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RESEARCH ARTICLE OPEN ACCESS

COMPARISON OF BRAZILIAN STANDARDS FOR THE QUALIFICATION OF THREE-PHASE INDUCTION MOTORS AGAINST A GLOBAL SCENARIO

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ABSTRACT

Electric motors are considered the most important equipment among those that consume final electric energy in Brazil. It is estimated that the induction motors and the systems driven by them are responsible for approximately 70% of the energy consumption of the Brazilian industrial sector. Countries like Japan, members of the European Union, the United States, Australia, India, and Brazil have specific standards to qualify their equipment. These, among other countries, have regulatory or even mandatory regime mechanisms that classify the efficiency of three-phase induction motors, using specific standards and regulations. In this way, this article aims to compare the application of national standard methods with international methods, making it possible to qualify the national standard against a global scenario. This articles compares the test standards IEEE 112 Method B, IEC 60034-2-1, JEC 37 and ABNT NBR 17094-3, these standards have different methodologies, so that when the same engine is tested by them their efficiency can present different results, generating large discourses among international committees on which standard is the most appropriate for this type of trial.

Keywords: Electric motors, Energy efficiency, Induction motor standards, Energy policies.

I. INTRODUCTION

The growing demand for electricity to sustain global development requires significant investments in power generation. However, these investments depend on increasingly scarce natural resources due to the constant degradation of the environment. The best strategy for maintaining power supply in the short term is to avoid waste and increase energy efficiency [1,2].

Electric motors play an important role in this strategy, as around 40% of global energy consumption is related to the application of this equipment [1]. Because of this need to reduce energy consumption and greenhouse gas emissions, governments in various countries around the world are establishing minimum energy efficiency requirements, also known as Minimum Energy Performance Standards (MEPS) for several devices, including electric motors [1].

In 2014, about 45.8 million low-voltage motors (LVM) were sold around the world. This amount is estimated to increase to 51.6 million in 2019, representing an annual growth rate of 2.5% [3]. In 2014, LVM sales were classified according to International Efficiency (IE) standards as Standard Efficiency (IE1) 44% of the units sold, High Efficiency (IE2) 34%, Premium Efficiency (IE3) 14% and Super Premium Efficiency (IE4) 1%. As presented in Figure 1, considerable transition to more efficient motors is expected until 2019. This result was partially driven by the MEPS.

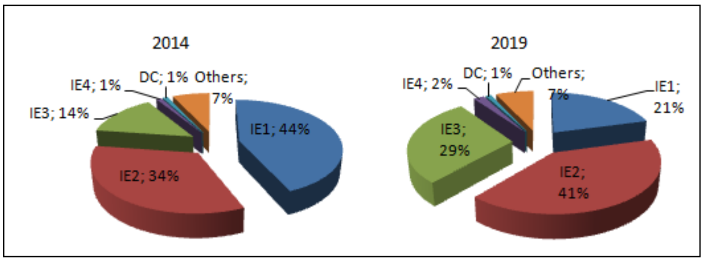

Figure 1: Classification of low voltage motors sold around the world according to international efficiency index.
Source: Adapted from [3].

The electric motor and motor-driven systems contribute significantly to the demand for energy consumption. In the European Union Industry, it is estimated that this equipment represents about 70% of all energy consumption [4].

When an old motor fails, it will probably be an IE0 or IE1 class equivalent motor, and this situation provides an opportunity for replacing the old motor with a properly sized IE3 or IE4 class motor, which offers significantly higher efficiency for a wide range of loads [5].

Some countries adopt strategies to reduce the electricity consumption of motors include the application scope of MEPS, the industrial electricity price, the load factor, and installation of a variable-speed drive (VSD) [6]. Since motors are the major energy consumers in industry and buildings, most economies have some kind of voluntary or mandatory regulatory scheme regarding the efficiency of the power equipment. Some of these economies also have mandatory minimum levels of efficiency for electric motors sold in their respective countries and labeling recommendations for the manufactures of higher efficiency machines. Motor efficiency regulations around the world are to date limited to AC induction motors, which represent by far the largest share of the motor market [7-9].

The strategy to implement the policies to improve efficiency in Brazil is similar to most of the countries around the world. The initiatives are usually government oriented and go through education initiatives, equipment regulation, labeling programs, project and R&D funding, rebate programs, and an Energy Efficiency Law. The government's National Energy Plan 2030 proposed a strategy for expansion of the energy supply, however, current Brazilian market mechanisms are not sufficient to promote desirable efficiency improvements in end-use of energy [10,11].

