E-motor selection

The advantages of premium efficiency, permanent magnet electric machines in marine applications extend well beyond lifecycle economies of installation, maintenance and operation

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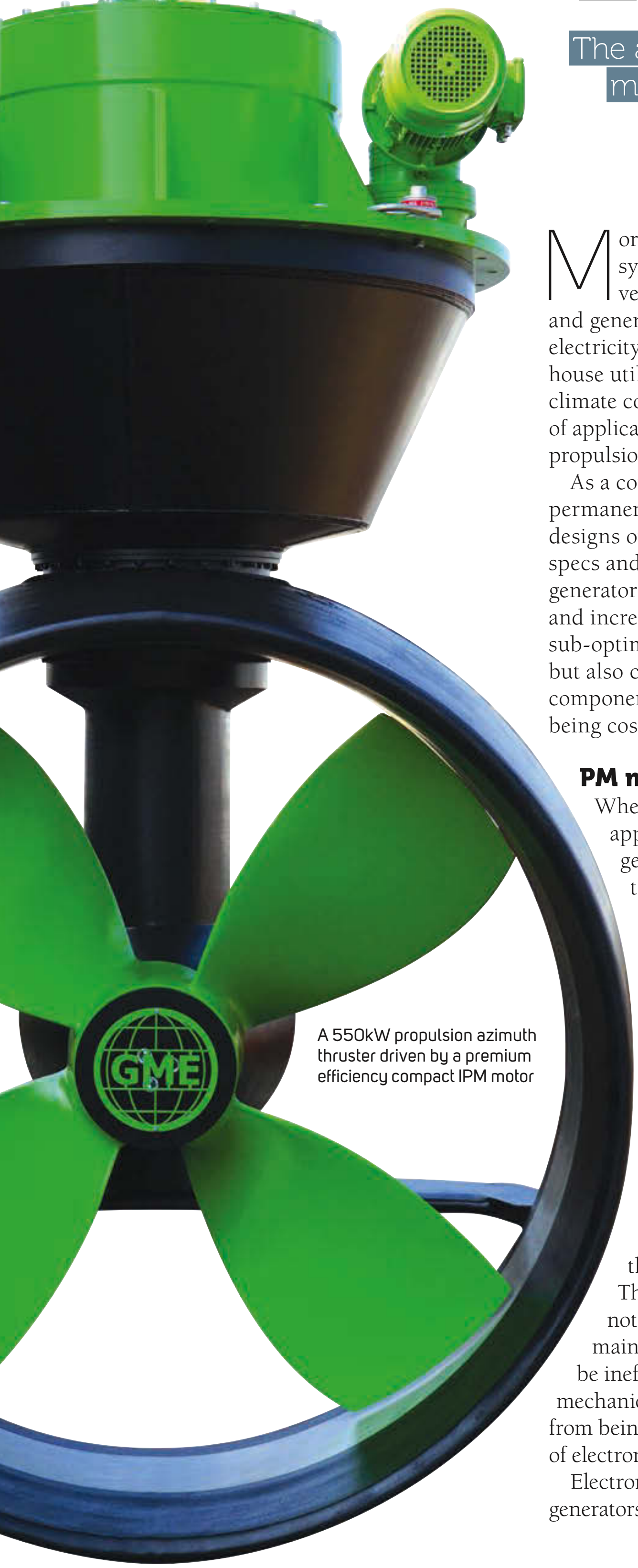


A 550kW propulsion azimuth thruster driven by a premium efficiency compact IPM motor

More than 80% of all electrical power system sources and uses on a marine vessel are related to electric motors and generators, and this includes generating electricity, deck and service machinery, house utilities (including appliances and climate control), and in a growing number of applications, electric or hybrid-electric propulsion operation.

As a consequence there are now several permanent magnet (PM) motor/generator designs on the market with various prices, specs and features. This can make motor/generator evaluation and selection confusing and increase the possibility of not only sub-optimizing the overall system design, but also choosing the wrong power system components for the application – with both being costly.

PM motors with a difference

Whether in marine or other industrial applications, PM electric motors/generators are generally based on the same synchronous physical principles, but it's important to note that these principles are applied in very different ways. Both marine power system designers and vessel owners should understand the differences among them and select the one that best fits the application.

By way of introduction, a traditional, direct current (DC) motor or generator uses mechanical commutators to rectify or convert electrical current coming into the motor or out of the generator. These mechanical commutators are not only subject to wear and frequent maintenance, but they also tend to be inefficient, thus preventing the mechanical-commutator motor /generator from being a high-efficiency transformer of electromechanical power.

Electronically commutated motors/generators, commonly termed AC motors or generators, use power-electronic components and computer-based digital signal processing (DSP) control algorithms to commutate current into or out of the motor or generator. Although these power systems generally require a bigger initial investment and are more complex by design, they are virtually maintenance free, with a long operating life and enhanced energy efficiency, resulting in much lower application costs and increased reliability.

Air-gap flux distribution is an important concept in electronically commutated designs, and in this respect the term brushless DC motor/generator (BLDC) refers to designs with air-gap flux distribution in trapezoidal form. Meanwhile, sinusoidal synchronous AC motor/generator refers to electronically commutated designs with sinusoidal rather than trapezoidal air-gap flux distribution.

