control
- Packaged fan, motor & drive

Limitations

- Requires DC Drive Rectifier
- Lower efficiency at part speed / load inefficient power converter
- Must replace entire unit with fan, restricts OEM fan designs
- Rare earth magnets

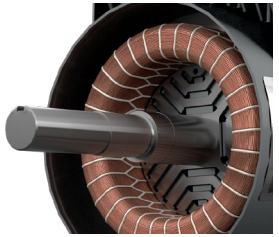
Interior PM (IE5)

Benefits

- Very high efficiency IE5
- High torque density
- Excellent torque to inertia ratio
- Excellent PF
- Excellent partial load efficiency
- Low noise levels

Limitations

- Rare earth magnets / high cost / limited availability
- Difficult service (high magnet strength)
- High back-EMF (safety concern)
- Requires VFD



SynRM² (IE5)

Benefits

- High Efficiency: IE5+
- Synchronous Speed
- Sustainable Ferrite material
- Low bearing / winding temp.
- Excellent Power Density
- Lower current draw requires smaller power converter
- Maintains efficiency at low speed and partial loads
- High PF (above 90%)

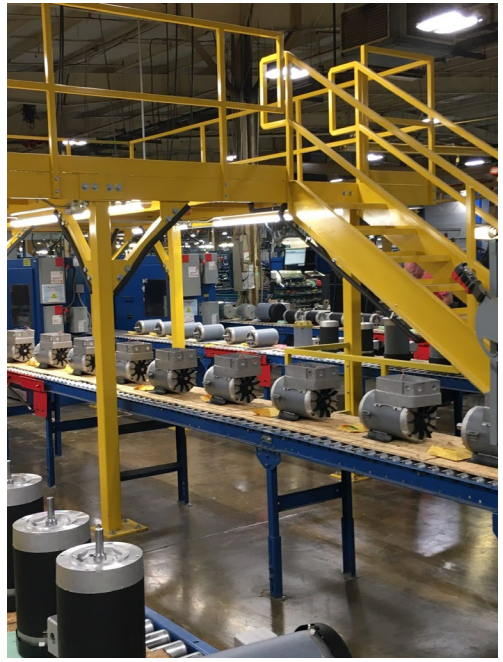
Limitations

- Requires VFD

SynRM² Motors

Summary Technology

- SynRM² motor technology employs **ferrite materials**
  - Readily available, price stable, and environmentally sustainable ceramic magnet material
  - Best motor in terms of cost and performance you can design using ferrite material
- Design allows **maximum utilization of the active materials**: electrical steel, copper and ferrites
  - Achieves extremely high efficiency and performance, very low losses in motor
  - Suitable for constant and variable torque applications
  - Performance is excellent in the constant power range.
  - **“Flat” efficiency map**; efficiency stays high at any speed and also at partial load
- Design is characterized by **high power factor**
  - Above 90% leading to the best utilization of the power converter
  - **Lower amp draw** per rating than induction motors = **smaller drive converter** required
- SynRM² motors share the **same building blocks as standard induction motors**.
  - Guarantees extreme high production capacity, manufactured Fort Smith, AR
  - High product configurability and versatility for applications



IEC Efficiency Standards

IEC Nominal Efficiency Limits

IEC 60034-30-1 Standard

IEC Efficiency Standards

IEC 60034-30-1 Standard

- Direct Line Motors or VFD
- Standard Induction Motors & Line Start PM
- IE1, 2, 3, 4

IEC 60034-30-2 Technical Standard (New)

- Frequency Converter Only
- SynRM, SynRM2 (FA), Permanent Magnet Motors
- IE1, 2, 3, 4, 5

The purpose of IEC/TS 60034-30-2 is to create a level playing field between established and new, innovative motor technologies in order to enable fair competition and market development.

