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Review of the Literature Referring to a Method to Achieve Active Electrical Energy Savings - Single-Phase 220 (VAC) and 50 (Hz) - in Synchronous Ventilation Motors, Greater than that Obtained with the "Fan Law"

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Abstract
It is a mechatronic method to achieve savings in single-phase active energy, greater than that obtained with the "Fan Law" in electrical machines applied to ventilation. The quantitative analysis methods were based on electrotechnical techniques, practiced with the corresponding laboratory instruments on the work materials (three prototypes of electrical machines). The results found from the experimentation on the test bench were expressed in tables that collect data on formulas, values and physical units. The discussion carries out a complete comparative study; mainly between power (watts), active energy consumption (kwh) and rotation speed (RPM). The PMSM type synchronous motor with the coupling of an RL mechatronic circuit design performs mechanical work at its maximum speed of 3000 (RPM) with only 6.3 (Watts), this is only 25.2% of the active power required by the single-phase asynchronous induction motor or shaded-pole motor that needed 25 (Watts) to rotate at 1690 (RPM). This translates into 75% lower active power, with a 44% superiority in speed, which translates into a 75% saving in single-phase active energy (kWh). The same thing also happens if we compare the universal AC motor with carbon and wound rotor, to maintain a speed at 3000 (RPM); given that it will consume 64.8 (Watts), that is, 90.3% more single-phase active energy than that required to match the same speed of the PMSM type synchronous motor. All with the same diameter of the impeller blades and the same conditions of temperature and atmospheric air pressure.

Keywords: Mechatronics, Active Energy Savings, Single-Phase AC, kWh. Fan Motors, Fan Law.

1. Introduction

The objective of this work is to demonstrate the development of an innovative mechatronic method to achieve energy efficiency and savings in single-phase active energy (kwh) in electrical machines intended for ventilation and refrigeration, higher than that obtained with the so-called "Law of Fans" if a type of RL circuit design (hypothesis) is applied in PMSM type synchronous motors that as a whole operates as a highly energy efficient RLC motor system; conducting a comparative study with another variety of alternating current (AC) electric motors. The comparative study was carried out between: (a) a type of permanent magnet synchronous motor (Permanent agnet Synchronous Motors); (b) a single-phase asynchronous induction motor or shaded-pole motor, also known as a short-circuit motor (fragger coil) or a small "squirrel-cage" induction motor Induction Motor) and; (c) a series-wound motor (Series-Wound Motor), also called universal motor with wound rotor (with carbons) in AC. The quantitative methods were based on physical formulas of electricity and magnetism applied from various electrotechnical techniques and practiced with the corresponding laboratory instruments and work materials (three prototypes of electrical machines). The results found from the experimentation of the prototypes on the test bench were reflected in six (6) tables that collect and illustrate the data with their: (a) name, (b) formula, (c) values and (d) physical units. The discussion made reference to the Theoretical and Bibliographic Framework, exposing the scientific novelty and technological innovation, carrying out a comparative study between power (watts), active energy consumption (kwh) and rotation speed (RPM) of the impeller blades of the motor. of the centrifugal fan.

2. Materials, Methods and Theoretical Framework

In general terms, this mechatronic innovation required taking into account classical physical principles and the fundamental laws of electricity and magnetism such as the behavior of Ohm's law in alternating current, the Faraday-Lenz law and other known alternating current laws. To cite some examples that represent classic concepts on the theoretical and physical foundations of motors that explain their electromagnetic operation [1-4]. Furthermore, keeping in mind a bibliography on alternating current electrical machines published in Spanish and other bibliographic material in English [5-22]. The bibliography was analyzed in light of the patent for the invention of the two-phase induction motor of 1885 attributed to the Italian electrical engineer Galileo Ferraris and patent no. 381968 of 1888 of the Serbian electrical engineer Nikola Tesla (US381968A) [23]. Likewise, attentive to the new and extensive specific literature on addressing environmental problems and the so-called "carbon footprint" and energy efficiency (EE), the study has focused on a specific bibliographic review on ecodesign and EE in energy efficiency systems. cooling and ventilation; taking into account a couple of personal works in Spanish and English and other more general works by several authors [23-40]. For the computational simulation methodology, NI Multisim software has been used (https://www.ni.com).

It is an objective of this work to demonstrate the development of an innovative method to obtain energy efficiency, or savings in single-phase active energy (kwh), higher than that obtained with the so-called "Fan Law" specified in the UNE 100 Standard. -230-95 and determined according to international standards ISO 5801-96(E) and ED 13348-1998; in PMSM type synchronous motors without the need for the use of Variable Frequency Drives (VDF). Carrying out a brief comparative study with another variety of alternating current (AC) electrical machines, specified according to NEMA [17].

2.1. Shaded-Pole Motor, a Type of Single-Phase Asynchronous AC Induction Motor

The shaded-pole motor or short-circuit motor (fragger coil) is a type of asynchronous single-phase AC induction motor, we can also describe it as a small "squirrel-cage" type induction motor (Squirrel-Cage Induction Motor). in which the auxiliary winding consists of a copper ring or bar surrounding a portion of each pole. When single-phase AC power is applied to the stator winding, due to the shading provided to the poles, a rotating magnetic field is generated. This single turn auxiliary winding is called shading coil. The currents induced in this coil by the magnetic field create a second electrical phase by delaying the phase of magnetic flux change for that pole (a shaded pole) enough to provide a two-phase rotating magnetic field. The direction of rotation is from the unshaded side to the shaded (ring) side of the pole. Since the phase angle between the shaded and unshaded sections is small, shaded-pole motors produce only a small starting torque relative to the torque at full speed.

They require alterations to the stator, such as shaded-pole, to provide starting torque. A single-phase induction motor requires a separate starting circuit to provide a rotating field to the motor. The normal operating windings within such a single-phase motor can cause the rotor to rotate in either direction, so the starting circuit determines the direction of operation.

These single-phase asynchronous motors, in which the stator has a single-phase winding and the rotor is a squirrel cage. They are small power motors and in them, by virtue of Leblanc's Theorem, the magnetic field is equal to the sum of two equal rotating fields that rotate in opposite directions. Indeed, Leblanc's theorem says that a winding carried by a single-phase alternating current creates a pulsating magnetic field, which is equivalent to two equal rotating magnetic fields that rotate in opposite directions that cancel each other out. A squirrel cage motor (such as the small shaded-pole motor), whose stator has a single winding through which a single-phase alternating current circulates, will not be able, according to Leblanc's theorem, to start by itself. Since these single-phase motors do not start on their own, some auxiliary means must be provided for starting (which is the so-called "Frager coil").

Because their starting torque is low, they are best suited for driving fans or other loads that start easily. Above 250 (Watts) of power are not common and for larger motors, other designs offer better features. A main disadvantage is its low energy efficiency. The low efficiency is tolerable relative to the reduced cost of the motor and starting method compared to other AC motor designs.

