24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

ICSV24
23-27JULY 2017
LONDON CALLING

STATISTICAL ANALYSIS USING SOUND PRESSURE LEVEL AND SOUND QUALITY METRICS ON ROTATING ELECTRICAL MACHINES FED BY PULSE WIDTH MODULATION

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Pulse width modulation techniques (PWM) are used to improve the quality of input voltage signal in electrical motors fed by power inverters. A suitable selection of different parameters can achieve, for example, total harmonic distortion of the inverter output signal or a certain value of the fundamental voltage term. Additionally, the influence of voltage harmonics on acoustic noise emission produced by electrical machines is well known. Then, a good selection of parameters could minimize the noise emission and therefore improve the sound quality of the motor. This study is focused on the influence of constructive parameters in induction motors such as number of poles, and PWM techniques parameters, which are correlated with both noise emission and sound quality. Results are shown by means of statistical analysis comparing Sound Pressure Level and sound quality parameters as Loudness, Roughness and Sharpness by different PWM techniques, harmonic distortion, number of poles and modulation index.

Keywords: pulse width modulation, loudness, roughness, sharpness, sound pressure level, rotating electrical machines.

1. Introduction

Currently, the power supply of induction motors is done through power investors with the aim of making work to these machines in different speed ranges for which these were originally designed.

The power inverter transforms a continuous signal in a pulse width modulated. This conversion is carried out by means of the insulated gate bipolar transistor (IGBT) that is controlled by a PWM modulation technique.

There are several previous studies on certain PWM techniques aimed at improving the harmonic distortion of the supply signal [1], other to reduce losses by switching of the IGBT inverter [2] and technique to reduce electromagnetic noise [3] using some combination of control parameters of the technique [4-7].

Traditionally the study of acoustic noise in an electric induction motor is based on the level of sound pressure as a parameter to classify the noise generated, with the purpose of detecting faults in different parts of the machine or to predict it. The use of the sound pressure level is used to assess the discomfort that could produce the noise in the human ear. Currently, there are other acoustical parameters to assess the sound quality [8, 9]. The parameters used in this work are the loudness, roughness and sharpness, although only the loudness is standardized.

This work focuses on the study of the relationship between both constructive and electrical parameters of induction motor with the parameters of the sound quality. On the one hand, the constructive and electrical parameters related to the motor are the number of poles, the modulation index of the PWM technique and harmonic distortion, and on the other hand, acoustic parameters used are the level of sound pressure, loudness, roughness and sharpness.

2. Research goals and test methodology

As mentioned above, this paper is focused on the relationship between the electrical parameters and constructive motor, with the parameters of the sound quality. With this aim, a series of tests performed a three-phase induction dalhander motor, by feeding it through an investor and this in turn controlled by PWM techniques previously analyzed. The choice of dalhander motor is due to the ability to modify the number of poles on the machine through external connections, modify the number of poles during the tests without changing the motor. During the tests shall be measured with a network analyzer the electrical parameters, and with a sound analyzer, the noise level emitted by the machine located on the inside of a semi-anechoic chamber. Subsequently apply to measures of sound filters necessary for the psychoacoustic parameters.

2.1 PWM Techniques used

2.1.1 Harmonics injections pulse width modulation with frequency modulated and triangular carrier (HIPWM-FMTC)

The HIPWM-FMTC technique [4] aims to achieve a power signal low harmonic content, getting a few low values of harmonic distortion in intensity and tension. With this technique, the quality of the supply signal is enhanced and you get a good acoustic behavior. The control parameter of HIPWM-FMTC technique is f_c that is the center frequency on which varies the frequency of the carrier signal [10].

2.1.2 Slope pulse width modulation (SLPWM)

The SLPWM technique [5] aims to achieve a power signal with a low number of commutations of the IGBTs to reduce losses due to switching. The control parameters of the technique are μ and k. The value of μ determines the maximum width of the pulses and the value of the parameter k determines the number of pulses during the transition. The values of μ and k determine the order of modulation (M), and certain combinations of their values get certain acoustic motor behaviors [2].

2.1.3 Harmonics injections pulse width modulation with frequency modulated and triangular carrier (HIPWM-FMTC2)

The main objective of the HIPWM-FMTC2 technique [2] is to generate a power signal to minimize the noise emitted by the motor. This technique has the advantages of the two previous ones but with some variations. In this way, this improves the acoustic parameters emitted by the motor. The control parameter of the technique is α and according to their values the harmonic spectrum varies gradually, so that it is possible to optimize the behavior of the investor to get the best rates of harmonic distortion and reduction acoustic motor noise [6].

