HARMONIC ANALISYS OF STATIC POWER CONVERTERS UNDER UNBALANCED INPUT CONDITIONS

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Abstract. *This article presents an analysis of static AC/DC power converter under unbalanced input conditions. In balanced operation mode, the output voltage contains only the sixth and higher order multiple harmonics. Under unbalanced input conditions, we can calculate the amplitude of many other harmonics present in the output voltage. Some measurements where made under a typical three phase static converter supplying an inductive 350kW industrial load.*
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Introduction

Measurements made under real loads on three-phase four-wire electric systems of some industrial consumers reveal the presence of low order harmonics (2^{nd}, 3^{rd}, 4^{th}, 8^{th}, i.e.) with more than 4 percent from the fundamental in amplitude. Measuring the input voltages, we discovered that the system is highly unbalanced (more then 20 percent). Technological progresses within the last 10 years imposed many AC to DC active power converters. However, in more than 75 percent of the cases, especially in the heavy industry, the converters are still static. The reason for such a choice is the price. In the following section, we'll analyze the behavior of such a converter in both cases: balanced and unbalanced input.

Unbalanced input analysis

We consider a classic three-phase rectifier bridge, the most used. The output voltage is the product of the transfer function and the input voltage:

$$V_0 = T.\bar{v} \qquad (1)$$

The transfer function of the converter is:

$$T = [S_{W1}, S_{W2}, S_{W3}] \qquad (2)$$

Where:

$$\begin{cases} S_{W1} = \sum_{k=1}^{\infty} A_k . \sin k(\omega t + \alpha) \\ S_{W2} = \sum_{k=1}^{\infty} A_k . \sin k(\omega t - \frac{2\pi}{3} + \alpha) \\ S_{W3} = \sum_{k=1}^{\infty} A_k . \sin k(\omega t + \frac{2\pi}{3} + \alpha) \end{cases} \qquad (3)$$

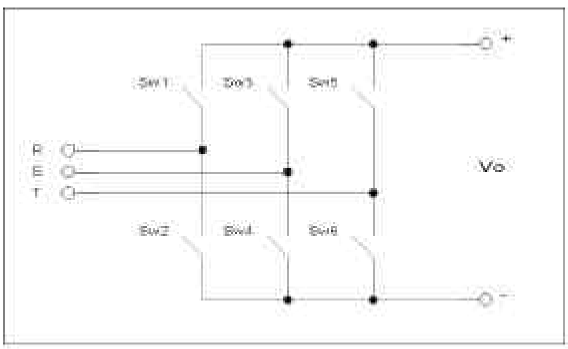

Figure 1. Typical static AC/DC three-phase converter

The input voltage can be written as:

$$\bar{v} = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} V.sin\,\omega t \\ V.sin(\omega t - \frac{2\pi}{3}) \\ V.sin(\omega t + \frac{2\pi}{3}) \end{bmatrix} \qquad (4)$$

Also, it can be written as the sum between two terms, positive and negative [1]:

$$\bar{v} = \bar{v}_p + \bar{v}_n \qquad (5)$$

Where:

$$\bar{v}_p = \begin{bmatrix} V_p.sin\,\omega t \\ V_p.sin(\omega t - \frac{2\pi}{3}) \\ V_p.sin(\omega t + \frac{2\pi}{3}) \end{bmatrix} \qquad (6)$$

and

$$\bar{v}_n = \begin{bmatrix} V_n.sin(\omega t + \beta) \\ V_n.sin(\omega t + \frac{2\pi}{3} + \beta) \\ V_n.sin(\omega t - \frac{2\pi}{3} + \beta) \end{bmatrix} \qquad (7)$$

Similarly, the transfer function of the converter may be written as follows:

$$T = T_p + T_n \qquad (8)$$

Where the two components are:

$$T_p = \begin{bmatrix} \sum_{k=1}^{\infty} A_{kp}.sin\,k(\omega t + \alpha) \\ \sum_{k=1}^{\infty} A_{kp}.sin\,k(\omega t - \frac{2\pi}{3} + \alpha) \\ \sum_{k=1}^{\infty} A_{kp}.sin\,k(\omega t + \frac{2\pi}{3} + \alpha) \end{bmatrix}^T \qquad (9)$$

and

$$T_n = \begin{bmatrix} \sum_{k=1}^{\infty} A_{kn}.sin\,k(\omega t + \alpha) \\ \sum_{k=1}^{\infty} A_{kn}.sin\,k(\omega t + \frac{2\pi}{3} + \lambda) \\ \sum_{k=1}^{\infty} A_{kn}.sin\,k(\omega t - \frac{2\pi}{3} + \lambda) \end{bmatrix}^T \qquad (10)$$

Therefore, the output voltage results:

$$V_0 = T_p.\bar{v}_p + T_p.\bar{v}_n + T_n.\bar{v}_p + T_n.\bar{v}_n \qquad (11)$$

This equation represents the DC output voltage of the converter.

