Abstract

Electric propulsion with on-board dc distribution has become the solution for large marine vessels due to the growing concerns of environmental pollution, operating cost, and better dynamic performance as compared to the conventional combustion engine propulsion. Variable frequency operating diesel generators and azimuth thrusters are the primary components in such electrified ships, and it currently became prevalent. However, the mechanical failures among bevel gear, coupling, and bearing in the propulsion system are reported commonly, and it may be attributed to the harsh operating condition in extreme sea state. The diesel generator system suffers disturbance from the engine side and the electrical load side, whereas the azimuth thruster is subjected to extreme hydrodynamic load disturbances. These disturbances result in torsional stresses in the drivetrain and are the main reasons for failure. One main advantage of using the electric propulsion is its flexible and instant torque control that can mitigate the adverse effect of torsional stress in the drivetrain. The electro-mechanical interaction and torsional vibration reductions using torque control were investigated in wind, steel, and automobile industries and solutions were suggested to reduce stress through advanced control of the power electronic converter. Similar studies can be carried out in marine propulsion system to explore potential electrical control solution to reduce fatigue and thereby prolong the life. This thesis is to develop advanced control strategies for mitigating electro-mechanical interaction and torsional vibration load in marine propulsion system which are excited due to extreme disturbances. This thesis is divided into four main parts: (1) Development of detailed models for marine propulsion system components (2) Development of power electronics based control algorithm to reduce elevated load levels induced during disturbances (3) Application of the proposed power electronic control algorithm to azimuth thruster and diesel generator system (4) Experimental validation of the proposed control algorithm on a multi-inertia lab test rig.

In the first part of the thesis, detailed models are developed for 2 MW azimuth thruster and diesel generator system, and their transient responses are analysed under extreme disturbances. The azimuth thruster is tested under rapid ventilation, whereas the diesel generator is tested under engine transients and electrical load disturbance. Simulations with the detailed models have illustrated torque overloads,

dynamic speed differences, torsional stresses, and potential damage to critical components. The results show the need for an active torque control algorithm to manage the excessive drivetrain torque caused by a sudden load change.

In the second part of the thesis, two control solutions are proposed to manage excessive drivetrain torque and torsional stress caused by the sudden load change. The proposed controllers can change the damping ratio and natural frequency by the introduction of virtual material damping and virtual stiffness in the system, and these changes can reduce resonant torque amplitudes in the driveline. Theoretical analysis and control gain design are presented for the proposed solutions and are bench marked against solutions in other industries such as wind, steel, and automobile.

In the third part of the thesis, the proposed solutions are applied to marine propulsion system. Active control gain design, positioning of sensors, and observer design are explained in detail in this section. The proposed solutions can reduce shaft over torque, torsional stresses, and vibration duration considerably in azimuth thruster and diesel generator system. The proposed solutions resulted in torsional energy transfer problem in DC link and which is solved using an effective torsional energy absorption system based on supercapacitor.

In the final part of the thesis, a 1.2 kW multi-inertia test rig which emulates the drivetrain of an azimuth thruster is designed and is subsequently used to validate the proposed control algorithms. Simulation model for the test rig is developed using SIMPACK software and MATLAB, and initial verification of the proposed control algorithm is done. A power electronic circuit is created to induce extreme load fluctuations in the experimental setup. The experimental results illustrated that the proposed solutions can reduce shaft over torque, dynamic speed difference, and torsional vibrations.

Finally, the conclusions of the mentioned studies are presented, and future directions of the research work are discussed.

Rapid ventilation- The propeller is momentarily lifted out of water due to rough sea state.

Foreign body impact- The propeller crushing a block of ice or foreign body.

Index Term: Azimuth propeller, diesel generator system, foreign body impact, electromechanical interaction, extreme sea condition, mechanical drive train, natural frequency, rapid ventilation, ship propulsion, speed control, torque control.