Harmonics of voltage and current in an electric power supply system for vertical cement mill

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***Abstract* —The results of a study of the levels of current and voltage harmonics, in a power supply system feeding a vertical mill for cement grinding, are presented in this paper. The obtained results are analyzed and compared with regulations.**

Keywords — current, harmonics, power supply system, vertical mill, voltage

I. INTRODUCTION

Devices (loads) with non-linear V-A curves are used in all sectors of the economy (industry, commerce, construction, etc.). These devices generate current and voltage harmonics. Such loads can be: industrial equipment (welding machines, electric arc furnaces, induction furnaces, rectifiers, etc.), adjustable speed drives with induction or DC motors, uninterruptible power supplies (UPS), office equipment, (computers, copiers, fax machines, etc.), household electrical appliances (TVs, microwaves, fluorescent lamps), devices with magnetic saturation (transformers).

Voltage and current harmonics can cause a number of negative effects in electrical networks:

- overloads in the electrical networks due to the increased RMS value of the current;
- overloads in the neutral conductors due to the summation of currents with higher harmonics multiples of three, which are generated by single-phase loads;
- overloads, vibrations and accelerated aging of generators, transformers, and motors, as well as increased noise of transformers;
- overloads and accelerated aging of capacitor banks for power factor correction;
- distortion of the supply voltage, which would interfere with the operation of sensitive users.

All these factors require control of the levels of current and voltage harmonics in the power networks.

The results of a study of the levels of voltage and current harmonics, in a power supply system that supplies a vertical mill for grinding cement, are presented in the paper. The obtained results are analyzed and compared with regulations. [1, 2, 3]

II. CHARACTERISTICS OF THE OBJECT OF STUDY AND MEASUREMENT POINTS

The cement production factory has two vertical cement mills to replace the old energy-intensive ball mills.

The object of study is the harmonics of voltage and current in the electrical network, which supplies the vertical cement mill №9. The power supply is realized with the use of rated voltages of 6kV and 400V. The following groups can be distinguished.

- **Group 1 Power supply of the main electrical drive of the vertical cement mill:** A wound rotor induction motor with a liquid resistance starter is used for the main drive of the cement mill. The drive has the following rated power and voltage - 2350kW and 6kV. The motor is switched by means of a vacuum circuit breaker Siemens NXAIR M;
- **Group 2 Power supply of the mill fan:** These include a dry-type transformer №30 1580kVA, 6/0,69kV, a frequency converter 1500kVA and a squirrel cage induction motor with a power of 1100kW, 690V;
- **Group 3 Power supply of transformer №27:** The 6/0,4kV transformer supplies the rest of the electrical equipment and own needs;
- **Group 4 Low-voltage 0,4 kV power supply from transformer №27:** Two 0.4kV sections are supplied, from which all auxiliary units and systems of the vertical cement mill №9 are fed.
- **Group 5 Low-voltage 0,4 kV power supply from transformer №27:** One 0,4kV section is supplied, from which the lighting installation and maintenance section are fed.

Five Siemens SIMEAS P meters [4] connected to the ProfiBus network of Siemens S7-400 controllers are used for measuring and collecting data. Each of the included meters measures 32 parameters or a total of 160 parameters for all. The averaging period is 1 minute, with the total number of

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measured values for each parameter being 7339. The measurement period is 5 days during which the production units worked or downtime due to accidents.

III. Results Analysis

For each group, the data for total harmonic distortion of voltage THD_U, total harmonic distortion of current THD_I, voltage harmonics, and current harmonics have been processed and analyzed.

Group 1 Power supply of the main electrical drive of the vertical cement mill.

The measured values of the current of the mill's main drive are minimum value 34.63A, average value 135.59A, and maximum value 263.67A. In an optimal mode and a production capacity about 95t/h, the operating current is about 200 A.

Fig. 1 shows the minimum, average and maximum values of the total harmonic distortion of voltage and the voltage harmonics.

