“ELECTRICAL SYSTEM USED IN TRANSPORTATION”

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ABSTRACT:

The shipping industry has come a long way as far as R & D for reducing costs of propulsion without increasing marine pollution is concerned. The conventional propulsion system of the ship is efficient but requires high operating costs and increases the marine pollution. The key challenge too often has been how to build the right ship around a given propulsion system, rather than creating tailored propulsion system for the ship. The propulsion systems, both mechanical and electrical, used in virtually all ships today operate less efficiency at lower speeds. If we can dramatically improve the power densities of marine propulsion motors and generators as well as their efficiencies -- i.e. make these efficiencies much higher and more uniform at varying loads, many of the other issues would be resolved too and ship design need not be compromised. In fact, with continuing **improvements in power density and efficiency,** electric drive propulsion systems are projected to displace mechanical drive systems across a broader spectrum of applications. This paper explores the maturation of **HTS rotating machine** design coupled with the upcoming **36.5 MW HTS motor** development and testing signals that high temperature Superconducting (HTS)-based propulsion systems represent a near-term solution to these long-standing challenges. The reason HTS motors are so efficient is that HTS wire can carry up to 140 times more current than the copper wire of the same size and weight**.**

KEY WORDS:

- Improvements in power density and efficiency,
- 36.5 MW HTS Motor,
- HTS Wires.
- Eco-friendly & More power in smaller size.
- Azipod unit

INTRODUCTION:

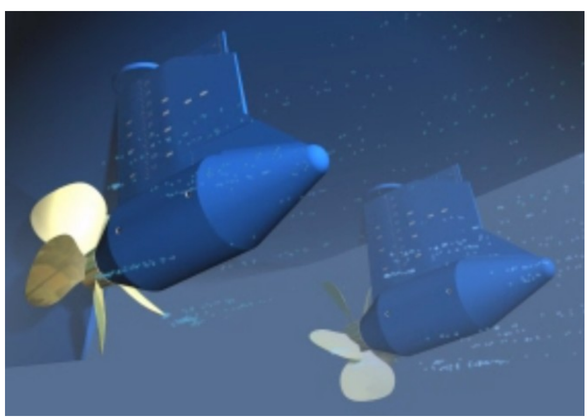
Electric propulsion is an emerging area where various competence areas meet. Successful solutions for vessels with electric propulsion are found in environments where naval architects, hydrodynamic and propulsion engineers, and electrical engineering expertise cooperate under constructional, operational, and economic considerations. Optimized design and compromises can only be achieved with a common concept language and mutual understanding of the different subjects. The objective of this paper is to give an introduction to electro-technology in general, and put special emphasis on installations for electric propulsion. It is the aim to give engineers with marine competence and background the necessary understanding of the most important electro-technical subjects used in design and configuration of ships with electric propulsion. The concept of electric propulsion is not new; the idea originated more than

100 years ago. Electric propulsion with gas turbine or diesel engine driven power generation is used in hundreds of ships of various types and in a large variety of configurations. Installed electric propulsion power in merchant marine vessels was in 2002 in the range of 6-7 GW (Gigawatt), in addition to a substantial installation in both submarine and surface war ship applications. By introduction of azimuthing thrusters and podded thrust units, propulsion configurations for transit, maneuvering and station keeping have in several types of vessels merged in order to utilize installed thrust units optimally for transit, maneuvering and dynamically positioning.

AZIPOD ELECTRIC PROPULSION (PODDED PROPULSION):

Azipod system used on ships is combination of both propulsion and steering systems. In conventional propulsion system, a large two stroke engine is connected to a shaft, which passes through shaft tunnel and stern tube and connects to the propeller outside the hull in the aft part of the ship. The steering of such system is done with the help of a rudder placed in the aft of the propeller.

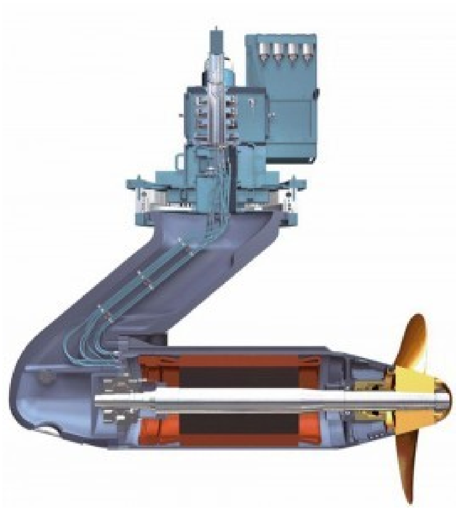
However, in azipod arrangement, the propulsion and steering systems are combined and made into one part. The system consists of a propeller which is driven by an electrical motor and the propeller is turned by the rudder which is connected to the system. The motor is placed inside the sealed pod and is connected to the propeller. It should be noted that the sealing of the pod should be perfect otherwise it can damage the whole motor and make the ship handicap from maneuvering. The motor used for this system is variable frequency electric motor. Using variable frequency, the rotational speed of the propeller can be controlled i.e. the speed can be increased or decreased.