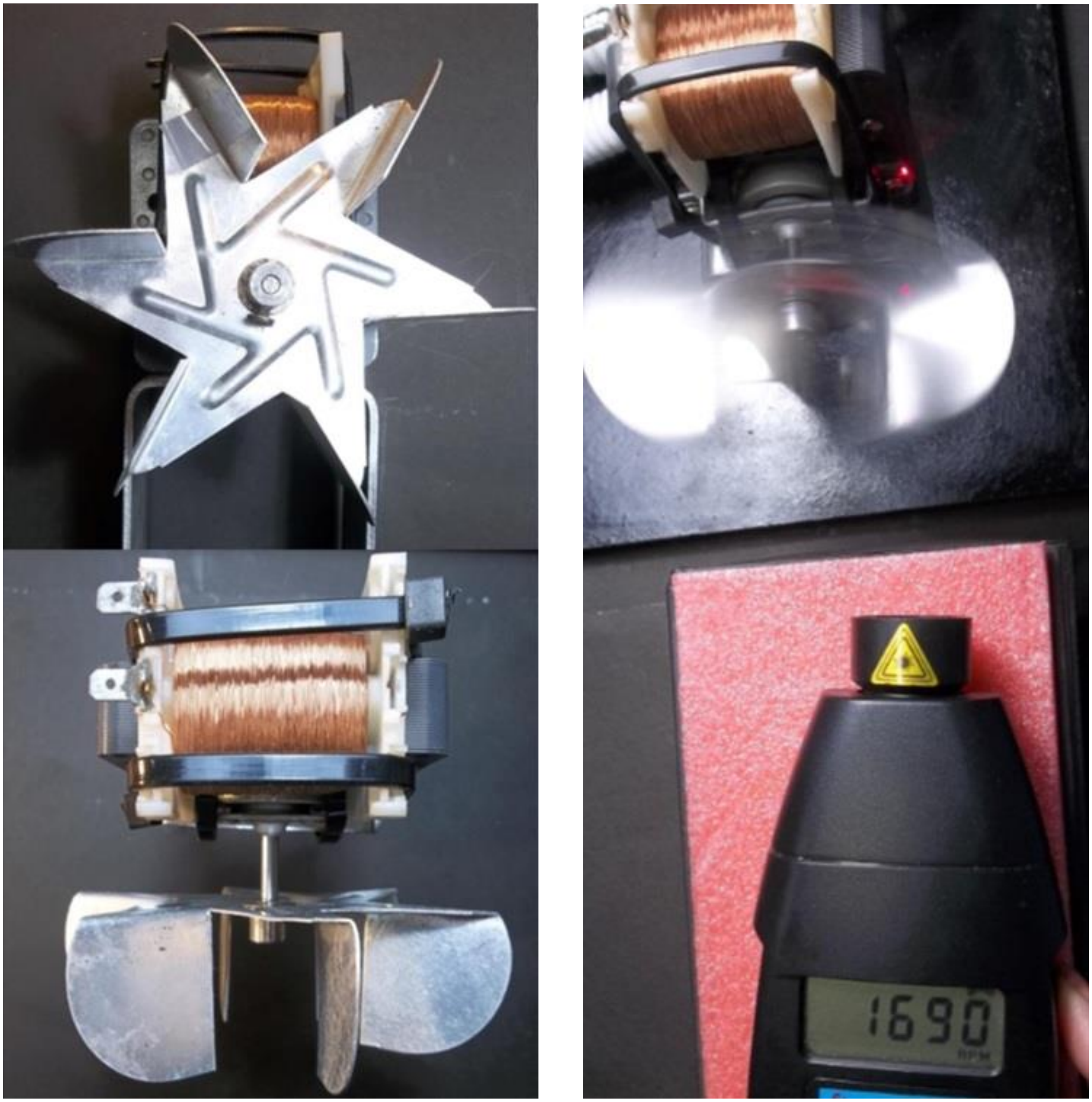

Figure 1: (a) Shaded-pole motor, a type of stopped AC asynchronous single-phase induction motor used in the experiment, with 10.5 (mm) blades used in the experiment; (b) the same motor running at 1690 (RPM) at maximum power of 25 (Watts). Source: self made.

2.2. Series-Wound Motor (Series-Wound Motor) or Universal AC Asynchronous Motor

Universal motor is a type of electric motor that can run on AC or DC power and uses an electromagnet as its stator to create its magnetic field. It is a switched series-wound motor where the stator field coils are connected in series with the rotor windings through a commutator. It is often referred to as an AC series motor. The universal motor is very similar to a DC series motor in construction, but is slightly modified to allow the motor to operate properly on AC power. This type of electric motor can operate well on AC because the current in both the field coils and armature (and the resulting magnetic fields) will alternate (reverse polarity) synchronously with the supply. Therefore, the resulting mechanical force will occur in a constant direction of rotation, independent of the direction of the applied voltage, but determined by the commutator and the polarity of the field coils.

Universal motors have high starting torque, can operate at high speed, and are lightweight and compact. They are commonly used in portable electrical tools and equipment, as well as many household appliances. They are also relatively easy to control, either electromechanically using tapped coils, or electronically. However, the commutator has brushes that wear out, so they are used much less frequently for equipment that is in continuous use. Additionally, partly due to the commutator, universal motors tend to be very noisy, both acoustically and electromagnetically.

It has less power in alternating current than in direct current, because in alternating current the torque is pulsating. Furthermore, the current is limited by the impedance, formed by the inductor and the resistance of the winding. Therefore there will be a voltage drop due to reactance when operating on alternating current, which will result in a decrease in torque.

Greater sparking in the brushes when operating on alternating current, because the armature coils are crossed by an alternating flux when they are short-circuited by the brushes, which forces a compensating winding to be put in medium motors to counteract the electromotive force induced for that reason.

They are high speed motors for light loads. The starting torque is also very large. Fractional horsepower series motors are used to power fans, electric drills, and other small appliances.

The wound-rotor motor has a rotor made up, instead of a cage, of a series of conductors wound on it in a series of slots located on its surface. In this way we have a winding inside the magnetic field of the stator, with the same number of poles, and in motion. This rotor is much more complicated to manufacture and maintain than the squirrel cage one, but it allows access to it from the outside through rings that short-circuit the windings. This has advantages, usually such as the possibility of using a starting rheostat that allows the starting speed and torque to be modified, as well as reducing the starting current.

