

# WAVEFORMS

**Objective:** Define the main factors used by the standards to characterise the voltage waveform, and give the levels imposed by these standards. Indicate the values obtained with the alternators in the LSA range.

## DETERMINING THE DIFFERENT FACTORS

### • TOTAL HARMONIC DISTORTION THD

The term total harmonic content (THC) is also used.

In French, the THD is called DHT (distorsion harmonique totale) and sometimes also TGH (taux global d'harmoniques).

$$\text{THD (\%)} = 100 \times \sqrt{\sum H_i^2}$$

$H_i$ : root mean square (RMS) value of the harmonic voltage of order  $i$  divided by the RMS value of the fundamental

$\sum H_i^2$ : The sum of the squares of all  $H_i$  terms extended to all harmonics (except the fundamental).

### • TELEPHONE HARMONIC FACTOR THF

In French: Facteur harmonique téléphonique (FHT)

$$\text{THF (\%)} = 100 \times \frac{\sqrt{\sum U_i^2 \cdot \lambda_i^2}}{U}$$

$U$ : RMS value of the voltage

$U_i$ : RMS value of the voltage of the order  $i$  harmonic

$\lambda_i$ : weighting factor for the frequency corresponding to the order  $i$  harmonic (defined by standard IEC 60034-1)

$\sum U_i^2 \lambda_i^2$ : sum of the products of the squares of the  $U_i$  and  $\lambda_i$  terms, including the harmonics and the fundamental.

### • TELEPHONE INFLUENCE FACTOR TIF

In French: Facteur d'influence téléphonique

$$\text{TIF} = \frac{\sqrt{\sum U_i^2 \cdot \lambda_i^2}}{U}$$

$U$ : RMS value of the voltage

$U_i$ : RMS value of the voltage of the order  $i$  harmonic

$\lambda_i$ : weighting factor for the frequency corresponding to the order  $i$  harmonic (defined by standard Nema MG1-33)

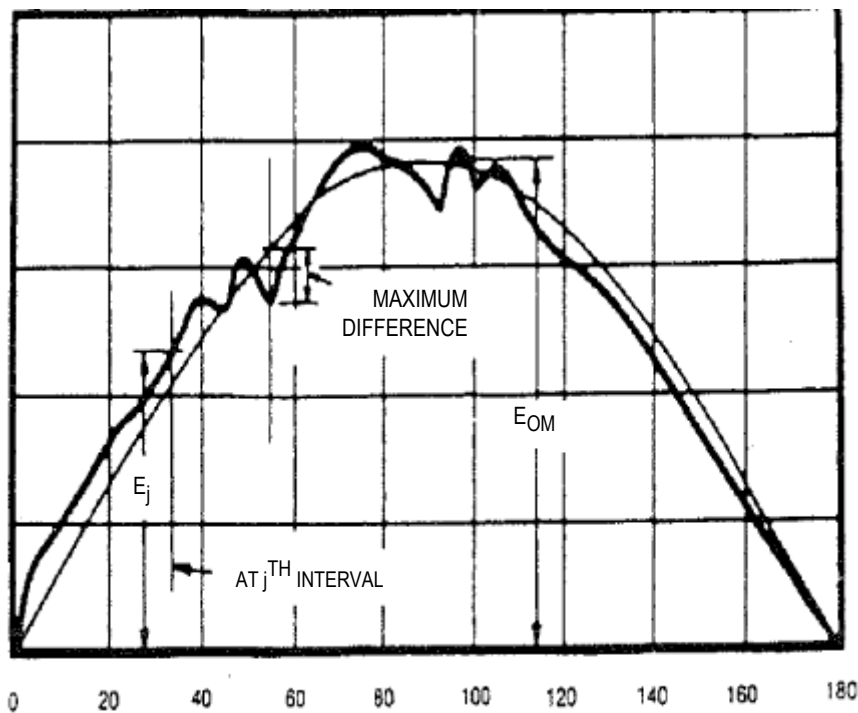
$\sum U_i^2 \lambda_i^2$ : sum of the products of the squares of the  $U_i$  and  $\lambda_i$  terms, including the harmonics and the fundamental.

## • DEVIATION FACTOR

The deviation factor is determined by comparing the actual voltage waveform with the equivalent sinusoidal waveform of the same frequency and RMS value. The deviation factor is the maximum difference between the corresponding ordinates of the actual waveform and the sinusoidal waveform, divided by the maximum value of the equivalent sinusoidal wave form, when the 2 waveforms are superimposed so that the deviation is as small as possible.

The figure below shows an example of the 2 waveforms superimposed, to define the maximum difference.

$$Fd(\%) = \frac{\text{Max. Difference}}{E_{om}} \times 100$$



The complete method for determining the deviation factor is set out in US standard IEEE 115.

An approximate value for the deviation factor can be given by the sum of the harmonics expressed in %.

