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Incidence of harmonic in asynchronous three-phase motors

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Abstract:

The objective of this work is to analyze the incidence of the time superior harmonics over the characteristics of a motor behavior. For this purpose, a computer program in Matlab was made, and it was possible, for different voltage supply waves, by the Fourier Series Analysis, to find the incidence of each harmonic over the motor parameters. Besides this, the machine general behavior can be obtained when all the harmonics of the highest order are present applying the superposition method.

The importance of this work is focusing firstly on the possibility to simulate the effect of each harmonic that is present in the wave that is analyzed over the motor behavior. In second term, from the didactic point of view because it allows to compare the machine characteristics over the influence of the different time harmonics.

Keywords: Time harmonics, incidence of the harmonic in the three-phase asynchronous motors.

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1. Introduction

The electronic converters that are used in the supply of voltages to asynchronous three-phase machines have as an output a waveform of voltage and current that is not sinusoidal [1]. Therefore, there is a great quantity of time harmonics, which can affect the behavior of those devices in different work rates [2].

These converters have been used progressively to control the speed of the asynchronous three-phase machines based on the variation in amplitude of the extent voltage applied and frequency changes too. As an example of these converters we have the chopper of alternating current, and now more used, the converters that are based on the pulse width modulation techniques [3].

In this work we have taken different waveforms as a reference such as a pure sinusoidal wave, a symmetrical square wave, an asymmetrical one and finally a staggered. Once separated this waveforms into its harmonics that composed each one, there was valued in detail the incident of every harmonic separately for the characteristics of the motor output, focusing on the mechanical characteristics obtained by such different harmonic at every time slot.

To simulate how the motor was working, we have used Matlab such as a calculus tool for the Fourier series analysis of the input signals and to obtain the mechanical characteristics of the motor behavior which makes possible to make a comparison between the harmonics with the same order that came from the different waveforms.

2. Development

For the simulation of the machine we have taken as an equivalent circuit the one that considers the rotational-losses as shown in the Figure 1, [4].

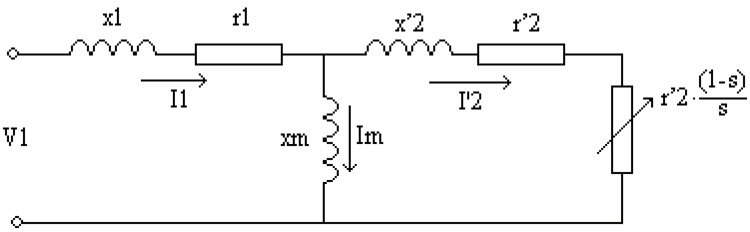

Figure 1. Equivalent circuit of the asynchronous motor

From this circuit we can obtain:

$$I_1 = \frac{U_1}{Z_T} \quad (1)$$

$$Z_T = Z_1 + Z_f \quad (2)$$

$$Z_1 = r_1 + jx_1 \quad (3)$$

Where:

I_1 : Current flowing through the stator's coils (A).

U_1 : Voltage applied to the motor's input (V).

r_1 : Resistance of one phase of the stator (Ω).

x_1 : Dispersion's reactance of the stator (Ω).

And besides we have that:

$$Z_f = \frac{jx_m \cdot \left(jx_2' + \frac{r_2'}{s} \right) \cdot}{jx_m + jx_2' + \frac{r_2'}{s}} \quad (4)$$

$$Z_f = r_f + jx_f \quad (5)$$

Knowing:

$$s = \frac{w_1 - w}{w_1} \quad (6)$$

$$w_1 = \frac{4 \cdot \pi \cdot f_1}{p} \quad (7)$$

Where:

x_2' : Dispersion's reactance of the rotor referred to the stator, which changes depending on the frequency of the harmonic analyzed (Ω).

r_2' : Resistance of the rotor referred to the stator (Ω).

s : Sliding.

w_1 : Synchronous speed of the fundamental harmonic (rpm).

w : Speed of the rotor (rpm).

From the power's balance of the asynchronous motor we have that:

$$Pen = 3 \cdot U_1 \cdot I_1 \cdot fp \quad (8)$$

Where:

Pen : Electrical input power (W).

fp : Power factor of the motor.