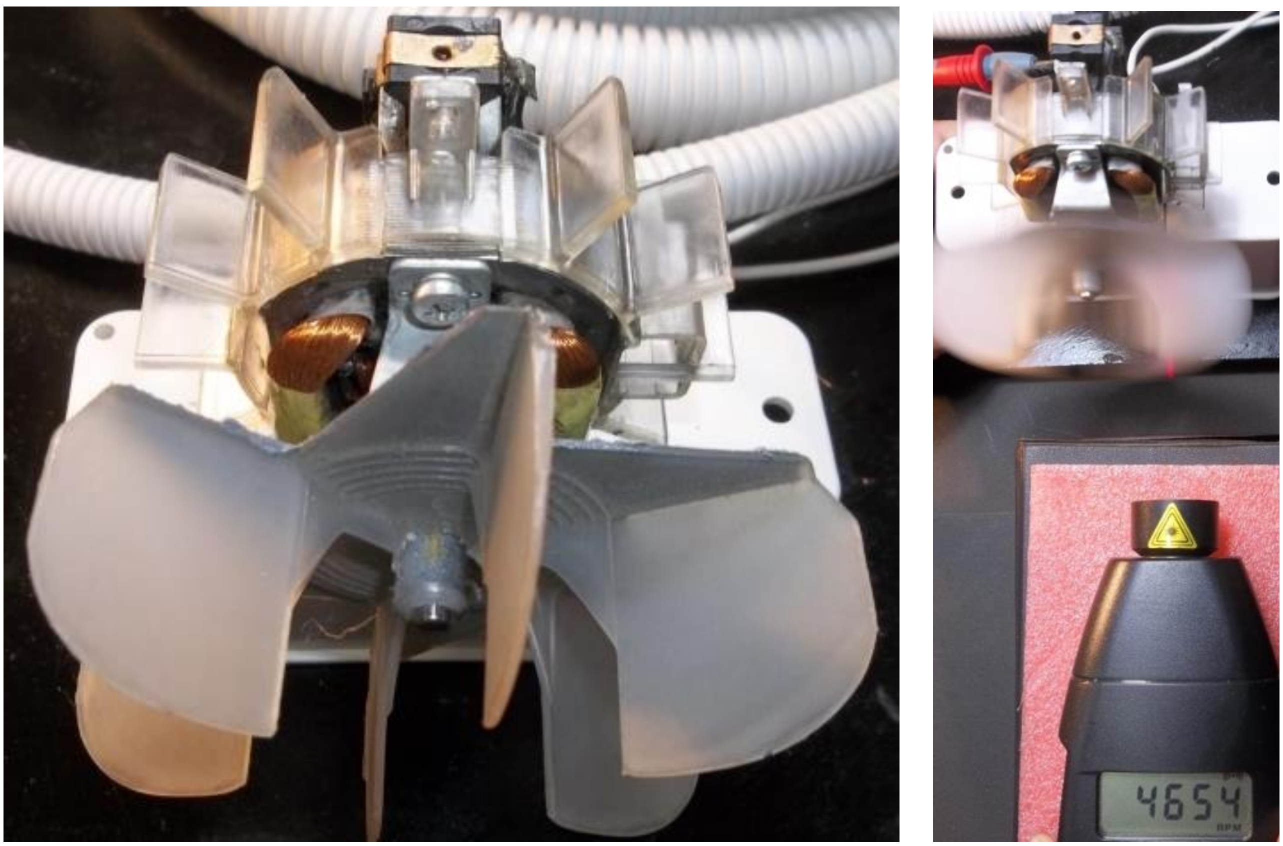

Figure 2: (a) The series-wound motor (Series-Wound Motor) or stopped AC universal asynchronous motor with 10.5 (mm) blades, used in the experiment, is observed; (b) the same motor running at 4654 (RPM) at maximum power of 242 (Watts). Source: self made.

2.3. Synchronous Motor-Permanent Magnet

It is not the objective of this work to describe the structure and operating principle of the synchronous motor, but it can be obtained from any bibliography on synchronous machines; It is a reversible machine since it can be used as an alternating current generator or as a synchronous motor.

Currently, within the family of synchronous motors we must distinguish that there are three types of synchronous motors: (1) reluctance motors, (2) hysteresis motors (Hysteresis motors) and (3) magnet motors. permanent (Permanent-Magnet Motors). We are particularly interested in the PMSM/IPM type motor (Permanent Magnet Synchronous Motor/Interior Permanent Magnet) or synchronous motor with permanent magnets (ferrite or neodymium) or with permanent magnets inside the rotor.

A Permanent Magnet Synchronous Motor (PMSM) uses permanent magnets embedded in the steel rotor to create a constant magnetic field. The stator has windings connected to an AC supply to produce a rotating magnetic field (as in an asynchronous motor). At synchronous speed, the rotor poles are locked in the rotating magnetic field. Permanent magnet synchronous motors are similar to brushless DC motors. Neodymium magnets are the most commonly used magnets in these motors. Although in recent years, due to the rapid fluctuation in prices of 14000 (Gauss) neodymium ($Nd_2Fe_{14}B$) magnets, many researches have been looking for an alternative in 4000 (Gauss) ferrite magnets. Due to the inherent characteristics of the ferrite magnets currently available, the magnetic circuit design of these machines needs to be able to concentrate the magnetic flux, one of the most common strategies is the use of radial type rotors. Currently, new machines that use ferrite magnets have lower power density and torque density, compared to machines that use neodymium magnets (but are less expensive). A permanent magnet synchronous motor (PMSM) uses permanent magnets embedded in the steel rotor to create a constant magnetic field. The stator has windings connected to an AC supply to produce a rotating magnetic field (as in an asynchronous motor). At synchronous speed, the rotor poles are locked in the rotating magnetic field.

Most PMSMs require a variable frequency drive (VDF) to get started. However, some incorporate a “squirrel cage” in the rotor for starting; These are known as online-start or self-start PMSMs. They are typically used as higher efficiency replacements for induction motors (due to lack of slip), but must be carefully specified for the application to ensure that synchronous speed is achieved and that the system can withstand torque ripple. during starting.

Permanent magnet synchronous motors are mainly controlled by “direct torque control” and “field oriented control.” However, these methods suffer from relatively high torque and stator flux waves, additionally requiring the use of variable frequency drives (VDF) that require complex and expensive electronics. The use of VDF associated with PMSM motors makes the process of using this type of motors much more complex and expensive (considering whether they are made of neodymium magnets). Costs increase and become less competitive compared to other types of technologies. It is not the objective of this paper to specify what a VDF consists of, only to cite it to take it into account, as this

