Effect of Integrated Mast on Power Quality of Naval Vessel in Island Configuration

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Abstract— **Analysis and measurements have been performed to justify the use of Commercial Off The Shelf products in combination with the power network of a naval vessel. It was concluded that the onboard supply is well controlled and suitable for such applications, except for harmonic distortion, which exceeds the limits in civil and military standards. Measurements were first performed without the integrated mast on the vessel. The integrated mast contains a variety of antennas and control cabinets, which could have an additional effect on the power quality of the island network configuration present inside the vessel. During a second measurement series, power quality measurements with respect to civil and military standards have been performed in order to verify the effect of the integrated mast. It was shown that the naval power network of the vessel including integrated mast, which is normally designed and tested against military standards only, also meets civil standards suitable for the placement of COTS equipment**.

I. Introduction

Power networks of military naval vessels shall be compliant with military standards. In Europe, compliance is usually verified with the STANAG 1008 standard [1]. More and more Commercial Off The Shelf (COTS) products are however being used in combination with these power networks nowadays, which are not designed to be connected to a STANAG 1008 supply system. This could lead to degradation in performance of the connected COTS products, especially during the setting to work process of equipment inside the network [2]. The main reasons for using COTS products instead of military tested products are straightforward; they are more easily available and are lower cost than dedicated military equipment. Because of these advantages it is thus necessary to verify if COTS equipment could be attached to a navy vessel power network.

The power distribution network of the HNLMS Holland patrol ship of the Royal Netherlands Navy has been applied as the network under test. When COTS compliance is proven for this particular vessel (power quality in agreement with the land-based commercial EN 50160 standard [3]), it is expected that COTS equipment in combination with naval vessels possessing a similar network is possible as well.

The primary objective is the same as described in [2]: to analyze if an island power configuration onboard a naval vessel is suitable in combination with COTS products, i.e. being fully compliant with the EN 50160 standard. In this paper the analysis is performed including the integrated mast from Thales Nederland B.V. This was previously not the case. Fig. 1 and Fig. 2 represent pictures of the vessel excluding and including mast respectively.

Fig. 1. HNLMS Holland naval vessel excluding integrated mast

Fig. 2. HNLMS Holland naval vessel including integrated mast [4]

It is of great importance to verify the effect of the integrated mast on the power quality during its setting to work process, since it possesses multiple antennas and many control cabinets, which could have an effect on the network. The effect of the integrated mast on power quality requirements is verified on basis of the mentioned civil standard EN 50160, as well as the military standard STANAG 1008. It was already observed that the power network excluding integrated mast complies with the civil standard EN 50160, except for the harmonic distortion; Total Harmonic Distortion (THD) as well as the 11^{th} and 13^{th} harmonics were not compliant [2]. Before compliance can be tested it is therefore of primary importance to verify the source of this distortion and to consequently

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decrease it by means of harmonic filtering. An extra concern which arose in the time interval between both tests is the transfer from shore power grid to the power network of the naval vessel. This could also lead to power quality issues and is therefore analyzed as well.

II. Integrated Mast

The integrated mast (I-MAST) is not just one product [5]. It is a series of various sizes, each one intended for a different class of naval vessels. The I-MAST 400 is the first member of the family and has been installed on the considered vessel. An overview of the I-MAST 400 is presented in Fig. 3.

Fig. 3. Integrated mast (I-MAST 400) including apparatus

The upper antenna is for satellite communication (SATCOM). Underneath, the Identification Friend or Foe (IFF) antenna, Integrated Communications Antenna System (ICAS) for VHF and UHF communication, Smart In Littoral Environment antenna (SMILE) for air warning, Sea Watcher 100 (SEASTAR) for sea observation and the Staring Electro-Optic Security System (Gatekeeper) for infrared and visible light observation are located, altogether providing a military naval vessel with a complete package of sensors for defense purposes.