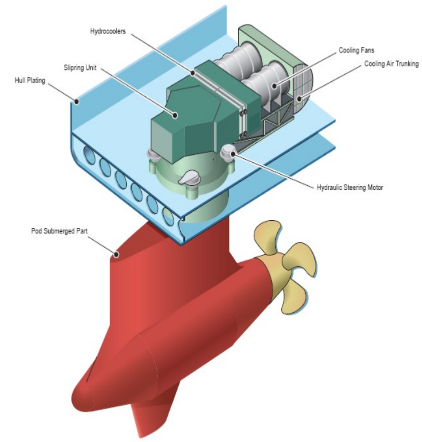


The azipod system is also known as POD drive system, where POD stands for Propulsion with Outboard Electric motor. The whole azipod system is situated outside the hull in the aft of the ship. The azipod can turn in all the directions i.e. 360 degrees with the help of a rudder, and thus provides a thrust in any direction which is not possible in the conventional system. The propeller in the pod system is moved by the rudder which is placed in the steering flat, also the power module for the system.

UNDERSTANDING THE AZIPOD SYSTEM:

The azipod system is a type of electric propulsion system which consists of three main components:





1) SUPPLY TRANSFORMER

The power produced from the generators is as high as 6600 KV, which is stepped down to the necessary voltage by the supply transformer required and is provided to the motor placed in the pod.

2) PROPULSION MOTOR

Propulsion motor is used to drive or to produce thrust. The system needs some method for rotating the propeller and this is done with the help of electric motor.

3) FREQUENCY CONTROLLER/CONVERTER

This is used to change the frequency of the supplied power so that the rotating speed of the motor can be controlled depending on the requirement.

ADVANTAGES OF POD DRIVE:

- ☐A podded drive has got clear and well proven advantages in maneuverability.
- ☐Higher overall efficiency at all loads
- ☐Higher hydrodynamic efficiency is possible by the use of smaller diameter pods.
- ☐Advantages in space usage
- ☐Weight and production efficiency which magnitudes depend on a case vibration and noise suppressing effect, and high flexibility of inboard layout.

DISADVANTAGES:

☐Compared to a conventional shaft line with a diesel electric power plant a podded drive is today more expensive.

☐ Smaller diameter pods cannot be achieved because of large size of conventional motors.

MAIN PROBLEM IN AZIPOD PROPULSION:

"SMALLER DIAMETER PODS CANNOT BE ACHIEVED BECAUSE OF LARGE MOTORS"

As the power output increases, then gradually the motor sizes also increases. This results in construction of big podded drive arrangement. To achieve lower motion resistance and higher propulsion efficiency, it is necessary to assure that the pod body diameter is small in relation to the propeller diameter.

THEN WHAT'S THE SOLUTION IS?????????????????????????

THE SOLUTION:

"HTS MOTORS – HIGH TEMPERATURE SUPERCONDUCTING MOTORS"

Smaller diameter pods can be achieved by employing high-temperature superconductor (HTS) synchronous propulsion motors. HTS motors have been under development since the late 1990s. These machines are compatible with standard variable speed drives (VSD) and they meet both Navy and commercial electric ship requirements. Having up to three-times higher torque (and power) density than alternative technologies, HTS machines are significantly more compact and lighter in weight. Compact and lighter HTS motors reduce pod structural requirements and simplify interfaces. Their inherent characteristics such as quietness and absence of vibrations make them most suitable for Naval and cruise ship applications. HTS machines tolerate larger harmonics from the system bus than conventional machines due to attenuation of harmonic fields in the wider air gap and the capability to withstand rotor surface heating. This feature reduces the need for harmonic filters and their associated weight and volume. HTS machines can be designed for any voltage from 4.16 kV to 10 kV, which provide a benefit in reduced cable size and weight as well as benefits in reducing the size of VSD. A typical HTS motor for pod applications and the current status of its development are described in this paper.

