Reduce the Harmonics from Mining Extraction Plants Operated with DC Motors

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Abstract: - Converter bridges used for electric drive system generate voltage and current harmonics. This paper undertakes a study on the distorting running generated by winding installations electric drives with controlled rectifier and D.C. motor. A series of measurements have been done at the winding installation at Lupeni Mining Plant by means of a coprocessor for data acquisition, thus realizing a harmonic analysis of the voltage and current in the mains. In order to eliminate such harmonics have been used passive and active filters. We developed a compensator to which an active filter is applied. As a result of tests, good compensation characteristics were obtained.

Key-Words: - Voltage and current harmonics, Active Filter, DC Filters

1 Introduction

In the electric energy transmission process besides the real electric power also appears the reactive electric power. The most alternating current networks are providing with series reactance and shunting capacitances.

When the electric charge and the power factor are modified one can observe that there are many disturbances of the voltage and current waveform.

In order to eliminate the dynamic disturbances and to ensure an efficient control of the voltage and current waveform, the reactive power control must be done very quickly.

The problem being quite intricate, when approaching the problem of compensating the distorting running, we have to take into account both the voltage variation in the mains and the power factor compensation.

In the mining industry, the winding machines are used for the extraction of the ore or for the workers transport. The winding machines electric drives use A.C. or D.C. motors. For the D.C. drives are used independent excitation D.C. motors. Due to the great development of power electronics the rectifier feed D.C. motor drive systems have become widespread.

2 The Distorting Power Line

We can exemplify with the distorting running generated by winding installations electric drives with controlled rectifier and D.C. motor. A series of measurements have been done at the winding installation at Lupeni Mining Plant (fig.1) by means of a coprocessor for data acquisition, thus realizing a harmonic analysis of the voltage and current in the mains.

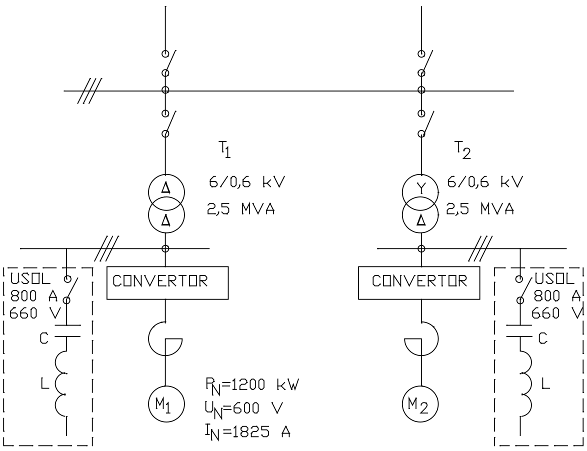

Fig. 1

The winding machine has two D.C. motors with 1200 kW each with two complete rectifier bridges. The transformers of the rectifiers supply are in Δ/δ and Y/δ connection, so the instantaneous values are in 30^0 phase difference.

Theoretically, the converters produce the voltage harmonics with orders defined as:

$$\nu = k \cdot p; \quad k = 1,2,3,... \qquad (1)$$

and current harmonics orders:

$$\nu = k \cdot p \pm 1; \quad k = 1,2,3,.. \qquad (2)$$

where p - the converter pulse number.

We present the harmonic value percentage from the first harmonic for converters with 2, 3 , 6 ,12 pulses in table no.1.

Table 1. Theoretical harmonic values.

Harmonic order	(I_n/I_1)x100			
	p=2	p=3	p=6	p=12
1	100	100	100	100
2	-	50	-	-
3	33.3	-	-	-
4	-	25	-	-
5	20	20	20	-
6	-	-	-	-
7	14.3	14.3	14.3	-
8	-	12.5	-	-
9	11.1	-	-	-
10	-	10	-	-
11	9.1	9.1	9.1	9.1
12	-	-	-	-
13	7.7	7.7	7.7	7.7
14	-	7.1	-	-
15	6.61	-	-	-

If the rectifier is a three-phase bridge one, then we find 6, 12, 18,...; voltage harmonics and 5, 7, 11, 13,...; current harmonics.

Higher harmonics, especially power, as forced switching current at one point asked the average power to be transmitted pregnancy, there are a number of effects assessed through a series of indices, called index of performance or quality

Operating mode most used in the extraction plant (on which we will focus in the study of the harmonics) with drives rectifier-DC motor is the recovery, which is why we refer particularly to it.