III. Power Supply Standards & Immunity Curves

The power supply quality of a public power network is defined in Europe by means of EN 50160: 'Voltage characteristics of electricity supplied by public distribution systems' [3]. This standard is confined to the electricity supplied at the supply terminals and does not deal with the supply system of an installation or equipment attached as loads to the network. The limits of this standard are summarized in Table I, where the percentages between brackets are the ranges of the time period, one week or one year, for the 10 minutes mean values. A subset of the limits for each individual harmonic up to the 13th order is listed in Table II. It is important to note that full EN 50160 compliance is met when the network is addressed during a full week period at minimum.

TABLE I
Overview EN 50160 Limits [3]

Voltage			
Nominal voltage	115 V	230 V	440 V
Over- / under- voltage	±10% *(95%)** +10/-15% *(100%)**		
Total harmonic distortion	8% *(95%)**		
Individual harmonic distortion	see Table II *(95%)**		
Frequency			
Nominal frequency	60 Hz	400 Hz	
Over- / under- frequency	+1/-1% *(99.5%)*** +4/-6% *(100%)***	-	

* range of 10 minutes mean values for 1 week
** range of 10 minutes mean values for 1 year

TABLE II
EN 50160 Harmonic Voltage Limits up to the 13TH Order

Harmonic Order	**Limit Mean RMS values (%)**	**Harmonic Order**	**Limit Mean RMS values (%)**
2	2	8	0.5
3	5	9	1.5
4	1	10	0.5
5	6	11	3.5
6	0.5	12	0.5
7	5	13	3

For military naval systems the power supply quality at the terminals of equipment is defined in STANAG 1008, 'Characteristics of Shipboard Electrical Power Systems in Warships of the NATO Navies'. The limits of this standard are summarized in Table III.

TABLE III
Overview STANAG 1008 Limits [1]

Voltage			
Nominal voltage	115 V	230 V	440 V
Over- / under- voltage	±16% (< 2s) ±5%		
Total harmonic distortion	5%		
Max. individual harmonic distortion	3%		
Frequency			
Nominal frequency	60 Hz	400 Hz	
Over- / under- frequency	±4% (< 2s) ±3%		

The most important differences between STANAG 1008 and EN 50160 can be made clear on basis of two characteristics. (1) The limits of the former are defined for the terminals of connected equipment, whereas the latter does not focus on the voltage supplied to connected equipment. (2) The STANAG 1008 limits are based on two discrete periods of time only, i.e. longer than 2 s and between 1 ms and 2 s, while EN 50160 does not define rigid limits. Therefore, voltage margins in EN 50160 cannot be used. COTS voltage immunity is considered by means of Information Technology Industry Council (ITI) curves [6]. In Fig. 4 the voltage immunity curves are shown, whereby the STANAG 1008 limits have been added as red lines.

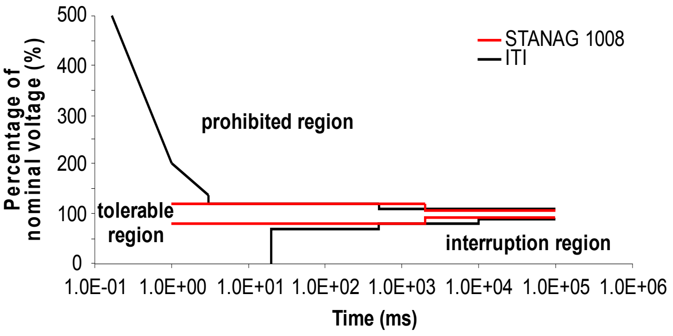

Fig. 4. STANAG 1008 and ITI curves (transient envelope), f = 60Hz

Harmonic current distortion has not been taken into account, since it is not included within STANAG 1008 and EN 50160.

IV. Measurements

Power quality measurements have been performed on-board of the HNLMS Holland patrol vessel of the Royal Netherlands Navy. The onboard power distribution network is fed by three 450 V_{ac} 60 Hz diesel generators, having a total apparent power of 3 * 1150 kVA. The power distribution system itself consists of 440 V_{ac}, 230 V_{ac} and 115 V_{ac} three phase delta supply networks. During the former measurement series it was shown that the harmonic distortion did not comply to both STANAG 1008 and EN 50160. It was also verified that harmonic non-compliance occurs when the electrical propulsion exceeds 30% of its maximum power. Afterwards, it was verified by the Royal Dutch Navy that the harmonic distortion was likely to be caused by the 230 V_{ac} mains network, which consequently affects the 115 V_{ac} and 440 V_{ac} mains supplies. It was therefore decided to place two harmonic (distortion) filters at this network.

