Preventing on-board power supply problems

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Introduction

The widespread use of electronic equipment such as power electronics for energy-efficient lighting, electric propulsion and other variable speed drive applications, on marine vessels such as ships and offshore oil platforms results in many electromagnetic compatibility (EMC) problems, including power quality issues [1][2][3]. These modern loads consume power in a pulsed manner, which is completely different to the days many power supply systems were designed. Conventional power supply systems were designed for linear loads, with maybe a lagging current for inductive loads, or a leading current for capacitive loads, resulting in a cos phi, or power factor (PF), different from unity. Modern electronic loads consume pulsed currents, with a high crest factor, i.e. peak current with respect to effective current, and if continuous, with a high total harmonic distortion of the current (THDi). As the power supply system on a ship has a high internal impedance, the THDi results in a high total harmonic distortion of the voltages (THDv). The impacts of harmonic voltage and/or current distortion are

- EMC problems with other (sensitive) electronic equipment like navigation, communication control and automation, and decrements in accuracy of measuring equipment, which are not designed for non-sinusoidal electric quantity measurements, and false tripping of protective switchgear e.g., fuse blowing, or incorrect thermal relays actuation,
- extra heating losses in electric machinery and cable wiring, leading to either premature aging and de-rating of the equipment due to overheating or to extra cooling requirements,
- excitation of resonance phenomena resulting to significant over voltages and/or over currents,
- erection of mechanical oscillations, vibrations, mechanical stresses and noise due to harmonic torque ripples produced,
- expanding the energy supply system to compensate the large reactive power. Timens showed that in a new building with only energy-saver but non-linear loads instead of energy-waster linear loads the power supply system had to be increased from 4 MVA to 7.2 MVA, consuming only 3 MW [2].

The high internal impedance of the power supply system results also in voltage dips due to the transients current consumption. Voltage dips are responsible for the EMC problems like tripping of computers, failing adjustable speed drives, interference in electronic equipment and process control equipment.

Basic conducted, low-frequency, phenomena are shown in Figure 1.

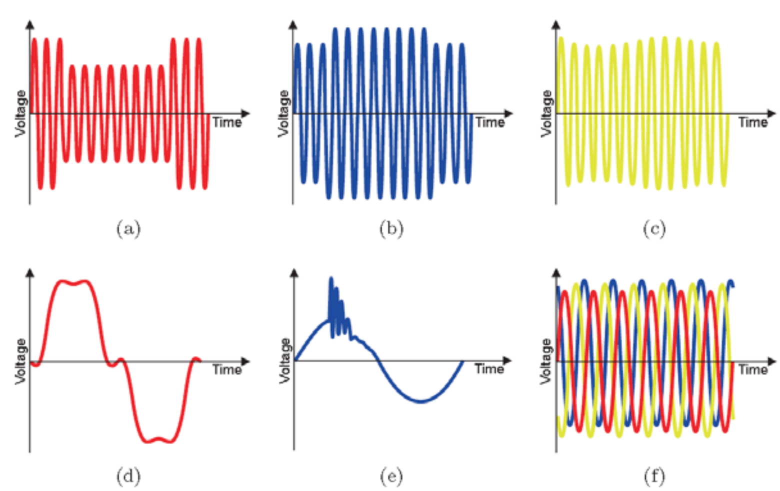

Figure 1: Basic conducted phenomena: voltage dip (a), surge(b), fluctuations(c), harmonic voltage distortion(d), transient voltage (e) and unbalance in three-phase supply (f) [2]

Harmonics are treated by many standards as a voltage quality issue, as voltage can be directly controlled and regulated by the power system [4][5][6][7]. On the contrary, current is determined by the various loads supplied, therefore, current quality cannot be easily controlled. Hence, much attention must be paid to current quality defined by the entity of loads installed on-board or at least the major ones, i.e., those of significant power demand with respect to electric system capacity [8][9].

All marine classification bodies are extremely concerned about harmonic voltage distortion and the possible consequences should some critical item of equipment malfunction or fail. Often viewed as a potential SOLAS (Safety Of Life At Sea) issue, classification bodies have imposed strict limitations on the magnitude of harmonic voltage distortion permitted on vessels classed under their rules, often based on international standards [10][11].