Example of no-load voltage harmonic levels:

| H3%  | H5%  | H7%  | H11% | H13% | H17% | H19% | H23% |
|------|------|------|------|------|------|------|------|
| 0.08 | 2.98 | 1.34 | 0.31 | 0.23 | 0.08 | 0.1  | 0.11 |

The deviation factor is approximately:

$$Fd = 0.08 + 2.98 + 1.34 + 0.31 + 0.23 + 0.08 + 0.1 + 0.11 = 5.23\%$$

## • RESIDUAL COMPONENT TIF

To obtain this factor, the stator winding is connected in a triangle and one of the vertices of the triangle is opened. The alternator is then run at rated no-load speed, with an excitation current corresponding to the rated no-load excitation current. Under these conditions, the different harmonics of the voltage are measured across the open end of the triangle.

The residual component TIF is calculated from the following expression:

$$\text{Residual component TIF} = \frac{E_{tif}}{3E_{rms}}$$

$$E_{tif} = \sqrt{\sum \lambda_i^2 \cdot U_i^2}$$

$\lambda_i$ : weighting factor corresponding to the frequency of the order i harmonic

(defined by standard Nema MG1-33).

$U_i$ : RMS value of the order i harmonic

$\sum \lambda_i^2 \cdot U_i^2$ : sum of the products of the squares of the  $U_i$  and  $\lambda_i$  terms, including the harmonics and the fundamental.

$E_{rms}$ : RMS value of the average of the 3 voltages of the 3 phases of the triangle.

In the case of the usual three-phase machines, the residual component TIF may be calculated from harmonic analysis of the neutral phase voltage, using the formula for calculation of the TIF (§, above) but considering only the 3rd harmonic and its multiples. The harmonics are measured with the machine at no load and at rated voltage.

## ● APPLICABLE STANDARDS

Basic standards:

- IEC 60034 -1
- ISO 8528 -3
- NEMA MG1- 33
- UL 1004 B (1004-4 after Sep. 2010)

Limits imposed by the standards

### a) IEC 60034 -1

The harmonic distortion requirements apply only to machines with a power of 300kVA or greater.

The limit is imposed for phase to phase voltages under no-load operation.

THD (DHT)  $\leq 5\%$

### b) ISO 8528 -3

Depending on the power, the following THF limits apply to phase to phase voltages under no-load operation.

|                                                  |   |                |
|--------------------------------------------------|---|----------------|
| $P_n \leq 62 \text{ kVA}$                        | : | THF $\leq 8\%$ |
| $62 \text{ kVA} \leq P_n \leq 300 \text{ kVA}$   | : | THF $\leq 5\%$ |
| $300 \text{ kVA} \leq P_n \leq 1000 \text{ kVA}$ | : | THF $\leq 5\%$ |
| $1000 \text{ kV} \leq P_n \leq 5000 \text{ kVA}$ | : | THF $\leq 3\%$ |

### c) NEMA MG1-33

The standard imposes limits on the 5 factors defined previously.

#### c.1) TIF applicable only at 60Hz

Depending on the power, the following TIF limits apply under no-load operation for phase to phase voltages.

|                                                   |   |                |
|---------------------------------------------------|---|----------------|
| $6.25 \text{ kVA} \leq P_n \leq 62 \text{ kVA}$   | : | TIF $\leq 250$ |
| $62.5 \text{ kVA} \leq P_n \leq 4999 \text{ kVA}$ | : | TIF $\leq 150$ |

#### c.2) THF applicable only at 50Hz

Depending on the power, the following THF limits apply to phase to phase voltages under no-load operation.

|                                                   |   |                |
|---------------------------------------------------|---|----------------|
| $6.25 \text{ kVA} \leq P_n \leq 62.5 \text{ kVA}$ | : | THF $\leq 8\%$ |
| $63 \text{ kVA} \leq P_n \leq 1000 \text{ kVA}$   | : | THF $\leq 5\%$ |
| $1001 \text{ kVA} \leq P_n \leq 5000 \text{ kVA}$ | : | THF $\leq 3\%$ |

#### c.3) THD $\leq 5\%$

The limit is imposed for phase to phase voltages under no-load operation.

**c.4) Deviation factor  $\leq 10\%$** 

The limit is imposed for phase to phase voltages under no-load operation.

**c.5) Residual component TIF**

Applies to alternators with rated voltage  $\geq 2$  kV.

**d) UL 1004-4**

The limits imposed by the standard must be met under no-load and on-load operation.

For on-load, the measurements are made at 33%, 66% and 100% of rated power with linear load at rated  $\cos(\phi)$ .

This standard imposes limits on individual harmonic voltages and total harmonic distortion, without specifying whether this is for phase to phase or phase to neutral voltages.

