IMPACT OF INVERTER-FED MULTI-MOTOR DRIVES ON THE QUALITY OF ELECTRIC POWER IN THE MAINS.

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Abstract-The article presents the results of analysis of higher harmonics of current and voltage in networks feeding six-puls rectifier.Analitycal dependences of this phenomena at inductance in a dc circuit is also given. evaluation of this applicability of the analysis for practical purposes, verification measurements is taken.it is done measurements on the reel cutter of a paper-making machine mp-IV in Świecie.

I. INTRODUCTION.

An increased share of power of non-linear receivers on the power network gives rise to significant transfiguration of the feeding power sine waves. The performed analyses [2] [3] clearly indicate that the degree of transfiguration of the feeding power is higher at definite times of day. This refers to user supply networks, on which the number of small recipients, like PC users, significantly increases. Upper harmonics are common in electric networks Their sources are all sorts of non-linear receivers like converter systems, arc furnaces etc. The receivers get a transmuted current and thus become sources of upper harmonic currents [4],[5]. Those currents cause voltage drops at network impedance and distort voltage sinusoid [2],[6],[7]. However, it seems important to suggest a relevant model of power supply network including linear and non-linear receivers and a capacitor set. It is even more vital to discuss the practicality of applying some proposed models. In converter drives, the rectifier load current is an oscillating one since the value of inductance in a DC circuit is limited. The phenomenon has a significant impact on the harmonic spectrum of the input current fed to the rectifier from the mains. Of course, converters are usually equipped with commutation reactors, so the commutation angle γ is not zero. Those factors are especially important with some electric drives, as due to the high circuit dynamics required, the drives have commutation reactors but no smoothing reactors in the load circuits[8],[9].

II. SPECIFICATIONS OF SUPPLY SYSTEMS FOR INDUSTRIAL PLANTS

Mixed-type networks are quite frequently used, especially when the internal network has suffered from problems with compensating for wattless power or with the negative impact of non-linear recipients on power supply network. The impact involves taking transfigured power from the network, which means that the power spectrum will include higher harmonics [10], [2]. So far the analyses of upper harmonics of current have usually neglected the resistance values of all supply system components due to an assumption that their impact on the value of upper harmonics is negligible. The size of distortion of incoming voltage is determined by two major factors, i.e.:

-type of non-linear source of current
-parameters of supply network

Fig. 1 illustrates a standard network supply system.

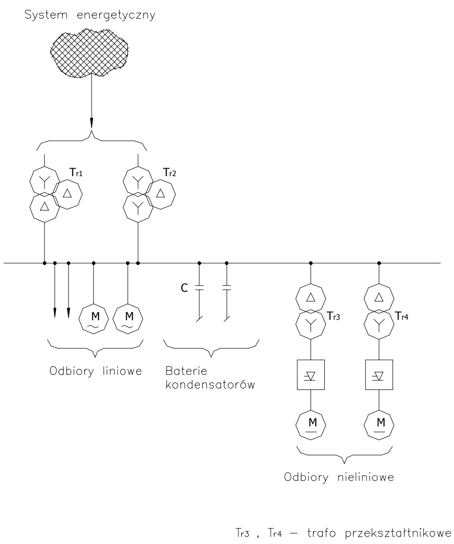


Fig. 1 Standard network supply system

In converter drives, the rectifier load current is an oscillating one since the value of inductance in a DC circuit is limited. The phenomenon has a significant impact on the harmonic spectrum of the input current fed to the rectifier from the mains. Of course, converters are usually equipped with commutation reactors, so the commutation angle γ is not zero. Those factors are especially important with some electric drives, as due to the high circuit dynamics required, the drives have commutation reactors but no smoothing reactors in the load circuits[8],[9]. Fig.2 shows a schematic diagram of a six-pulse rectifier fed from a transformer of $D\gamma$ vector group as well as a current waveform $i_W(x)$ in the transformer's secondary at any phase.

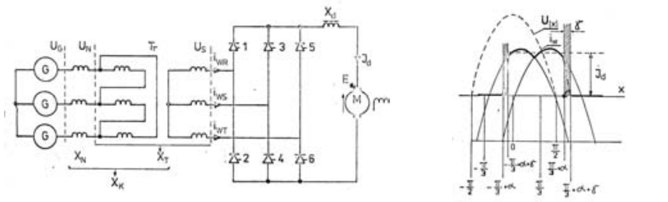


Fig.2. Schematic diagram of a six-pulse rectifier and a waveform of current at any phase, where:
G – generators
M – DC induction motor
1, 2, 3 to 6 – valves in individual bridge branches.

The oscillation of load current of a rectifier drive depends not only on the load reactance X_d, as it is frequently assumed, but rather on a sum of the load circuit reactance and the commutation reactance $X_d + 2X_K$. If it is assumed that non-linear receivers are 6-pulse SCR transformers (with high shorting power S_Z), then the feeding current will be:

$$i_p(\omega t) = \sqrt{2} I_1 (\cos\omega t - \frac{1}{5}\cos 5\omega t + \frac{1}{7}\cos 7\omega t - \frac{1}{11}\cos 11\omega t + ...) \quad (1)$$

where:

$i_p(\omega t)$ is a momentary amperage value at the pri of a transformer, and I_1 is an effective value of the first harmonic.