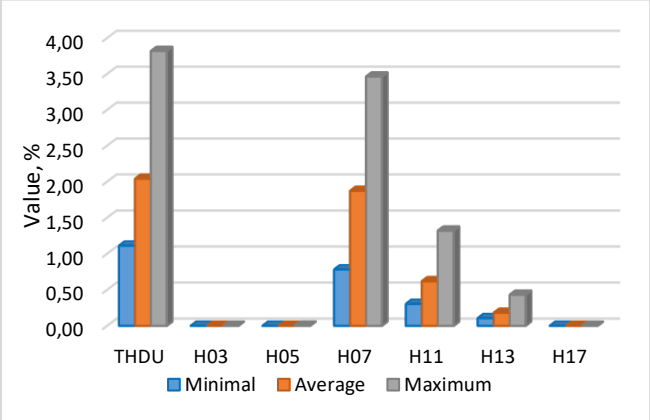

Fig. 1. THD_U and voltage harmonics of the main drive of vertical cement mill №9

The total harmonic distortion of voltage THD_U has very low values that range from 1.11% to 3.82%. These values are much lower than the allowable value of 8% for medium voltage networks [1, 3]. Voltage harmonics with numbers 7, 11 and 13 are observed. The maximum measured value of the 7th harmonic for the entire measurement period is 3.46%. The maximum values of the 7th harmonic, which are above the admissible value of 4%, are obtained when the mill is operated unloaded. In the cases when the mill operates loaded the values of the 7th harmonic are less than 2%. The measured values with a loaded mill are lower than the permissible value of 4% for the 7th harmonic. The maximum measured values for 11 and 13 harmonics of 1.32% and 0.43% are much lower than the allowable values, respectively 3% for 11 harmonics and 2.5% for 13 harmonics [1, 3].

Fig. 2 shows the minimum, average and maximum values of the total harmonic distortion of current THD_I and the current harmonics. When the mill is loaded THD_I has values between 3% and 10%, and when it is not loaded it reaches 35%. Current harmonics with numbers 3, 5, 7, 11, 13, 17, and 19, are observed. The maximum measured values of the 5th, 7th, and 11th harmonics of the current are 8.88%, 9.33%, and 4.29%, respectively. The levels of 7 and 11 harmonics are above the norms of 7.2% for the 7th harmonic and 3.1% for the 11th harmonic [2, 3]. The other current harmonics are within the permissible norms. Here, too, the elevated levels of 7 and 11 harmonics are at the time when the mill is not loaded.

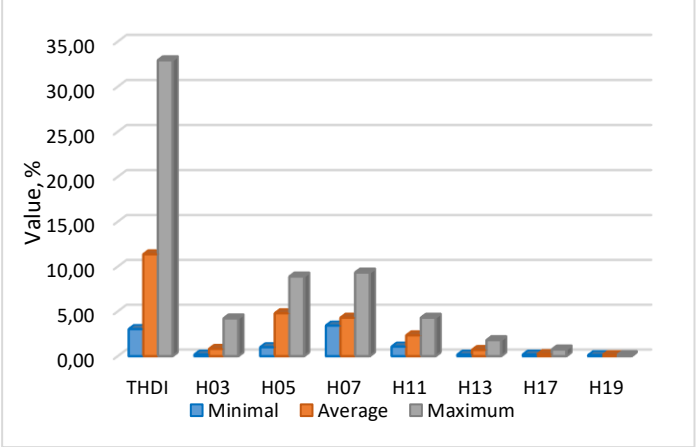

Fig. 2. THD_I and current harmonics of the main drive of vertical cement mill №9

A passive LC filter 800kVAr is located near the electric motor driving the mill. The 6kV cable line from the substation to the liquid resistance starter and the electric motor of the mill exceeds 300 m and is a basic prerequisite for the increased levels of harmonics. The current harmonic levels are not critical and there is no danger of overloading the cable lines or overheating of the equipment.

Group 2 Power supply of the mill fan.

The ABB ACS 800 transformer and frequency converter are located next to each other and in close proximity to the mill. The cable line from the adjustable drive to the electric motor is about 30 m long.

The measured values of the current of the mill fan drive are: average value of 39.49A and maximum value of 91.99A.

Fig. 3 shows the minimum, average and maximum values of the total harmonic distortion of the voltage and the voltage harmonics. The total harmonic distortion of voltage remains low in operating mode - in the range of 1.5% to 5%. These values are much lower than the permissible value of 8%. The maximum measured values of the 7th, 11th, and 13th voltage harmonics are 3.53%, 1.29%, and 0.40%, respectively. All measured values of voltage harmonics here are within the permissible norms of 4% for 7 harmonics, 3% for 11 harmonics, and 2.5% for 13 harmonics [1, 3].