Efficiency Bands

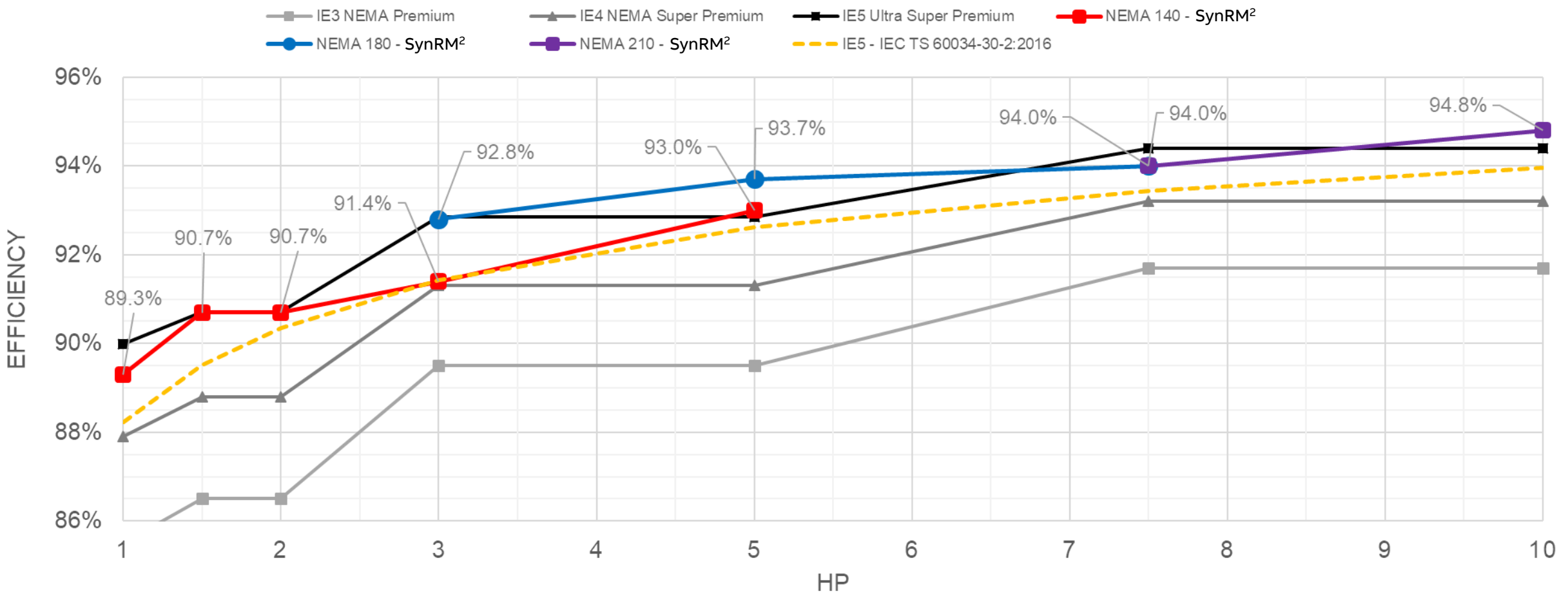
- IEC Defines Efficiency Bands Internationally
- NEMA Energy Efficiency in United States
- Each band of efficiency equates to 10% less motor losses

IEC	NEMA
IE1	Standard Efficient
IE2	High Efficiency
IE3	Premium Efficiency
IE4	Super Premium
IE5	No Standard

Each band of efficiency = 10% less motor losses

SynRM² motors meet or exceed IE5 efficiency level

IE5+ Motors for variable speed drive applications



IEC and NEMA SynRM² Motors

Comparison Ratings

IEC 1500 RPM 50 HZ Designs

Catalog Number	IEC Motor Data @ 1500 RPM 50 HZ						
	Motor Input Voltage	kW	Motor Frame	IEC Frame	Efficiency	Motor PF 1st HRM	Motor Input Current
ECS101M0H1DF4	190/380	0.746	140	80/90	86.3%	97%	2.6/1.3
ECS101M0H2DF4		0.746		80/90	90.6%	96%	2.8/1.4
		1.5		80/90	88.2%	96%	5.2/2.6
ECS101M0H3DF4		1.5		80/90	90.9%	85%	6.8/3.4
		2.2		80/90	89.1%	95%	8.8/4.4
ECS101M0H3EF4		2.2	180	100/112	91.4%	97%	8.4/4.2
ECS101M0H5DF4		2.2	140	80/90	94.3%	98%	8.4/4.2
		3		80/90	92.7%	97%	10.4/5.2
ECS101M0H5EF4		3	180	100/112	93.2%	97%	9.6/4.8
		4		100/112	92.3%	98%	12.8/6.4
ECS101M0H7EF4		5.5		100/112	93.3%	96%	19.2/9.6
ECS101M0H7FF4		5.5	210	132	93.6%	97%	19/9.5
ECS101M0H10FF4		7.5		132	94.5%	96%	27.2/13.6
ECS101M0H15FF4		11		132	94.8%	95%	39/19.5
ECS101M4H20FF4	380	15		132	93.8%	93%	26.1

