ASPECTS REGARDING THE ENERGY EFFICIENCY AND HARMONIC SPECTRUM AT DRILLING WELLS

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Abstract **– The paper presents the results of quality analysis measurements of the electric- power-supply network in the connection point of consumers like Drilling plants containing non-linear equipment which induces harmonics in the network and works in the same time with reduced power factor. The measurements, the analysis and the technical-economic study were realized at the request and with the co-operation of the users.The purpose was to define the pollution level of the network at this type of consumer, to evaluate the energy efficiency and the implications concerning the safety in operation and the identification of proper operating solutions in the new conditions and norms imposed by the Electric Energy suppliers.**

Keywords: *Harmonics, Power factor, Energy efficiency, Active power filter*

1. INTRODUCTION

The quality of the electric energy, unlike others activity sectors, depends not only on the supplier, but also on all the consumers connected at the same supply network; some of them can cause interferences in the supplier network, which affect the operation of other consumers, connected at the same network; consequently, the consumers which contribute to the alteration of the electric energy quality over the admissible values must take measures in order to limit the produced disturbances to the allocated values or accept the possibility of their deconnexion.
The harmonics appear from the proper installations of the consumer and they can propagate or not in the network and affect also, in this way, other consumers. It is the responsibility of the consumer to take measures for being sure that the delivered energy for its process has an adequate quality.
A concrete case of non-linear consumer which requires the carrying out of a special study and an analysis of harmonics in the real conditions of exploitation for choosing the solution for the rise of energy efficiency at the consumer with posititve repercussions in the electric power transmission and generation are the drilling wells.
In our country the drilling wells have driving systems with D.C. motors, supplied from the three-phase distribution network by means of 6 pulses three-phase rectifiers. These ones introduce in the network significant harmonics of the 5-th order up to the 19-th order, their weight depending on the working conditions of the well (running state, drill state , pumping state with one or two pumps). The total current distorsion factor (THD_I) exceeds in some cases 50%. Besides the pollution of the network with harmonics, the drilling plant works with a very low power factor (up to 0,25). This case is one of high pollution of the electrical network and of inefficient utilization of the energy in the industrial processes. Compensation and filtration installations of ECF type which equip at present the drilling stations are totally inefficient and most of them are out of operation. The ECF have filters for the 5-th and 7-th harmonic and a control device which does not respond to the system dynamics. It is designed tens years ago with out-of-date technologies.
The harmonics appear because of the currents and the most part of harmful effects are due to these currents. It is not possible to draw useful conclusions without knowing the current harmonics spectrum. But it is necessary to measure both the values of harmonic voltages and the values of the currents and the determined values are explicity specified as values of the voltage and the current.
While the most of voltage dips and breakings have the origin in the transmission and distribution system and they are in the responsibility of the supplier, the problems of the harmonics are mainly in the responsibility of the consumer. The harmonic currents create problems in the installations and when these currents circulate back by the impedance of supply path, in the common point of connection appears an harmonic voltage. This voltage distortion or at least some of its components are transmitted in the whole system and they add up with the present voltage harmonics fund in any transport system (e.g. because of the non-linearity of the transformer). Limiting the harmonic currents that the consumers can generate it is possible to keep the distorsion level of the voltage at the supply in the admissible limits. The presence of the reactive power and harmonic currents components in the electric energy transmission and distribution lines diminishes their efficiency and capability.
The consumption of electric energy in Romania is one of the highest of the Central and Eastern Europe. The

improvement of energy management could be a direct factor of the economic growth, of the pollution reduction and resources saving, so that these ones are used in a much more productive way.
The improvement of energy efficiency is a priority of the national energy policy which must counterbalance the tendency of exageratted growth of energy consumption in all the areas of the economy and identify the possibilities and the ways for energy intensity reduction by implementing of adequate programs.