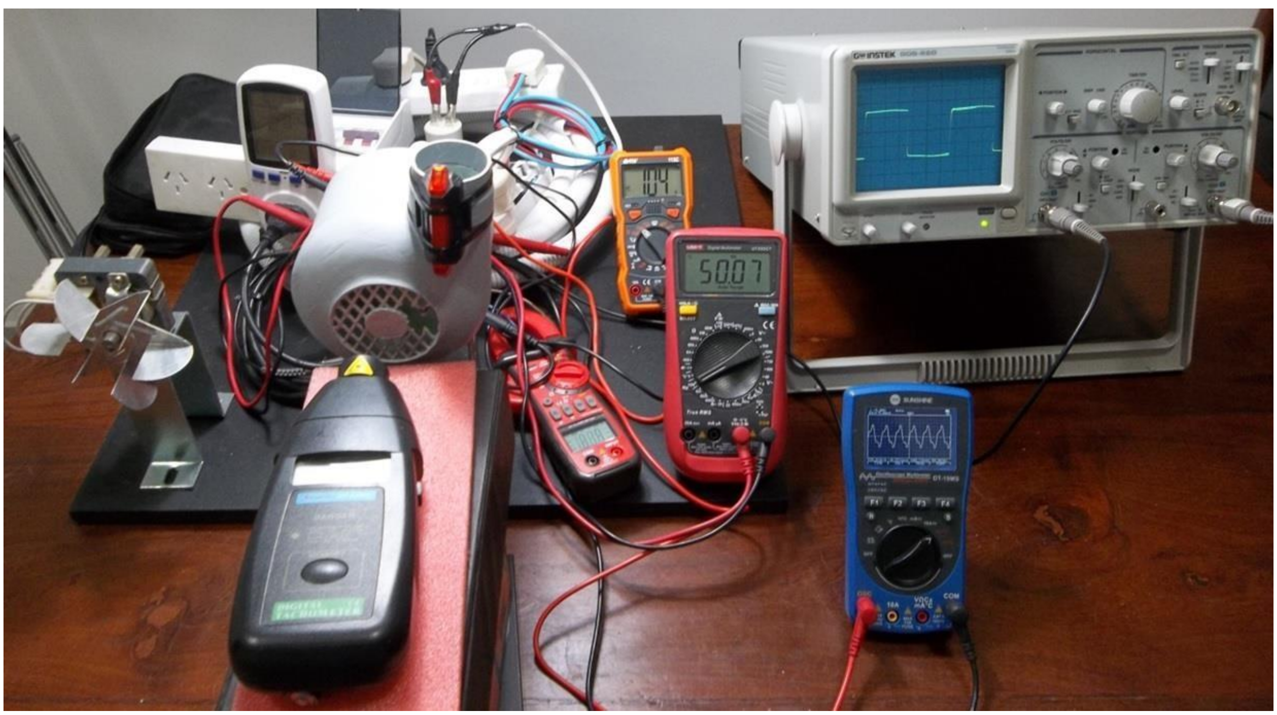

Figure 3: Test bench connected to the PMSM type synchronous motor (as an example). With digital multimeter (volt meter in AC), amperometric clamp (current intensity meter in AC), frequency meter (Hertz meter), laser photocometer (speed meter in RPM), digital oscilloscope waveform meter the alternating current in voltage (Vpeak -peak, Vavg , Vrms), for calculation of the crest factor of harmonic distortion, analog oscilloscope for qualitative observation of the THD (harmonic distortion of alternating current), wattmeter (active power meter in watts or watts), power factor (cosine of fi), power -meter (meter of active energy consumption in kilowatt-hours: kWh). Source: self made.

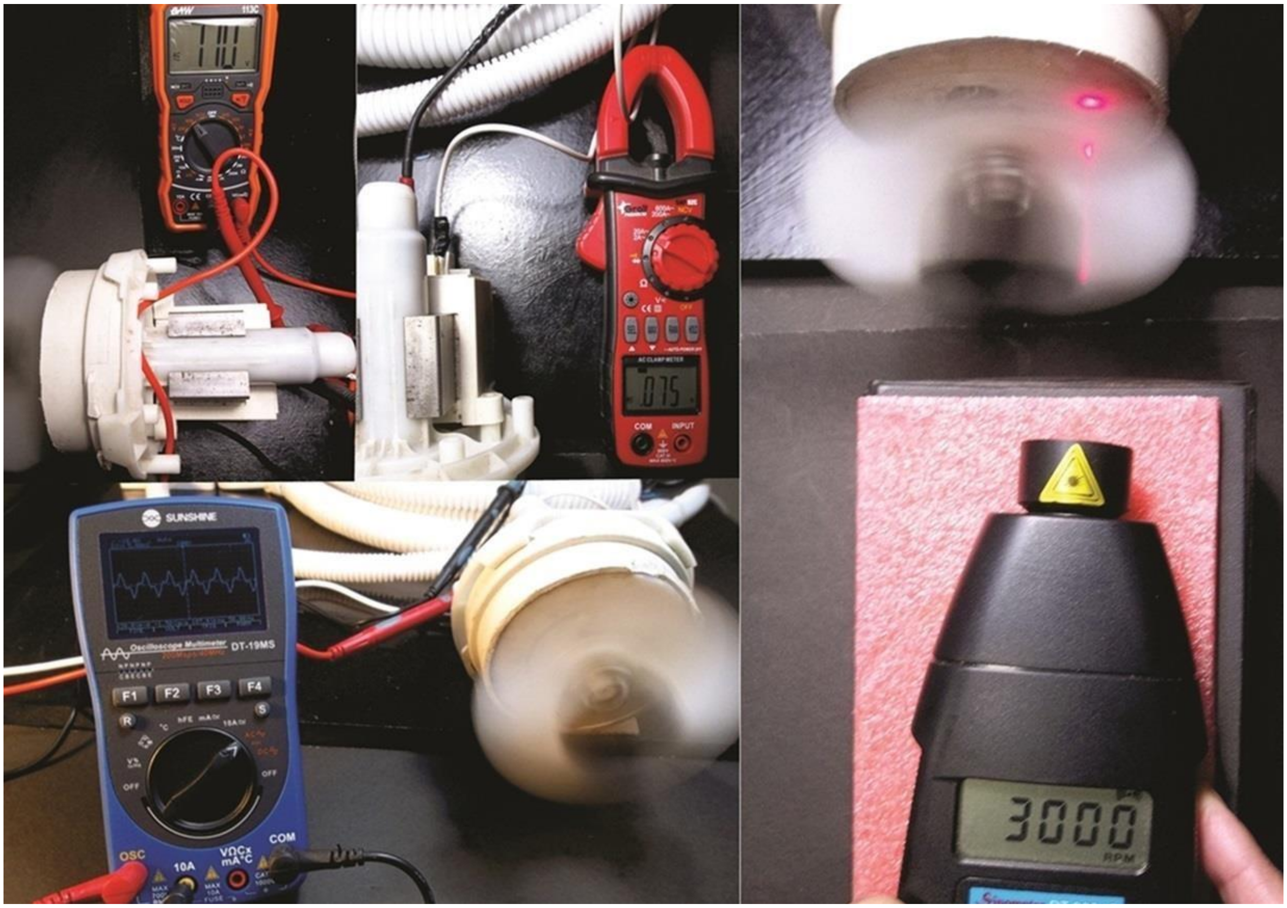

Figure 4: PMSM/IPM type synchronous motor (with the energy efficiency system "on") connected to the oscilloscope showing the non-linear voltage waveform, also connected to the digital multimeter showing the voltage drop of 110 (Volts) , and the amperometric clamp evidencing the drop in the circulation of the electric current at 0.075 (amperes) and the constant in the speed of the blade at 3000 (RPM). Source: self made.