NEMA 1800 RPM 60 HZ Designs

Catalog No.	Motor Data @ 1800 RPM 60 HZ						IE3 Induction Motor Current
	Motor Input Voltage	HP	Motor Frame	Efficiency	Motor PF 1st HRM	Motor Input Current	
ECS101M0H1DF4	230V/460V	1	140	89.30%	96.60%	2.3/1.2	3/1.5
ECS101M0H2DF4		2	140	90.70%	96.00%	4.5/2.3	5.6/2.8
ECS101M0H3DF4		3	140	91.40%	94.90%	7.0/3.5	
ECS101M0H3EF4			180	92.80%	96.60%	7.3/3.7	8.2/4.1
ECS101M0H5DF4		5	140	93.00%	97.30%	10.4/5.2	
ECS101M0H5EF4			180	93.70%	97.30%	10.5/5.3	13/6.5
ECS101M0H7EF4		7.5	180	94.00%	94.30%	17.5/8.8	
ECS101M0H7FF4			210	94.00%	92.30%	17.4/8.7	19/9.5
ECS101M0H10FF4		10	210	94.80%	93.70%	22.0/11.0	25/12.5
ECS101M0H15FF4		15	210	95.60%	97.20%	34.8/17.4	36.2/18.1
ECS101M4H20FF4	460	20	210	95.90%	90.50%	21.6	24

Efficiency Test Data

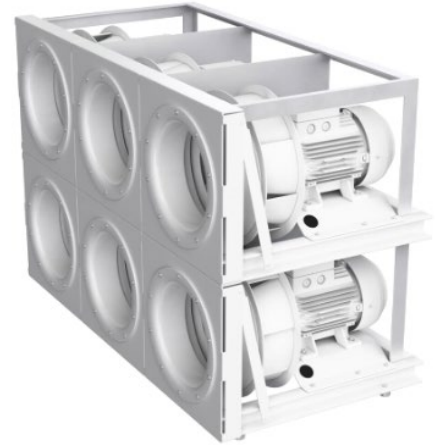
Energy savings in practice

Why wire-to-air efficiency is critical

- Most HVAC systems operate at 80% load or less more than 99% of the time
- Systems should be optimized for part load operation and energy consumption should be documented at the actual load points

Factors impacting system wire-to-air efficiency

- Fan or Pump Design is the most important factor in optimal wire-to-air efficiency and while impact total wire-to-air efficiency more than the motor in of itself (the FASR motor allows flexibility to pick the best system design)
- The motor and the fan in the package might be efficient, but if the motor is blocking the airflow through the fan or there is air interference between fans, then wire-air efficiency drops
- Many fan designs today are only sold as a package, efficiency of each component is unknown
- If the drive controlling the motor isn't efficient under part load conditions, then 1 + 1 might equal 1.5, however motor control efficiency has been developed over several years
- Using variable frequency drives, it is possible to over speed (ex. +15% on nominal speed) for the 1% of peak requirement (flat efficiency region but increased audible noise)



Design of the Fan or Pump is the primary contributor of the overall wire-to-air efficiency

SynRM² Motor

Energy efficiency system savings

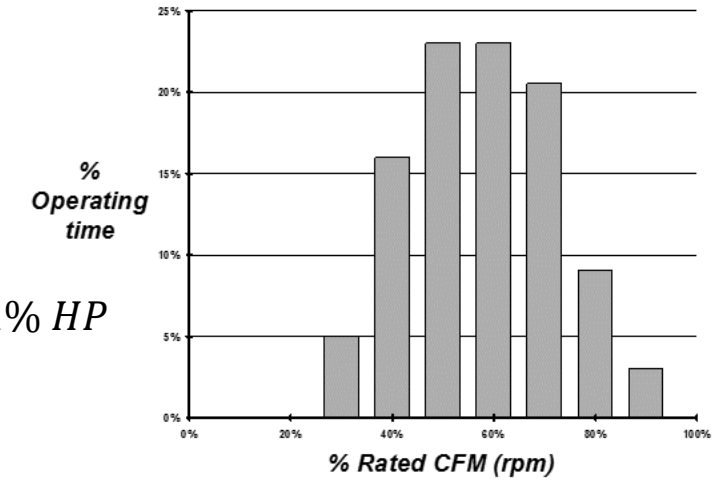
Affinity laws and energy savings

Variable speed control takes advantage of the affinity laws:

Flow is proportional to speed

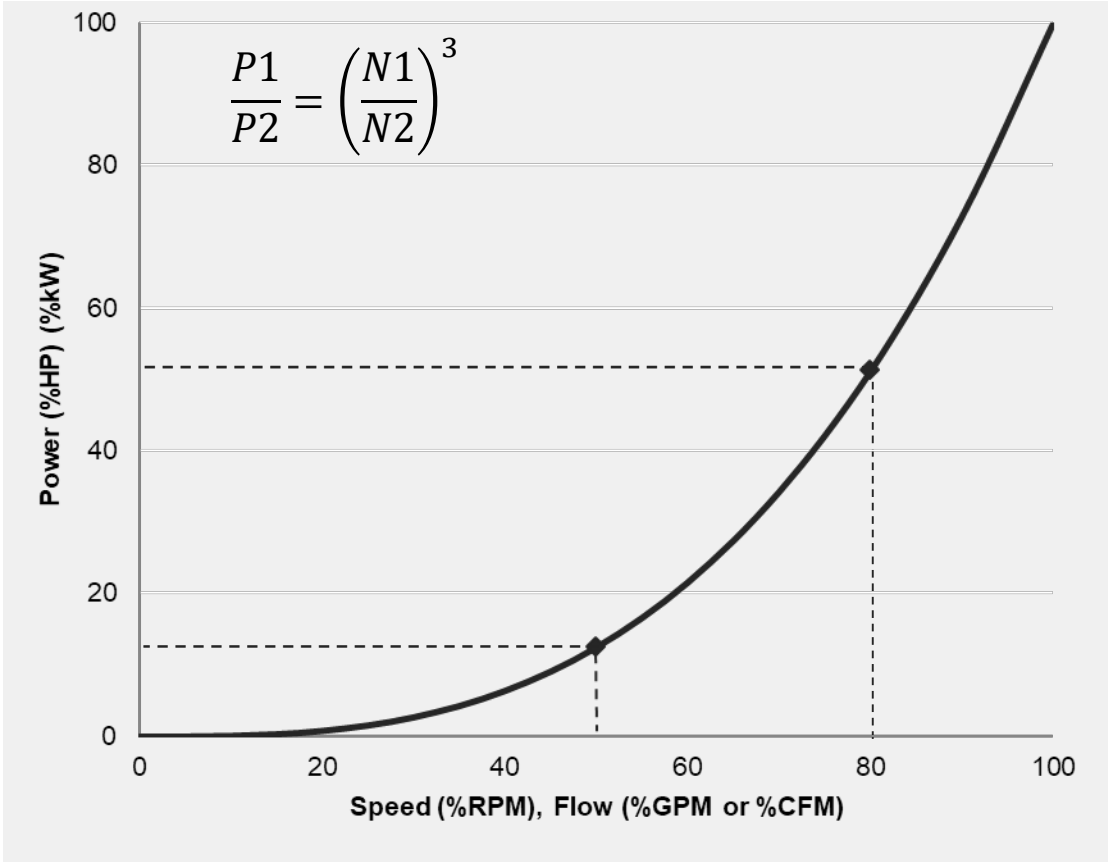
Power is proportional to the cube of speed:

$$\frac{P1}{P2} = \left(\frac{N1}{N2}\right)^3$$



Example: 80% flow:

$$(0.8)^3 = 0.512 \; or \; 51\% \; HP$$



Efficiency versus load

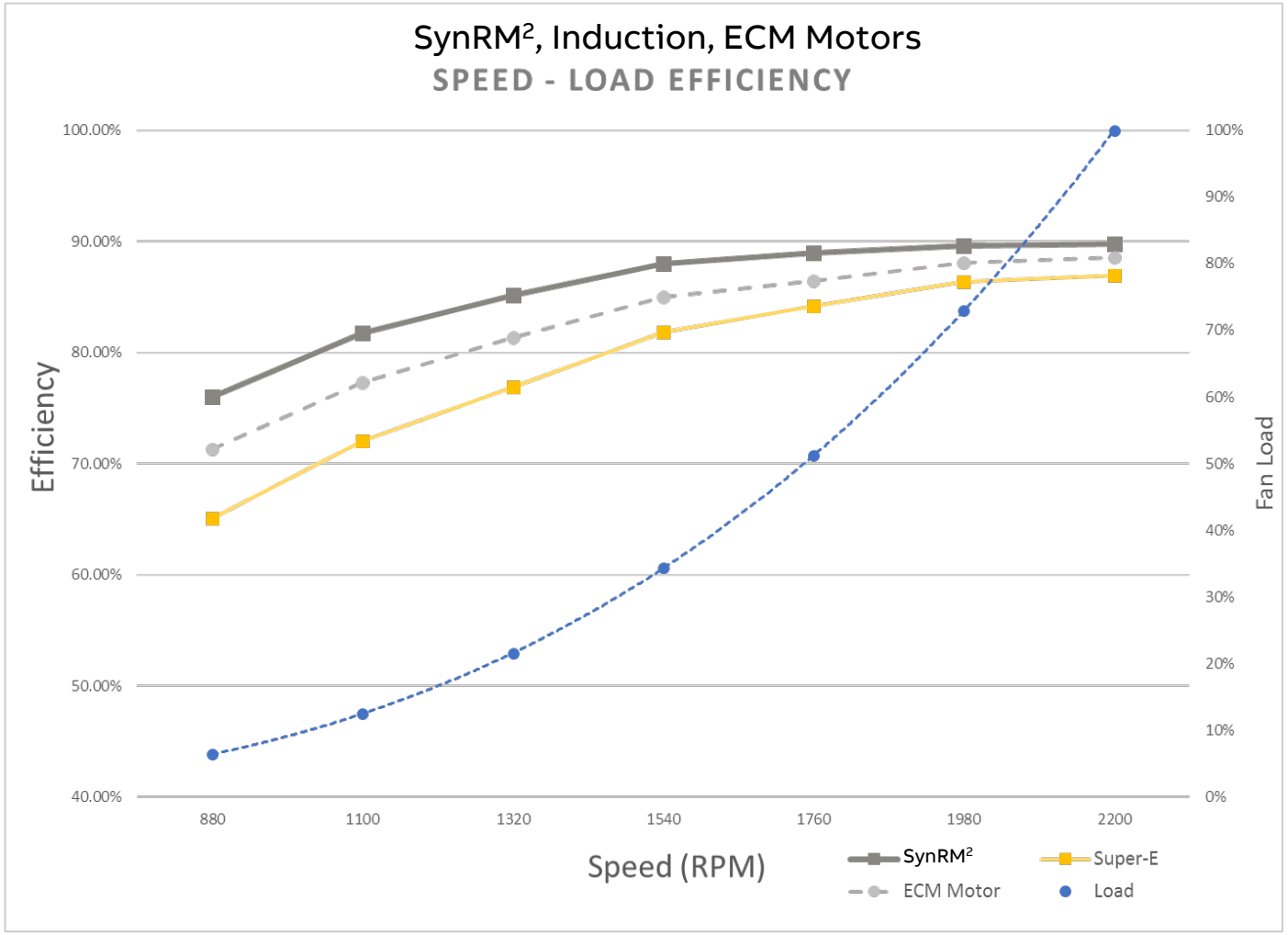
SynRM², ECM, Induction Efficiency

System Efficiency (Motor + Drive)

Lab test including losses in power converter

3 HP, 1800 RPM base speed, 2200 RPM top speed
Variable Torque Load Profile

- Superior efficiency performance over other motor technology at rated and partial load speed points
- SynRM² wider speed torque range with higher efficiency allows more flexibility to match a fan impeller and reach a nominal fan duty point
- Other motor technology may have high efficiency, however it may be over a more a restrictive speed and torque range
- Potential to operate at higher speeds (constant horsepower range)