CHARACTERISTICS OF HTS MOTORS AND COMPARISON:

The major components of HTS-based synchronous propulsion motors are shown in Figure. The stator assembly uses copper windings, because HTS is only lossless in a DC environment**.**

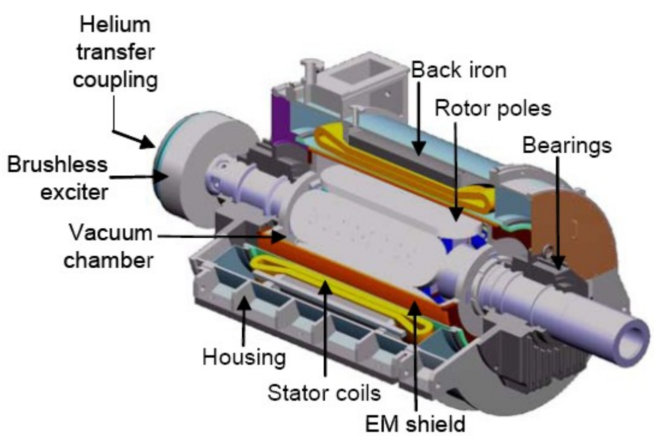
This assembly includes back iron to contain the field and increase the coupling with the rotor field. The stator windings are supported by teeth keyed into the back iron. Because HTS rotor fields can saturate conventional metal-toothed stator iron in high-power-density applications, the teeth are constructed from nonmagnetic composite. The balance of the stator consists of a cooling system to remove the heat from the losses in the stator.

The rotor field winding is comprised of several HTS coils that are conduction-cooled to approximately 30 K through the support structure. The HTS field winding is an assembly containing multiple pole sets, each fabricated using HTS wire capable of withstanding the powerful magnetic and mechanical forces experienced in the rotor.

The rotor field winding and its support are connected to the shaft through a torque-transfer member that carries torque from the "cold" (cryogenically-cooled) environment to the "warm" (room-temperature) shaft ends, and is capable of thermal expansion and contraction. The pole sets and support structure are enclosed in a vacuum-sealed cryostat that minimizes radiant heat input and provides the insulated operating environment required by the HTS field coils. The rotor assembly includes a cooling loop that thermally connects the field winding to the external cryocooler module (not shown in Figure) at the non-drive end of the shaft.

<u>THE EM SHIELD, WHICH IS LOCATED AT THE OUTSIDE SURFACE OF THE ROTOR, PERFORMS THE FOLLOWING FUNCTIONS:</u>

- Protects the field winding by attenuating asynchronous fields produced by the stator winding and harmonic fields from VSD currents
- Carries high transient torque during a fault
- Provides damping for low frequency torsional oscillations.



The electromagnetic (EM) shield is designed to be mechanically robust to withstand the large forces generated during faults, and is designed to directly transfer torque to the warm shaft and absorb heating caused by negative sequence currents and any other harmonic currents generated by a VSD.

Cold helium gas, circulated in a closed loop, is used as the heat transfer fluid to transport heat from the field winding to a refrigeration system mounted independently from the motor. Gifford-McMahon (GM) cold heads are used to provide the refrigeration required to keep the winding at the 30 K operating temperature. The refrigeration system achieves high reliability by employing n+1 modular, single-stage GM coolers and long-life seals in its helium transfer coupling.

The highest-power-density stator winding designs employ nonmagnetic teeth to avoid iron-tooth saturation and copper Litz conductor that is made up of small diameter insulated and transposed wire strands to reduce AC losses. With no iron teeth in the winding region, the support and cooling of the stator coils require special attention. Most of the machines constructed to date have used liquid cooling in the stator. The back EMF in this motor is nearly a pure sine wave and the harmonic field components are much smaller than those observed in conventional motors.

<u>THE BENEFITS OF AN HTS MOTOR INCLUDE:</u>

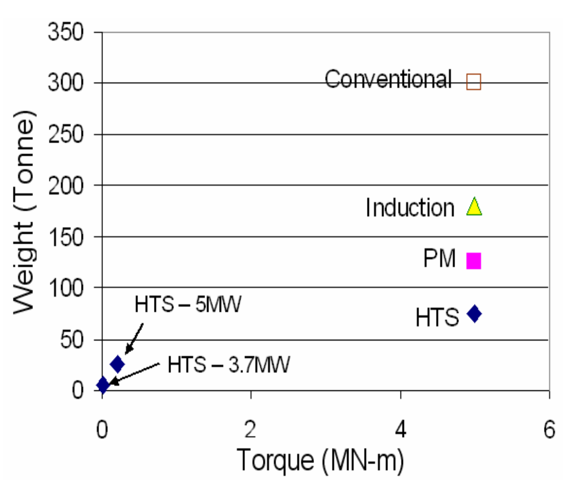
- Up to five-times higher torque density than conventional technologies; HTS machines can be far more compact and lighter in weight. The size and weight benefits make HTS machines easier to transport and install, as well as allowing for arrangement flexibility in the ship. Machine weight vs. torque, along with estimates for a conventional synchronous generator and an advanced, minimum weight induction motor is shown in Figure 3.