In the system presented in Fig.1, the passage of non-linear current I_n will cause voltage drops at the resultant impedance of Z_n system. Those voltage drops coincide with the supply voltage sinusoid and cause its distortion. Therefore we can say that

$$|\Delta U_n| = |I_n| \cdot |Z_n| \quad (2)$$

where

$$|Z_n| = \sqrt{R_n^2 + (n \cdot X_{L_{50}})^2} \quad (3)$$

$|\Delta U_n|$ - voltage drop with a harmonic of n-th order at the impedance of Zn system, $|Z_n|$ - module of system impedance with a harmonic of n-th order, $|I_n|$ - module of power with a harmonic of n-th order, R_n - system resistance with harmonics of n-th order, $X_{L_{50}}$ - system inductive reactance with the basic harmonic of 50Hz, n - harmonic order. The value of resultant impedance of Z_n system will change when upper harmonics filters or a capacitor set is incorporated into the system to compensate for passive power. Its module will be determined as follows [3]:

$$\frac{1}{Z_{z_1}} = \frac{1}{Z_L} + \frac{1}{Z_S} + \frac{1}{R_O} + \frac{1}{jX_O} + j\frac{1}{X_C} \quad (4)$$

where

$Z_L = R_L + jX_L$ - impedance of supply system,

$Z_S = R_S + jX_S$ - impedanc of linear recivers

III. MEASUREMENT-BASED ANALYSIS OF THE HARMONICS PHENOMENON

In the process of evaluating the inter-harmonics amplitude range, the harmonics in the power fed to an MP2 paper-making machine operated in Skolwin were measured and analysed. The machine power supply circuit beyond the marked measurement points is shown in Fig. 3.

The measurement points were established at clamps feeding PANT six-pulse rectifier 500 kW T7.T8 and on the clamps of the secondary winding of Tr7a transformer feeding the group of 1100kW total installed power. Some measurement points were also located in the secondary winding of Tr7 transformer feeding a group of inverters of 1000kW total installed power. Measurements of the harmonics levels for loads and voltages on the primary windings of those transformers.

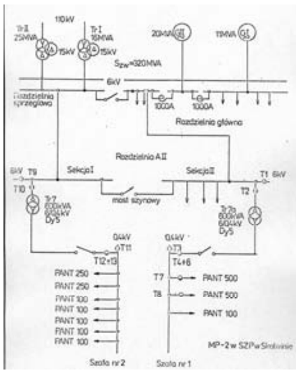


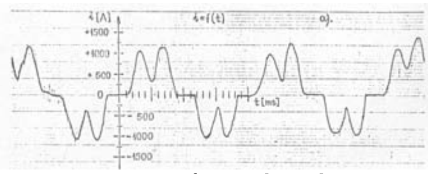
Fig.3.Schematic diagram of the power supply circuit in the A11 switching station feeding the MP2 paper-making machine in Skolwin.

The measurements were performed on a system with an open bus bar and the Tr7a transformer fed from the GII generator at own power plant. Such a measurement setup allows protection of a tested circuit from any impact of the supply system. For comparison purposes, the Tr7 transformer was supplied from the commercial power system.

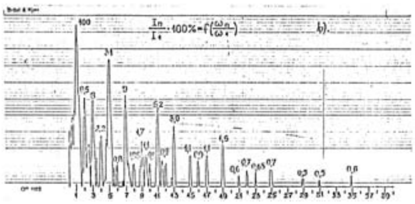
IV. ANALYSIS OF MEASUREMENT RESULTS.

Measurement results are usually presented in the form of a spectrum of typical – sometimes non-typical – harmonics that are integral multiples of the base frequency [$\omega_1 = 50Hz$]. This results from the fact that the commonly used measurement instruments use a phaselocked loop and sample the analysed signal during one or several wave periods. The analysis is done with the Fast Fourier Transform (FFT) or sometimes with the Discrete Fourier Transform (DFT). With inter-harmonics analysis the problem is more complicated since their frequencies are not integral multiples of the base frequency and moreover they often change during the measurements. They manifest themselves as sidebands around the characteristic harmonics. In the beginnings, their appearance would be considered a measurement error and then as a methodological error. Nowadays their is no doubt that those frequencies are actually present in the system [12],[13].

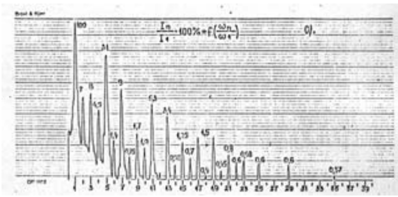
Figure 4 presents current waveform in the T phase of Tr7a transformer feeding the inverter set of MP2 machine drive at the paper mill in Skolwin as well as its spectrum for varied periods of measurement averaging.