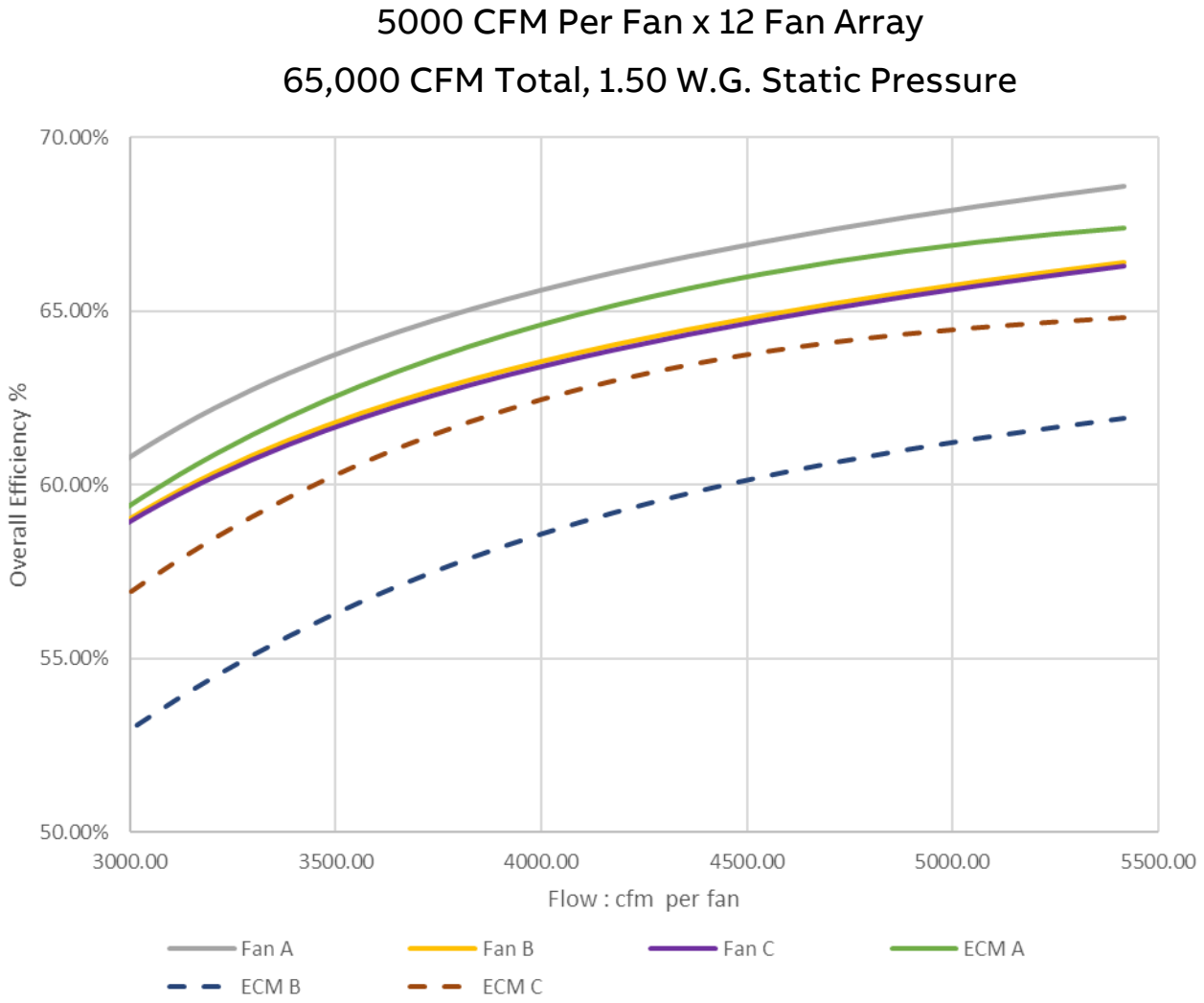


Fan Design Considerations

Fan Design Considerations

Optimizing System Design & Flexibility

- SynRM² motors provide a wide best efficiency region (BER)
  - Allows the best fan design with highest efficiency to be selected and the motor fitted to this curve, optimizing wire-to-air efficiency
  - SynRM² motors maintain efficiency at partial load and speed
  - Allows operation above speed in a flat efficiency region
  - Individual ECM fans may be more efficiency, however the high efficiency SynRM² motor still comes out ahead
- ECM Fan Designs
  - The EC Motor best operating efficiency region is limited
  - Requires fan design be fitted to motor operating region
  - Depending on loading you may need to step up to the next size ECM unit, which causing the system to run partial loading and loose efficiency due to inefficient dc power converter