Multiple Dranetz® "Power Explorers" have been connected to the mains circuitry of the IT power network inside the ship to automatically register power quality events and data according to the preferred standard. In this way simultaneous measurements at different locations can be performed for monitoring and verification. The following important quantities have been measured:

1. Voltage fluctuations inside the network (mains 3x115 V_{ac}, 3x230 V_{ac} and 3x440 V_{ac}),
2. Frequency fluctuations (mains 3x115 V_{ac}, 3x230 V_{ac} and 3x440 V_{ac}),
3. Harmonic distortion (mains 3x115 V_{ac}, 3x230 V_{ac} and 3x440 V_{ac})

The power explorers automatically register when predefined limits (see Table I and Table II) are exceeded, within a minimum interval of 1 ms (much shorter than a period from 60 Hz). Furthermore, the rms voltage and harmonic distortion are automatically logged every 200 ms, whereby averages are taken from 10 minute intervals. STANAG 1008 compliance was taken into account by the Royal Dutch Navy. Measurements were performed during a one week period, while the setting to work of the I-MAST 400 took place and the electric propulsion of the ship was varying between 30% and 100%.

V. Results

Distinct events with respect to diesel propulsion, electric propulsion, water cannon and fire extinguisher were only analyzed in the case of exceeding EN 50160 limits, because their effects have already been accounted for during the measurements excluding integrated mast [2].

It appeared as if the total harmonic distortion, and 11^{th} and 13^{th} harmonics still exceeded STANAG 1008 and EN 50160 with respect to 115 V_{ac} and 230 V_{ac} supply networks. It was however verified that these distortions were caused by turning off the harmonic distortion filters; snapshots have been taken for both situations (230 V_{ac}, filters connected / disconnected, see Fig. 5 and Fig. 6).

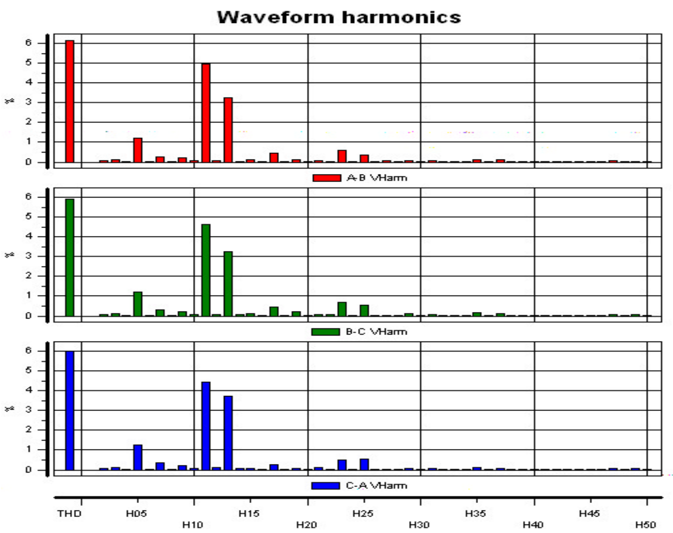

Fig. 5. Snapshot of harmonic distortion when both harmonic distortion filters were disconnected (100% electric propulsion).

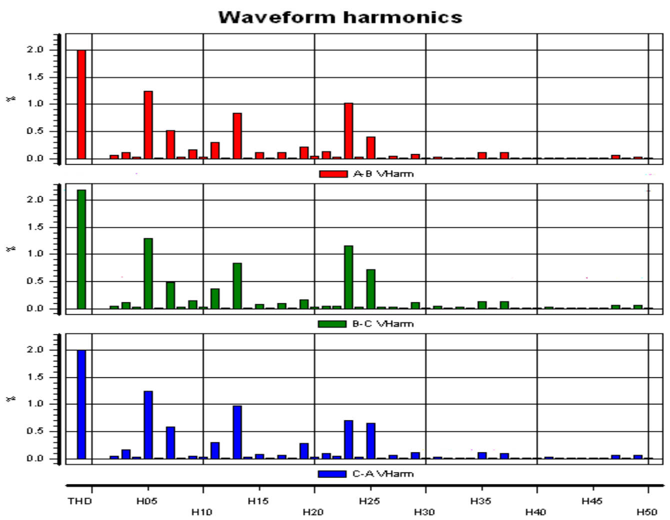

Fig. 6. Snapshot of harmonic distortion when both THD filters were connected (100% electric propulsion).