In 1993, the PROCEL Label of Energy Economy, or simply the PROCEL label, was introduced with the objective of informing the consumer about better equipment and reinforcing the value of more efficient products [12]. Complementary to the qualifying labels of PBE, this endorsement label emphasizes the most efficient products which mean class A equipment, according to the efficiency label and presents additional quality attributes, such as safety, low noise, and lower water consumption. The concession of this label is the responsibility of PROCEL, which essentially uses the same equipment performance database as PBE (Brazilian labelling program) [13].

This paper reviews the Brazilian experimental procedures for determining the efficiency level of electric motors, compare them with international standards and qualify the results against the world scenario. In section Efficiency Policies, the application of efficiency policies will be presented, where over the years it is possible to observe the reduction of the sales of IE1 electric motors and the increase of sales of IE2 and IE3 electric motors. In section Analysis of the Brazilian Standard, an analysis of the NBR 17094-3 through a type test in the three-phase induction motor is presented. In sequence, there are two sections showing how to compute induction motor losses, and making a comparison between the standards IEE 112, IEC 60034-2-1 and JEC 37 indicating the main differences in the test methods. Finally, the last section presents conclusions about the main differences in the presented measurement procedures.

II. EFFICIENCY POLICIES

Several strategies can be used to increase the efficiency of induction motors: advances in motor design, smaller tolerances, use of best magnetic materials, a greater cross-section of copper/aluminum in stator and rotor to reduce resistance among others [13].

To accelerate the market penetration of efficient motors, the implementation of minimum efficiency standards is being discussed by the European Commission (EC). Motors belonging to the same group size must fit specific eco-design requirements [14].

MEPS are legislative instruments used by national governments and the EU to remove the most inefficient electric motors and Power Drive Systems (PDS) from the markets. The change, however, takes some time because it usually lasts from 4 to 6 years for the transition from a new MEPS to be completed [11].

Overall, the regulations on electric motors were first introduced in North America. The United States implemented standards through the Energy Policy Act of 1992, but only in 2007 that the standards were applied. The so-called EPAct (Energy Policy Act) 92 standard was comparable to the IE2 class, but the US has already begun moving the IE3/NEMA Premium Motors in 2010. In Canada, the first requirements came into force in 1997 and Mexico adopted the standard EPAct in 1998 [15]. Brazil and China issued the first MEPS in 2002, but these referred to standard efficiency electric motors. MEPS for the IE2 level came into force in Brazil in 2009 and in China in 2011 and Brazil implemented higher minimum efficiency values going from IR2 to IR3 level on August 30, 2017. On this date was signed the Ministerial Ordinance No. 1, dated June 29, 2017, where the maximum levels of specific energy consumption or minimum energy efficiency of energy consuming machines and appliances in Brazil are established [13]. Australia and New Zealand have placed MEPS at the IE2 level since 2006. Other countries with MEPs at the level of at least IE2 include Chile (2011), Israel (2008), South Korea (2013, IE2 / 2015, IE3 level), Switzerland (2011, level IE2 / 2015, same level as Eco-design in Europe), Taiwan (2015) and Turkey (2015, same level of Eco-design in Europe).

In addition, several countries have implemented requirements at the IE1 level [13]. In India, an IE1 standard motor was first adopted in 2004 and was revised for IE2 and IE3 in 2011, covering the IE2 and IE3 electric motors. The MEPS at the level of IE2 were adopted in 2016. At present, IE1 or less efficient electric motors cannot be commercialized in the Brazilian market, however, they are sold abroad and returned applied in finished products [16-20].

Figure 2 shows the impact of energy efficiency policies on the volume of electric motors sold per efficiency class, where we can see the growth in the number of more efficient electric motors sold after the implementation of policies in the countries and the decrease in the sale of inefficient electric motors [3]. The horizontal axis represents the year of the analyses and the vertical axis the amount of the units (motors) sold [21].

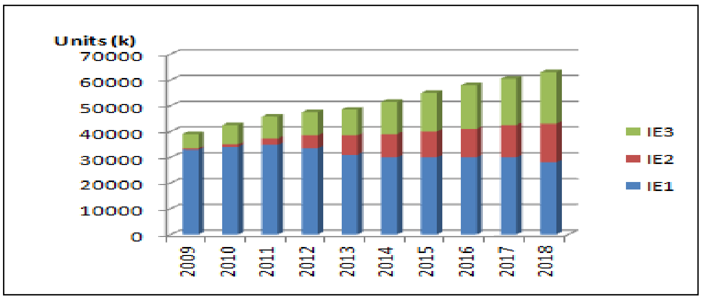

Figure 2: Impact of energy efficiency policies on the volume of electric motors sold per efficiency class.
Source: Adapted from [3].