Interference cases

Also in consumer and industrial environments a rapidly increasing number of serious EMC issues due to conducted interference effects is observed. Especially in the frequency range 2-150 kHz, where only a few standards exists and nearly no requirements are taken into account. In [12] several conducted EMI cases have been described. The NTT Customer Complaint database of complaints shows that the majority of the complaints are between DC and 150 kHz, as shown in Figure 2, Noise frequencies that cause equipment malfunction, from the NTT Customer Complaint Database [13].

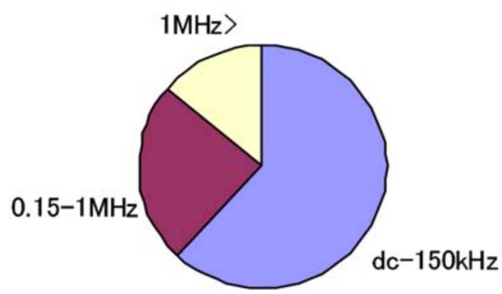

Figure 2:

A typical conducted noise pattern in time domain caused by a power drive system is shown in Figure 3. Conducted emission exceeded the EN 55011 limits from 150 kHz (tens of dB) up to and beyond 30 MHz.

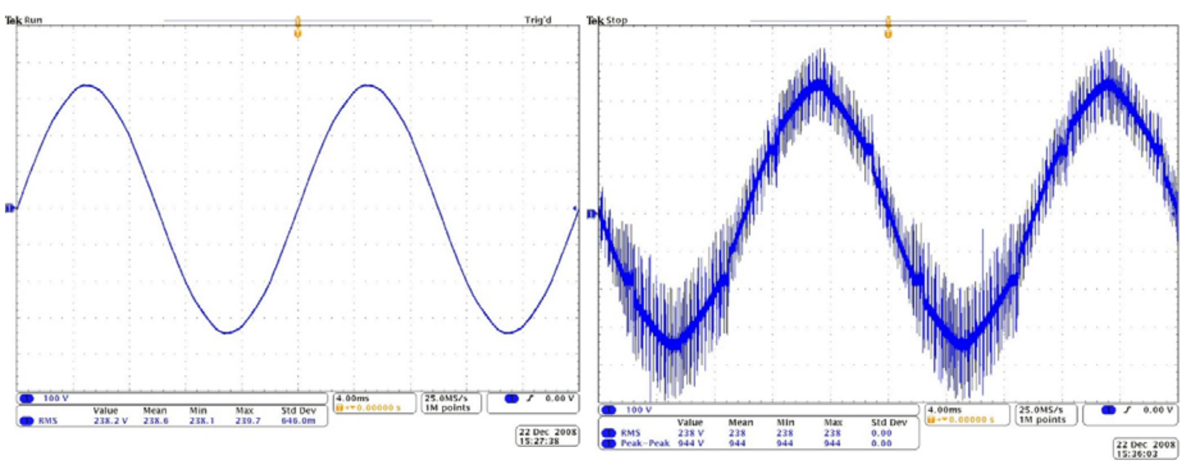

Figure 3: Line voltage without and with the PDS, 400V 50Hz. Figures from Kees Post [16] .

Although power drive systems are a common cause of EMC problems, also a large number of small loads are creating issues; Within a period of 27 months, 20 hospitals in The Netherlands had problems with the emergency generators. Detailed investigations learned that the problems were caused by the increasing number of modern non-linear equipment. This kind of equipment have a high crest factor and are demanding a high inrush current due to the initial charging current for capacitors. This inrush current caused the emergency generators to shut off immediately after energizing the power to the equipment. The mandatory emergency generator tests are now performed only after the electronic equipment is manually switched off.

A new energy efficient building, without conventional linear loads but with many nonlinear electronic equipment, resulted in a voltage waveform distortion at socket level as shown Figure 4. As a consequence transformers got overheated and EMC problems occurred. The power supply system was designed using the conventional assumptions of cos θ and linear loads. The simplest, but costly, solution was to install 2 additional transformers of 1.6 MVA each. Now the total supply apparent power is 7.2 MVA, while on completion of the building it was 4.0 MVA. The real power consumption is still about 3.0 MW.