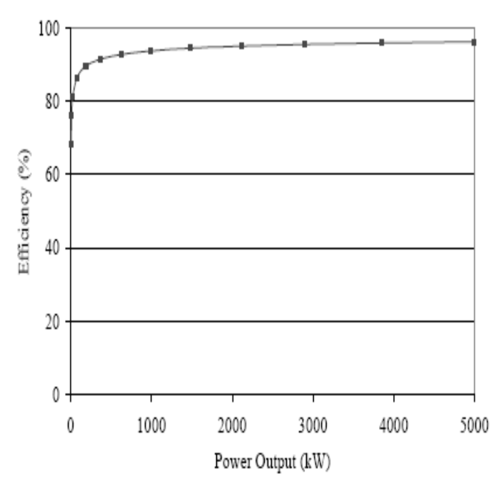
- Absence of iron stator teeth eliminates the 'cogging noise' component in structure-borne noise.

- Exceptional part-load as well as unique full-load efficiency, boosting fuel economy, sustained speed, and mission range.

- Isothermal field winding that is not affected by the thermal effects of repeated load changes.

A variety of HTS machines built by AMSC are compared with conventional synchronous, induction and permanent magnet (PM) technologies in Figure 3. It is evident that at high-torque ratings, HTS motors are several times lighter than other technologies. HTS motors with less than ½ size and weight of optimized PM motors require less mass and volume of pod structure. The smaller profile of pods with HTS motors will translate into less drag, ease of azimuthing operation and high hydrodynamic efficiency.



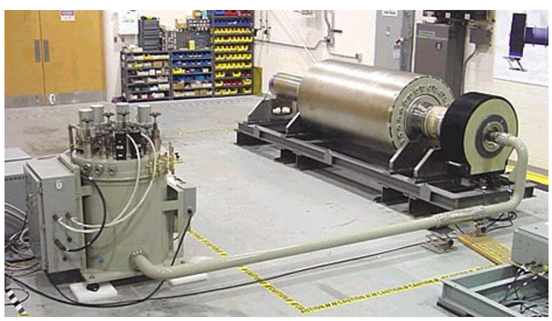


HTS MOTOR EXPERIENCE:

American Superconductor has built the following HTS motors during the last eight years;

- 1000 hp, 1800-rpm motor co-built with Rockwell Automation4 in 1999
- 5000 hp, 1800-rpm motor5 in 2001
- 5 MW, 230-rpm ship propulsion motor1 in 2003
- 8 MVAR, 1800-rpm synchronous condenser6 in 2004
- 36.5 MW, 120-rpm ship propulsion motor7 – scheduled for delivery in Autumn '06

HTS MOTOR FIELD WINDING TESTING AND COOLING:



ONR 36.5 MW MOTOR:

The objective of the ONR-funded 36.5 MW HTS Motor Program is the development of a full-scale, high-power-density, lightweight, advanced propulsion motor suitable for future naval main propulsion applications. The program objectives include the design, construction and testing of a 36.5 MW (49,000 hp), 120 rpm, HTS motor integrated with a commercial variable speed drive. The design drivers included low system weight with a specific target of 75 metric tons. Other drivers were improved efficiency, low noise and shock capability.

The selected motor design is an air-core synchronous machine using HTS in the field winding mounted on the vacuum insulated rotor. The stator is designed without iron teeth and is liquid cooled. This design approach fully benefits from the high MMF field winding to produce 2,200,000 ft-lbs of torque in a compact design without noise-producing iron teeth.

The topology of the 36.5 MW, 120-rpm HTS motor is shown in Figure 8. It employs many of the technologies developed for the 5 MW motor, including HTS field winding, high-current-density, liquid-cooled stator, rotor cooling system, support and excitation systems.