2.2 Material used

An inverter SEMIKRON SEMITECH composed of a bridge rectifier full wave along with a filter to obtain a current signal continues to feed three branches of IGBTs, a branch for each phase and two IGBTs per phase. The maximum speed of switching of the IGBTs is 20 kHz.

A microcontroller Atmega328PU for loading the vector of inverter control and IGBTs activation control.

A three-phase induction dahlander motor with four poles (2, 4, 6 and 12), in this way, we can modify the number of poles in the motor used in the tests without modifying the previous constructive parameters such as the number of slots in the rotor and the stator, or the thickness of the magnetic core [11].

A network analyzer FLUKE 435 to record the electrical parameters along with the Fluke View Power Quality has been used. The equipment to measure the sound is a compact multi-channel along with the software Soundbook Samurai v1.7 of sinus Messtechnik GmbH (Germany). The microphones used are free field and prepolarizados G.R.A.S. half inch type, and a gauge B & K for calibration of the microphones.

All measurements are done in the interior of a semi-anechoic chamber to reduce interference in the measures according to the protocol of measures for electrical machines [12].

2.3 Test methodology

An application made with the software National Instrument Labview© 2009 (versión 9.03f 32-bits) generates and load control vectors in the microcontroller. The microcontroller controls the activation of the IGBT inverter to play the power signal generated by the PWM technique. The tests are carried out by changing the number of poles in the motor and combining the values of the control parameters of the various techniques for measurements with different values of the modulation index (M=3, 5, 7, 9, 11, 13, 15, 17, 19, 21).

The noise level emitted by the machine will be measured and recorded during 10 seconds in each test, including electrical measurements. Between each test, there is a time of stabilization of the motor to get the rated speed of the machine with the new settings of the parameters

The fundamental frequency of the power signals generated by the techniques via the inverter PWM is 50 Hz and the test voltage will be a 70% of the nominal voltage in order not to saturate the magnetic core. A scheme of the test procedure is showed at Fig. 1.

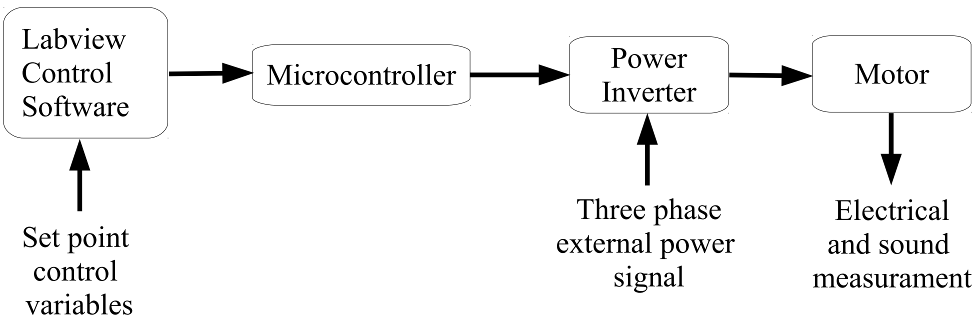

Figure 1: Test procedure scheme.

3. Result analysis

In Table 1 the values used in the tests of the SLPWM technique are shown, the ranges of values used for the testing of the HIPWM-FMTC technique are presented in the Table 2 as well as for the HIPWM-FMTC2 technique, the values of the control parameter α ranges from 17º to 45º in increments of 1º.

With the data obtained in the tests, an outliers study was carried out using the boxplot tool with a value of s = 1.5 as shown in Figs 2, 3 and 4. Once the tests with values considered as outliers were eliminated, the resulting dataset has been subjected to a linear correlation study using the Pearson coefficient.

Table 1: Values of the control parameter k of SLPWM technique.

