MONITORING THE POWER QUALITY IN A NAVAL POWER SYSTEMS

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Lucrarea prezintă rezultatele unui studiu experimental privind calitatea energiei electrice pe o platformă marină în regim de foraj. În cadrul platformei analizate există un mare număr de receptoare electrice cu caracteristici diferite care determină, la bara de alimentare de 600 V, un regim complex cu variații importante de tensiune (efect de flicker), regim deformant şi un necesar important şi variabil de putere reactivă.Pentru a se propune o soluție tehnico-economică viabilă, a fost necesară prelevarea unor eşantioane de date într-o serie de puncte caracteristice ale rețelei electrice din cadrul sistemului electroenergetic naval (NPS). Datele obținute prin măsurători sunt considerate ca fiind reprezentative, însă, nu au surprins intervalele de solicitarea maximă a generatoarelor (motorul de acționare principal nu a fost încărcat la maxim pe durata măsurătorilor).

The paper presents the results of an experimental study on power quality in an offshore drilling regime. In the platform analyzed there are many electric receivers with different characteristics which determine the power bar 600 V, a complex system with significant voltage variations (flicker effect), and a distorting regime and an important variable reactive power. To propose a viable techno-economic solution, it was necessary data collection of samples in a series of characteristic points of the power grid NPS (Naval Power Systems). The data obtained by measurements are considered representative, but they did not surprise the intervals of maximum request of the generators (the main drive engine was not fully loaded during the measurement)

Keywords: NPS (Naval Power Systems), power quality, voltage fluctuation, reactive power

1. Introduction

The experimental study was carried out on an offshore platform under the drilling regime analyzing, in particular, the aspects regarding the power quality and reactive power load in excess of the generators in the power plant.

The craft systems are of special construction to withstand moisture, extreme operating conditions, indoors very small in size, ventilation, etc. and are subject to special rules regarding the power quality compared to plants on the ground [2].

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To examine changes in electrical quantities, including reactive power and power factor in measuring point M_1 (Fig. 1) was installed an equipment ION 7600, and in the measuring point M_2 was mounted an equipment CA 8332. The measurements included a range of almost 12 hours, considered characteristic [1].

Such type of measurements into the NPS was made for the first in Romania.

2. The electrical diagram of NPS (Naval Power Systems)

The analysed platform comprises a powerplant with 6 synchronous electric generators [4], having each the nominal power S_n = 1400 kVA, nominal power factor cosφ = 0.8, nominal current at 1408 A and nominal voltage at terminals equal to 600 V.

The electric scheme has two voltage levels (Fig. 1), 600 V to supply the main motors of the platform and 400 V for other receivers (electric lighting, operating systems etc.).

