LNG INDUSTRY

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PERMANENT MAGNET TECHNOLOGY – RELIABLE AND ECO-FRIENDLY

Jussi Puranen and Ville Parpala, Yaskawa Environmental Energy / The Switch, Finland, outline the benefits of diesel-electric propulsion over diesel-mechanical propulsion for LNG vessels.

Thanks to its many advantages over diesel-mechanical propulsion, a diesel-electric propulsion system – based on the power station principle and electric propulsion motors – is already becoming a top choice for LNG and other types of vessels. Smaller power plants, for LNG vessels in particular, lead to immediate savings. Other benefits of diesel-electric propulsion include reduced fuel costs, redundancy, excellent torque-speed characteristics, fast dynamics, and reduced vibrations.

The many advantages of PM technology for electric propulsion

When choosing to use a permanent magnet (PM) machine as the propulsion motor for a vessel, it is possible to achieve excellent energy efficiency over the entire operating range, resulting in significant fuel savings for gensets. A PM machine is typically 2 – 4% more efficient at full load, and 10% more efficient at part loads when compared with conventional machines. These efficiencies result from a lack of current losses in the rotor, the absence of an exciter, and reduced winding losses.

Often, propulsion motor output is dimensioned to have a relatively large safety margin between the nominal and worst-case scenario. In practice, this means that during normal cruising conditions propulsion motors are operating below their rated power – in other words, at part load. Furthermore, vessels often save fuel by not operating at top speed. This has a big impact on propulsion motor power due to the cubical relationship between power and speed. Since PM motors operate most efficiently at partial loads compared to conventional motors, significant fuel savings can be achieved.

Further benefits of PM technology are space and weight savings and increased reliability due to simple mechanical construction. Thanks to their neodymium-iron-boron (NdFeB) magnets (materials with a very high flux density), they are ideal for variable speed generators throughout the entire speed range. The magnetic field is created with almost zero rotor losses.

The rest of this article will provide a closer look at the advantages of PM technology for electric propulsion.

Reduced fuel costs

Especially with ships that travel at reduced speeds most of the time, diesel-electric propulsion provides significant fuel savings, since some of the power station gensets can be shut off at lower speeds. This results in greatly reduced specific fuel-oil consumption (sfoc). Variable-speed gensets enable even more fuel savings. Instead of supplying genset power directly to the grid, in which only constant speed is allowed, the power is provided through the frequency converter, thus allowing variable speed for the genset, depending on power demand.

The types of vessels that benefit most from electric propulsion include large cruise ships, ferries, super yachts and vessels with dynamic positioning (DP), such as offshore supply vessels (OSV), drilling vessels, dredgers, shuttle tankers and cable-laying vessels. By using PM machines instead of conventional machine types, such as induction or electrically excited synchronous machines, fuel savings can be further increased, since losses related to magnetisation in the generators are eliminated. This difference is significant, especially when direct-drive PM propulsion motors are compared to electrically excited synchronous machines.

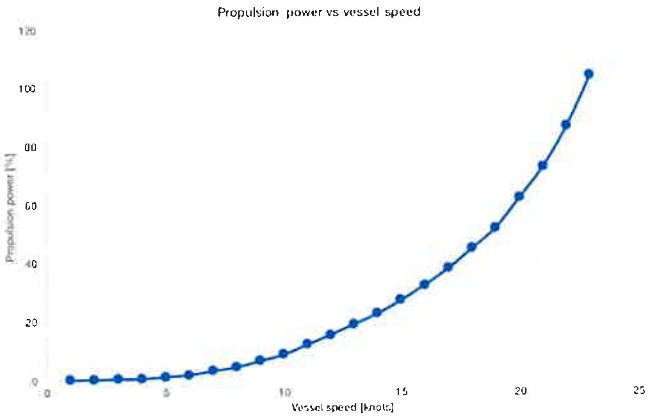

Figure 1. PM motors operate most efficiently at partial loads compared to conventional motors, achieving significant fuel savings.