Current waveform in the T phase



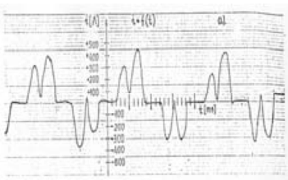
Current spectrum for the averaging period 40ms.

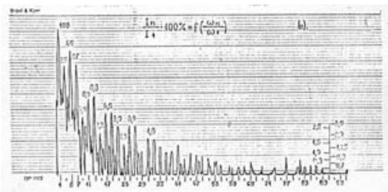


Current spectrum for the averaging period 115ms.

Fig.4.Waveform and amplitude-frequency spectrum of the current feeding the MP2 machine drive Switching station A11, transformer Tr7a, band 2kHz, cabinet no.1

There are well visible sidebands around all the frequencies that are integral multiples of the base frequency. Their amplitudes reach 1.5%. When comparing spectra for various averaging periods, it becomes evident that the spectrum share of those harmonics increases with the length of averaging periods. Another factor affecting the size of inter-harmonics amplitude is the level of distortions in the current fed from the mains.





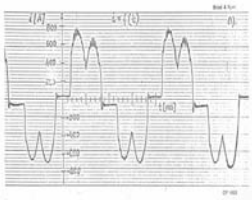
Current waveform in the R phase. Current waveform for the averaging period of 40ms.

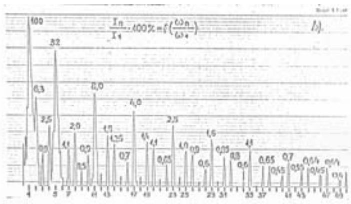
Fig.5.Waveform and amplitude-frequency spectrum of the current feeding drives 1 and 2 of the MP2 press. Switching station A11, transformer Tr7a, band 2kHz, cabinet *no1*

It is clearly visible in Fig.5 which shows the waveforms for one of the component drives in the same switching station, this time in the R phase,when the amplitude of upper harmonics of current reach 45% of the base.

Similar results were obtained from measurements of other components of a multi-motor drive, as shown in Fig.6

Interesting results were obtained from measurements of the screen drive current, as shown in Fig.6.In this particular case the feeding system apparently works in near-resonance conditions, as proved by the oscillations overlapping with the current waveform.Harmonics amplitudes reach 32% in this case.

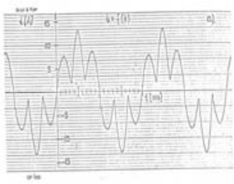


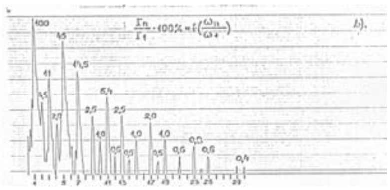


Current waveform in the S phase Current spectrum for the averaging period of 183.6ms.

Fig.6.Waveform and amplitude-frequency spectrum of the current feeding the MP2 screen roll drive Switching station A11, transformer Tr7a, band 2kHz, ASEA cabinet

Similar results were obtained from measurements on the primary winding of the feeding transformer. Fig.7 presents the current waveform on the 6kV side of the tested transformer and its spectrum.

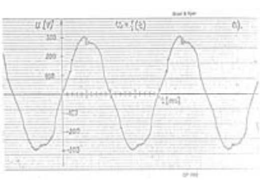




Current waveform in the S phase (6kV) Current waveform for the averaging period of 145ms

Fig.7.Waveform and amplitude-frequency spectrum of the current feeding the MP2 machine drive Switching station A11, transformer 7a, band 2kHz, cabinet no.1, 6kV level

Conclusions from this measurement are basically identical as those for the secondary winding, even though attenuation by transformer reactance $X_{Tr(k)}$ could be expected. Some attenuation is visible in the voltage harmonics, as shown in Fig.8.



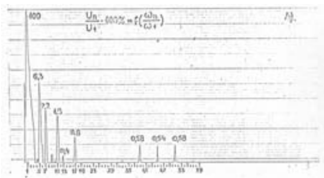


Fig.8.Waveform and amplitude-frequency spectrum of the voltage feeding 0,4 kVthe MP2 machine drive Switching station A11, transformer Tr7a, band 2kHz, cabinet no.1

V CONCLUSIONS

1.A significant increase in the number of non-linear receivers results in a significant decrease in electric power quality, especially in multi-motor drive systems.
2. Analytical methods for assessing this phenomena are complicated and their practical application is difficult. Therefore the method of direct measurements is preferable.
3. Multi-motor systems with inverter-fed drives require unconditional application of filters for higher harmonics of the feeding current.

VI DISCUSSION

The article does not include a discussion of the methodology of current harmonics measurements, i.e. the impact of applying various waveform analysers / measurement windows / averaging periods on the measurement results. Differences in measurement results that arise from the above are usually neglected, but they can reach as much as several dozen percent. This problem requires a deep analysis.

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