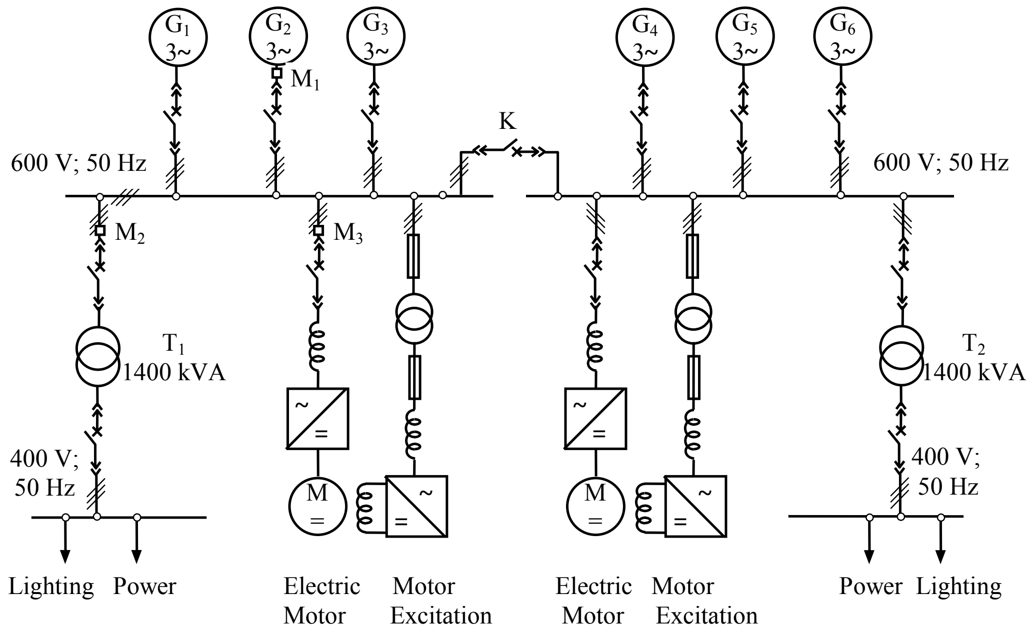


Fig. 1. The scheme of the electrical circuit of the platform.

The main motors of the platform are d.c. voltage with parallel excitation and are supplied through converters. The adjusting control of the speed, depending on the load of the machine is achieved by adjusting the amount of electric current in the primary circuit of the electric machine [3].

3. Analysis of the distortion phenomena in the electrical circuit of the platform

The measurements were performed with performance monitoring and measurement equipment following, in particular, the level of distortion in different parts of the scheme.

Platform-specific technological process leads to a strong variability of both active power consumption and reactive power, which leads, naturally, a variable power factor, and lack of reactive power compensation systems.

Power factor values recorded in different operating conditions can be seen in Fig. 2. We can observe variation of power factor between 0.45 and 0.82.

Fig. 2. Values recorded by the local equipment (U, I, P, λ).

Taking into account that the power factor λ expressed as a ratio of active power, P, and the apparent power, S [1,3,5,7]:

$$\lambda = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2 + D^2}} \tag{1}$$

is determined by the reactive power, Q, and the distorting power, D, two main issues were analyzed:

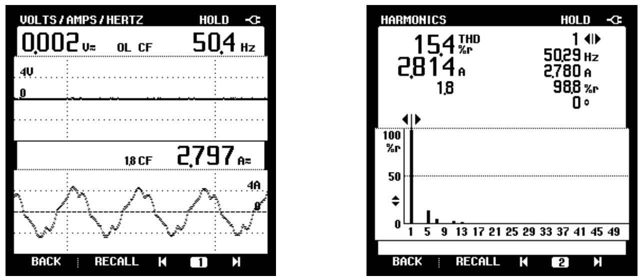
- the existence of receivers that lead to strong nonlinear distortion curves and to non-active power;
- the important need for reactive power in the electrical diagram of the platform.

3.1. Measurements at the generator terminals G_2

Fig. 3 presents the results of measurements at the generator terminals G_2 (load at 650 kW, 645 kVAr, 915 kVA), in the measuring point M_1 (Fig. 1) for the analysis of the waveform of the electric current generated by the generator.

Average data measured at the point M_1 (from the generator terminals G_2) are shown in Table 1 [1].

The data analysis of Fig. 3 reveals that the current harmonic distortion is 15.4%, the r.m.s. value of the current 2.797 A, the crest factor CF = 1.8 (ratio of signal peak value and actual value) and the K factor, k = 1.8. The significant harmonics are rank 5 (γ 5 = 14,3%) and rank 7 (γ7 =5,3%).



a. *b.*

Fig. 3. The electric current shape in the generator circuit G_2 (*a*) and its spectrum (*b*)

The K factor, analyzed in the study is a sensitive indicator of the thermal loading of transformers and electrical machines [3,5].

$$k = \frac{\sum_{h=1}^{M} (h \cdot I_h)^2}{\sum_{h=1}^{M} (I_h)^2} \qquad (2)$$

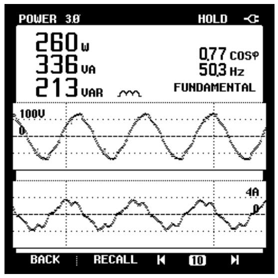
where I_h is the r.m.s. value of the electric current having the rank k and M - number of harmonics taken into account (typically M = 40).

During the measurements at point M_1 the current total distortion factor varied between 14.6% and 15.4%, and the voltage total distortion factor between 5.9% and 6.8%.