For the electrical losses of the stator we have:

$$Pcu_1 = 3 \cdot I_1^2 \cdot r_1 \quad (9)$$

The electromagnetic power transferred to the rotor is calculated by the following equation:

$$Pg = 3 \cdot I_1^2 \cdot rf \quad (10)$$

The electrical losses in the coils the rotor is:

$$Pcu_2 = s \cdot Pg \tag{11}$$

The power developed by the axis of the rotor is calculated by the following equation:

$$Pdes = (1 - s) \cdot Pg \tag{12}$$

The output power of the motor is obtained by:

$$Psal = Pdes - \Pr ot \tag{13}$$

Torque or moment developed by the axis of the rotor (N-M):

$$Mdes = \frac{Pg}{ws} \tag{14}$$

Where:

$\Pr ot$: Losses rotational of the motor (W)

The work did consist on take these equations and by a program written in Matlab simulate the behavior of the engine for each harmonic. Knowing that the magnetic field created by the Magnetomotive force of the first harmonic is that have the highest value and turns into the synchronous speed and by the same way that the rotor's movement, however the fifth harmonic turns with a frequency with equal value to five times the frequency of supply, and in an opposite direction to the draft of the rotor, [5]. The slide for harmonic is calculated by the following equation:

$$s_5 = \frac{w_{s5} + w}{w_{s5}} \tag{15}$$

Where:

$$w_{s5} = \frac{4 \cdot \pi \cdot (5 \cdot f_1)}{p} \tag{16}$$

Where:

$$f_5 = 5 \cdot f_1 \tag{17}$$

Since we have been appreciated that the speed of rotation of the magnetic field that produces the fifth harmonic is five times the synchronous speed of the first harmonic whereas the same procedure now for the 7th harmonic we can find that:

$$s_7 = \frac{w_{s7} - w}{w_{s7}} \tag{18}$$

Therefore, we can determine for the harmonics which have an order $k = (3n + 1)$, where n =1, 2, 3… they produce magnetic fields of the order $k = (3n - 1)$, turn in the opposite direction to the movement of the rotor.

For the simulation we took as an example a three-phase conventional motor which information for the nominal frequency is the following:

U_1=220V,	4 poles,	f_1=60Hz,	Psal=10 hp,
Star connection,	r_1=0.39Ω,	r'_2=0.14Ω,	x_1=0.35Ω,
x'_2=0.35Ω,	x_m=16Ω,	Prot=350W	

We simulated the functioning of the motor fed with different voltage waveform and in presence of different harmonics (1st, 5th, and 7th) due to the highest incident of those. The results obtained are valuated only when 1st harmonic is taken from the different waveforms by the moment and the power developed by the motor is shown in the Figure 2.

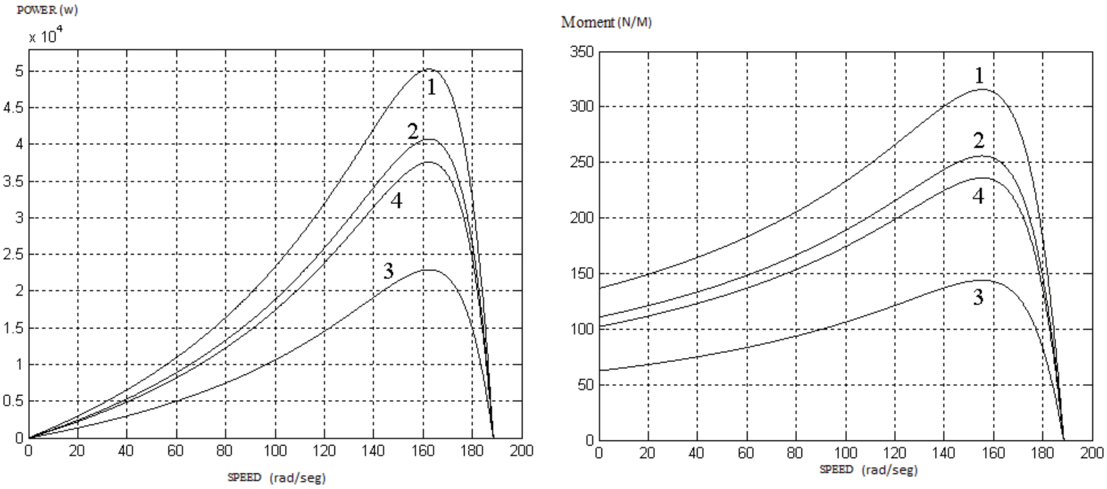

Figure 2. Features for the first harmonic

Where:

