Hybrid Motor Technology to Achieve Efficiency Levels Beyond NEMA Premium

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ABSTRACT

This paper will discuss the latest advances in AC motor design that combines induction with permanent magnet (PM) synchronous technologies, to achieve efficiency performance levels two to four bands beyond the current National Electrical Manufacturers Association (NEMA) premium efficiency criteria.

Numerous aspects of the hybrid motor technology will be presented including efficiency performance, starting and running characteristics, sine wave and adjustable frequency power operation and motor repair considerations. Application considerations will also be presented to help identify those applications that are most ideally suited for this technology.

This paper will also compare the characteristics of the hybrid motor technology to other motor technologies.

Hybrid Motor Technology

Industrial users have lead the way in driving the motor industry to develop and offer more energy efficient AC motors in an effort to help reduce manufacturing costs. Motor technology has evolved from standard efficient motors to energy efficient motor into today's premium efficient motors. The United States Government has follow this industry lead with regulations that now require all motor manufacturers to build exclusively premium efficient motors, also known as table 12 – 12 in the NEMA standards, for general purpose applications with only a few specialty motor exceptions allowed. In the global International Electrotechnical Commission (IEC) markets these energy levels are defined as IE1, IE2 and IE3 respectively.

One way to increase motor efficiency without increasing the motor size and also be able to offer a conventional design B motor is to combine the technologies of an induction motor with an interior permanent magnet (PM) synchronous motor into a hybrid motor. This hybrid technology uses a conventional induction rotor cage to bring the motor up to its slip speed just like any traditional induction motor. Once at slip speed, the powerful interior magnets pull the rotor into true synchronous speed with the rotating magnetic field. The transition from slip speed to full synchronous speed results in the elimination of the rotor secondary circuit. The net result is the elimination of the secondary (rotor) I^2R losses and a significant improvement in efficiency. The motor then runs at true synchronous speed without any slip regardless of the motor load or motor temperature unlike the induction motor. Another advantage is that unlike traditional PM motors that generally require a feedback device and a drive control these hybrid motors start and run across the line without any feedback device required. Sometime these motors are call "line start PM motors" or "LSPM" due to their ability to run on sine wave power.

The diagram below (Figure 1) shows an example of the hybrid rotor interior with both the induction cage and permanent magnet rotor construction.

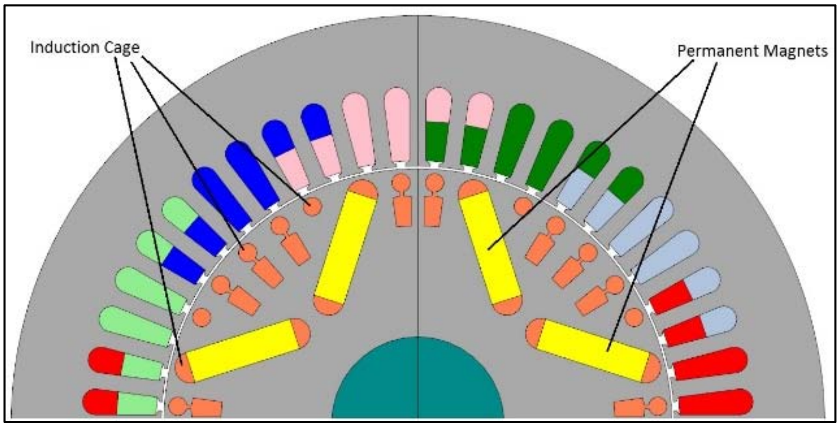

Figure 1. Interior View of Rotor Design

Unique Operating Characteristics

The hybrid motor has several distinctive characteristics:

Motor efficiency. Hybrid motors can provide efficiency levels two to four NEMA efficiency bands above premium efficiency levels. In addition these efficiency levels can be achieved staying within the NEMA design B torque and inrush current limitations. Both efficiency and power factor are significantly improved even under low load conditions.

Replacement: The motor can be a drop in replacement for a traditional induction motor and are most suitable for centrifugal fan, centrifugal pump and centrifugal compressor applications.