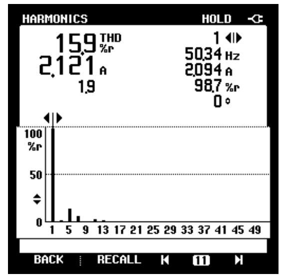
The current transformer has the ratio 1500 / 5 A, so that values shown in Fig. 3 must be multiplied by a factor of 300.

Measurements for another load of generator G_2 are presented in Fig. 4. Data analysis of Fig. 4 highlights the maintaining of the shape of the electrical current in the generator circuit and a less distorted waveform of the busbar voltage. The voltage power factor of the fundamental harmonic is $\cos\varphi_1 \cong$ 0.77 per phase A. The ratio of voltage transformer is 600/100 V. The main harmonics recorded are of rank 5(γ 5= 14.6%) and rank 7 (γ7 = 5.9%).

The current has a distortion factor THDI = 15.9% and the K factor is k = 1.9. During recording, the total distortion factor on voltage THDU has variations between 5% and 6%.



a.



b.

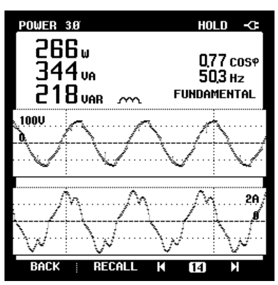
Fig. 4. Current shape (phase A) and voltage between phases B and C (*a*) measured at point M_1 and spectral composition of the current (*b*)

Records presented in Fig. 5 refer to phase C of the generator. We can observe a similar shape of electric current generated, characterized by CF = 1.5 and a K factor, k = 2.0. The power factor, on the fundamental harmonic on the phase C, $\cos\varphi_1 \cong 0.77$. The main harmonics are those of rank 5 ($\gamma 5$ =15.4%) and rank 7 (($\gamma 7$ =5,9%).

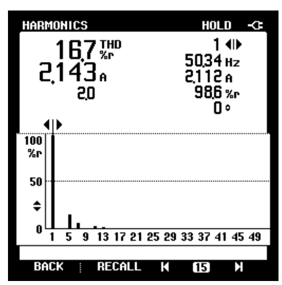
Table 1.

Values measured at the generator terminals G_2

	Active power, kW	**Reactiv power,** kVAr	**Apparent power,** kVA	**THDI** %	**THDU** %	**Power factor** λ
Phase A	221	–	–	14,6	6,8	–
Phase B	219	–	–	14,7	6,6	–
Phase C	215	–	–	15,4	5,9	–
Total	655	645	915			0,716



a.



b.

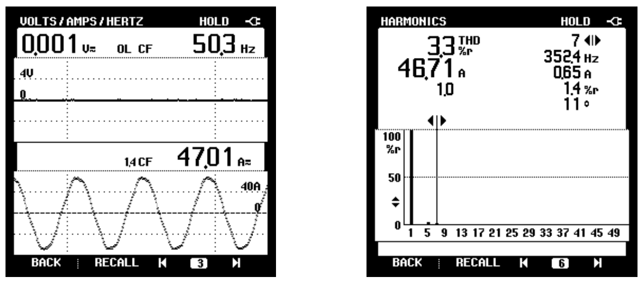
Fig. 5. Current shape (phase C) and voltage between phases B and C (*a*) measured at point M_1 and spectral composition of the current (*b*)

3.2. Measurements in primary circuit of the transformer T_1

The registered form of electric current in the primary circuit of transformer T_1 in the measuring point M_2 is shown in Fig. 6.

The data analysis of Fig. 6 reveals that the shape of electric current absorbed by T_1 transformer supplying 400 V bar is practically sinusoidal, characterized by a crest factor CF = 1.4 (compared to the ideal value 1.41) and a K factor, k = 1 (equal to the ideal). The total distortion factor of the current is 3.3% and the r.m.s. value of the fundamental harmonic is 99.9% of the r.m.s. value of current. The main harmonics of the electric current are of rank 5 (3.1%) and rank 7 (1.4%).