1- Sine pure wave
2- Square Symmetrical wave
3- Square Asymmetrical wave
4- Staggered wave

The variation of the starting moment, maximum moment, power and developed moment for the 1st harmonic for different waveforms is shown in the table 1.

Table 1. Moments and power for the 1st harmonic

Waveforms	**Moment of take-off (N-m)**	**Maximum moment**		***w*= 1746 rpm**	
		M(N-m)	**P(kW)**	**Mdes (N-m)**	**Pdes (kW)**
Sine	136,63	315,65	49,027	132,87	24,29
Symmetrical Square	110,75	255,86	39,74	107,70	19,69
Asymmetrical Square	62.29	143,92	22,35	60,58	11,08
Staggered	102,17	236,04	36,66	99,36	18,16

It is possible to observe how, when the motor is fed by a sine pure signal, the highest values are achieved for the moment and developed power, which we can show that while at least it looks like a sine, the input signal there will be more incidence of the top-order harmonics, diminishing as a consequence, the amplitude of the first harmonic.

The incidence of the 5th harmonic on the supply signal of the motor is being shown in the Figure 3 and the Table 2

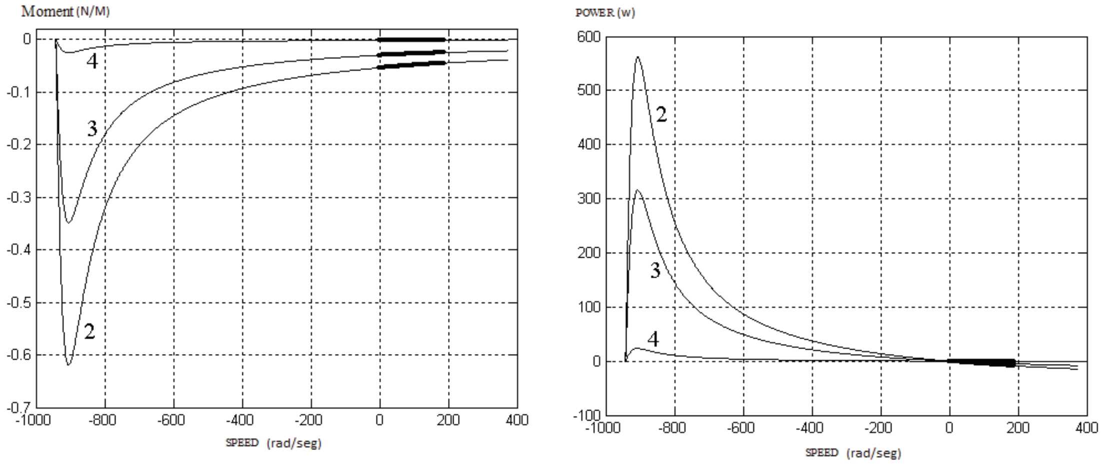

Figure 3. Characteristics for the fifth harmonic

Table 2. Moments and power for the 5th harmonic

Types of waves	Moment of take-off (N-m)	Maximum moment		w= 1746 rpm		
		M (N-m)	% $\frac{M_5}{M_1}$	Mdes (N-m)	% $\frac{Mdes_5}{Mdes_1}$	Pdes (W)
Sine	0	0	0	0	0	0
Square	-0.0545	-0.6200	0,24	-0.0458	0,018	-8.3769
Asymmetric	-0.0307	-0.3487	0,242	-0.0258	0,042	-4.7120
Staggered	-0.0023	-0.0258	0.011	-0.0019	0.002	-0.3482

From the results obtained there is shown that the fifth harmonic exists in the not sine signals and it turns in the opposite direction of the first and therefore it develops a negative moment in the motor that means in a moment of breaking on the axis of the motor. The moment developed in the zone of work of the motor, is of a small magnitude and negative that elicit a decrease of the moment developed by the first harmonic, the speed and the output power of the motor, having therefore an effect on the efficiency as a consequence of this, [3].