All harmonics are within STANAG 1008 and EN 50160 limits. This means that exceeding harmonic distortion limits can be taken care of by filtering the 230 V_{ac} network.

The effect of the I-MAST 400 on the power network is verified by means of EN 50160 supply quality histograms with respect to the measurement series excluding (Fig. 7) and including mast (Fig. 8). The considered characteristics were the voltages between phases, voltage unbalance, and frequency. The logged interval for both situations is 24 hours, whereby the values within 5%, 95% and 99% of this interval are represented. During this interval the electric propulsion varied between 30% and 100% for both cases.

The results from Fig. 7 and Fig. 8 show that the effect of the I-MAST 400 on the power network is negligible.

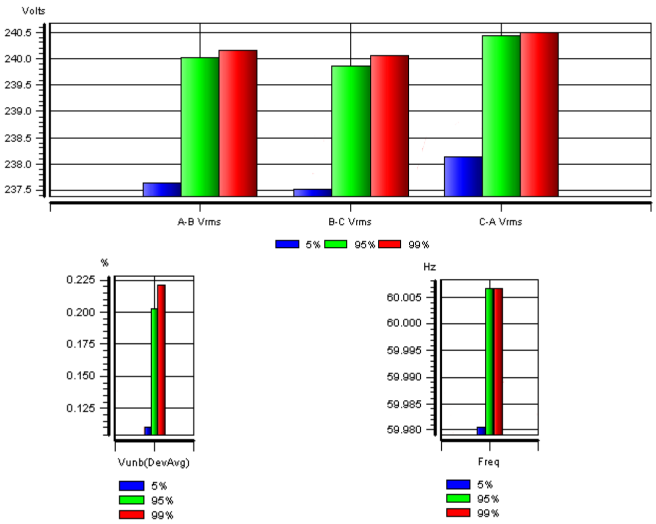

Fig. 7. Voltage quality of 230 V_{ac} supply, excluding Integrated Mast. Measurement time is 24 hours.

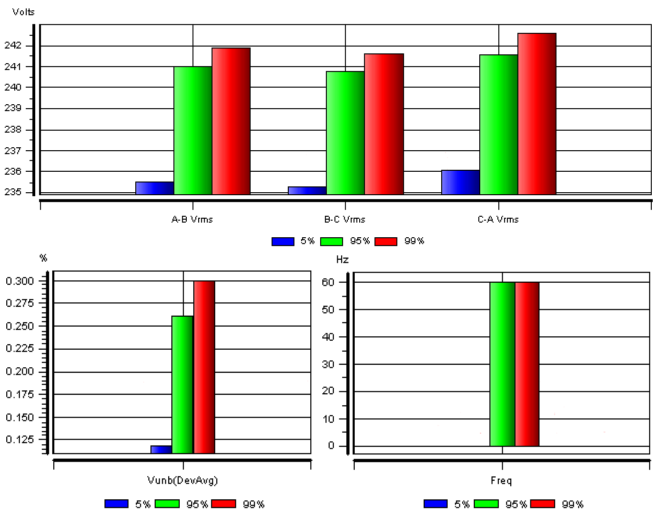

Fig. 8. Voltage quality of 230 V_{ac} supply, including Integrated Mast. Measurement time is 24 hours.

No special events have been observed when the power distribution was switched from shore to the internal power grid of the ship. The influence on voltage parameters can be verified in Fig. 9.

