Ocean Engineering 107 (2015) 108–117

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Problems of power quality in the wake of ship technology development

Janusz Mindykowski, Tomasz Tarasiuk [1]

Gdynia Maritime University, Department of Ship Electrical Power Engineering, Morska 81-87, 81-225 Gdynia, Poland

ARTICLE INFO

Article history:
Received 21 June 2014
Accepted 21 July 2015
Available online 14 August 2015

Keywords:
Power quality
Ship systems safety
Classification society rules

ABSTRACT

This paper addresses the problem of electrical power quality and its influence on ship safety. There has been a perceptible increase in the importance of power quality in recent years due to the introduction of new methods for electrical energy production and utilization in ship systems. As a result, new challenges for ship designers, crew members, and ship classification societies are looming. In this paper, these challenges are considered in the context of their legal meaning and good engineering practice. The paper presents the authors' stance in the ongoing discussion ensuing after the accident on board the Queen Mary 2. The authors briefly discuss the following questions: How is it possible to describe the power quality in ship systems and by what indexes? What limiting values are to be imposed? How, when and where should the power quality be measured? Finally, how can the rules and procedures of ship classification societies related to power quality be improved to avoid catastrophic consequences of worsening power quality?

1. Introduction

Electrical energy is a basic medium supplied to various objects and industrial installations, including marine systems. In many cases, they are technically very complex and use the most advanced technologies.

Continuous progress in electrical and electronic engineering on ships covers two layers: a technical one, related to the complexity of marine electrical and electronic device construction and control and a personal layer, crew competence – related and connected with new requirements for watchkeeping officers responsible for the control, maintenance, diagnostics and repair of electrical and electronic installations on board. The first is based mainly on the development of new technologically sophisticated ships, such as passenger ships, large ferries, chemical and gas tankers, container vessels, oil rig suppliers and large offshore structures. In this respect, the increase in the number of complex all-electric ships, often equipped with dynamic positioning systems, or ships with main engines without camshafts with electronic control injection-common rail systems has to be mentioned.

Even the most sophisticated devices cannot be operated effectively if they are supplied with electrical energy of inferior quality. In consequence, the reliability, as well as the operational safety of the systems, is adversely affected. It is common knowledge that the usage of power converters, despite the other advantages, has an adverse effect on power quality. In particular, voltage and current distortions are observed, which have sometimes led to the application of more or less sophisticated filters in ship systems. However, no solution can guarantee ship safety due to unpredictable changes of the system characteristics and unavoidable malfunctions or failures of important system parts, e.g., harmonic filters. There are many potential dire results, including the increased likelihood of vessel catastrophe. One of the most spectacular examples of marine casualty in recent years was the accident onboard the RMS Queen Mary 2 (QM2) in September 2010 on passage near Barcelona, described and analyzed in a Marine Accident Investigation Branch report (MAIB, 2011), caused by the catastrophic failure of a capacitor in the aft harmonic filter room. The report and its conclusions are briefly described in the following section, as a starting point for the subsequent considerations.

The first problem in dealing with power quality on modern ships is its reliable assessment under all system configurations and in all circumstances. This is not a trivial task, particularly if one takes into account that there are numerous combinations of power system configurations and exploitation patterns. This therefore requires a proper choice of sensor placement and related indexes to cover all of the cases of possible waveform distortions without an unnecessary increase in the amount of sometimes hard-to-interpret data. Other phenomena, such as voltage and frequency deviations and voltage asymmetry, have to be considered as well. Furthermore, the choice of permissible values for the transient and steady states is necessary. This should include the desired time of

E-mail address: totar@am.gdynia.pl (T. Tarasiuk).
[1] Tel.: +48 58 6901470; fax: +48 58 6901261.

http://dx.doi.org/10.1016/j.oceaneng.2015.07.036

aggregation of the measurement results. Finally, problems of the required measurement instrumentation are to be discussed in both the aspects of hardware and software. The latter concerns recommended methods of signal processing, especially parameters of waveform distortions. There are justified doubts about the performance of commercial power quality analyzers during the measurements of real ship signals because the application of the related standards of 61000-4 series for this purpose can result in unreliable and misleading results (Tarasiuk, 2009/2). The discussion will be completed by considerations of measurement device placement, e.g., on the bus bars of main switchboards and/or on terminals of important receivers, as well as the exact timing of the measurements, e.g., once per year and/or after important system overhauls, such as bow thruster power converter repairs. All of the above considerations will be illustrated and justified by the investigation of real ship signals.

2. Accident on board the RMS Queen Mary II

This section describe the above-mentioned accident onboard the RMS Queen Mary 2 (QM2), based solely on the Marine Accident Investigation Branch report and its main findings and conclusions. Although the authors were convinced that some undertakings were necessary prior to the accident, it seems that it caused quite a discussion among marine engineers. Therefore, the authors consider the accident a good starting point for the justification of their stance.