**d.1) Harmonic voltage limits**

| Harmonic order | $P_n \geq 15\text{kW}$<br>Limit (%) | $P_n \leq 15\text{kW}$<br>Limit (%) |
|----------------|-------------------------------------|-------------------------------------|
| Odd            |                                     |                                     |
| 3 to 9         | 4                                   | 8                                   |
| 11 to 15       | 2                                   | 4                                   |
| 17 to 21       | 1.5                                 | 3                                   |
| 23 to 33       | 0.6                                 | 1.2                                 |
| 35 to 39       | 0.3                                 | 0.6                                 |
| Even           |                                     |                                     |
| 2 to 10        | 1                                   | 2                                   |
| 12 to 16       | 0.5                                 | 1                                   |
| 18 to 22       | 0.375                               | 0.75                                |

**d.2) THD**

$P_n \leq 15\text{ kW}$  : THD  $\leq 10\%$

$P_n \geq 15\text{ kW}$  : THD  $\leq 5\%$

## SUMMARY TABLE OF WAVFORM FACTORS OBTAINED WITH ALTERNATORS IN THE LSA RANGE

|                                                        |                  |            |                   |                     |                   |           |
|--------------------------------------------------------|------------------|------------|-------------------|---------------------|-------------------|-----------|
|                                                        | *THD / DHT / TGH |            | *FHT / THF        | *TIF                | *Deviation Factor |           |
| THREE PHASE                                            |                  |            |                   |                     |                   |           |
| 4 Pole                                                 | No-load          | On-load    | No-load / On-load | No-load / On-load   | No-load           | On-load   |
| LSA 40                                                 | < 3%             | < 2%       | < 2%              | < 50                | < 7%              | < 6%      |
| LSA 42.2                                               | < 3%             | < 3%       | < 2%              | < 50                | < 5%              | < 5%      |
| LSA 42.3                                               | < 3%             | < 2%       | < 2%              | < 50                | < 4%              | < 5%      |
| LSA 43.2                                               | < 2%             | < 2%       | < 2%              | < 50                | < 4%              | < 4%      |
| LSA 44.2                                               | < 2%             | < 2%       | < 2%              | < 50                | < 4%              | < 4%      |
| LSA 46.2                                               | < 2.5%           | < 2.5%     | < 2%              | < 50                | < 5%              | < 5%      |
| LSA 47.2                                               | < 1.5%           | < 2%       | < 2%              | < 50                | < 3%              | < 4%      |
| LSA 49.1                                               | < 4%             | < 4%       | < 2%              | < 50                | < 6%              | < 4%      |
| LSA 50.2                                               | < 3.5%           | < 3%       | < 2%              | < 50                | < 6%              | < 5%      |
| 2 Pole                                                 |                  |            |                   |                     |                   |           |
| LSA 37                                                 | < 5%             | < 5%       | < 4%              | < 50                | < 8%              | < 8%      |
| LSA 42.2                                               | < 4%             | < 4%       | < 2%              | < 50                | < 5%              | < 5%      |
| SINGLE PHASE FF                                        |                  |            |                   |                     |                   |           |
| 4 Pole                                                 | No-load          | On-load    | No-load / On-load | No-load / On-load   | No-load           | On-load   |
| LSA 40                                                 | < 3%             | < 8%       | < 2%              | < 50                | < 10%             | < 12%     |
| LSA 42.2                                               | < 3%             | < 5%       | < 2%              | < 50                | < 8%              | < 11%     |
| LSA 42.3                                               | < 2%             | < 10%      | < 2%              | < 50                | < 5%              | < 12%     |
| LSA 43.2                                               | < 2%             | < 4.5%     | < 2%              | < 50                | < 4%              | < 7%      |
| LSA 44.2                                               | < 2%             | < 5%       | < 2%              | < 50                | < 4%              | < 9%      |
| LSA 46.2                                               | < 2.5%           | < 6.5%     | < 2%              | < 50                | < 5%              | < 10.5%   |
| * between phases at no-load and on non-distorting load |                  |            |                   |                     |                   |           |
| SINGLE PHASE DEDICATED                                 |                  |            |                   |                     |                   |           |
| 4 Pole                                                 | No-load          | On-load*** | No-load / On-load | No-load / On-load** | No-load           | On-load** |
| LSA 40                                                 | < 4%             | < 10%      | < 2%              | < 50                | <10%              | < 13%     |
| LSA 42.2                                               | < 4%             | < 2%       | < 2%              | < 50                | < 6%              | < 5%      |
| LSA 42.3                                               | < 2%             | < 5%       | < 2%              | < 50                | < 5%              | < 10%     |
| LSA 43.2                                               | < 2%             | < 2%       | < 2%              | < 50                | < 4%              | < 5%      |
| LSA 44.2                                               | < 3%             | < 4%       | < 2%              | < 50                | < 7%              | < 6%      |
| 2 Pole                                                 |                  |            |                   |                     |                   |           |
| LSA 42.2                                               | < 3%             | < 4%       | < 2%              | < 50                | < 5%              | < 7%      |

\*\*\* on non-distorting load at cos(phi) 1