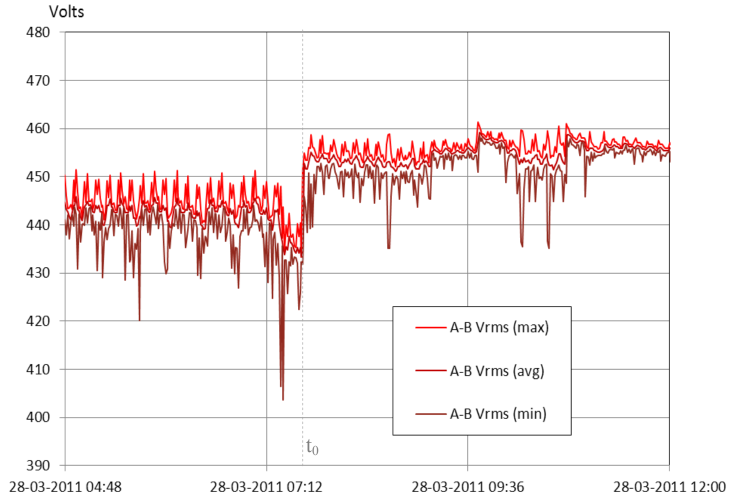

Fig. 9. Transfer from shore power grid to internal power network of ship regarding 440 V_{ac}. The transfer occurred at t_0 (approximately 07:30). Multiple measurements per minute were performed; minima, averages and maxima have been plotted per minute interval.

Table IV summarizes the EN 50160 compliance of the complete measurement series from 03-09-2012 to 21-09-2012.

TABLE IV
EN 50160 SUMMARY PROVIDED BY POWER EXPLORERS
(3x115V_{AC}, 3x230V_{AC}, 3x440V_{AC})

115V supply network	
Voltage: ±10% *(95%)**	Passed
Voltage: +10/-15% *(100%)**	Passed
THD-V: 8% *(95%)**	Passed
Individual harmonic distortion *(95%)**	Passed
Frequency: ±1% *(99.5%)**	Passed
Frequency: +4/-6% *(100%)**	Passed
230V supply network	
Voltage: ±10% *(95%)**	Passed
Voltage: +10/-15% *(100%)**	Passed
THD-V: 8% *(95%)**	Passed
Individual harmonic distortion *(95%)**	Passed
Frequency: ±1% *(99.5%)**	Passed
Frequency: +4/-6% *(100%)**	Passed
440V supply network	
Voltage: ±10% *(95%)**	Passed
Voltage: +10/-15% *(100%)**	Passed
THD-V: 8% *(95%)**	Passed
Individual harmonic distortion *(95%)**	Passed
Frequency: ±1% *(99.5%)**	Passed
Frequency: +4/-6% *(100%)**	Passed

* Range of 10 minutes mean values for measurement period

With respect to 230 V_{ac} it was only possible to verify EN 50160 compliance for a three day period, because of a defective memory card.

STANAG 1008 compliance was verified by the Royal Dutch Navy: no exceeding in voltage and frequency fluctuations was observed.

VI. DISCUSSION

Harmonic distortion is compliant with STANAG 1008 and EN 50160 requirements in combination with harmonic filters attached to the 230 V_{ac} network. It appeared that the harmonic distortion inside the 230 V_{ac} network affects the 115 V_{ac} and 440 V_{ac} networks as well, since the harmonics of these supplies were also decreased simultaneously by means of the mentioned filtering.

The integrated mast (I-MAST 400) does not have significant influence on the power quality of the power network. This can be verified by comparing the EN 50160 voltage quality with and without mast (see Fig. 7 and Fig. 8): during a 24 hour measurement interval the voltage unbalance with mast is 0.3% at maximum in comparison with 0.2% when the mast is not present, difference in voltage variation is less than 1%, and difference in frequency distortion is negligible.

It was verified that no significant power quality effects occur when transfer from external power grid to internal power network of the vessel takes place.

VII. CONCLUSIONS

It is possible to use COTS equipment in combination with IT networks on-board navy vessels. It is however recommended to guard or monitor the power grid with respect to the EN 50160 standard, since COTS equipment is used in a different environment (EN 50160 is a non-naval standard).

The I-MAST 400 has no significant effects on the power quality of the vessel network, i.e. both the STANAG 1008 and EN 50160 standards were fulfilled.

ACKNOWLEDGMENT

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