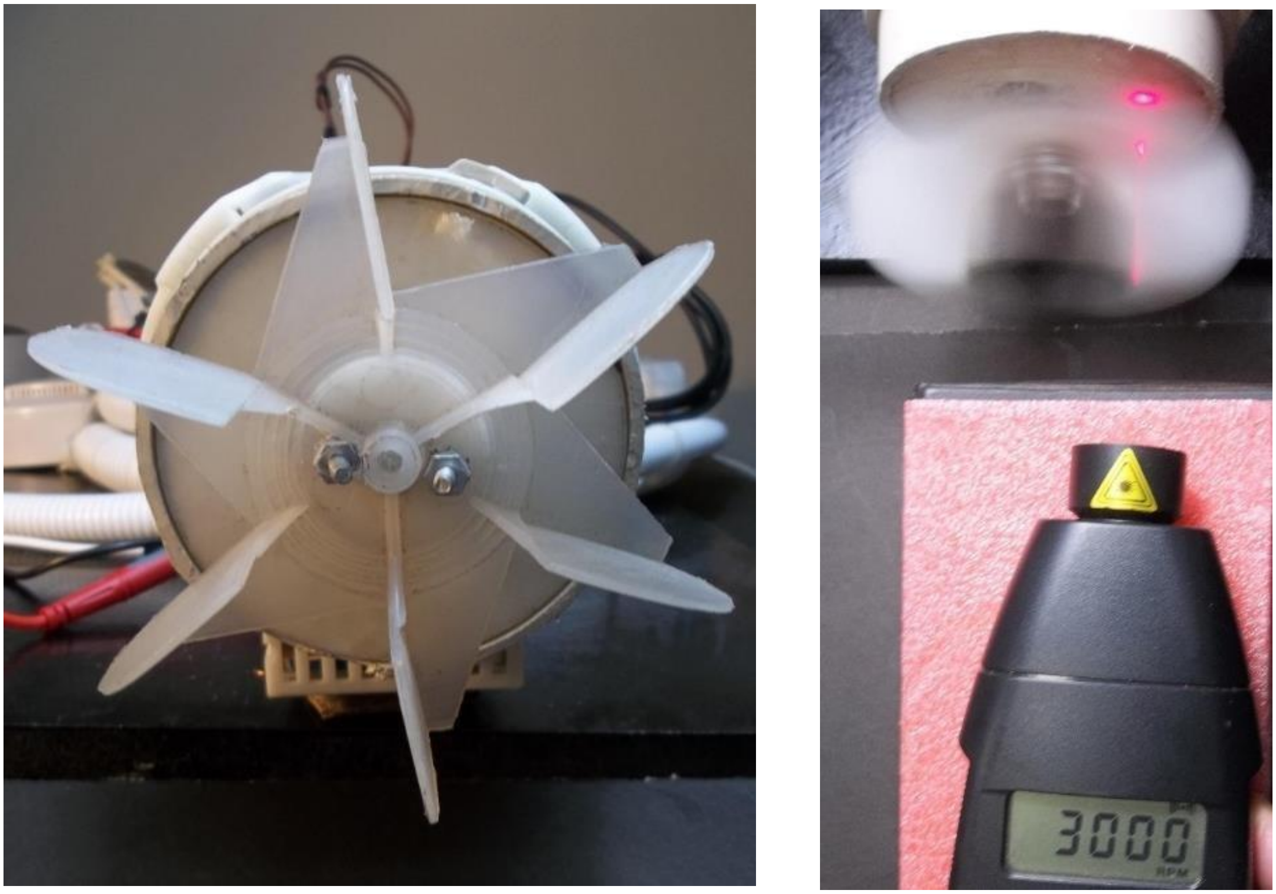

Figure 5: (a) Stopped PMSM type synchronous motor with 10.5 (mm) blades used in the experiment; (b) it rotating at 3000 (RPM) at maximum power of 6.3 (Watts). Source: self made.

3. Results

Denomination	Formula	Worth	Units
Active power	$P = V_{rms}.I_{rms}.\text{Cos}\,\emptyset$	25	(W) : Watts
Effective voltage	$V_{RMS} = \frac{V_{pico}}{\sqrt{2}}$	224	(V) : Volts
effective current	$I_{RMS} = \frac{I_{pico}}{\sqrt{2}}$	0.13	(A) : Amps
Power factor (cosine of fi)	$\text{Cos}\,\emptyset$	0.86	(n.d.p.)
Reactive power	$Q = \text{Sen}\,\emptyset.\ \frac{P}{\text{Cos}\,\emptyset}$	14.93	(VAr) : Volt-ampere reactive
Apparent power	$S = V.I$	29.12	(VA) : Volt-ampere
Total impedance RL	$Z_{RL} = \frac{V_{RMS}}{I_{RMS}}$	1,479	(kΩ) = kiloohms
Endurance	$R = \frac{P}{{I_{RMS}}^2}$	1479.2	(Ω)
Inductive reactance	$X_L = \sqrt{Z^2 - R^2}$	879.6	(mΩ) : milliohms
Angular frequency (pulsations)	$\omega = 2.\pi.f$	314,159	(Rad/S) : Radians/Seconds
Network frequency	f	50	(Hz) : Hertz
Inductance	$L = \frac{X_L}{2.\pi.f}$	2.81	(H) : milliHenries

Phase shift between total voltage and total current$(V_T)(I_T)$	Inductive circuit, the voltage precedes the current.	0.03408 (º) 5,947 (Rad)	(º) : Degrees (Rad) : Radians
Impeller blade speed	$ns = \frac{120.f}{p}$	1690	(RPM) : Revolutions per minute

Table 1. The data of the shaded-pole motor (Shaded-pole motor) or short-circuited motor (fragger coil) calculated by formulas and data extracted by laboratory instruments (with the energy efficiency system "off") are detailed below. in the following table with their respective formulas, values and physical units. Source: self made.

Denomination	Formula	Worth	Units
Active power	$P = V_{rms}.I_{rms}.\text{Cos}\,\emptyset$	4	(W) : Watts
Effective voltage	$V_{RMS} = \frac{V_{pico}}{\sqrt{2}}$	128	(V) : Volts
effective current	$I_{RMS} = \frac{I_{pico}}{\sqrt{2}}$	0.149	(A) : Amps
Power factor (cosine of fi)	$\text{Cos}\,\emptyset$	0.21	(n.d.p.)
Reactive power	$Q = \text{Sen}\,\emptyset.\ \frac{P}{\text{Cos}\,\emptyset}$	18.64	(VAr) : Volt-ampere reactive
Apparent power	$S = \sqrt{P^2 + Q^2}$	19,072	(VA) : Volt-ampere
Total impedance RL	$Z_{RL} = \frac{V_{RMS}}{I_{RMS}}$	859	(Ω) = Ohms
Endurance	$R = \frac{P}{I_{RMS}{}^2}$	180.1	(Ω)
Inductive reactance	$X_L = \sqrt{Z^2 - R^2}$	838.8	(mΩ) : milliohms
Capacitive reactance	$X_c = \frac{1}{2.\pi.f.C}$	1.06	(kΩ) : Kiloohms
Total LC impedance	$Z_{LC} = 2.\pi.f.L - \frac{1}{2.\pi.f.C}$	1.06	(kΩ) : kiloohms
Angular frequency (pulsations)	$\omega = 2.\pi.f$	314,159	(Rad/S) : Radians/Seconds
Network frequency	f	50	(Hz) : Hertz
Inductance	$L = \frac{X_L}{2.\pi.f}$	2.67	(mH) : millihenries
Capacitance	$C = \frac{1}{\omega.X_c}$	3	(: MicrofaradsμF)
Phase shift between total voltage and total current$(V_T)(I_T)$	Inductive circuit, the voltage precedes the current.	90 (º) 1.57 (Rad)	(º) : Degrees (Rad) : Radians
Impeller blade speed	$ns = \frac{120.f}{p}$	582	(RPM) : Revolutions per minute
Resonance frequency	$f = \frac{1}{2\pi\sqrt{L.C}}$	1.77	(kHz) : kilohertz

Table 2. The data of the shaded-pole motor (Shaded-pole motor) or short-circuited motor (fragger coil) calculated by formulas and data extracted by laboratory instruments (with the energy efficiency system "on") are detailed below in the following table with their respective formulas, values and physical units. Source: self made.