SynRM² Motor Efficiency Map

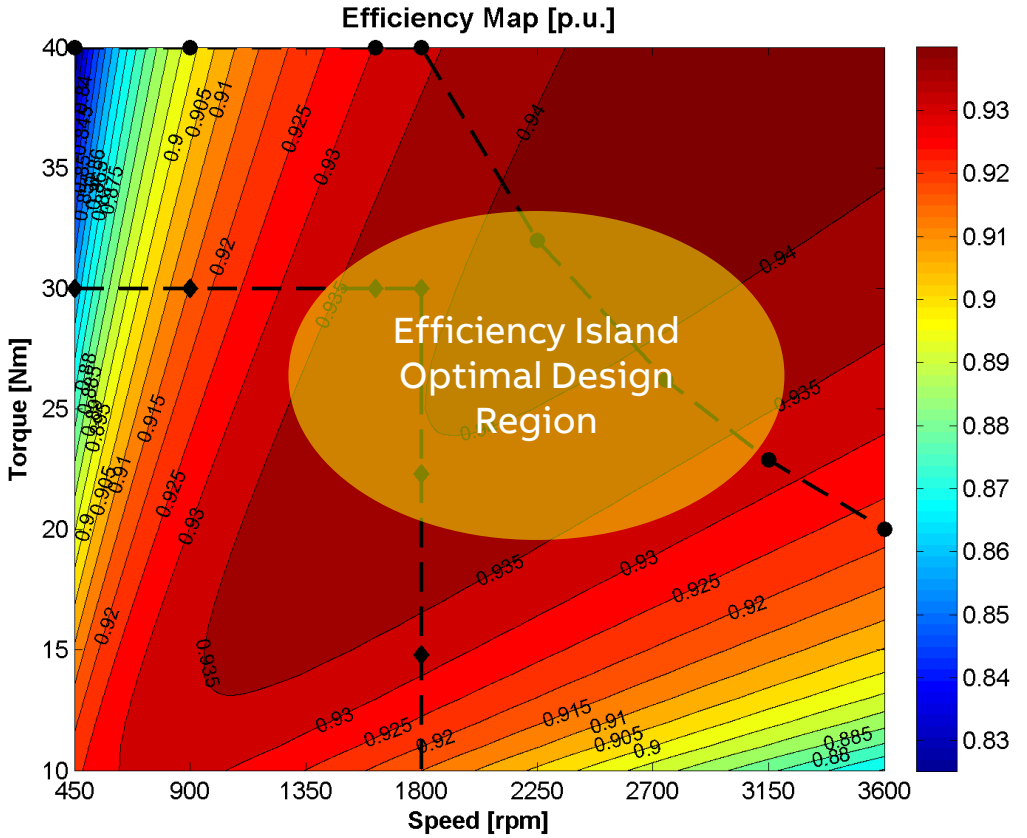
Best Efficiency Region – Efficiency Island

NEMA 180 – 7.5 Hp – Efficiency Map – 1800 RPM

Speed [rpm]	Torque [Nm]	Power [Hp]	V [V]	I [A]	η [%]	PF [%]	TR [K]
450	29.7	1.9	117	8.7	86.6	91.1	66
900	29.7	3.8	226	8.7	91.4	91.6	62
1620	29.7	6.7	405	8.8	93.6	92.0	61
1800	**29.7**	**7.5**	**446**	**8.8**	**93.8**	**92.3**	**60**
1800	22.3	5.6	408	7	93.9	92.5	41
1800	14.8	3.7	365	5.1	93.1	92.1	29
1800	7.4	1.9	299	3.1	90.4	94.4	18
1800	**39.6**	**10**	**473**	**11.2**	**93.5**	**93.0**	**85**
2250	31.7	10	476	9.9	94.3	96.2	70
2700	26.4	10	470	9.9	93.9	98.9	64
3150	22.6	10	476	9.8	93.1	99.5	64
3600	19.8	10	475	9.9	92.4	99.6	63

IE5+ **IE4+**

Select different base speed motors 900,1200, 1800, 3600 RPM to shift island to fit the fan curve and optimal best efficiency region