Even a rough overview of the part of the report (MAIB, 2011) dedicated to the electrical system installed onboard the QM2 leads to some telling observations. First, although the power management system was a function of the integrated automation system, it was not designed to have any input from the protection relays of the generator main circuit breakers. Moreover, this solution did not reduce the propulsion power or react in any way to the failure of the harmonic filters. Second, the basic knowledge of the harmonic distortion assessment in the QM2 electrical system was based on limited and not exhaustive sea trials and simulation programs. For instance, no trials were carried out with three diesel generators (DGs) and one harmonic filter (HF) working concurrently, which was the combination being used at the time of the accident (MAIB, 2011). Third, the results of simulations before the accident could have been underestimated because they covered only a selected number of configurations of generators supplying the load. The simulation study of harmonic distortion levels carried out after the accident showed that for the case with no filter in use (corresponding to a situation with one filter in use and its failure), the THD_v index was predicted to exceed 22% at 70% ship speed, which is significantly above the permissible limit of 8% laid out in the Lloyd's Register rules (LRS, 2001). The company responsible for this post-accident simulation study has stated in conclusion that "*additional measurement* […] *should be done on board to check the harmonic level with the low voltage pollution*". It indicates that the anterior study referred only to the high voltage supply. The authors of this paper also have some doubts related to the covered frequency band up to the 49th harmonic order, as well as the THD_v definition used in accordance with LR's requirements, in the wake of the discussion of the power quality issues undertaken by IACS (MCA, 2010). Another observation included in the report concerns the fact that the harmonic distortion was not routinely measured in service, as the crew were not aware that they had the appropriate measuring equipment on board (MAIB, 2011). In other words, some ambiguities within the KUP competences (knowledge, understanding and proficiency) of watchkeeping officers in IMO meaning occurred (IMO, 2011).

The report under consideration concluded that the harmonic filter capacitor degradation was probably caused by a combination of transient high voltage spikes due to frequent switching operations and occasional network overvoltage fluctuations. Capacitor deterioration had not been detected, and because there were no internal fuses or pressure relief devices, it was not noticed until the capacitor casing failed catastrophically.

Although the exact cause of the capacitor failures could not be determined univocally, we have no doubts that the reasons for this accident originated in power quality disturbances. Additionally, the safety lessons from the previously cited report are directly linked to power quality issues, such as harmonic filters with current imbalance protection systems, the effects of harmonic distortion and their mitigation, and the necessity of regularly monitoring the electrical network to detect transient voltage spikes, resonances and excessive harmonic levels. This accident was classified in the Marine Casualty Information as a Less Serious Casualty because the appropriate columns of the MAIB report declared: "*Fortunately, the vessel was clear of navigational hazards and no one was injured*". This time, the situation ended happily. However, taking into account the 3823 persons present on board at the time of the accident and the fact that the reasons of the accident are very clearly defined by the commission as power quality problems, it seems clear that the effect of the power quality decrease in the context of marine accidents cannot be neglected. Taking into account previous experiences in the world of shipping, one essential point that should be addressed to improve the rules and procedures of ship classification societies is related to power quality. Particularly, the following topics have to be addressed: how is it possible to describe power quality in ship systems and by what indexes? What limiting values are to be imposed? How, when and where should the power quality be measured?

3. Power quality in ship electric power systems

3.1. Fundamentals

The concept power quality includes two aspects: continuity of power supply and appropriate parameters of delivered and used electrical energy. In other words, electrical energy must first be continuously delivered in appropriate quantity and afterwards its parameters should be evaluated. According to IEC standard 61000-4-30 (IEC, 2015) the term power quality means "*characteristic of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters*" and this term is mainly related to voltage parameters (Dugan et al., 2002; Tarasiuk and Mindykowski, 2012). The parameters are to describe the rms value of the voltage, its frequency, unbalance and waveform distortions. However, this above-cited general definition, especially in the context of ship systems, should be completed by another approach to power quality laid out in the IEEE Std. 1159-2009 (IEEE, 2009). This standard gives a description: "*The term power quality refers to a wide variety of electromagnetic phenomena that characterize the voltage and current at a given time and at a given location on the power system*". According to this definition, the power quality is not described simply by a set of technical parameters, but rather should be considered as the outcome of the interaction of numerous variables and accompanying conditions, taking into account electromagnetic phenomena. The related categories of power system electromagnetic phenomena (IEEE, 2009) are: transients, short-duration variations, long-duration variations, voltage imbalance, waveform distortion, voltage fluctuations, and power frequency variations. These phenomena are characterized by appropriately defined power quality indices that are determined on the basis of the methods, algorithms and procedures partly described in related standards and rules (IEC, 2015, 2002/1, 2002/2; IEEE, 2002, 2009), mainly by means of