Denomination	Formula	Worth	Units
Active power	$P = V_{rms}.I_{rms}.\text{Cos}\,\emptyset$	242	(W) : Watts
Effective voltage	$V_{RMS} = \frac{V_{pico}}{\sqrt{2}}$	225	(V) : Volts
effective current	$I_{RMS} = \frac{I_{pico}}{\sqrt{2}}$	1.1	(A) : Amps
Power factor (cosine of fi)	$\text{Cos}\,\emptyset$	0.98	(n.d.p.)
Reactive power	$Q = \text{Sen}\,\emptyset.\ \frac{P}{\text{Cos}\,\emptyset}$	51.8	(VAr) : Volt-ampere reactive
Apparent power	$S = V.I$	247.5	(VA) : Volt-ampere
Total impedance RL	$Z_{RL} = \frac{V_{RMS}}{I_{RMS}}$	200	(Ω) = Ohms
Endurance	$R = \frac{P}{I_{RMS}{}^{2}}$	200	(Ω)
Inductive reactance	$X_L = \sqrt{Z^2 - R^2}$	713.99	(mΩ) : milliohms
Angular frequency (pulsations)	$\omega = 2.\pi.f$	314,159	(Rad/S) : Radians/Seconds
Network frequency	f	50	(Hz) : Hertz
Inductance	$L = \frac{X_L}{2.\pi.f}$	2.27	(mH) : milliHenries
Phase shift between total voltage and total current$(V_T)(I_T)$	Inductive circuit, the voltage precedes the current.	0.20454 (º) 0.00357 (Rad)	(º) : Degrees (Rad) : Radians
Impeller blade speed	$ns = \frac{120.f}{p}$	4654	(RPM) : Revolutions per minute

Table 3. The data of the series-wound motor (Series-Wound Motor) or universal asynchronous motor calculated by formulas and data extracted by laboratory instruments (with the energy efficiency system "off") are detailed below in the following table with their respective formulas, values and physical units. Source: self made.

Denomination	Formula	Worth	Units
Active power	$P = V_{rms}.I_{rms}.\text{Cos}\,\emptyset$	25	(W) : Watts
Effective voltage	$V_{RMS} = \frac{V_{pico}}{\sqrt{2}}$	91	(V) : Volts
effective current	$I_{RMS} = \frac{I_{pico}}{\sqrt{2}}$	0.42	(A) : Amps
Power factor (cosine of fi)	$\text{Cos}\,\emptyset$	0.67	(n.d.p.)
Reactive power	$Q = \text{Sen}\,\emptyset.\ \frac{P}{\text{Cos}\,\emptyset}$	28.91	(VAr) : Volt-ampere reactive
Apparent power	$S = \sqrt{P^2 + Q^2}$	38.22	(VA) : Volt-ampere
Total impedance RL	$Z_{RL} = \frac{V_{RMS}}{I_{RMS}}$	216.66	(Ω) = Ohms
Endurance	$R = \frac{P}{I_{RMS}{}^{2}}$	141.72	(Ω)
Inductive reactance	$X_L = \sqrt{Z^2 - R^2}$	163.86	(Ω) : Ohms
Capacitive reactance	$X_c = \frac{1}{2.\pi.f.C}$	1.06	(kΩ) : Kilohms

Total LC impedance	$Z_{LC} = 2.\pi.f.L - \frac{1}{2.\pi.f.C}$	193.78	(Ω)
Angular frequency (pulsations)	$\omega = 2.\pi.f$	314,159	(Rad/S) : Radians/Seconds
Network frequency	f	50	(Hz) : Hertz
Inductance	$L = \frac{X_L}{2.\pi.f}$	0.5216	(H) : Henrios
Capacitance	$C = \frac{1}{\omega.X_c}$	3	(: MicrofaradsμF)
Phase shift between total voltage and total current$(V_T)(I_T)$	Inductive circuit, the voltage precedes the current.	90 (º) 1.5708 (Rad)	(º) : Degrees (Rad) : Radians
Impeller blade speed	$ns = \frac{120.f}{p}$	2103	(RPM) : Revolutions per minute
Resonance frequency	$f = \frac{1}{2\pi\sqrt{L.C}}$	127.23	(Hz) : Hertz

Table 4. The data of the series-wound motor (Series-Wound Motor) or universal asynchronous motor calculated by formulas and data extracted by laboratory instruments (with the energy efficiency system "on") are detailed below in the following table with their respective formulas, values and physical units. Source: self made.

Denomination	Formula	Worth	Units
Active power	$P = V_{rms}.I_{rms}.\text{Cos}\,\emptyset$	17.7	(W) : Watts
Effective voltage	$V_{RMS} = \frac{V_{pico}}{\sqrt{2}}$	220	(V) : Volts
effective current	$I_{RMS} = \frac{I_{pico}}{\sqrt{2}}$	0.456	(A) : Amps
Power factor (cosine of fi)	$\text{Cos}\,\emptyset$	0.17	(n.d.p.)
Reactive power	$Q = X_L.I_{RMS}{}^2$	98.73	(VAr) : Volt-ampere reactive
Apparent power	$S = V.I$	100.32	(VA) : Volt-ampere
Total impedance RL	$Z_{RL} = \frac{V_{RMS}}{I_{RMS}}$	482.4	(Ω) = Ohms
Endurance	$R = \frac{P}{I_{RMS}{}^2}$	85.12	(Ω)
Inductive reactance	$X_L = \sqrt{Z^2 - R^2}$	474.83	(Ω)
Angular frequency (pulsations)	$\omega = 2.\pi.f$	314,159	(Rad/S) : Radians/Seconds
Network frequency	f	50	(Hz) : Hertz
Inductance	$L = \frac{X_L}{2.\pi.f}$	1.51	(H) : Henrios
Phase shift between total voltage and total current$(V_T)(I_T)$	Inductive circuit, the voltage precedes the current.	79.82 (º) 1.39 (Rad)	(º) : Degrees (Rad) : Radians
Impeller blade speed	$ns = \frac{120.f}{p}$	3000	(RPM) : Revolutions per minute

Table 5. The data of the PMSM/IPM type synchronous motor calculated by formulas and data extracted by laboratory instruments (with the energy efficiency system "off") are detailed below in the following table with their respective formulas, values and units physical. Source: self made.