II.1 ANALYSIS OF THE BRAZILIAN STANDARD

NBR 17094-3: 2018 [22] which recently replaced NBR 5383-1 [23] prescribes test methods for determination of the performance a compliance characteristics of the three-phase induction motor, where the efficiency values found must meet the minimum values required by NBR 17094-1: 2018 [24]. The use of an ABNT NBR is voluntary and is based on the consensus of society, becoming mandatory when established by the public power, in the form of laws, decrees, ordinances, and etc. [23,25].

According to item VIII of Article 39 of the Consumer Protection Code in Brazil, it is prohibited to place on the consumer market any product or service that does not comply with the standards issued by the competent official bodies or, if there are no specific rules, by the Brazilian Association of Technical Standards or another entity accredited by Conmetro (National Council of Metrology, Standardization and Industrial Quality) [22].

Table 23 of NBR 17094-1: 2018 separates the tests from NBR 17094-3-2018 into three classes: Routine, Type, and Special Tests. Routine tests are applied to all induction motors, during or after their manufacture, to verify that it meets defined criteria. Type tests are applied to one or more electric motors, manufactured according to a particular design, to prove that the design meets certain specifications. Special tests are those not considered as routine or type tests and are performed only by agreement between the manufacturer and buyer [26].

In Brazil there are procedures to obtain the characteristics of the three-phase induction motor according to NBR 17094-3. The electric motor tested presented on Table 1 has a great application in the Brazilian industries and therefore know its characteristics and determine its efficiency is relevant.

The methods for determining the characteristics of the three-phase induction motor are presented in NBR 17094-3 and described in the procedures of method 2, dynamometric test with indirect measurement of additional losses and direct measurement of the stator, rotor, core, friction and ventilation losses.

The initial test considers that the motor is cool and in thermal equilibrium with the environment, the ambient temperature and the average line resistance must be measured. To measure the ambient temperature, thermocouples or other types of sensors can also be installed, also for temperature measurement on the motor, coil heads or slots (outside the cooling air circulation path), to have a good average winding temperature. It is necessary to choose the method that will perform the resistance measurement, where the method used in this article is the Kelvin bridge because according to NBR 17094-3 is the most accurate to perform the direct measurement of resistance. Measurement results are presented in Table 2 [22, 24-26].

Table 1: Motor Data.

Model	132S	Power (CV)	5
Rotation (rpm)	3495	Voltage (V)	220
Current (A)	12.2	Insulation class	F
Frequency (Hz)	60	Relation IA/IN	5.9
Regime	S1	Power Factor	0.91
Index protection (IP)	55	Category	N
Number of phases	3	Service factor	1
Number of poles	2	Efficiency (%)	87.5

Source: Authors, (2020).

Table 2: Measure of The Initial Electric Motor Resistance.

R-S (Ω)	0.715	S-T (Ω)	0.714
T-R (Ω)	0.709	Room temperature(°C)	24.6

Source: Authors, (2020).

After performing the resistance measurement with the cold electric motor, the temperature rise test is done, the motor is running continuously at nominal load until it reaches the thermal stability, in order to obtain the temperature at which the stator and rotor losses will be corrected. When the thermal equilibrium is reached, the power supply is switched off and the winding resistance measurement is checked. The results are presented in Table 3 [26].

Table 3: Temperature Rise Test.

Measurement Time	08:54	09:24	09:54	10:24	10:54
Housing (Middle - Right Side) (K)	12.1	15.1	13.7	13.5	13.8
Housing (Middle - Left) (K)	11.2	13.9	12.6	12.5	12.8
Room temperature (° C)	25.5	26.1	26.2	26.1	26.2
Torque (N.m)	12.1	10.0	10	10.0	10.0
Power (W)	5037	4150	4141	4145	4144
Current (A)	14.6	12.0	12.0	12.1	12.0
Voltage (V)	219.9	220.2	220.0	219.6	219.9
Speed (rpm)	3490	3512	3513	3513	3512

Source: Authors, (2020).