No feedback device required. This type of motor will always run at true synchronous speed. Therefore a four pole motor running on 60Hz sine wave power will always run at precisely 1800RPM. On inverter power the motor will run at the precise output frequency of the drive. No feedback device is required.

Motor coupling. During starting the hybrid motor is working to “catch” the rotating magnetic field of the winding. Because of the imbedded magnets in the rotor the motor will experience transient torque pulses during acceleration. Although not noticeable, with highly repetitive starting, these torque pulsations may cause coupling damage. Therefore it is necessary to select a proper coupling to prevent premature coupling failure. The ‘tire style’ couplings have proven to be an excellent coupling for this type of motor. Once the motor is up to full synchronous speed these transient torque pulsations are no longer present.

Soft starting with adjustable frequency drive. The LSPM hybrid motor will always run at true synchronous speed regardless of the application load applied. Unlike an induction motor the motor speed does not vary with motor temperature heating or the applied load.

Inertia starting considerations. When applying on sine wave power, knowledge of the application inertia is also important because the motor must "pull" the rotor into synchronization with the load. Because the starting inertia limitation are somewhat lower than the very generous NEMA standards starting high inertia loads can be problematic. Inertia starting limits are established by rating by the motor manufacturer. Starting most centrifugal applications should not be a problem. Application synchronization capability is also adversely affected by the motor temperature (hot motor) and low voltage line conditions. For high inertia starting applications using a mechanical soft start coupling or running with an adjustable frequency drive will resolve these issues. See the next topic on advantages of running on adjustable frequency (AF) power.

Regenerative nature. All PM motors are regenerative in nature. This means that even with the motor not being under power if the shaft is turned or driven by the application the motor will produce voltage. This voltage known as back or counter EMF (Cemf) and is directly proportional to the shaft rotating speed. In other words the PM "motor" make as ideal generator when back drive by the application. The full speed Cemf is generally somewhat lower than the motor nameplate rated voltage. This is the reason that PM technology is widely used in the wind generation applications. Another interesting characteristic of the PM machine is that when not running if any two of the three power leads are connected or touching each other the permanent magnets acts as a brake and help prevent the motor shaft from turning. Being regenerative necessitates that additional safety awareness is need for applications that can 'back drive' the motor. This is very common in fan applications where the wind or back draft from other fans in a fan array can act to drive the motor. The "motor" then becomes a generator.

Advantages When Running on Adjustable Frequency Power

There are numerous advantages to running the LSPM motors on adjustable frequency power.

The combined system efficiency of both the drive and the motor will result in a premium efficiency solution. Because of the high efficiency nature of the motor the additional losses of the drive and increased motor losses due to the PWM power still results in a solution that can achieve premium efficiency levels as a total system.

All of the issues with inertia starting limitations and transient starting torque are eliminated because the motor is always held in synchronous speed control. On inverter power you can even exceed the NEMA sine wave inertia starting limits by holding the drive at full load current limit during acceleration.

The motor will work with any drive running in scalar or Volts/Hertz mode. Therefore no special drive firm ware is required.

- Due to the motor's inherently low full load amps the drive can most often be down sized helping to offset the motor's price premium.
- Providing smooth starting performance results in reduced mechanical stress on the application providing longer life.
- Applications can be speed controlled and optimized for optimal energy savings.
- The motor runs cooler for extended motor insulation and grease life.
- The motor always runs at true synchronous speed based upon the output frequency of the drive and therefore does not require a speed feedback device.

Application Considerations and Recommendations

The LSPM motors are ideal for centrifugal fan, centrifugal pump and centrifugal compressor applications. They are not recommended for high slip applications (punch press) or applications requiring a wide constant torque speed range or wide constant horsepower speed range above base speed such as winder applications.

OEMs may choose to take advantage of the precise speed nature of the LSPM motor by optimizing their equipment around the motors true synchronous speed versus the verifying slip speed of the induction motor.

It is important to know the application inertia starting requirements or consider using an adjustable frequency drive.

Consult the motor manufacturer for application guidelines including starting inertia capabilities (cold and hot), low voltage starting capabilities and recommended coupling selections.