Denomination	Formula	Worth	Units
Active power	$P = V_{rms}.I_{rms}.\text{Cos}\,\emptyset$	6.3	(W) : Watts
Effective voltage	$V_{RMS} = \frac{V_{pico}}{\sqrt{2}}$	110	(V) : Volts
effective current	$I_{RMS} = \frac{I_{pico}}{\sqrt{2}}$	0.106	(A) : Amps
Power factor (cosine of fi)	$\text{Cos}\,\emptyset$	0.8	(n.d.p.)
Reactive power	$Q = \text{Sen}\,\emptyset.\ \frac{P}{\text{Cos}\,\emptyset}$	4,725	(VAr) : Volt-ampere reactive
Apparent power	$S = \sqrt{P^2 + Q^2}$	7,875	(VA) : Volt-ampere
Total impedance RL	$Z_{RL} = \frac{V_{RMS}}{I_{RMS}}$	482.4	(Ω) = Ohms
Endurance	$R = \frac{P}{{I_{RMS}}^2}$	85.12	(Ω)
Inductive reactance	$X_L = \sqrt{Z^2 - R^2}$	474.83	(Ω)
Capacitive reactance	$X_c = \frac{1}{2.\pi.f.C}$	1,061	(kΩ) : Kilohm
Total LC impedance	$Z_{LC} = 2.\pi.f.L - \frac{1}{2.\pi.f.C}$	857.97	(Ω)
Angular frequency (pulsations)	$\omega = 2.\pi.f$	314,159	(Rad/S) : Radians/Seconds
Network frequency	f	50	(Hz) : Hertz
Inductance	$L = \frac{X_L}{2.\pi.f}$	1.51	(H) : Henrios
Capacitance	$C = \frac{1}{\omega.X_c}$	3	(: MicrofaradsμF)
Phase shift between total voltage and total current$(V_T)(I_T)$	Inductive circuit, the voltage precedes the current.	90 (º) 1.5708 (Rad)	(º) : Degrees (Rad) : Radians
Impeller blade speed	$ns = \frac{120.f}{p}$	3000	(RPM) : Revolutions per minute
Resonance frequency	$f = \frac{1}{2\pi\sqrt{L.C}}$	74.77	(Hz) : Hertz

Table 6. Values of the PMSM/IPM type synchronous motor calculated by formula and other data obtained by laboratory instruments are detailed below in the following table (with the energy efficiency system "on") with their respective formulas, values and physical units. Source: self made.

4. Discussion

The design consists of inductive-capacitive type circuits.

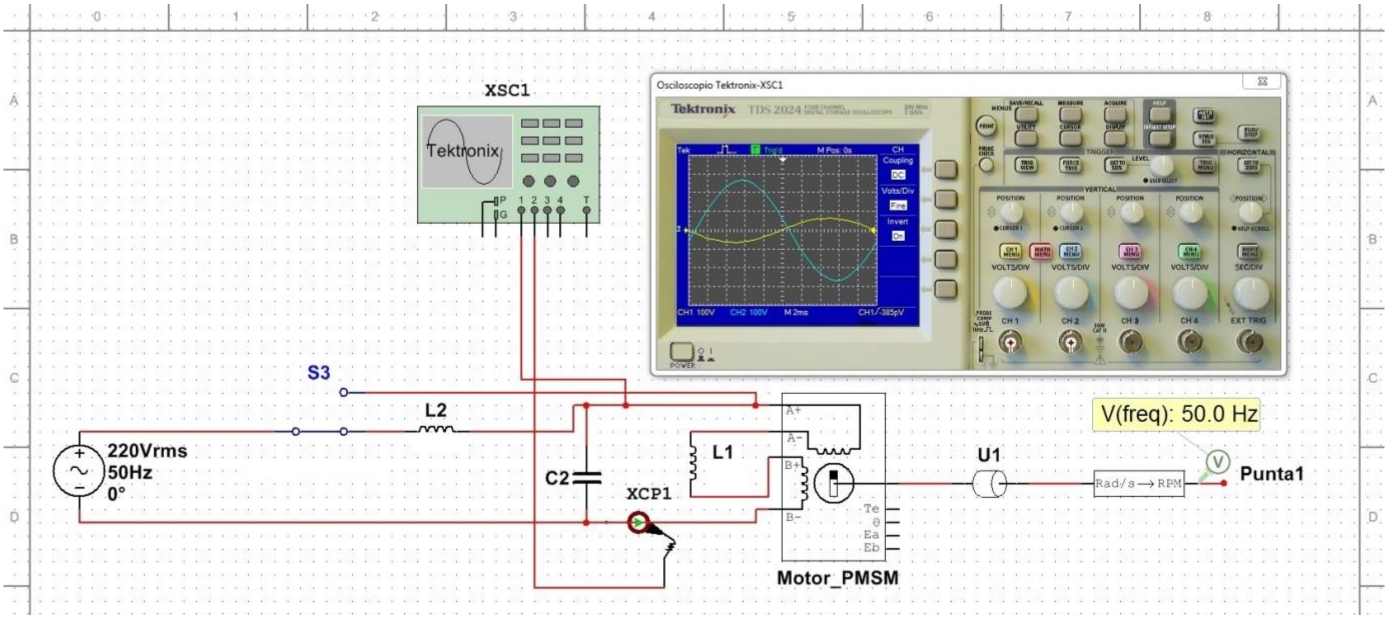

Figure 4: LC circuit design simulated by NI Multisim 14.0 computer software, the circuit is turned on and off through the SPDT switch (S3), powered by a single-phase alternating current emf source of 220 (VAC) and 50 (Hz). It consists of a capacitive reactance (C2) and an inductive reactance (L2), which are responsible for processing the binomial expression of impedance. The capacitive reactance is obtained from a 3 (μF) capacitor connected in parallel to the two phases, and whose function is to correct the power factor (cos de fi). The 1.5 (Henry) inductance is connected in series to one of the phases of the emf source and whose function is to limit the passage of current or intensity (Amperes) so that the consumption of single-phase active energy decreases. Although the PMSM type synchronous motor is simulated with a bipolar stepper motor (which would require a two-phase half-step driver), it still behaves analogously to a PMSM type synchronous motor if powered by an AC electrical current. single phase. It has an internal resistance (L1) since it is a coil, so the entire system behaves like an RCL circuit (simultaneously filtering current and voltage harmonics). The system is connected to a load (U1) that represents the impeller blades and there is a (Rad/s) to (RPM) converter at Tip (1) that displays the speed (or frequency) in Hertz. Source: self made.

The oscilloscope displays the phase shift between the total voltage and total current of the LC circuit. It is an inductive circuit with a phase shift of 79.82º (with the energy efficiency circuit "off"), the voltage is ahead of the current. When the energy efficient circuit is "on", the phase shift between voltage and current is 90º and the voltage (Volts) continues to lead the current (Amps). It is clearly observed how the voltage 220 (V) and the current 0.45 (A) decrease in intensity to 110 (V) and 0.10 (A). The important thing is what happens in both cases - SPDT connector circuit "off" or "on" - in the probe (Point 1) that records the detail of the analyzer tip, converting radians over seconds (Rad/s) to revolutions per minute (RPM) and these in frequency (Hertz), of the mechanical work performed by the rotor on the radial centrifugal blades (load). It is observed that it always rotates at 3000 (RPM) which is equivalent to 50 (Hz), product of the frequency of the synchronous motor. Regardless of whether the SPDT switch is "off" or "on" in energy efficient (EE) mode; since in both cases, the frequency of the alternating current is always 50 (Hertz). For this reason, the motor, even if its torque decreases, does not decrease its speed.