In real-world applications, the trapezoidal form is never equivalent to a pure mathematical trapezoid, but the sinusoidal form is a natural representation of smooth rotor movement through the internal magnetic field of the motor or generator. This is the basic reason that, even though the BLDC requires a less complex control algorithm, the sinusoidal synchronous AC design delivers better performance, much lower total harmonic distortion (THD) and less torque ripple. For the system designer and owner, this simply means the highest possible efficiency and extended life, least maintenance and lowest lifetime cost.

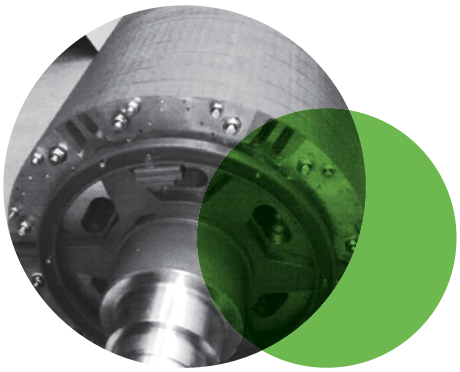
Further PM distinctions

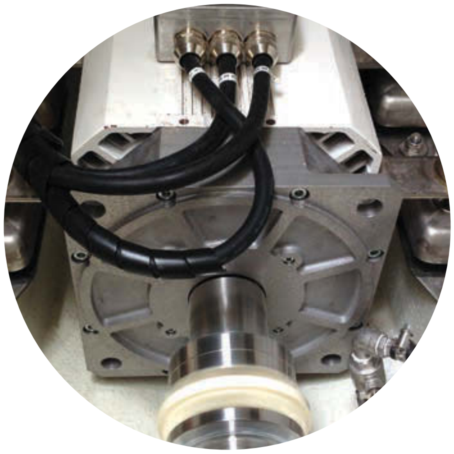
As a technology, PM machines can also be classified as either radial or transverse flux depending on the characteristics of the rotor shaft. Different mechanical shaft and bearing configurations have a direct impact on a motor or generator's expected operating life and maintenance requirements. It's for this very important reason that the radial flux design solution is recommended for large PM motors and generators in order to fully realize maximum efficiency levels as well as impressive durability.

Permanent magnets can be installed in PM machines in two ways: surface mount (SPM) or internal mount (IPM). In SPM designs, magnets are glued to the exterior surface of the motor or generator's rotor and this design is considered to be easier to assemble than the IPM setup. However, SPM offers marginally lower mechanical and chemical protection of the magnets than IPM and requires more magnetic material to ensure reliability against short circuits. What's more, especially in larger units, there is a far greater chance that SPM magnets can be damaged during assembly of the rotor and stator. Cracked magnets in large SPM motors are very difficult to detect, even in factory testing. Moreover, as the nominal power, diameter and temperature of the motor or generator increases, maximum RPM is proportionately limited under the SPM design. In addition, electronic control of constant power over the full RPM range is limited to 20% above the rated nominal speed.

The second approach to mounting magnets is the IPM design. In such an assembly, magnets are inserted into specially machined voids in the rotor. The IPM rotor must be carefully designed to maximize the use of magnetic flux for increased efficiency and to avoid suboptimal performance, including loss of torque.

Today's state-of-the-art IPM designs, with permanent magnets embedded in the rotor structure and synchronous reluctance harnessed for higher performance, result in the most advanced motors and generators with the highest efficiency over the widest range of nominal and actual power. These are also the most compact and reliable motors/generators on the market. This special IPM design offers reliable, high-speed, high-power operation, robust mechanical and chemical protection for magnet segments, and optimum use of magnetic material. These motors and generators experience no demagnetization, offer a broad range of constant power control, and are better matched to standardized torque/speed control units when used as motors, or to output voltage controls when used as generators with advanced rectifiers.





The optimal choice

Regardless of the overall power system size or budget, designers and owners will get the best return on motor/generator investment with electronically commutated sinusoidal synchronous AC PM motors and generators, with rotor internal mount PM segments and a design that includes synchronous reluctance torque support. This ensures maximum application benefits, including highest efficiency; lowest lifetime cost; minimal maintenance; smooth, quiet operation with minimum torque ripple and harmonic distortion; constant torque from zero to maximum RPM; broad power control range; integral overload and short circuit resistance; mechanical and chemical PM segment protection; compact dimensions (high power-to-size ratio); and light weight.

In the near term, fossil fuel main propulsion will continue to dominate trans-ocean shipping applications where massive loads, constant speeds, full power and long transit times are common. However, driven by advantages of cost and reliability over fossil fuel, commercial and pleasure marine power applications are moving steadily toward PM electric technology for propulsion, generators and pumps, fans, actuators, auxiliary equipment and house power.

However, like all other advanced technologies, PM electric motors and generators have room for development. Specific improvement areas include higher energy magnets with improved thermal stability and chemical resistance; new, low-loss magnetic materials; and super conductive winding materials.

Current research indicates that these improvements will be available to further enhance PM motors and generators in the coming decade, but advanced PM design remains available today, as has been outlined in this article, allowing designers and owners to make informed choices and optimize their investment in PM marine power systems.

Above: A typical PM motor sailboat propulsion system

Below left: A compact PM rotor with internal magnets

Below: The different types of PM rotor design. Traditional SPM design (below), external SPM rotor design (center) and advanced IPM design (top)