During the measurements, T_1 transformer was loaded with 293 kVA (power values in Fig. 6 must be multiplied by a factor 6). T_1 transformer absorbs an almost sinusoidal power, so it cannot be a source of distortion of the electric current absorbed by the generators of the system.



a. *b.*

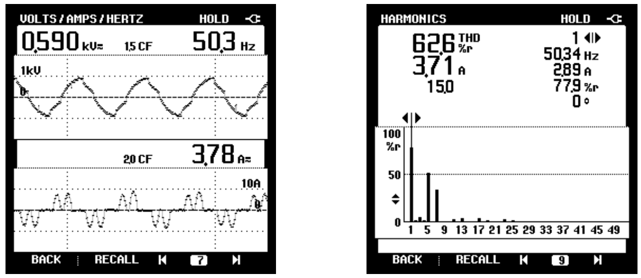
Fig. 6. Shape (*a*) and spectral composition (*b*)of the electric current absorbed by the transformer T_1 (primary side), at the measuring point M_2

3.3. Measurements in the power converter circuit

The electric current in the supply circuit of the d.c. voltage motor, in the measuring point M_3, on the phase A, is shown in Fig. 7. During the measurements the electric motor was not operating (about 19.5 kVA power handling; the specified values of the electric current in Fig. 7 should be multiplied by a factor 5).

In the Fig. 7 are presented the electric current on phase A and the voltage between phases B and C. The shape of electric current is typical for a converter system with 6 pulses. The spectral components of rank 5 and 7 are the most important (γ_5 =66,6% and γ_7 =43,4%) that is normal for a such type of converter. The crest factor of the electric current is CF = 2 and K factor is k = 15.0. The fundamental component of the electric current on phase A is dephased capacitively (before the voltage corresponding to 7.2 degrees). In this way, the electric current curve is practically in phase with the corresponding phase voltage curve [1,3].

Although the total distortion power factor is high 62.6%, its influence on the generator terminal voltage distortion is negligible, given the small value of electric current (about 19 A).



a. *b.*

Fig. 7. Current and voltage shapes (*a*) and spectral composition (*b*) of electric current drawn by voltage converter (at measuring point M_3) – low load of the electric motor

The analysis of the curves presented in Fig. 7 highlights the approximately sinusoidal shape of voltage at the bars of 600 V and the specific shape of electric current drawn by the voltage converter at a d.c. voltage.

Both the electric current on phase A and the electric current on phase B have in their spectrum harmonics of rank 5 (γ_5 = 68,5%) and 7 (γ_7 = 46%). The calculated power factor on phase A, is equal to 0.56. The electric current on phase A is characterized by a total distortion factor of 64.2%.

The measurements made for different loads of converter of the electric motor revealed a typical form of electricity, with significant spectral components of rank 5 and 7. The presence of coils having the limiting the current distortion determine a phase shift of the current in relation to applied voltage, requiring, thus, an important input reactive power [3, 7]. During the measurements, the power factor ranged between 0.45 and 0.83 depending on load.

Although total distortion factor of electric current drawn by the converter of the motor is relatively high, the compensation of the harmonics in the power system of the platform determines the form of electricity absorbed by the generators not to be strongly distorted [3]. To limit the harmonic disturbances, both the main converter and converter for excitation are provided with inductive filters connected in series.

4. Conclusions

Given that on the platform there is a large number of electrical receivers with different characteristics which determine at the power busbar of 600 V, a complex system with significant variations of voltage unbalance and important variable reactive power as resulted from monitoring data presented (for some types of electrical equipment within a NPS) we can go to a technical analysis of the solutions to limit the large load with excessive reactive power of the generators in the system.

A simple solution to limit the current distortion could be installing a filtering circuit for harmonic 5 (the main harmonic the electric current spectrum) and harmonic 7. The filter circuit will be a source of reactive power to cover the fixed part (minimum load chart) of the reactive power requirements.

Although the tests carried out allowed to obtain relevant information on changes in electrical quantities at representative points of the scheme, to obtain all the necessary data sizing up the elements of the compensation assembly it is necessary to perform measurements on a longer time period (at least a week) to capture significant ranges of load of the generators in the naval system.

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