According to the "Fan Affinity Law" specified in Standard UNE 100-230-95, the power absorbed by a fan with an asynchronous motor varies with the cube of its speed.

Testing one of the fan affinity laws, with the impeller (blade) diameter constant, the electrical power absorbed by the blower motor is proportional to the cube of the shaft speed, according to the equation:

$$P_1 / P_2 = (N_1 / N_2)^3 , \qquad (1)$$

Being "P" power (in Watts) and "N" speed (in RPMs).

This means that for a small variation in rotation speed, the power changes considerably. This has great implications from an energy efficiency (EE) point of view.

For all the comparisons presented below, it has been taken into account that the density of the air fluid does not vary in any case (it is always the same): approximately 1.204 kg/m3 (0.0752 lb/cu ft), depending on the atmosphere international standard (ISA), at 101.325 kPa (abs) and 15 °C (59 °F).

First Discussion: If the shaded-pole motor (Shaded-pole motor), or short-circuited motor (fragger coil) which is a type of single-phase asynchronous AC induction motor without brushes (without carbons) and with a "squirrel cage" rotor; of those normally used in refrigeration or ventilation equipment and works with a maximum speed of 1690 (RPM) due to the sliding of the rotor, with 100% of its maximum active power of 25 (Watts) at its maximum working capacity . Due to their design and electromechanical configuration, they are unable to exceed the limit of 3000 (RPM). In contrast, the PMSM/IPM type synchronous motor designed for this project (with the energy efficiency system "on") works at 100% of its maximum speed of 3000 (RPM) with only 25.2% of the same power. active, using only 6.3 (Watts). This is summarized in a 44% higher capacity to perform mechanical work (RPM) on the impeller blades and transfer it as velocity of the air fluid, with a 75% lower active power (in Watts), which translates into lower energy consumption. single-phase active (kWh).

Considering that the "Fan Affinity Law" applies to asynchronous motors and does not apply to synchronous motors, such as the one used in the project; The energy efficiency (EE) advantage is notably higher (and impossible to compare since there is no Standard that establishes such comparison parameters). But, if we apply the so-called "Fan Affinity Law", specified in the UNE Standard 100-230-95, the way in which the power (Watts) and speed (RPM) variables are affected, determined according to international standards. ISO 5801-96(E) and ED 13348-1998 by formula of equation (1), with "P" power (in Watts) and "N" speed (in RPM) with the impeller diameter (blades) constant. Hypothetically speaking (and we clarify that only hypothetically) the asynchronous motor, to achieve the impossible 3000 (RPM) to reach due to the rotor's own slip, should require: 139.8 (Watts).

$$\frac{P_1}{25\ (W)} = \left(\frac{3000\ (RPM)}{1690\ (RPM)}\right)^3 = (1{,}775)^3 * 25\ (W) = 139{,}8(W), \qquad (2)$$

The 139.8 (Watts) required – hypothetically – to reach 3000 (RPM) for a shaded-pole asynchronous motor is 559% greater active power than the 6.3 (Watts) required by the synchronous motor, which shows the disadvantage energy of this type of motors, which are currently used in refrigeration. Very inefficient, but economically cheap to build.

Noting that this is a controversial hypothesis because the shaded-pole asynchronous motor can never reach 3000 (RPM) due to the so-called own slip of the rotor, which is measured in percentage terms, so this is the reason why the Induction motors are called asynchronous, since the rotor speed differs slightly from that of the rotating field. Slip in an electrical machine is the relative difference between the speed of the magnetic field (synchronism speed) and the speed of the rotor. The expression of the formula is necessary to find the slip of the shaded pole motor:

$$S = \frac{\omega_s - \omega_m}{\omega_s} . 100\% = \frac{n_s - n_m}{n_s} . 100\% = \frac{3000\ (RPM) - 1690 (RPM)}{3000\ (RPM)} . 100\% = 43{,}67\%, \qquad (3)$$

Where:
S, sliding speed, expressed on a per unit basis or in percentage (%).
ω_s, synchronous angular velocity in radians per second (rad/sec).
ω_m, rotor angular velocity in radians per second (rad/sec).
n_s, synchronous angular speed in revolutions per minute (RPM).
n_m, angular speed of the rotor in revolutions per minute (RPM).

Slip is especially useful when we analyze the operation of the asynchronous motor since these speeds are different between different asynchronous motors.

The energy efficiency achieved by using a modified PMSM type synchronous motor with an RL energy efficient circuit in a fan is obvious, compared to the conventional motors used in shaded pole refrigeration equipment. These short-circuited motors or brushless single-phase AC induction asynchronous motors with a "squirrel cage" rotor, less efficient, are only justified in ventilation and cooling because they are cheaper.

Second Discussion: If the series-wound motor (Series-Wound Motor) or universal AC asynchronous motor with brushes (carbons) and wound rotor, which is not what is normally used in ventilation or refrigeration equipment; but in other appliances and machine tools that require high torque and high work speeds for a relatively short period of time (such as a food multiprocessor or a hand drill, etc.). Due to their design and electromechanical configuration, they are able to exceed the limit of 3000 (RPM). In the case of the engine analyzed, it reaches 4654 (RPM) with 100% of its maximum active power of 242 (Watts) at its maximum work capacity. If we apply the "Law of fan affinity" to said motor, where the power absorbed by a fan with an asynchronous motor varies with the cube of its speed. By formula, testing one of the fan affinity laws, with the impeller (blade) diameter constant, the electrical power absorbed by the blower motor is proportional to the cube of the shaft speed, as described in the equation (1). Being "P" power (Watts) and "N" speed (RPM), we replace and calculate the formula:

$$\frac{P_1}{242\ (W)} = \left(\frac{3000\ (RPM)}{4654\ (RPM)}\right)^3 = (0{,}6447)^3 * 242\ (W) = 64{,}8(W), \qquad (4)$$

So if such a universal AC asynchronous motor with brushes and wound rotor, its speed must decrease to 3000 (RPM), to equal the speed of the synchronous motor and we compare the power; It will consume 64.8 (Watts), that is, 90.3% more active power than that required to match the same speed of the PMSM-type synchronous motor that works at 6.3 (Watts).

5. Conclusions

The PMSM type synchronous motor with the coupling of an RL mechatronic circuit design to perform mechanical work that translates into speed on the impeller blades and transfer it as speed of the air fluid, works at 100% of its maximum speed of 3000 (RPM) With only 6.3 (Watts), this is only 25.2% of the active power required by the single-phase asynchronous induction motor or shaded pole motor which needed 25 (Watts) to rotate at 1690 (RPM). This results in 75% lower active power, with a 44% superiority in speed, which translates into a 75% saving in single-phase active energy (kWh). The same thing also happens if we compare the universal AC motor with carbon and wound rotor, to maintain a speed at 3000 (RPM); given that the asynchronous motor will consume 64.8 (Watts), that is, 90.3% more active power than that required to match the same speed of the PMSM type synchronous motor; Therefore, the synchronous motor consumes only 10% of the single-phase active energy of the universal AC asynchronous motor. All with the same diameter of the impeller blades and the same conditions of temperature and atmospheric air pressure.

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