Increased Energy Consumption at Synchronous Speed on Sine Wave Power

Because the motor is operating at true synchronous speed the motor will be running at a somewhat faster speed than an induction motor. A centrifugal application running on sine wave power will result in an increase in the fan, pump or compressor output. Since load is also increasing as output increases the input power is also increasing. In fact the input power requirements are increasing or decreasing as a cubic function of the speed. This increase in speed, application output and resulting increasing in motor power consumption may not be desirable. This is the same effect seen as the motor industry moved from standard efficient, to energy efficient, to premium efficient motors. The motor slip speed increased with each design iteration. The solution of course is to use an adjustable frequency drive to optimize the speed, application output requirements and energy savings as described above.

Comparison to Other Motor Technologies

The following Table 1 is a comparison of different motor technology characteristics.

Table 1. Motor Technology Characteristics

Characteristic	Induction	Interior PM	Hybrid Ind + PM
Operating Speed	Slip Speed	Synchronous	Synchronous
Sine Wave Power Operation Capable	Yes	No	Yes
Suitable for AF Power	Yes	Controller Required	Yes
Special Software required for AF Power Operation	No	Yes	No
Sine Wave Efficiency	NEMA Premium	N/A	2 - 4 Bands above NEMA Premium
Inertia Starting Limitations – Sine Wave Power	NEMA Standards	N/A	Special
Regenerative in Nature	No	Yes	Yes

Motor Repair Considerations

The LSPM motor is identical to a traditional induction motor except for the rotor construction. In other words the winding repair and bearing repair is identical to an induction motor. The rotating assembly will have a strong magnetic pull so for safe removal it is recommended that it be pulled out vertically with a hoist to overcome the magnet strength. Likewise in a similar fashion, when replacing the rotating assembly lower it slowly using a hoist down into the stator winding. The magnet symmetry will keep the rotor center within the stator housing so rotor rub is not an issue during removal or reinstallation. Once the rotating assembly is removed it needs to be kept clean and away from any metallic particles. It is very difficult to remove any metallic particles once they adhere to the outer rotor surface due to the strong magnetic forces of the interior magnets.

Always follow the manufacturer's operation manual for safe and proper repair procedures.

The rotor should never become demagnetized. However, if a demagnetizing condition does occur a new rotor or rotating assembly (shaft with rotor) will need to be sourced from the original motor manufacturer. It is extremely difficult to re-magnetize a rotor back to its original strength once it has been demagnetized. The most accurate method to determine if a rotor has become demagnetized is to measure the Cemf at full speed and compare to the manufacturer's Cemf defined value.

Example Case Studies and Economic Justification

The following independent case study was performed by a large user on their 75 HP cooling water pump being driven by an adjustable speed drive (ASD). Table 2 defines the application and motor ratings.

Table 2. Application data

Application	Cooling Water Pump
Operation	ASD
Rating	75 HP, 1800 RPM
IM	365T, TEFC, 1781 RPM, 460V, 86 A, 95.4% Efficiency, 85.6% PF
LSPM Motor	365T, TEFC, 1800 RPM, 460 V, 73 A, 96.8% Efficiency, 99.2% PF

In this case, the existing induction motor (IM) was being operated on an adjustable speed drive (ASD). The IM was replaced with the LSPM motor and operated on the same ASD. The only changes made to the drive input setting were rated current and speed. Data was taken at various speeds from 450 RPM through 1800 RPM for both the IM and CRPM motors. The power measurements were made at the input to the ASD so that any losses associated with the ASD would be included. As such, this case is a comparison of the system energy reduction achieved by using the LSPM design. As indicated in Table 3 and Figure 2, the power consumption for the system with the LSPM design was significantly lower than for the existing IM/ASD combination. The inclusion of the ASD allowed the operation of the LSPM motor at the exact same speeds as the IM, eliminating the "extra" flow and power consumption that would occur if running on sine wave power.