Temperature measurement after an electric motor shutdown is evaluated considering changes in the resistance value, according to Equation 1. The equations in this article are based on [22].

$$\frac{R_2}{R_1} = \frac{t_2 + K}{t_1 + K} \tag{1}$$

Where:

t_2 is the winding temperature at the end of the test, expressed in degrees Celsius (°C);

t_1 is the winding temperature (cold motor with stabilized temperature) at the moment of measuring resistance R_1, expressed in degrees Celsius (°C);

R_2 is the winding resistance at the end of the test, expressed in ohms (Ω);

R_1 is the winding resistance at temperature t_1, expressed in ohms (Ω);

K is equal to 234.5 for electrolytic copper with 100% conductivity or 225 for aluminum with 62% IACS (International Annealed Copper Standard) conductivity. The measured resistance value after the temperature rise test is presented in Table 4.

Table 4: Measure of Resistance After Temperature Rise.

Measurement of resistance after temperature rise (Ω)	0.771	Room temperature (°C)	26.4
Read time (s)	11		

Source: Authors, (2020).

If the resistance reading is obtained within the time interval indicated in Table 5, this reading should be used to compute the winding temperature [24].

Table 5: Time Interval with the Initial Reading of Resistance Adopted as Temperature Measurement.

Rp ≤ 37.5 kW	0 -30
37.5 < Rp ≤ 150 kW	0-90
150 < Rp ≤ 5050 kW	0 -120
5000 kW< Rp	By agreement

Source: Authors, (2020).

The next step is to perform a load test, applying rated voltage and frequency to the motor, and placing load at four different operational points: 25%, 50%, 75%, and 100% of the rated load. In addition, the tests must be performed with two load operational points above 100 % of the rated load, but without exceeding 150%. In this work, tests were performed with 125% and 150%. The electric motor loading must be done in descending order and considering a point with the dynamometer turn off to determine the dynamometer correction.

For each load point, it is necessary to measure: the output torque (Nm), the input power (kW), the average line current (A), the motor speed (rpm), the winding temperature and the ambient temperature (°C), and the applied midline voltage (V). It is possible to replace direct winding temperature measurement with resistance measurement. In this case, the winding resistance shall be measured at the beginning and end of the load test according to Table 6. The test is valid if the ratio between the two values does not exceed 3.5% for electric motors up to 15 kW and 3.0% for electric motors above 15 kW. The mean value of the measured resistances should be used to compute electrical losses [24]. The load test is shown in Table 7.

The next step is to perform the no-load test and determine the friction and ventilation losses, according to NBR 17094-3. If the dynamometer is still coupled to the motor under test, it must be disengaged, leaving the motor shaft completely free. Before starting data acquisition, it is necessary to ensure that the power source is stable.

Table 6: Measurement of Resistance in Load Test.

Resistance before test (Ω)	0.775	Resistance after the test (Ω)	0.765
Temperature before test (°C)	26.4	Temperature after test (°C)	26.4

Source: Authors, (2020).

Table 7: Load Test.

Torque (%	150	125	100	75	50	25	0
Torque (N.m)	14.9	12.5	10.0	7.5	5.0	2.5	0.7
Power (W)	6342	5250	4203	3168	2164	1183	477
Current (A)	18.3	15.13	12.21	9.38	6.8	4.54	3.4
Speed (rpm)	3451	3482	3507	3531	3554	3574	3587
Voltage (V)	220	220	220	220	219	220	221

Source: Authors, (2020).

Voltage and current readings must be performed, the motor must initially be fed with a nominal voltage. Then the voltage must be varied in a decreasing way between the points of 110 to 20% [22] of the nominal voltage. However, in this case, for over-voltage forces on the motor, the voltage variation was 125 to 20% of the nominal voltage. After each decrease, with stable signals, voltage and current readings shall be recorded. The tests results are shown in Table 8.

Table 8: No Load Test.

Voltage (%)	125	100	80	60	40	20
Voltage (V)	275.3	220.4	176	132.4	88.2	44.5
Current (A)	4.0	3.2	2.5	1.9	1.5	2.0
Power (W)	245.9	201.2	175.6	152.9	137	126

Source: Authors, (2020).

In this test, it is also possible to estimate the winding temperature using the measured resistance values measured at the beginning and end of the no-load test, as shown in Table 9.

Table 9: Measurement of Resistance Before and After No-load Testing.

Resistance before test (Ω)	0.766	Resistance after the test (Ω)	0.752
Temperature before test (°C)	26.4	Temperature after test (°C)	26.3

Source: Authors, (2020).