2. HARMONIC SOURCE

Drilling electric equipment is intended to drive the main equipment of the drilling plant (drilling rig, revolving table, mud pump) and to supply the auxiliary services (asynchronous motors of 380 V with powers between 0,37-75 kW, normal lighting at 220 V and emergency lighting at 24 VDC) of the well.
Drilling plant for the the wells of type F200, with mains supply, comprises the following main driving electric equipment :

- one energy distributor of 20 kV
- 2 transformers of 2000 kVA, 20/0.66 kV
- 2 SDACR type control and regulation substations
- one compensation and filtration equipment for harmonics type ECF-M-0,66-750/900
- 4 DC electric motors with series excitation, 850 kW, 770 V, 1150 rot/min, MCF type.

Control and regulation substations assure the supply, the control and the speed regulation of DC motors 850 kW which drive the main aggregates of the drilling plant by 4 thyristor convertors – 6 pulses three-phase rectifiers representing the non-linear load which pollutes the network with harmonics. The electronic control and the power conversion equipment generate harmonics imposing impedance cyclic changes at the switching of energy supply circuit.

3. THE RESULTS OF MEASUREMENTS

3.1 Parameters of the analysed network

- three-phase supply transformer : 20/0.66 kV, 2000 kVA, 50 Hz, U_{sc} = 5,87 %
- with isolated neutral
- short-circuit power: 34.07 MVA
- short-circuit current: 30 kA

3.2 Apparatus and measuring points

To carry out the measurements it was used one network analyzer type AR5 with software for harmonics recording. The measurements of energy parameters were carried out at two drilling wells of SC FORAJ SONDE SA Craiova, at a voltage level of 0.66 kV in the secondary of the power transformer:

▫ the current was measured with clamps of 2000 A on two phases, on the supply cables between the transformer and the control and regulation substation;

▫ the voltage was directly measured, on the plug-in terminations of 660 V at the substation input.

3.3 Harmonic spectrum analysis

During the carrying out of measurements the well 1 worked in „drill" state, at a drilling depth of 1700 m, with a single mud pump, driven by a DC motor of 850 kW supplied from a three-phase bridge rectifier entirely controlled.
The measurements were carried out in the following conditions:

♦ with the coupled automatic compensation installation with passive filters.

From the analysis of registered parameters in this case it resulted [2] :

- phase voltages between 392-395 V, with a growth of 3-3.5% in comparison with the nominal value (U_n= 660 / $\sqrt{3}$ = 381)
- phase currents 312 A ± 7 A
- the three-phase active power changes between 346-354 kW (working state at constant load);
- average capacitive power factor 0.94 (whence the voltage growth)
- the waveforms for the voltage fig. 1 and for the current fig. 2 are distorted

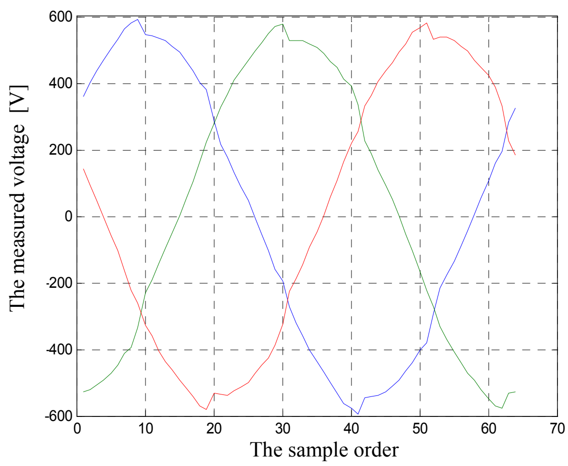

Figure 1: Waveform for voltages

- the individual voltage harmonics, in comparison with the imposed limits by PE 143/94 [1] exceed those ons of the order 15, 21, 27, 28, Table 1

Harmonic order	15	21	27	28
Measured value (%)	0,7	1	0,6	0,3
Rated value (%)	0,2	0,2	0,2	0,2

