INVITED PAPER

Motors for Ship Propulsion

ABSTRACT | Electric propulsion of ships has experienced steady expansion for several decades. Since the early 20th century, icebreakers have employed the flexibility and easy control of direct current (dc) motors to provide for ship operations that split ice with back and forth motion of the ship. More recently, cruise ships have employed diesel-electric propulsion systems to take advantage of the flexibility of diesel, as opposed to steam engines, and because the electric plant can also be used for hotel loads. Research vessels, ferries, tankers, and special purpose vessels have also taken advantage of increased flexibility and fuel efficiency with electric propulsion. Today, the U.S. Navy is building an "all electric" destroyer to be named "Zumwalt," which employs two induction motors for propulsion. There are several different classes of motors that might be considered for use in ship propulsion, ranging from dc (commutator) motors through conventional induction and synchronous motors to permanent magnet synchronous machines, doubly fed machines and superconducting alternating current (ac) and acyclic homopolar machines. This review paper describes features of some of the major classes of motor that might be used in ship propulsion.

KEYWORDS | Acyclic motors; direct current (dc) motors; induction motors; permanent magnet motors; ship propulsion; synchronous motors

I. INTRODUCTION

Motors for electric ship propulsion are, relative to most motors for industrial, commercial, and residential purposes, large in terms of rating and slow in speed. Therefore, they are quite large in terms of torque. A number of different motor types have been proposed for this application, including direct current (dc) (commutator) motors, induction motors, ordinary wound field synchronous motors, synchronous motors with permanent magnets serving in place of the field winding, synchronous motors with superconducting field windings, acyclic (homopolar) motors with superconducting field windings and doubly fed induction motors. Some of these, notably commutator motors, wound field synchronous (permanent magnet synchronous for smaller applications up to a few megawatts) and induction machines are already in use for ship propulsion, and there has been experimental development work on the others. Other machine types have been proposed, including synchronous reluctance machines and transverse flux machines but these are "long shots" in the competition for use in ship propulsion.

Electric propulsion has been used in ships for some time. Between the two world wars of the 20th century, some battleships with steam turbine engines employed synchronous motors for propulsion, ostensibly because this obviated the need for mechanical gear reduction. The first aircraft carrier of the U.S. Navy, *CV-1*, was a conversion of a collier that had a similar propulsion system and therefore was an "electric ship" [1]. Icebreakers have long used dc propulsion motors because they permit very flexible operation, including back and forth motion to "ram" ice floes. When sophisticated power electronics devices became available, a move to synchronous and induction machines was made. For example, the Finnish *Otso* was the first icebreaker using cycloconverters and twin 7.5-MW synchronous propulsion motors [2]. Similarly, cruise ships, requiring adjustable speed and frequent stops, required drive systems more flexible than steam turbine drives. They used, first, cycloconverter drives and synchronous motors that could provide load commutation for the cycloconverters. More recently, transistorized drive systems have been used with induction motors [3].

There is a substantial advantage in having a motor that can drive the propeller of a ship directly, not requiring a