Harmonic amplitude spectrum and they place these converters can be calculated by Fourier analysis. In general, the Fourier series expansion i_s input rectifier current is:

$$i_s = I_{ds} + \sum_{k=1}^{\infty} (a_k \cos k\omega t + b_k \sin k\omega t) \qquad (3)$$

where:

$$I_{ds} = \frac{1}{2\pi} \int_0^{2\pi} i_s d(\omega t) \qquad (4)$$

is the mean value;

$$a_k = \frac{1}{\pi} \int_0^{2\pi} i_s \cos k\omega t \, d(\omega t) \qquad (5)$$

is the amplitude of the cosine component:

$$b_k = \frac{1}{\pi} \int_0^{2\pi} i_s \sin k\omega t \, d(\omega t) \qquad (6)$$

is the amplitude of the sine component.

Typically, the current is symmetrical about the abscissa and therefore its average value is zero,

$$i_s = \sum_{k=1}^{\infty} \sqrt{2} \, I_{sk} \sin(k\omega t + \Phi_k) \qquad (7)$$

Where the effective value of harmonic order k is

$$I_{sk} = \sqrt{\frac{a_k^2 + b_k^2}{2}} \qquad (8)$$

Depending on the actual values of harmonics, RMS current input rectifier is:

$$I_s = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} i_s^2 d(\omega t)} = \sqrt{I_s1^2 + I_s2^2 + I_s3^2 + ...} \qquad (9)$$

The Quality indices that characterize the performance rectifiers are:

1. The total harmonic distortion (FTD)

A better measure of the degree of distortion component is obtained by dividing the actual value of the total harmonic distortion obtaining fundamental

$$FTD = \frac{\sqrt{I_s^2 - I_s1^2}}{I_s} 1 = \sqrt{\left(\frac{I_s}{I_s}1\right)^2 - 1} \qquad (10)$$

It is obvious that a rectifier is even better the FTD approaches zero. If three-phase rectifier bridge fully controlled FDT = 0.3.

2. Form factor FF

Is defined as the ratio of actual and average values of a quantity and refers usually rectified voltage:

$$FF = \frac{U_{def}}{U_d} \qquad (11)$$

3. FO ripple factor

$$FO = \frac{U_{d\_}}{U_d} = \sqrt{\left(\frac{U_{def}}{U_d}\right)^2 - 1}$$

The root mean square value of the current harmonics is calculated with equation:

$$I_\nu = \frac{I_1}{\nu} [\frac{2}{3} \cdot (1 - \cos \nu \frac{2\pi}{3})] \qquad (12)$$

where I_1 - the root mean square value of the fundamental current.

Analyzing the results obtained by means of theoretical harmonics can see that pollution is reduced

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through the use of converters with a higher number of pulses, the amplitudes of these harmonics decreasing in periods of change in speed (when referring to electric drive) so when the control angle is zero semiconductor.

As we know the switching angle increase causes the decrease of the peak value of the harmonics.

The real values of the current harmonics are different than the theoretically values, so we made some measurements of the current and voltage spectrum composition, in different winding working regimes. To this end we used a coprocessor for data acquisition in real time.

If the form factor is higher than 5%, we have a nonsinusoidal regime that must be limited, because the superior current or voltage harmonics produce some disadvantages.

If these harmonics are not filtered out, several problems can be expected, such as:

- telecommunication interference;
- overheating of ac equipment;
- converter control interference;
- overvoltage due to resonance.

For the winding drives from Lupeni Mining Plant we present some results in fig. 2 - 5.