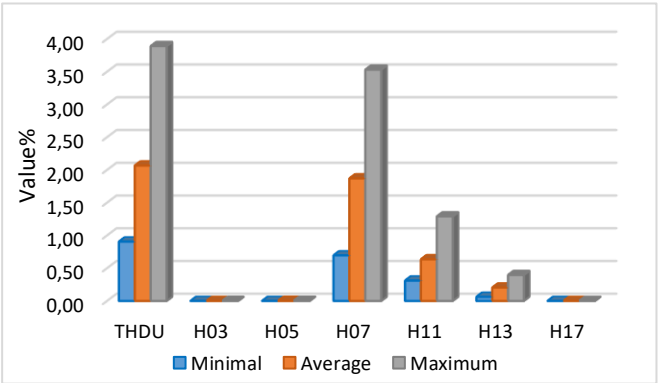

Fig. 3. THD_U and voltage harmonics of the mill fan

Fig. 4 shows the minimum, average and maximum values of the total harmonic distortion of current and the individual current harmonics. When the mill is loaded, the THD_I varies in the range from 8% to 10%, and when it is not loaded it reaches up to 14%. The maximum measured values of all current harmonics except the 11th harmonic are within the permissible norms. For the 11th harmonic, a maximum value of 6.19%, an average value of 5.42%, and a minimum value of 4.6% were measured, which are higher than the permissible value of 3.1% [2, 3].

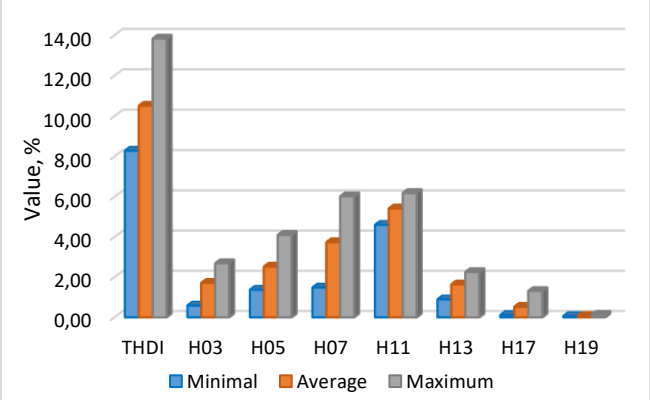

Fig. 4. THD_I and current harmonics of the mill fan

It can be summarized that THD_I is close to 10% and it is not necessary to take measures or install additional filters or reactors to compensate for interference induced by power electronics.

Group 3 Power supply of transformer №27.

Transformer №27 supplies the rest of the process equipment and self needs. These are auxiliary electric motors, frequency regulators, soft starters, switching devices, measuring transmitters, and electronics. The measuring instrument is connected to the same section of 6kV as in the study of Group 1 and Group 2.

Fig. 5 shows the measured minimum, average and maximum values of the total harmonic distortion of voltage THDU and the voltage harmonics. The measured maximum value of the total harmonic voltage distortion THDU of 3.76% is well below the permissible value of 8% for medium voltage networks. The maximum measured values of the 7th, 11th, and 13th voltage harmonics are 3.39%, 1.29%, and 0.34%, respectively. All of them are within the permissible norms.

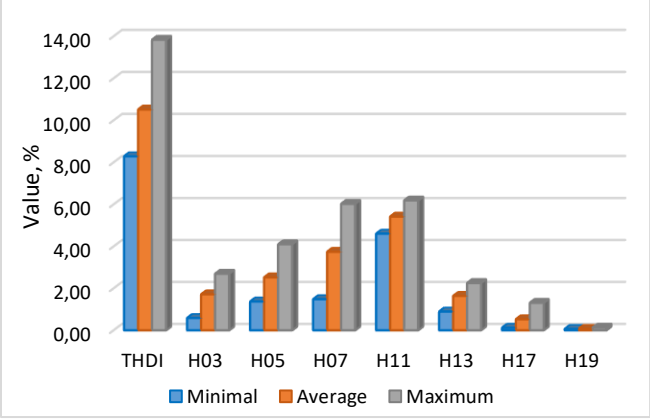

Fig. 5. THD_U and voltage harmonics of the power supply of transformer №27

Fig. 6 shows the measured minimum, average and maximum values of the total harmonic distortion of the current and the harmonics of the current. The average THD_I is 27.56% and the maximum value reached is 35.14%. These values are above the permissible value of 25%, which indicates significant harmonic contamination. The values of the 3rd, 5th, 7th, 11th, 13th, 17th, and 19th current harmonics are measured. The maximum measured values of all current harmonics except 11th and 13th harmonics are within the permissible norms. For the 11th harmonic maximum value of 3.7% has been measured, which is higher than the norm of 3.1%. A maximum value of 4.31% has been measured for 13 harmonics, which is higher than the permissible value of 2% [2, 3].