Supposing the transfer functions of the converter doesn't contain odd harmonics, V_0 may be written as follows:

$$\begin{aligned} T_p.\bar{v}_p = {} & \frac{3}{2}.[A_{1p}.V_p.cos\,\alpha - \\ & A_{5p}.V_p.cos(6\omega t + 5\alpha) + \\ & A_{7p}.V_p.cos(6\omega t + 7\alpha) - \\ & A_{11p}.V_p.cos(12\omega t + 11\alpha) + \\ & A_{13p}.V_p.cos(12\omega t + 13\alpha) + ...] \end{aligned} \qquad (12)$$

$$\begin{aligned} T_n.\bar{v}_n = {} & \frac{3}{2}.[A_{1n}.V_n.cos(\lambda - \beta) - \\ & A_{5n}.V_n.cos(6\omega t + 5\lambda + \beta) + \\ & A_{7n}.V_n.cos(6\omega t + 7\lambda - \beta) - \\ & A_{11n}.V_n.cos(12\omega t + 11\lambda + \beta) + \\ & A_{13n}.V_n.cos(12\omega t + 13\lambda - \beta) + ...] \end{aligned} \qquad (13)$$

We can observe the presence of the 6^{th}, 12^{th}, 18^{th} harmonics, a predictable result. The two other terms can be written as follows:

$$\begin{aligned} T_p.\bar{v}_n = {} & \frac{3}{2}.[-A_{1p}.V_n.cos(2\omega t + \alpha + \beta) + \\ & A_{5p}.V_n.cos(4\omega t + 5\alpha - \beta) - \\ & A_{7p}.V_n.cos(8\omega t + 7\alpha + \beta) + \\ & A_{11p}.V_n.cos(8\omega t + 7\alpha - \beta) - ....] \end{aligned} \qquad (14)$$

$$T_n.\bar{v}_p = \frac{3}{2}.[-A_{1n}.V_p.cos(2\omega t+\lambda)+$$
$$A_{5p}.V_n.cos(4\omega t+5\lambda)- \qquad (15)$$
$$A_{7p}.V_n.cos(8\omega t+7\lambda)+$$
$$A_{11p}.V_n.cos(10\omega t+11\lambda)+....]$$

In this case, we can notice some even harmonics of the output voltage. This couldn't be predicted from the beginning.

We made some measurement on industrial loads (this study was determined by the measurement results). The results are presented bellow:

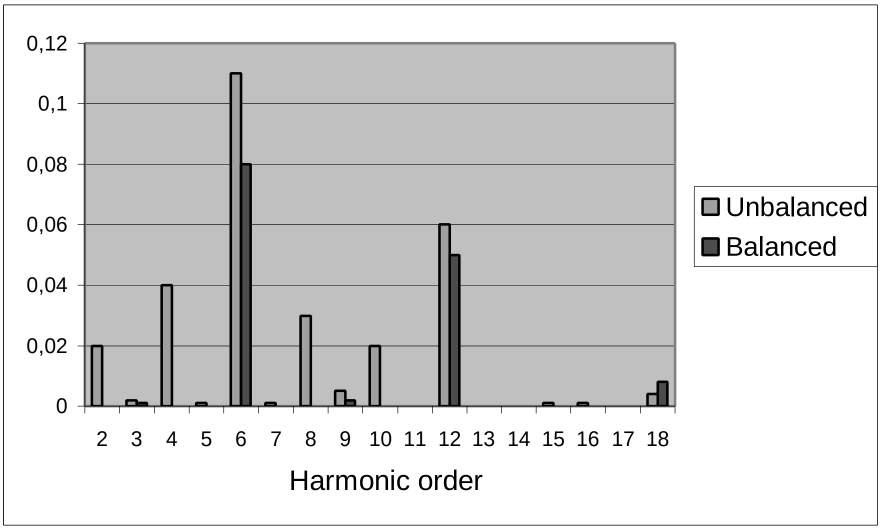

Figure 2. Harmonics measured on a static AC/DC converter in balanced/unbalanced input conditions in industrial system

We can observe the presence of low order harmonics only in the case of unbalanced input conditions (the amplitudes was measured considering the magnitude of the input voltage frequency equal to 1).

References

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