M	k (SLPWM)
5	-0.74, -0.84, -0.94, -1.04, -1.14, -1.24, -1.34, -1.44, -1.54, -1.64, -1.74
7	1.24, 1.34, 1.44, 1.54, 1.64, 1.74, 1.84, 1.94, 2.04, 2.14, 2.24
9	-2.74, -2.64, -2.54, -2.44, -2.34, -2.24, -2.14, -2.04, -1.94, -1.84, -1.75
11	2.25, 2.35, 2.45, 2.55, 2.65, 2.75, 2.85, 2.95, 3.05, 3.15, 3.24
13	-3.74, -3.64, -3.54, -3.44, -3.34, -3.24, -3.14, -3.04, -2.94-2.84, -2.75
15	3.25, 3.35, 3.45, 3.55, 3.65, 3.75, 3.85, 3.95, 4.05, 4.15, 4.24
17	-4.74, -4.64, -4.54, -4.44, -4.34, -4.24, -4.14, -4.04, -3.94, -3.84, -3.75
19	4.25, 4.35, 4.45, 4.55, 4.65, 4.75, 4.85, 4.95, 5.05, 5.15, 5.24
21	-5.74, -5.64, -5.54, -5.44, -5.34, -5.24, -5.14, -5.04, -4.94, -4.84, -4.75

Table 2: Values range of control parameters k_c and f_c of the HIPWM-FMTC technique.

M	k_c (min.-max.)	f_c (min.-max.)	Δk_c	Δf_c
5	0-10	5-10	0.25	0.125
7	0-14	7-14	0.25	0.125
9	0-18	9-18	0.3	0.15
11	0-22	11-22	0.35	0.175
13	0-26	13-26	0.5	0.25
15	0-30	15-30	0.5	0.25
17	0-34	17-34	0.5	0.25
19	0-38	19-38	0.5	0.25
21	0-42	21-42	0.5	0.25

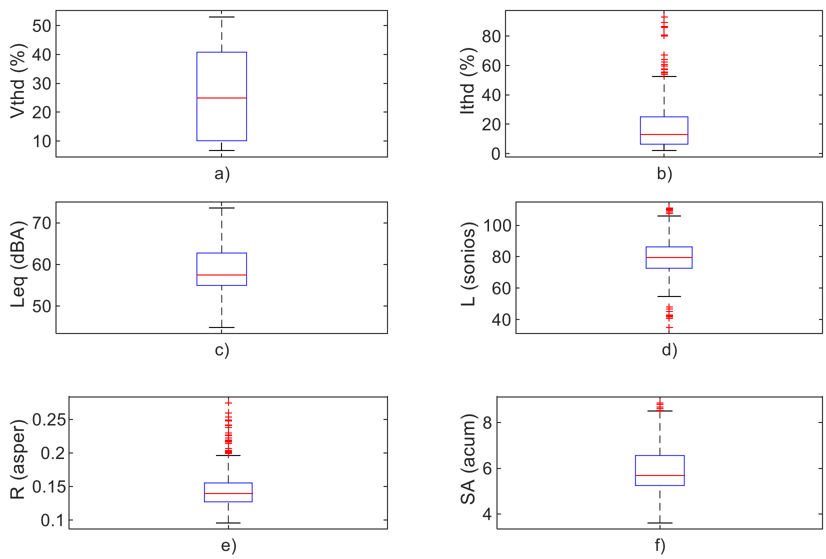

Figure 2: Study of outliers for s=1.5 for data obtained from testing the technique SLPWM.

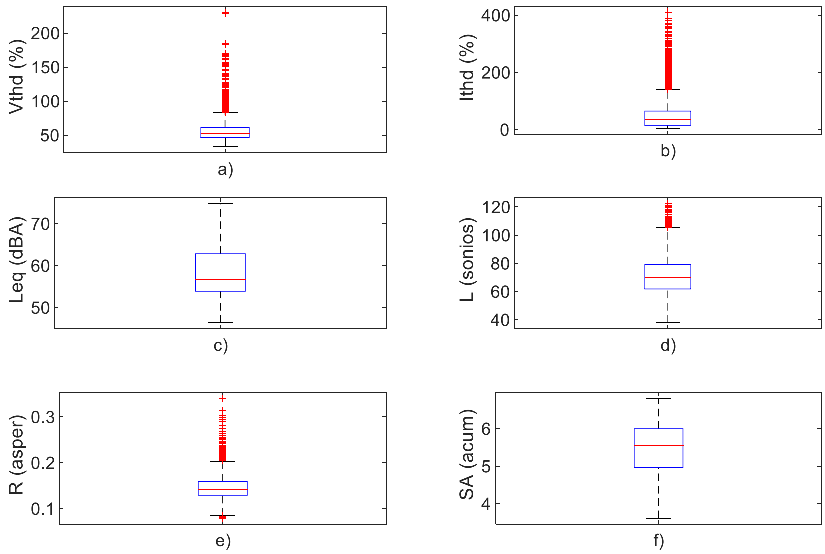

Figure 3: Study of outliers for s=1.5 for data obtained from testing the technique HIPWM-FMTC.