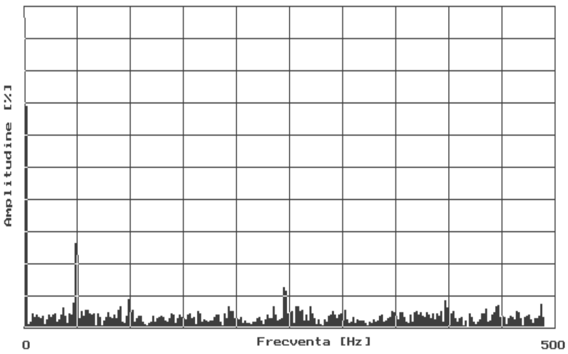

Figure no.2. Brake current analysis

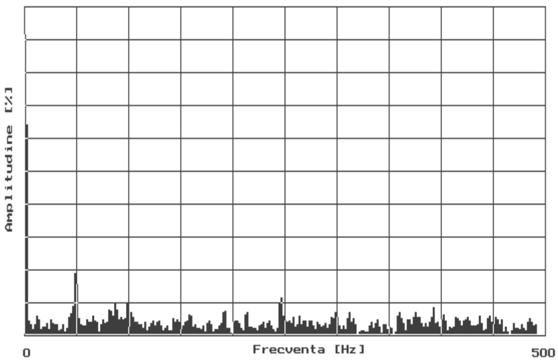

Figure no.3. Stable current analysis

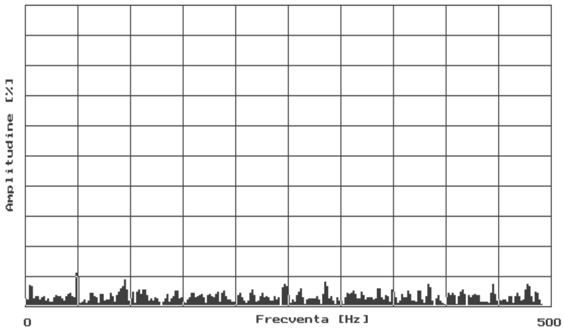

Figure no.4. Brake current analysis

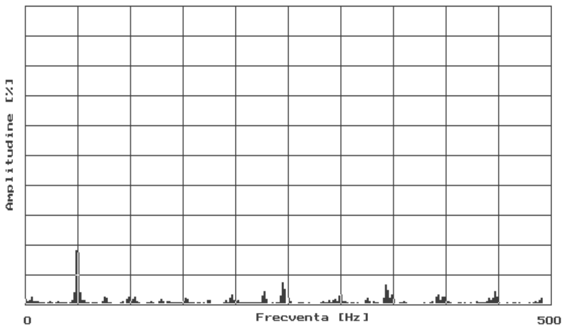

Figure 5. Stable current analysis

In the table no.2. we present the measured harmonic values percentage from the first harmonic.

Table 2. Real harmonic values.

No.	Harmonic		
	5^{th}	7^{th}	9^{th}
1	32	19.5	18.6
2	61.5	23	26.9
3	40	35	20.5
4	60	30	23.6
5	51.8	25.9	14.8
6	46.6	16.6	13.3

3 Active Shaping of the Input Line Current

The use of the rectifiers produces the distorting of the A.C. current or voltage waveforms.

For the winding drives at Lupeni Mining Plant we made some measurements of the current and voltage spectrum composition, in different winding working regimes and we propose a new compensator type to which an active filter is applied.

The basic design of the controlled reactance compensator is shown in fig.6.

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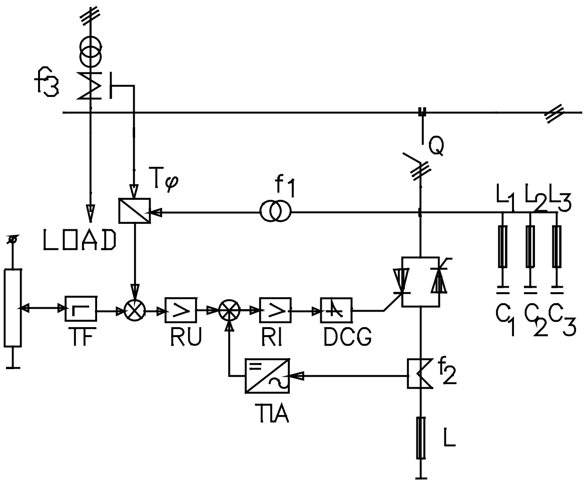

Fig. 6. Controlled reactance compensator

V - three-phase switching mode converter;
TI - current transducer;
L - three-phase inductance;
L_1, C_1, L_2, C_2, L_3, C_3 - filters;
T - power factor transducer;
TF - transformer;
RU - voltage controller;
RI - current controller;
AI - impulses amplifier;
DCG - control device.

The reactive power control for the desired value of the power factor is made by capacitive current I_{ce} given into the power line (fig. 7.).

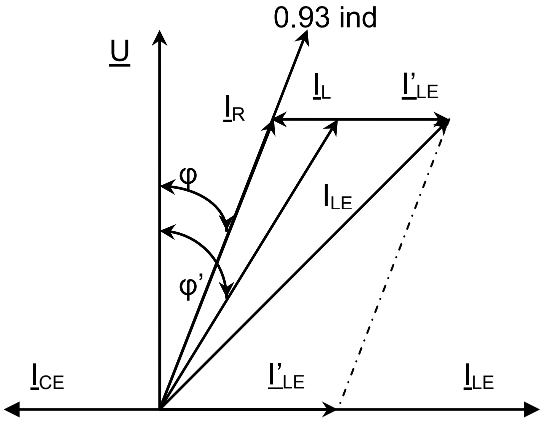

Figure 7

The equipment has the possibility to give into the power line this capacitive current absolute value and phase-difference constants and takes form the power line an inductive current I_L phase-difference constant value.