Less need for installed power

Certain vessel types, such as LNG ships and floating storage and regasification units (FSRUs), have a very high power demand when the vessel is not moving, due to LNG loading, unloading or cooling. Therefore, the power plant of such ships consumes a lot of power even without any propulsion. Since propulsion power and standstill power are not needed at the same time, using diesel-electric propulsion reduces installed power needs considerably compared to conventional diesel-mechanical propulsion.

For example, an LNG ship with 20 MW of propulsion power and 10 MW of standstill power would need 30 MW of total power capacity – 20 MW from the mechanical propulsion source and 10 MW of electric power from the power plant. In the case of a diesel-electric system, total power demand from the power plant would be 20 MW plus the hotel load of perhaps a few MW and margins, which is significantly less than a diesel-mechanical system.

Increased redundancy and safety

The Switch DC-Hub is a multi-source and multi-load DC system, based on standardised Power Drive units from The Switch. This solution offers a wide and flexible choice of power generation, energy storage, charging, propulsion power and clean power for any ship system. The Switch DC-Hub includes independent inverter and rectifier modules connected to the same DC grid. The inverter modules, based on insulated-gate bipolar transistor (IGBT) technology, are identical building blocks and can be stacked in parallel to achieve the desired power. All power modules are designed, produced and rigorously tested in Yaskawa's factory in Norway, before being delivered to a vessel.

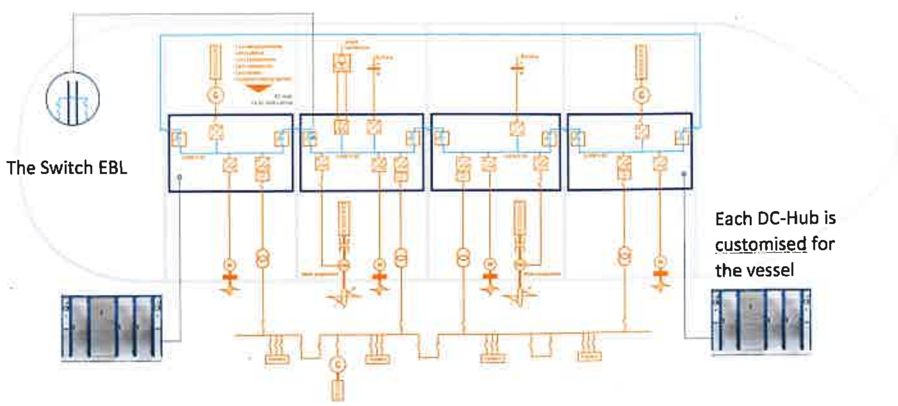

Figure 2. The Switch DC-Hub provides reliable DC systems in separated sections, like those of a vessel's bulkheads. The Switch unique electronic bus link (EBL) cuts and isolates any possible fault between the DC-Hubs in the same way as bulkheads prevent access mechanically.

One of the major challenges of a reliable DC system is to ensure selectivity and fail-safe operational security. This is where The Switch EBL, an electronic bus link breaker, comes into play. The EBL connects the DC-Hubs together. The main function of an EBL is to maintain and ensure selectivity between the DC-Hubs if a major fault occurs. Any major fault in one DC-Hub will not significantly weaken the voltage level of the other healthy DC-Hub. The EBL acts like a fuse, but one that responds electronically within 10 microseconds. For comparison, a fast thermal fuse or an electromechanical breaker works within milliseconds, which is 1000 times slower than the EBL. Also, they struggle to maintain selectivity.

Excellent torque characteristics – even in tough environments

The fact that conventional diesel engines produce maximum torque only in a very narrow speed range causes significant problems in vessels needing high torque at low speeds. A good example of this would be when LNG carriers sail in demanding conditions. Diesel-electric propulsion is a superior choice for such applications, since electric motors can supply full torque from zero up to rated speed.

Also, when direct-drive PM motors are used for propulsion, the dynamical performance of the shaft line is better, due to the very low rotating mass and inertia of a direct-drive PM motor. The inertia of a PM motor can be a tenth of the inertia of electrically excited synchronous machines – the main alternative in direct-drive propulsion – which improves the dynamic performance significantly in a PM-motor-based system.