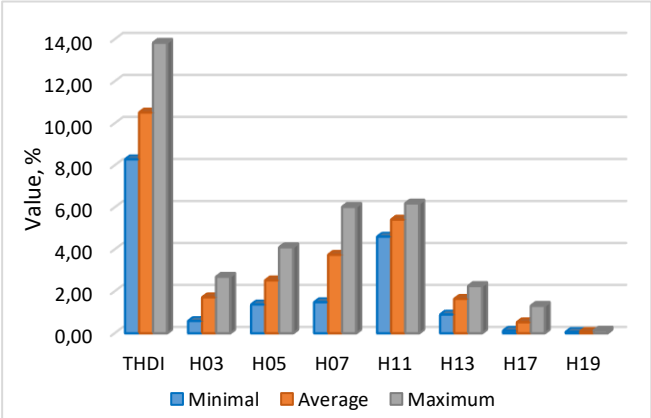

Fig. 6. THD_I and current harmonics of the power supply of transformer №27

Due to the large power reserve of the source, there is no need to switch to a more powerful one. Further research and audit are needed to find the reason for measuring high THD_I values.

Group 4 Low-voltage 0,4 kV power supply from transformer №27.

The measurements were performed on the low voltage side of Transformer №27 in the switchboard. The considered switchboard supplies low voltage consumers located in the electric hall of the mill providing supply of materials, separation, unloading, transportation and other functions. The measured operating current is about 400A. All consumers are provided with various electronic equipment for starting, ensuring normal operation and protection of electrical equipment and mechanical equipment. All this electronics introduces various distortions of voltage and current.

The measured maximum value of the total harmonic distortion of voltage THD_U (Fig. 7) of 4.69% is well below the permissible value of 8% for low voltage networks. The presence of 7th, 11th and 13th voltage harmonics is observed, with maximum measured values of 4.17%, 3.21% and 2.33%, respectively. All of them are within the permissible norms, respectively 5%, 3.5% and 3%.

The measured average value of the total harmonic distortion of current THD_I (Fig. 8) is 25%, and the reached maximum value is 34%, with a permissible value of 25%. This indicates significant current harmonic contamination. The values of the odd current harmonics have been measured. The measured maximum and average values of all current harmonics except for the 3th and 19th harmonics are above

the permissible norms [2, 3]. The reason for this is the significant amount of inverters, soft starters and electronic transmitters.

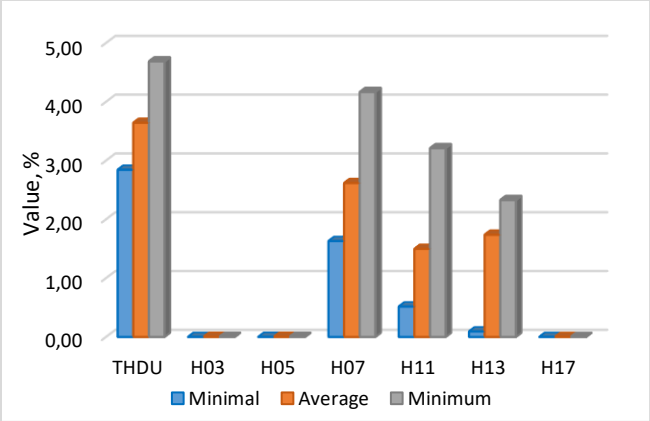

Fig. 7. THD_U and voltage harmonics at the low voltage side of transformer №27.

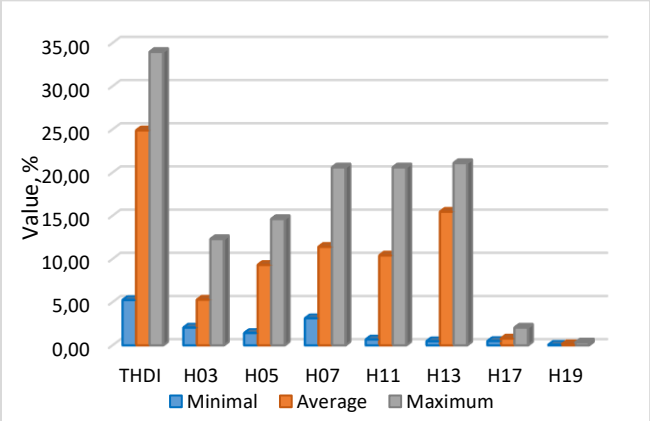

Fig. 8. THD_I and current harmonics at the low voltage side of transformer №27.

It can be summarized that it is necessary to study the individual nodes, especially the more powerful ones. One of the main units that can bring a significant part of the interference is the system frequency converter Siemens G150 and asynchronous motor with short-circuited rotor 250kW for mill separator, as well as several low-power frequency converter for motors to drive transport systems and one converter for electric motor fan primary air burner heating mill.