In the case of the 7^{th} harmonic, it has an incidence over the characteristics of power and moments developed by the motor. It is less than the 5^{th} harmonic and we show that in the Table 3, also we can show that depending on the waveform of the signal input its amplitude is changing.

Table 3. Moments and power given for the 7th harmonic

Types of waves	**Moment of take-off (N-m)**	**Maximum moment**		***w*= 1746 rpm**		
		M (N-m)	**% $\frac{M_7}{M_1}$**	**Mdes (N-m)**	**% $\frac{Mmáx_7}{Mmáx_1}$**	**Pdes (W)**
Sine	0	0	0	0	0	0
Square	0.0103	0.1664	0.065	0.0119	0.018	2.2028
Asymmetric	0.0058	0.0936	0.065	0.0067	0.011	1.2391
Staggered	0.00044	0.0071	0.003	0.00051	0.00051	0.0945

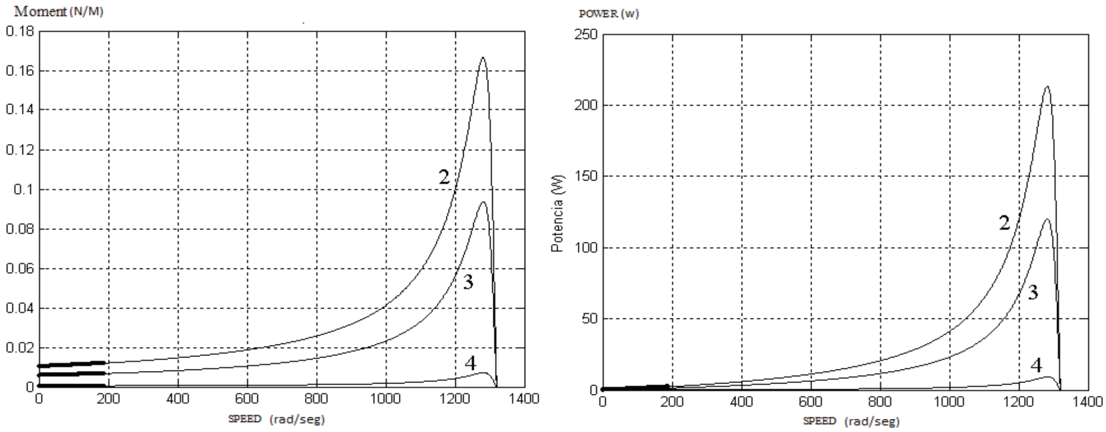

Figure 4. Characteristics obtained for the seventh harmonic

We have been verified that for the 7th harmonic coming from the square wave it has the highest amplitude, it has also been showed from the 5th harmonic. The last assimilation is due to the waveform taken has the highest number of harmonics.

Besides, we have verified, that it turns in the same way for all cases, and although it develops negative values for the moment and the output power it doesn’t really matter because of when a high-frequency currents are flowing through the circuit it really helps the increase of the electrical, magnetic and other lossless; for the first case there were given by the effect of increase in the resistance with the singular effect, the second ones are depending directly on the frequency. Finally, the other lossless are given as a consequence of the flux dispersion that is created by these harmonics in the slots of the rotator and stator, [6, 7 y 8].

3. Conclusions

1. The present work allows evaluating the incidence of the harmonics in the time characteristics of behavior in the asynchronous three-phase motor as well as to evaluate the incidence of the harmonics depending on what kind of waveform is the input signal. It means that for the developed programs, we can evaluate the harmonic in not sinusoidal signals from the different static converters used in the electrical drives of the three-phase asynchronous motors.

2. The methodology developed can be applied to three-phase asynchronous motors fed by converters from voltage and frequency.

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