Reduced vibrations

Since diesel engines and gearboxes produce high levels of vibrations and noise, it has been common to use direct-drive diesel-electric propulsion for example in fishing, research and naval vessels, among others. The main reason for doing this is to decouple the diesel engine that drives the gensets from the propeller, significantly reducing underwater noise.

In the past, DC motors were used exclusively, since, in addition to good low-speed torque characteristics, they produce very smooth torque, causing less underwater noise than AC motors. With modern frequency converters based on IGBT technology, a very low level of current ripple can be achieved.

Nowadays, when combined with properly designed AC motors, this has enabled electric drives based on AC rather than DC technology in silent vessels. Typically, AC propulsion motors have been either induction or electrically excited synchronous machines, since they are a well-known technology. The drawbacks, however, are reduced efficiency, bigger size and more weight.

PM machines can overcome these issues. With proper design they exhibit very low levels of structural-borne noise, making them ideal for propulsion motors in many vessels.

Low structural-borne noise levels

During the spring of 2018, Yaskawa Environmental Energy / The Switch delivered variable-speed PM gensets and direct-drive propulsion motors for a fishing vessel with DNV-GL Silent F notation. To minimise airborne and structural-borne noise levels from these machines, the electromagnetic vibration level was minimised by optimising the rotor pole shape and by applying skewing for the magnets. The propulsion motor's cogging torque amplitude – the tendency of magnets to align themselves with the stator teeth – which is more critical since it is directly coupled to the propeller, was only 0.15% of the rated torque.

At full load, torque ripple always increases from the no-load value, or cogging. This is because stator current harmonics will cause their own torque harmonic components under load, causing the torque ripple to increase. Regarding the propulsion motor, torque ripple amplitude at full load was still only 0.48% of the rated torque, imparting very low torsional vibrations to the propeller and giving a low underwater radiated noise level.

To illustrate the effectiveness of magnet skewing, torque ripple was reduced from 2.5% down to 0.48%. Since skewing has a minimal downside and needs only slightly higher current, it should always be applied to any motor design.

Sleeve bearings were used to keep mechanical excitations low. Low-speed cooling fans were used to limit audible noise. Resilient mountings, or 'mechanical dampers,' were used for connecting the machines onto the test bed, since they were to be used in the final application as well. Typically, they have the biggest impact on structural-borne noise emitted from the motor.

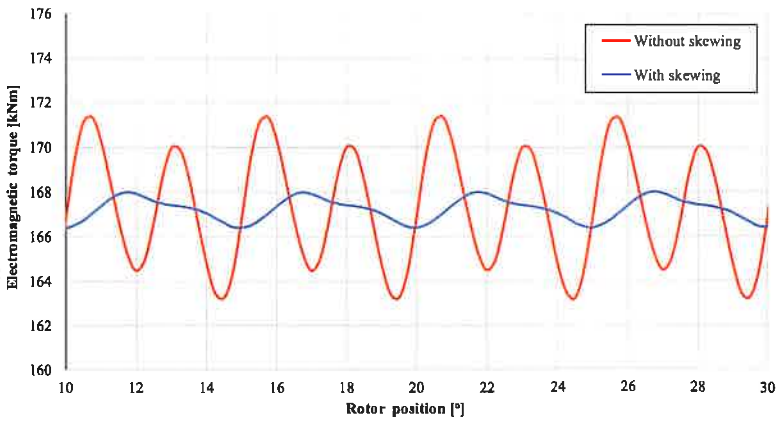

Figure 3. Torque ripple of a propulsion motor at full load with and without skewing. As can be seen, there is a significant drop in the torque ripple when skewing is applied.

Conclusion

PM technology and The Switch DC-Hub solution in vessels, such as LNG ships and FSRUs, offers a more energy-efficient way of operating. Some of the benefits of electric propulsion include reduced vibrations and fuel costs, increased redundancy and more efficient use of energy. The simple mechanical construction of a PM machine also results in less need for maintenance and higher overall system reliability.

Together with PM generators, The Switch DC-Hubs make it possible to use variable speed for the prime movers, enabling generators and diesel engines to always run at optimal speed. By optimising speed and load, fuel efficiency increases while lowering emissions. **LNG**