Table 1: The voltage harmonics

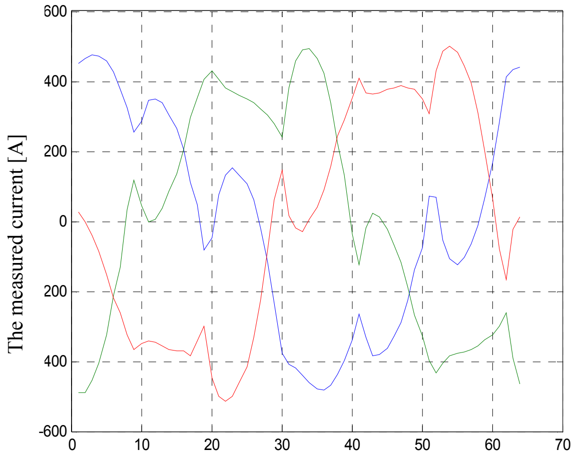

Figure 2: Waveform for currents

- the individual current harmonics have the amplitudes in the module presented in the fig.3 and compared with the imposed limits in per cent of the value of the fundamental according to PE 143/94, they exceed those presented in the Table 2;

Harmonic order	3	5	11	23	25	29
Measured value(%)	28	21	9	3	3	2,4
Rated value (%)	12	12	5,5	2	1	1

Table 2: The current harmonics

- the total distorsion voltage factor (THD%_Vi): max . 4,2 % < 8 % imposed
- the total distorsion current factor (THD%_Ii): max . 34% > 15 % imposed

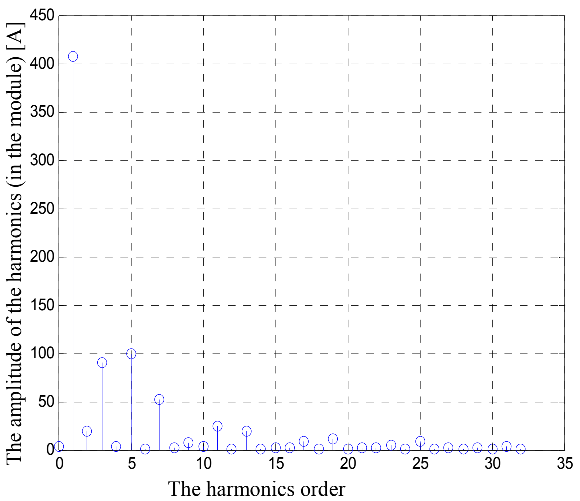

Figure 3: The values of individual harmonics for the current

♦ the same state, with disconnected power factor compensation installation
- the phase voltages are at the nominal value
- the r.m.s. values of the phase currents are 550 A; it observes the load current growth from 312 A to 550 A, thanks to the low power factor, at the same active installed power.
- the three-phase active power about the value of 340 kW – working at constant load
- the three-phase inductive reactive power is 490 kvar, being non-compensated
- the average power factor is inductive: 0.53
- the waveforms for the voltage – fig. 4 and for the current – fig. 5 are distorted, specific to the controlled rectifier
- the individual voltage harmonics, compared to the rated limits, exceed those presented in the Table 3.

Harmonic order	15	19	21	27
Measured value (%)	1,1	2	1,4	0,8
Rated value (%)	0,2	1,5	0,2	0,2

Table 3: Compared individual voltage harmonics with imposed limits

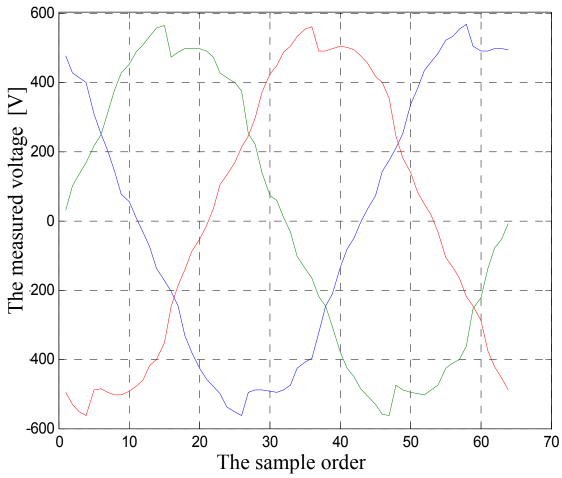

Figure 4: Waveform for voltages

- the individual current harmonics – fig.6, compared to the imposed limits, exceed those presented in the Table 4.