Key differences between the two motors is the result of the different objectives of the two programs. While the 5 MW was a prototype for a pod motor resulting in small diameter and low pole count, the 36.5 MW motor is a weight-optimized machine. This led to a motor design with a larger diameter and sixteen poles.

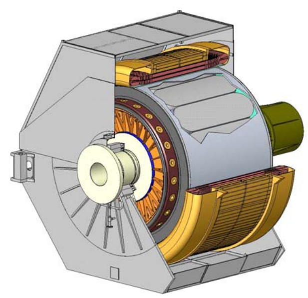
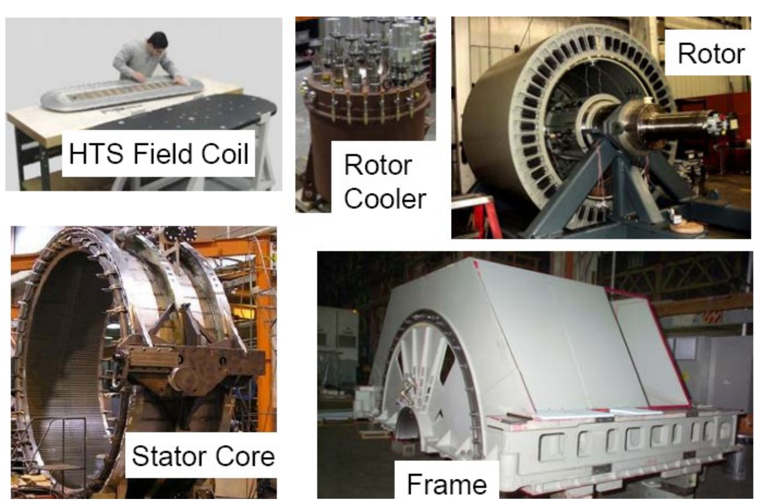


FIGURE: TOPOLOGY OF THE 36.5 MW HTS MOTOR

The major rotor and stator components during construction are shown in Figure. The field winding, which consists of racetrack-shaped coils wound with first generation HTS wire, is shown in the top left of Figure. The refrigeration assembly, which is shown in the top center, includes multiple coldheads to provide both redundancy and degraded modes of operation. The rotor, assembled on a fixture for factory testing of the field winding, is shown in the top right. The exciter is a transformer-type, brushless exciter (not shown). The stator core before assembly of the composite teeth and Litz coils is shown at the bottom left and the base frame with attached panels (upside down) is shown in the bottom right.

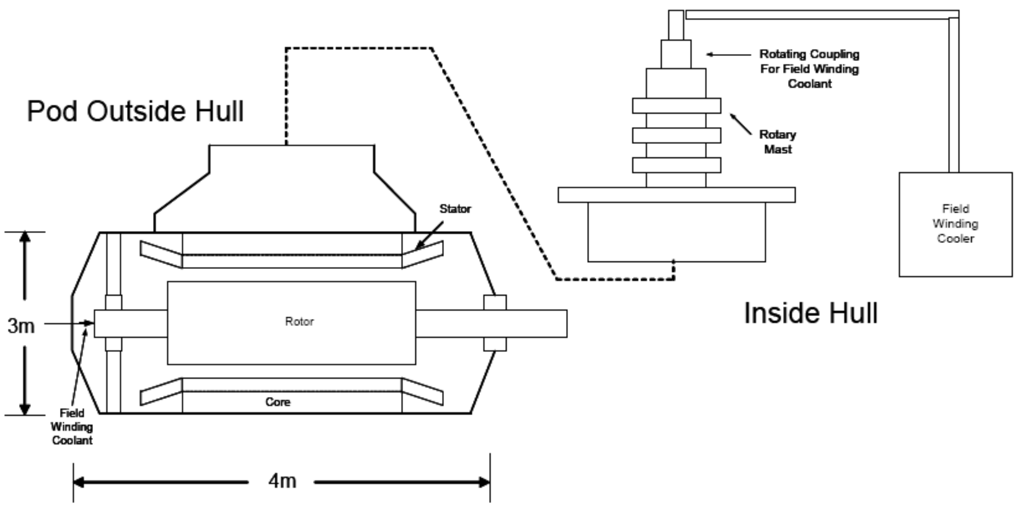


The rotor assembly has been completed. Following assembly of the rotor, the field winding was tested with the rotor in a static fixture. The assembled rotor was cooled to operating temperature with the refrigeration system and excited in excess of rated current.