III. LOSSES DETERMINATION

Based on standard the NBR 17094-3: 2018 and adopting method 2, the losses used to compute the electric motor performance are friction and ventilation losses, core losses, stator losses, rotor losses, and Supplementary losses.

III.1 FRICTION AND VENTILATION LOSSES

The value of the input power minus the I^2R loss on the stator versus the voltage is plotted, and the curve obtained is extended to zero voltage. The intersection with the zero-voltage axis is equal to the friction and ventilation losses. For the low voltage range, the intersection can be determined more precisely if the input power values subtracted by the I^2R losses in the stator are plotted in function of the squared voltage (Figure 3).

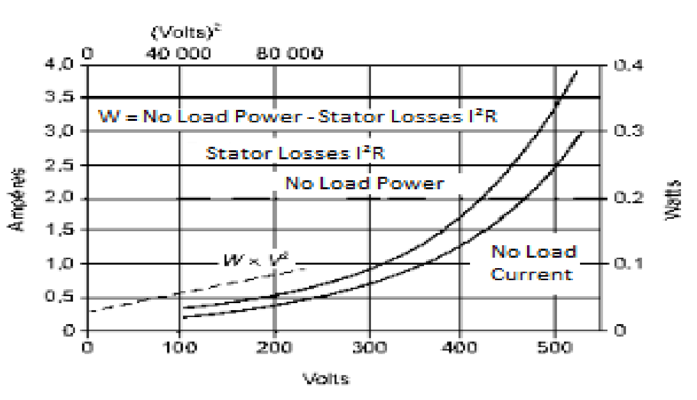

Figure 3: Friction and Ventilation Losses.
Source: Adapted from [18].

III.2 CORE LOSSES

The core losses in the no-load test at rated voltage is obtained by subtracting the friction loss and the loss of the sum of the losses obtained from the no-load losses.

III.3 STATOR LOSSES

Calculate the loss (I²R) of the stator expressed in watts, according to Equation 2.

$$1.5\ R.I^2 \tag{2}$$

for three-phase motors, where:

I is the measured or calculated effective current per line terminal at a specified load (A);

R is the direct current resistance between any two line terminals, corrected to the specified temperature (Ω).

III.4 ROTOR LOSSES

Compute the loss of the rotor for each load point. This loss, which includes the brush contact losses for motors with the winding rotor, must be determined by sliding in decimal fraction using Equation 3.

$$P_{rot} = (P_{in} - P_{est} - P_{cor}.S) \tag{3}$$

Where:

P_{rot} is the Rotor Loss (W);

P_{in} is the Input power (W);

P_{est} is the Stator Loss (W);

P_{cor} is the Core Loss (W);

S is the slip.

Correcting the slip to the temperature measured at the point.

III.5 SUPPLEMENTARY LOSSES

The determination of the additional loss for each load point is obtained by the methodology:

a) Calculate the apparent total loss, such as input power minus output power (with corrected output torque);

b) Subtract from the apparent total loss the sum of the corrected conventional losses to the temperature of the laden test, obtaining the additional losses;

c) Adjust the additional loss data using the linear regression method, considering Equation 4.

$$P_s = P_{sn}\left(\frac{I_2}{I_{2n}}\right)^2 \tag{4}$$

Where:

P_s is the supplementary loss (W);

P_{sn} is the nominal supplementary loss (W);

I_2 is the operational current (A);

I_{2n} is the nominal operational current (A).

If the slope is negative or if the correlation factor γ is less than 0.95, suppress the worst point and recalculate the slope of the line and the intersection with the zero conjugate line. If, after this procedure, the correlation factor increases to values equal to or greater than 0.95 and the slope is positive, use this calculation; otherwise, the test is unsatisfactory. Possible instrumentation errors and readings should be present. The source of errors should be investigated and corrected, and the trials should be repeated.

d) The corrected value of the supplementary loss to be used is obtained for each point with A, by Equation 5.

$$P_s = A.T^2 \tag{5}$$

Where:

P_s is the supplementary losses (W);

A is the slope obtained in item C;

T is the torque (Nm).

Recalculate the I²R stator loss for each load point, correcting the resistance to the final temperature rise test temperature and considering the ambient temperature of 25 °C.

Recalculate the I²R losses of the rotor for each load point, correcting the slip to the final temperature of the temperature rise test and considering the ambient temperature of 25 °C.