Table 3. Case Study test data

Motor	V	A	kW, in	RPM
IM	473	62.6	48.12	1800
CRPM	477	59.3	46.04	1800
IM	474	62.1	47.82	1797
CRPM	476	59.0	45.89	1797
IM	474	24.1	17.82	1350
CRPM	77	22.6	16.97	1350
IM	474	7.3	4.49	900
CRPM	478	6.5	4.04	900
IM	474	2.7	1.46	450
CRPM	477	2.1	1.17	450

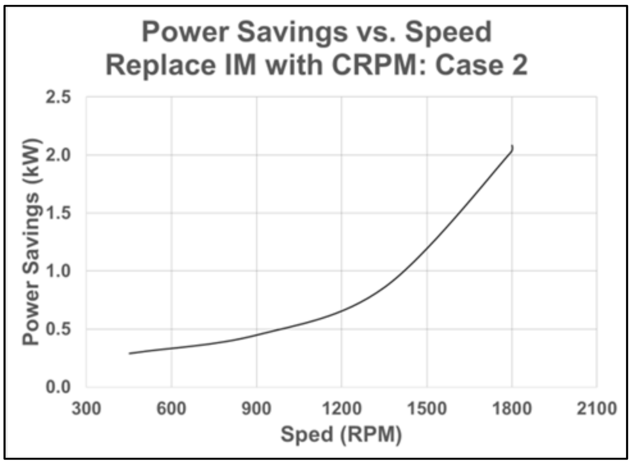

Fig. 2 – Power savings vs. speed

Figure 3 on the following page shows the cost savings per year achievable by making this motor change operating under the following conditions: full speed operation 70% of the time, 75% speed operation 20% of the time and 50% speed operation 10% of the time. Depending on the cost of electricity, savings of $2200/year could be achieved on this 75 HP installation. Analysis such as this can be used when deciding to purchase a LSPM or IM for a particular application.

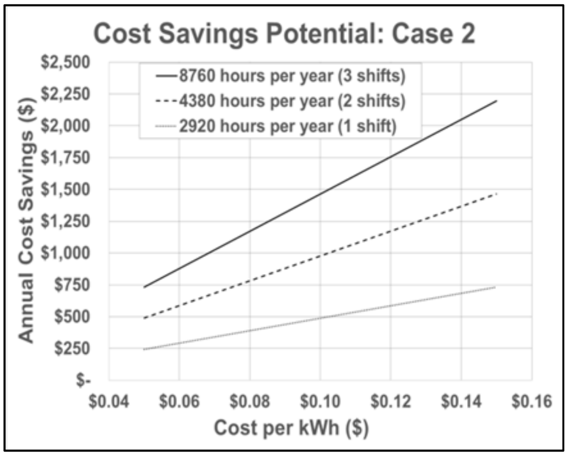

Fig. 3 – Cost Savings Potential/Year

Additional case studies run under different operating conditions can be found in (McElyeen Jr. 2017).

Summary

In an effort to improve motor efficiencies the motor industry is developing the next generation of industrial motor that combines the advantages of an induction motor with that of a synchronous (PM) motor. These new hybrid motor designs can operate successfully on either sinewave or adjustable frequency power supplies. These motor are best suitable for centrifugal pump, fan and compressor applications. They can be found in both standard NEMA frame sizes as a "drop in replacement" or in power dense versions where space is limited.

Conclusions

No one single motor technology solution is ideal for all applications. Knowledge of the application, performance requirements and energy consumption must all be taken into account when properly selecting any motor. Advances in motor technology continue to provide the industrial and commercial markets with a wide range of choices. Just like the automotive industry is moving to hybrid cars combining the internal combustion engine (ICE) with electric motor technology for improved fuel efficiency the motor industry is now starting to combine induction motor technology with synchronous PM motor technology to achieve a quantum step in efficiency and power factor improvement. Understanding of these different motor technologies is needed to properly and successfully select the right motor for the desired application.

References

Robert F. McElveen Jr., P.E. and Richard Holub and William E. Martin, 2017, "Replacing Induction Motors with Caged Rotor Permanent Magnet Motors: Application Considerations & Cost Analysis", IEEE copyright material.