If the load current I_L is behind the voltage, the power factor transducer gives the power factor value and the outline of the voltage regulator - RU is a proportional voltage with the difference of the real and desired power factor.

This compensation and filtration method gives advantages such as:

- simple construction;
- continually controlled reactive power and current;
- quick response;

The compensator has also an important disadvantage because of the great installed power consumption. So, if the reactive power load which must be compensated has □Qvalue, the capacitances power is $-Q_s$, and the controlled reactance is between zero and $+2Q_s$. We can see that the compensator power is $3Q_s$.

Another disadvantage is that the compensator gives current harmonics, but they have small values besides the first harmonic and are filtered.

4 The Resulted Filter for Lupeni Mining Plant

To calculate the filter parameters we use the following equations:

$$I_{ad} = n \cdot Q \cdot \frac{K}{U_n} \tag{13}$$

$$I_{50} = n \cdot Q \cdot \frac{U_r}{U_n} \tag{14}$$

$$I_{ech} = I_{50}^2 + I_y^2 \tag{15}$$

$$Q_{inst} = 3 \cdot n \cdot Q \tag{16}$$

$$Q_{comp} = 3 \cdot I_{50} \cdot U_r \tag{17}$$

$$X_{c50} = \frac{1}{\nu_{50} \cdot n \cdot C} \tag{19}$$

$$X_{l50} = \frac{1}{\nu^2} \cdot X_{c50} \tag{20}$$

$$L_{50} = X_l \cdot \frac{50}{\nu_{50}} \tag{21}$$

where:
n - condensers number in parallel on each phase;

Q - reactive power of one condenser;
U_n - condenser nominal voltage value;
U_r -network voltage value;
C - condenser capacitance;
Q - installed reactive power;
X_{c50} - capacitive reactance;
X_{L50} - inductive reactance;
ν - harmonic order; K=1,3-coefficient;

Table 3. Filter parameters.

H.O.	Parameters				
	I_a [A]	I_e [A]	X_c [Ω]	L_y [mH]	Q [kVAr]
5^{th}	357	341 591	3.316 1.045	0.133	750
7^{th}	250	238 414	4.736 1.573	0.102	525
11^{th}	179	160 278	6.631 2.210	0.058	375
13^{th}	143	134 231	8.289 2.763	0.052	300

In table no.3 there are shown the calculated results for the reactive power compensator which can be used at the winding machine at Lupeni Mining Plant which used D.C. motor with a complete control rectifier bridge. We used condensers with U_n=740 V, Q_n=34,4 kVAR, C=200μF.

The condensers must have discharge resistances, which must ensure the discharge in maximum one minute. To calculate this resistance we use the following equation:

$$R_d = \frac{1}{C} \cdot \frac{t}{\ln(\frac{U_{rem}}{U_{adm}})} \qquad (22)$$

where:
U_{adm} - admissible voltage;
Urem - remaining condenser voltage;
U_{rem}=2 U_n;
t - time between disconnect and the moment when the voltage
become U_{rem};
C - capacitance;

The resistances power is calculated with:

$$P = \frac{U_n^2}{R_d} \qquad (23)$$

The results are shown in table no.4.

Table 4. Resistance parameters

Harmonic order	Resistance [kΩ]	Resistance power [W]
5^{th}	8.41	65.08
7^{th}	12.02	45.56
11^{th}	16.82	32.45
13^{th}	21.03	26.03

The calculated tyristors are in the following. Type T 158 N with the following characteristics: V_{DRM}=800 V; I_{TRMS}=280 A; I_{TAV}=160 A; di/dt=190 A/μs; V_{GT}=2 V; I_{GT}=200 mA;

5 Conclusion

We developed a compensator of a new type to which an active filter is applied. As a result of tests, good compensation characteristics were obtained.

Using a controlled reactance, reactive power form can be controlled continually.

Passive L-C filters conventionally used to suppress the harmonic distortion.

The features of the proposed active filter are as follows:

- simple configuration of the control system;
- high accuracy and high stability control scheme;
- robust property for the control system
- fast response based on the instantaneous active and reactive power detection control.

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