Harmonic order	5	11	25	29
Measured value (%)	30	6	2	1,9
Rated value (%)	10	4,5	0,7	0,7

Table 4: Compared individual current harmonics with imposed limits

- the total voltage distortion factors (THD%_Vi): max. 7,4 % < 8 % imposed

- the total current distorsion factors (THD%_Ii): max. 30% > 12 % imposed

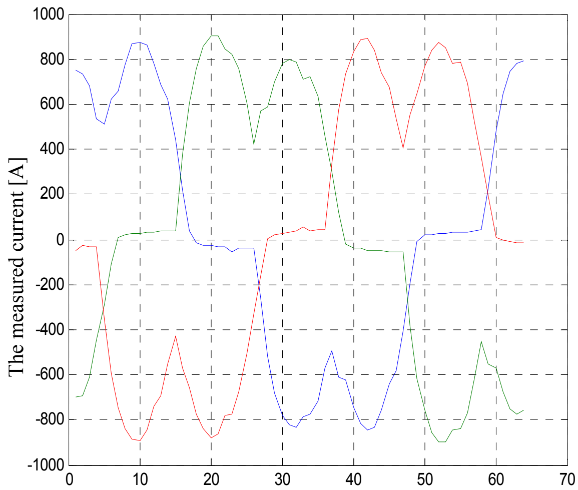

Figure 5: Waveform for the currents

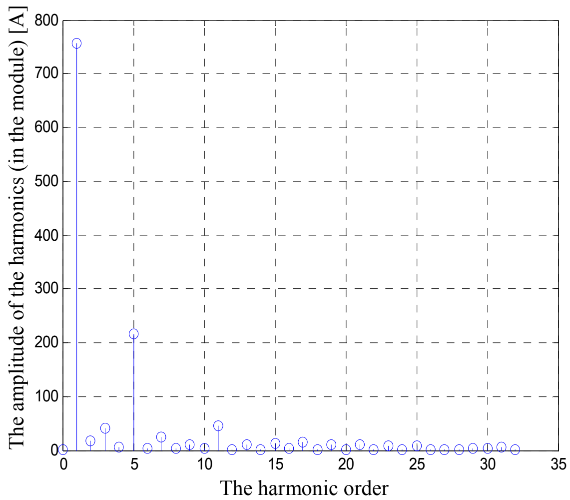

Figure 6: The values of individual current harmonics

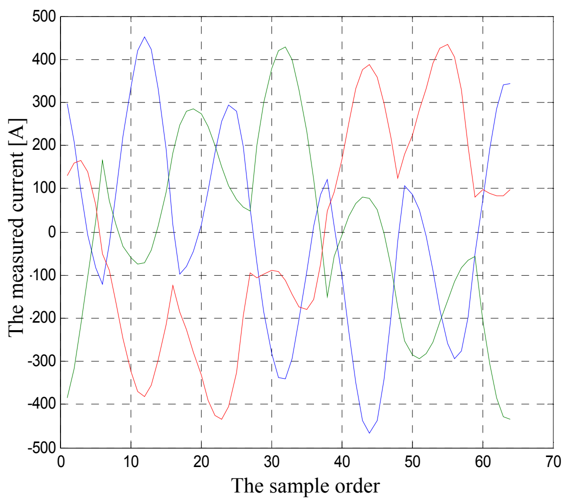

Figure 7: Waveform for the currents

During the measurements carrying out the well 2 worked in the „bringing out" state, at a drilling depth of over 3000 m, with one pump. The working had a cycle of 75 sec. at an active power about the value of 210 kW and 145 sec. at an active power about the value of 30 kW. From the registered diagrams analysis it resulted:

- the waveforms of the measured currents are highly distorted, fig. 7.
- the individual current harmonics have a special situation when the cureent of the 5-th harmonic is higher than the current of the fundamental, fig. 8, after that they return at the situation from the fig. 9.
- the total current distorsion factor is 72.6% in comparison with 12% imposed.