Group 5 Low-voltage 0,4 kV power supply from transformer №27

The measurements were performed on the power supply of one section 0.4 kV, from which the lighting installation and the repair section are supplied. The measured consumption is about 1A.

The measured minimum, average and maximum values of the total harmonic distortion of voltage and the voltage harmonics, are shown in Fig. 9. Fig. 10 shows the measured minimum, average and maximum values of the total harmonic distortion of current and the harmonics of the current.

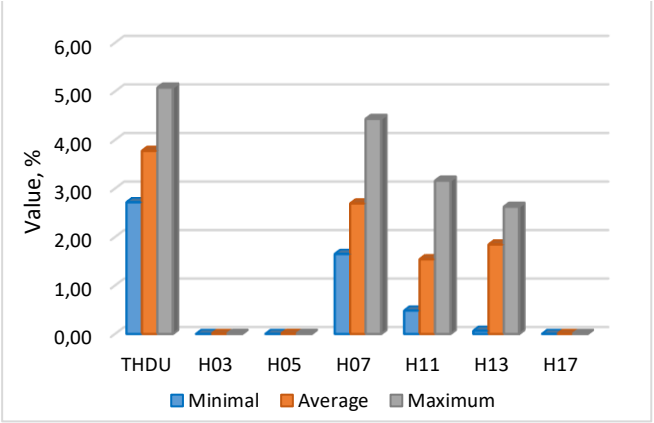

Fig. 9. THD_U and voltage harmonics at the low voltage side of transformer №27.

The measured maximum value of the total harmonic distortion of voltage THDU of 5.08% is below the permissible value of 8% for low voltage networks. The presence of 7th, 11th and 13th voltage harmonics are observed, with maximum measured values of 4.43%, 3.16% and 2.62%, respectively. All of them are within the permissible norms, respectively 5%, 3.5% and 3%.

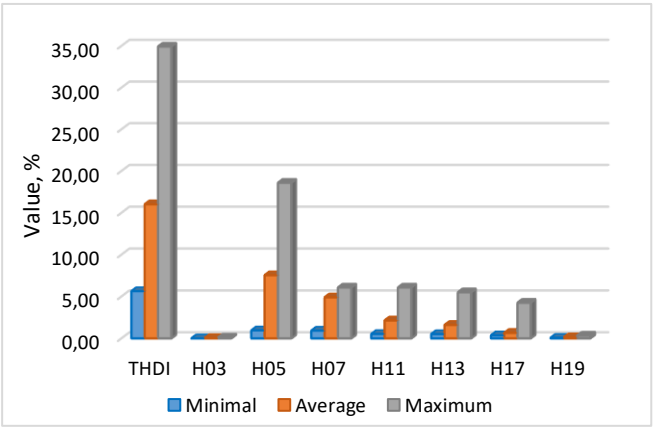

Fig. 10. THD_I and current harmonics at the low voltage side of transformer №27.

The maximum value of the total harmonic distortion of current THD_I is 32%, with a permissible value of 25%. The values of the 3th, 5th, 7th, 11th, 13th, 17th and 19th current harmonics are measured. The measured maximum values of 11th, 13th and 17th harmonics of the current are above the permissible norms [2, 3].

Despite the extremely low consumption of lighting (about 1A), which is realized with fluorescent and LED luminaires, the analysis shows a high degree of pollution with current harmonics in the network. Its percentage effect is very small due to the low power, but it shows a strong degree of distortion caused by the electronic components of the luminaires.

IV. Conclusions

The installed stationary measuring devices in the power supply system of the factory allow for a quick and accurate determination of the levels of harmonics of current and voltage.

The recorded data serve as a basis for preventive maintenance of the elements of the electricity supply system,

as they allow the registration of disturbances at an initial stage before causing serious damage. In addition, harmonics have significant economic consequences:

- the accelerated aging of the equipment necessitates earlier replacement (repair) from the planned period unless an appropriate redundancy is foreseen from the outset;

- overloads of the network can lead to higher levels of electricity consumption and increased losses;

- distortion of current may cause the circuit breakers to malfunction, which may cause ceases the production process.

REFERENCES

[1] BDS EN 50160:2011 Voltage characteristics of electricity supplied by public electricity networks.

[2] BDS IEC 61000-3-4:1998 Electromagnetic compatibility (EMC). Part 3-4: Limits - Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A.

[3] T. Tzanev, S. Tzvetkova, Quality of electrical energy, Avangard Prima, Sofia, 2011.

[4] BDS IEC 61000-4-30:2015 Electromagnetic compatibility (EMC) - Part 4-30: Testing and measurement techniques - Power quality measurement methods.