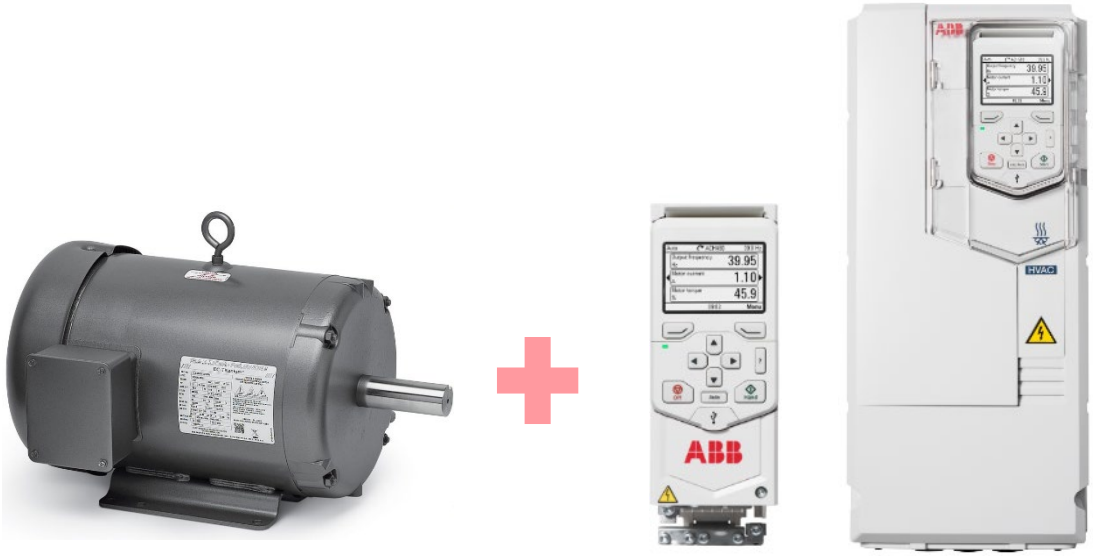
SynRM² Motor and Drive

Best of both worlds – Standard Frame Motor & Component Drives

ABB Drive and EC Titanium motor

- Superior performance and low speed operation
- Optimized Partial Load Efficiency
- Over-speed Constant Horsepower Range operation
- Integral harmonic mitigation (5% DC link choke)
- Ultra Low harmonics compatible
- Wide range network interfaces
- Extensive Pump and Fan Drive Features
- Motor Ground Brush Standard

SynRM² motor and ABB ACH480 / ACH580 drives



Standard discrete components are easy to integrate, readily available and allow drop in replacement and ease of service

EC Titanium – SynRM² Product – Summary

Baldor-Reliance® EC Titanium™ - SynRM² Motor Technology

Top Mount IMD

1 – 10 HP	NEMA 140, 180 & 210 frames	
1-Phase Input	1HP 115V	1-2 HP 230V
3-Phase Input	1-3HP 230V	1-10HP 460V

Motor only

1 – 20 HP
NEMA 140, 180, and 210 Frames
230V/460V 3-Phase input

Axial Mount IMD

1 – 7.5 HP	NEMA 140 and 180 frames	
1-Phase Input	1HP 115V	1-2 HP 230V
3-Phase Input	1-3HP 230V	1-7.5HP 460V

Ultra Efficient - Innovative Magnet Technology – Sustainable – Reliable - Wirelessly Connected

Baldor-Reliance® EC Titanium™ - SynRM² Motor Technology

Features that improve performance

IE5 Efficiency – Stay Ahead of the Curve

- High Total System Efficiency at full and partial load

Minimizing your Environmental Impact

- Sustainable Non-Rare Earth Magnet Material
- IE5+ Efficiency – Low Energy Use

Together as One – Cut the Cord

- Integrated motor & drive
- Eliminate expensive wiring and installation time
- Reduce personnel risks and access hazards
- Reap the benefits of pairing the drive together for better energy efficiencies

Plug and Play

- Pre-programmed motor & drive to run out of the box
- Easy Start-up – Keypad, PC or Mobile Tools (option)
- Bluetooth Option for ABB Ability™ and Mobile Tools

Reliability & Low Noise

- Extremely low starting current and less cogging Reduces mechanical stress and produces ultra- quiet operation

Power Density

- Higher ratings per frame size than traditional motor designs
- Reduces cost and saves valuable space

Energy savings in practice

Why wire to air efficiency is critical – OEM Voice Customer, Comments & Feedback

- As an OEM, the total system efficiency (or end-result) is the primary focus for improvement.
- The United States Department of Energy (DOE) has been trying to pass legislation to various industry segments and applications to improve energy efficiency of industrial equipment
- At what point does regulation get in the way of innovation?
  - "There's been a push from AMCA to mandate 'wire to air' test to calculate how much power a fan uses.
  - A fan-alone legislation would hurt innovation. When you put a fan in a unit, it changes the performance.
  - Component metrics already exist for motors, so we're trying to keep the DOE from adding more efficiency metrics"
- So why is motor efficiency such a hot topic? There are many reasons to target the motor:
  - It consumes a lot of energy and roughly 50% of electricity consumption in systems is by motors.
  - By targeting the component, equipment designers can still design their equipment to improve overall system efficiencies.

"The efficiency is part of the story - this product has a lot more capabilities - more flexibility"

"basically, allow us to innovate, to the end-result, but don't specify components because it hurts innovation"


ABB