HTS MOTOR APPLICATIONS TO PODS:

The HTS motor can be designed to be small in diameter and long in length. It can be integrated in a pod, as shown in Figure 10. Motor and pod body, which are in water (outside the ship hull), are physically supported from a platform inside the hull. All services for the pod and its motor are provided through this platform. Motor power is supplied through slip rings mounted on the shaft of azimuthing pod. Coolant for the field winding would also be transmitted through the pod shaft. A rotating coupling is included to transfer field winding coolant from stationary to rotating pod body. The field winding coolant is cooled with COTS G-M coolers7 assembled into a rotor cooler assembly similar to one shown in Figure 9.

The 25 MW, 120-rpm motor sized for a pod application is 2.4 m in diameter, 2.65 m in axial length and 65 k-kg in weight. A pod based on this motor would be about 3 m in diameter and about 4 m in length. Although sizing of the pod and its support structure is outside the scope of this paper, it is possible to speculate that the HTS pod diameter (3 m) would be very attractive because a pod based on a conventional machine of similar rating would be about 5-6 m in diameter. A more compact pod with an HTS motor will also weigh less and would, therefore, reduce the size of the stay and its associated weight and water resistance.



AZIPOD INTEGRATED SYSTEM

THESE MOTORS PROVIDE BENEFITS FOR BOTH SHIP OWNERS AND BUILDERS. FOR A CRUISE SHIP THESE BENEFITS INCLUDE:

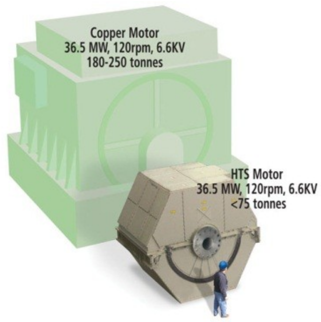
☐HTS motor’s low noise and vibration attributes assure passenger comfort and facilitate easier maneuvering.

☐High efficiency at all loads (down to 20% of nominal load); higher efficiency can translate into 1-2% lower fuel cost as compared with a conventional motor.

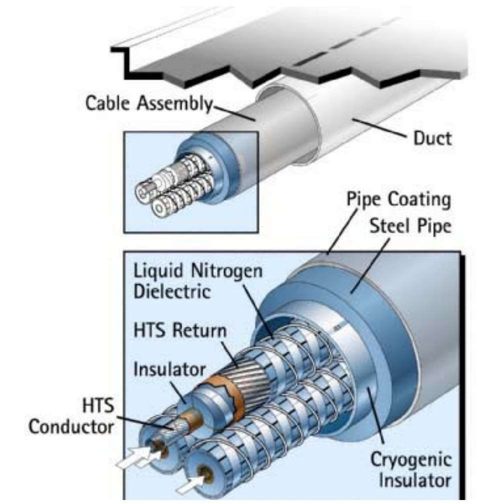
☐Additional free space for more passenger cabins.

☐The frequency of rewinding the motor rotor that has been fatigued by repeated load changes is reduced.

☐Easy to maintain cooling system.



HTS CABLES:



Today's conventional power lines and cables are being operated closer to their thermal limits, and new lines are becoming hard to site. Compact, high-capacity underground HTS cables offer an important new tool for boosting grid capacity. Today's advanced HTS cable designs enable controllable power flows and the complete suppression of stray EMF. HTS power cables transmit 3-5 times more power than conventional copper cables of equivalent cross section, enabling more effective use of limited and costly rights-of-way. Significant progress toward the commercialization of HTS cable is underway. Three major in-grid demonstrations have been completed in the US including the world's first HTS power transmission cable system in a commercial power grid which is capable of transmitting up to 574 megawatts (MW) of electricity, enough to power 300,000 homes. Two more demonstrations are in the planning stage in the US and another dozen projects are active around the world.

HTS CABLE INSTALLATION IN NEWYORK

CONCLUSIONS:

Podded propulsion drives have proven their worth in the cruise line industry. Enhancements in ship operations such as greater maneuverability, space savings, low vibration levels, and greater power plant efficiency, as well as reduced pollution are expanding the use of these drives on other marine craft, including military ships, ferries, and tankers. HTS propulsion motors are the best candidate for such applications because they are compact and light weight. These motors provide benefits for both ship owners and builders. For a cruise ship, HTS motor's low noise and vibration attributes assure passenger comfort, facilitate easier maneuvering, provide high efficiency at all loads (down to 20% of nominal load) and frees space for more passenger cabins. Successful testing of 5 MW HTS motor and anticipated good test results of 36.5 MW HTS motor will firmly establish the maturity of this technology for ship applications.

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