Harmonic Distortion in an Integrated Power System for a Surface Combatant

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The Navy is committed to utilizing an integrated electric power system to power both the propulsion and advanced weapons systems on its next generation warships. The solid state power supplies for these high-power systems draw non-linear current that will affect the voltage waveform on the main distribution bus. Any future high-powered weapons added to these platforms will employ a similar non-linear power supply. The distortion caused by these non-linear devices leads to increased losses, over voltages due to resonance, and may interfere with the operation of sensitive electronic equipment. There is a need to understand the impact of these non-linear loads on overall power system and individual component performance. Compounding these issues is the operational profile of a typical warship. Unlike most commercial ships, a warship's mission requires it to spend a significant portion of its lifetime operating at off-design conditions. Appropriate numerical simulation of a proposed power system can be an aid to understanding the issues associated with harmonic contamination and additionally can aid in the selection of harmonic mitigation techniques.

This thesis quantifies the voltage distortion over the broad range of operating conditions experienced by a Naval warship. A steady state model of an Integrated Power System (IPS) was developed in a commercially available power system simulation tool. The system chosen for this study was a three-phase, 4160 VAC, 80 MW power system with a 450 VAC bus to supply traditional ship service loads. Sensitive loads, such as combat systems equipment, are isolated from the harmonic content of the 450 volt bus via solid state inverters. Power generation for this system included two 30 MW and two 10 MW generators. The sizing of these generators was based on operating configurations that would result in the best fuel efficiency under the most common loading conditions. Model components were simulated and compared to data recorded for the U.S. Navy's Full Scale Advanced Development (FSAD) test system for the IPS at the Philadelphia Land Based Engineering Site (LBES). The propulsion motor used in the simulations was developed based on the advanced induction motor installed at LBES. Various loading conditions, including battle, cruise and anchor were simulated for both 10°F and 90°F ambient design conditions and with propulsion loads ranging from 0% to 100%. Numerous system configuration changes were implemented to determine their impact on system harmonics. These included operating the propulsion converter front end rectifiers in both controlled (varying commutation angle) and uncontrolled (diode bridge) configurations; implementation of both twelve and six pulse rectification; and installation of a tuned passive 5th harmonic filter. The simulation results are compared to both IEEE Std 519-1992 and Mil-Std 1399.