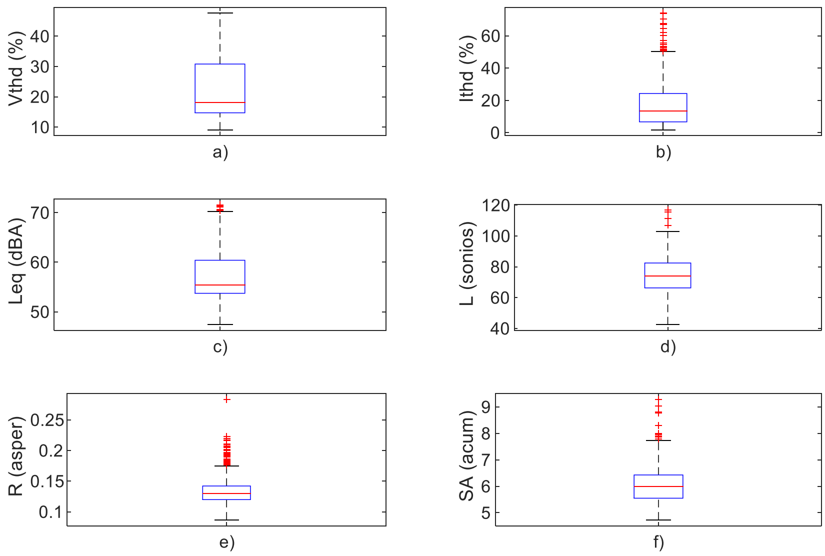

Figure 4: Study of outliers for s=1.5 for data obtained from testing the technique SLPWM.

Table 3 shows the results obtained from the linear correlation study using the Pearson coefficient. It can be appreciated the different correlations between the constructive and electrical parameters of the motor tested with the parameters of sound quality.

Table 3: Coefficients of Pearson's linear correlation of the different variables.

	SPL	L	R	SA
Vthd	0.761	0.596	-0.745	-0.748
Ithd	0.529	0.486	-0.408	-0.408
p	-0.719	0.31	-0.634	-0.640
M	-0.636	0.645	-0.616	-0.600

From the point of view of the SPL parameter, there is a positive correlation with Vthd and Ithd, consequently to greater harmonic distortion in both voltage and current, higher SPL value. For the case of the number of poles and modulation index the correlation is negative, this means that unlike in the previous case, the lower value of the number of poles and modulation index, the higher the value of the SPL parameter. The parameters with the highest correlation are the harmonic distortion in voltage and the number of poles of the motor.

The correlations of the parameter *L* with the motor and electrical parameters of the motor, in this case, are the lowest. It should be noted that all correlations are positive, the highest is the parameter *M* and the lowest with the number of poles.

With roughness all correlations are negative, to lower values of electrical and constructive motor parameters higher roughness level. It can be seen that the highest correlation value is with the harmonic distortion in tension and the lowest with the harmonic distortion in intensity. For all other parameters, the correlation is above -0.6 which is a value to be taken into account.

Finally, all the sharpness correlation values regarding electrical and constructive motor parameters are very similar in the case of roughness, both values as the negative sign. The highest value of correlation is with Vthd and lowest with Ithd, for the number of poles -0.64 and -0.6 for the modulation index, respectively.

4. Conclusions

The electrical parameter with a higher correlation with respect to the sound quality is the harmonic voltage distortion, this parameter is directly dependent on the technique used and the PWM values selected for the control parameters of the same.

Loudness is a parameter that depends more inversely on the modulation index, a higher modulation index results in more pulse numbers per cycle of the power signal, this means that the level of loudness can be reduced in return of sacrificing a greater number of commutations and the associated losses due to heating.

The number of poles is a constructive parameter of the motor which is very inversely correlated to the value of the SPL, since at a lower number of poles higher speed and consequently higher aerodynamic noise. Since the number of poles is a constructive parameter, it limits the options in the reduction of the SPL, but if one can take into account the possibility of modifying the value of the SPL by the values of Vthd and *M*, parameters that depend on the PWM techniques chosen for Generate the power signal and the values of its control parameters.

Moreover, the roughness and sharpness have similar correlations, so that a similar behavior can be estimated in function of the values of the electrical and constructive parameters of the motor reason why it facilitates the study to find optimal points of operation.

Finally, the harmonic distortion in voltage is the parameter that is related to the sound parameters of the noise generated by the motor, so it must be taken into account as the main parameter for the improvement of the noise emitted by the motor.

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