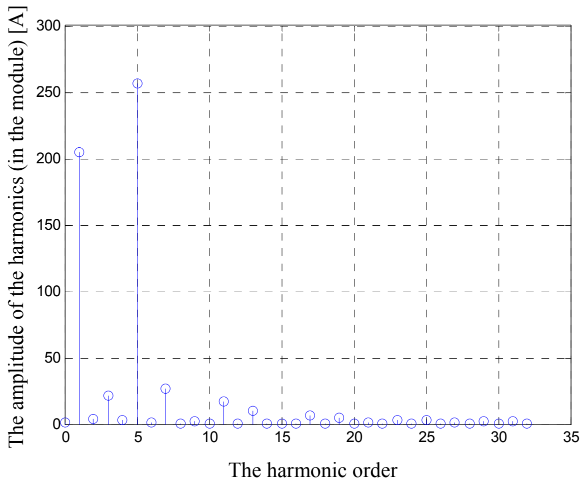

Figure 8: The values of the individual current harmonics

With a computing program of the Fourier transform, using the FFT algorithm, by the Fourier analysis of the phase currents it was possible to decompose them in the components harmonics [2] .

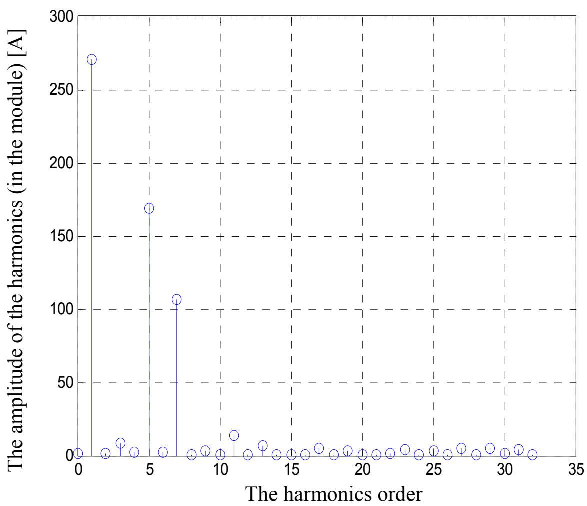

Figure 9: The values of the individual current harmonics

Recomposing the signal, using only the harmonics of upper order (without the first harmonic), it resulted a signal having the form presented in the fig.10 (it chose the case of the highest harmonic current) which must be introduced in the network with a changed sign for compensation so that on the electric network will circulate only the resulted signal of fundamental harmonic, fig.11.

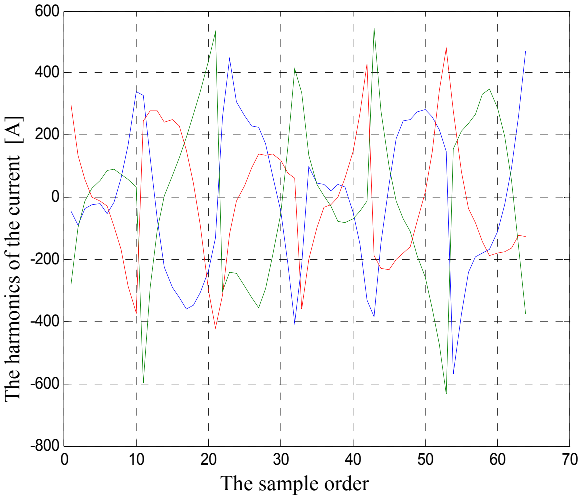

Figure 10: The signal of the recomposed current harmonics

The conclusions of the harmonic analysis at the drilling wells at which were carried out the measurements are the following:

- the current and voltage waveforms are distorted with distorsion factors which permanently change with the load;
- the voltage harmonics are under the rated limits;
- the current harmonics exceed in all the situations the limits imposed by the norms (up to 80%) and the current harmonics have considerable values;