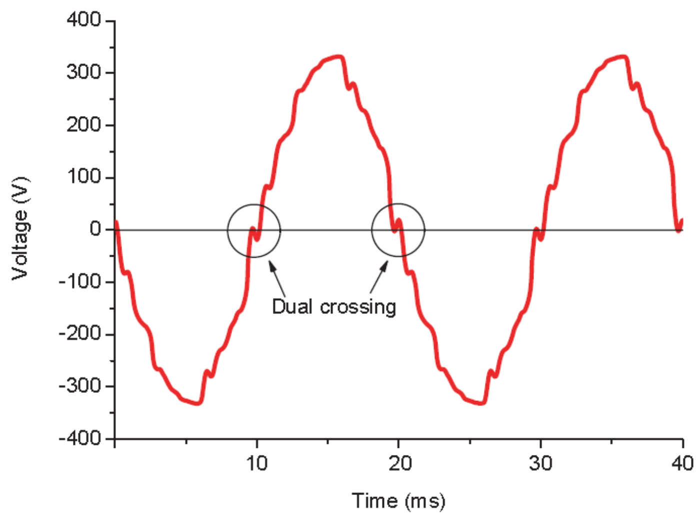

Figure 4: High level of harmonic distortion

Solutions

The most cost effective way to prevent EMC, and PQ, problems is to implement the measures already in the design, i.e. use equipment with

- power factor (PF) near to unity,
- low current total harmonic distortion (THDi), and
- include the appropriate EMC measures

The power factor shall be as close to one as possible, where the current waveform is proportional to the voltage waveform. When this is the case, the voltage and current are in phase and the reactive power consumption is zero, enabling the generators, transformers and cabling to efficiently deliver power. In other words, all of the energy supplied by the source is consumed by the load and none is returned to the source.

The current total harmonic distortion of equipment shall be minimized such that at vessel level the voltage distortion is within the limits: 5% to 8%, depending of the classification bodies. At equipment level the current THD can be minimized by using for instance active frond ends which consume current in a sinusoidal way. An active front end is, from an electronic circuit perspective, a mirrored power drive system; instead of converting DC to AC voltage, it converts AC to DC voltage. And thus it also needs an EMC filter to limit the high frequency interference. A slightly lower cost, but lower performance, THD reduction measure is the use of a 12 or 24 point transformer. Also line inductors can be used to decrease the THDi, but as transformers and inductors add weight and loss. If everything fails, and the THDv in the vessel is too high, then harmonic filters can be added.

This is a very common measure, but costly, as it can be applied only in the final stage of whole platform testing [17]. It can however save the installation of additional generators which are needed for systems with high THDv [9].

The correct EMC measures should be implemented in the equipment before installation on board. Either by following the rule-based approach using the applicable EMC standards, or using the risk-based approach, as mentioned in LR [18][19]

Ballast Water Treatment application

All marine classification bodies are extremely concerned about harmonic voltage distortion and the possible consequences should some critical item of equipment malfunction or fail. Often viewed as a potential SOLAS (Safety Of Life At Sea) issue, classification bodies have imposed strict limitations on the magnitude of harmonic voltage distortion permitted on vessels classed under their rules, often based on international standards.

Specially for retrofit activities of (high) power electronic systems, like ballast water systems on vessels, topics like EMC and Harmonic Distortion are getting more and more important. Due to space limitations often cheaper and smaller systems are selected without active PF circuits and sufficient filtering, causing many severe problems on-board later on. In ballast water systems that use Ultra Violet (UV) lamps, the applied electronic lamp drivers with active PF circuits, low mains distortion (THD), filtering for low EMC levels and improved immunity to mains voltage surges, will lead to a superior performance in the application. The active PF correction will protect the lamp from extinguishing during input voltage dips and brownout and will prevent system shut down due to the required cool-down time needed for the UV lamp for re-ignition. Properly designed power electronics and surge suppression circuits in electronic lamp drivers can prevent over-voltage damage and stress on components and also will prevent overvoltage peaks reaching the UV lamp in the system. Overvoltage peaks can deteriorate or destroy the lamps in the ballast water system.

The implementation of the proper measures can achieve significant cost savings such as reduced energy demand, reduced electrical equipment operating temperatures and extended electrical equipment life, and eliminating the risk of electromagnetic interference, and thus reduce the total ownership cost.

Conclusion

Conducted interference including power quality becomes increasingly important due to the high penetration of non-linear loads. New technologies will introduce new types of interference. Due to the lack of (interest and) standards, the 2-150 kHz has been the garbage bin for power electronics. Interference problems are occurring already and is delaying the introduction of systems and deployment of complete vessels.

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