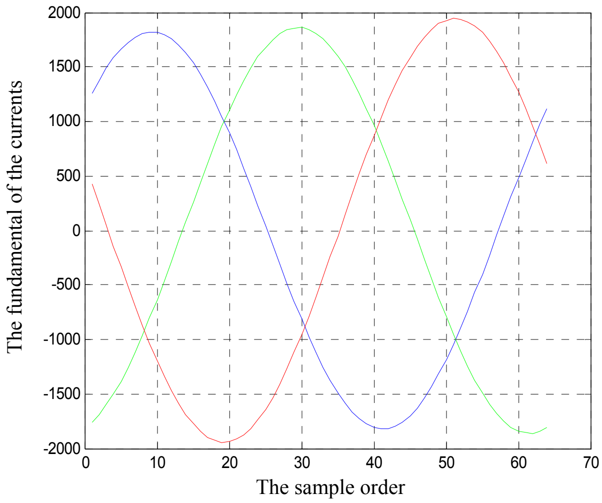

Figure 11: Fundamental harmonic current signal

- although there are passive filters tuned on the harmonics 5 and 7, their effect is imperceptible; they cannot respond to the requirements of the working dynamics of the driving system, to the different load states with spectrum of harmonics with permanently variable weight and power factor also variable, the installations working either with overcompensation (capacitive power factor in some unpermitted situations), or with inductive power factor under the penalty limit with triple tariff (0,62) up to 0.3.

4. ATTENUATION SOLUTIONS

The problems related to the harmonics can be eliminated by a combination of a good design of the installation and the providing adequate limiting equipment.

For the installations whose dynamics cannot be followed with passive systems (the case of drilling wells) the adequate solution is to use active filters with the following characteristics: they do not overcharge, they are easy to extend and to modify, the filtration degree is independent to the network, the filtration is independent to the reactive power generation, it is possible to select the filtration degree, it is possible to select the harmonics which must be filtered.

The active power filters are located in the low voltage distribution substations at which are connected the important consumers of reactive and distorting power and they realize the improvement of electric energy parameters – only the active power is absorbed from the network [3].

The active filters are a new technical solution permitting that the power electronics which cause the voltage and current distorsion taken over from the supply network may be used, with other type of control, for the improvement of the form of the same voltages and of the same currents. The active filters permit the compensation of the harmonics with a percentage up to 90%.

There are different topologies and constructive types of active filters, more or less complexes, which are choosen and adapted to the aplication. Doing an analysis of all the structures of active filters, for the application for drilling wells the most indicated seems to be the parallel structure, with active filter realized with voltage source current controlled inverter.

Electric energy supply system at the drilling wells work with the isolated neutral. Thus, the active filter will be realized with three wires (without neutral) and the current information will be taken on two phases.

The parallel structure (fig.12) is the most spread.

The active filter compensates the harmonic content of the load current which would be injected in supply network in compensation absence.

Depending on the structure and the control mode, this topology has the possibility to realize the compensation of reactive power and the balancing of the currents on the three phases. The filter conducts only the compensation current (plus an insignificant addition for the compensation of the losses from the system) and it works with current limitation; this is an extremly important advantage of the parallel connection.

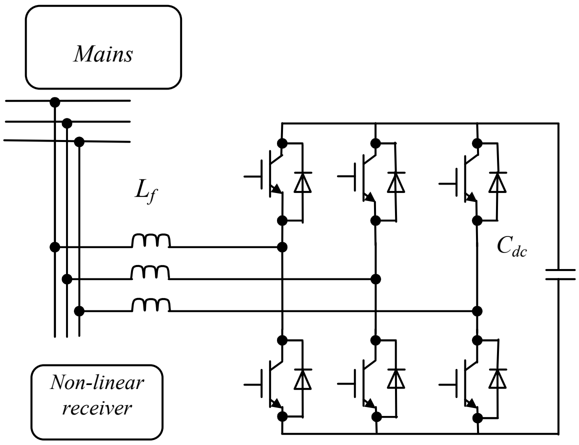

Figure 12: Active parallel filter with voltage inverter structure

At the same time, many units of this type can be connected in parallel to obtain a rise of total power of the system.

References

[1] PE 143/94 Norm regarding the restriction of unbalanced and distorting regime in electrical networks. RENEL, Bucharest, 1994

[2] A. Iacob, s a"Harmonics Filtration-Compensation Equipment for Petroleum Drilling wells", PNCDI RELANSIN project 2122 / 2004, research report : 1/2004 and 2/2005

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