Calculate the corrected output power for each load point according to Equation 6.

$$P_{oc} = P_{in} - P_{core} - P_{fv} - P_{stc} - P_{rotc} - P_{sc} \tag{6}$$

At where:

P_{oc} is the corrected output power (W);

P_{in} is the measured input power (W);

P_{core} is the nucleus loss (W);

P_{fv} is the friction and ventilation losses (W);

P_{stc} is the I²R corrected stator loss for the final temperature (W);

P_{rotc} is the I²R corrected rotor loss for the final temperature (W);

P_{sc} is the corrected supplemental loss (W).

Determine the efficiency for each loading point of the test using the following Equation 7.

$$\eta = \frac{P_{out}}{P_{in}} \tag{7}$$

Where:

η is the efficiency;

P_{out} is the corrected output power (W);

P_{in} is the measured input power (W).

To determine the efficiency at precise points of charge, an efficiency curve versus corrected output power was obtained and the desired values are obtained as shown in Figure 4.

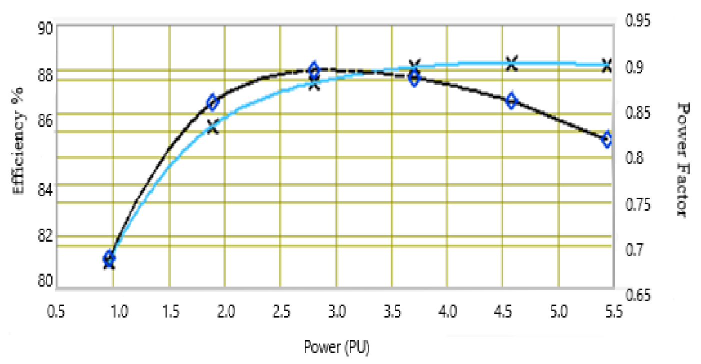

Figure 4: Efficiency X Output Power.
Source: Authors, (2020).

Table 10 shows the synthesis of the results obtained in the three-phase induction motor test.

Table 10: Synthesis of Results Output X Output Power.

Torque (%)	**150**	**125**	**100**	**75**	**50**	**25**
Frequency (Hz)	60	60	60	60	60	60
Speed (rpm)	3452	3482	3507	3531	3554	3574
Slip (rpm)	148.1	117.2	92.5	68.7	46.3	26
Voltage (V)	219.9	220.	220.0	220.	220	220.7
Current (A)	18.4	15.1	12.2	9.4	6.8	4.5
Input power (W)	6342.5	5250	4203.	316	2164	1183
Core losses (W)	66.2	66.2	66.2	66.2	66.2	66.2
Stator loss(W)	19.0	11.4	7.3	4.3	2.7	4.5
Power through the air gap (W)	6257	5173	4130	309	2095	1113
Rotor losses (W)	257.5	168.4	106.1	59.0	26.9	8.0
Friction and windage losses (W)	123.5	123.5	123.5	123.5	124	123.5
Total Conventional Losses (W)	466.3	369.6	303.2	253.2	219.2	202.4
Conjugate (N.m)	14.9	12.49	10.01	7.5	5.0	2.5
Correction of the dynamometer (N.m)	0.03	0.03	0.03	0.03	0.03	0.03
Corrected Conjugate (N.m)	15	12.5	10.0	7.5	5.0	2.5
Output power (W)	5422	4566	3687.8	2792	1876	946.9
Total apparent losses (W)	920.1	684.3	515.3	376.6	288.2	236.5
Supplementary Losses (W)	453.8	314.8	212.11	123.4	68.9	34.1
Intersection with the axis (B)		0.01	Correlation Factor (g)		1	-
Stator loss corrected (W)	389.7	263.4	171.5	101.2	53.2	23.7
Corrected power through air gap (W)	5887	4921	3965	3001	2045	1093
Corrected sliding (rpm)	141.5	112.	89.8	67.1	45.5	25.7
Speed Corrected (rpm)	3458	3487	3510	3532	3555	3574
Loss of rotor (W)	242.2	160.1	101.9	57.22	26.3	7.9
Supplementary losses corrected (W)	87.3	60.8	39.1	22.1	9.9	2.5
Total corrected losses (W)	908.4	674.1	502.3	370.3	279	223.9
Corrected output power (W)	5435	4577	3701	2798	1885	959.5
Output Power (CV)	7.4	6.2	5.03	3.8	2.6	1.3
Efficiency (%)	85.7	87.2	88.1	88.3	87.1	81.1
Power factor	0.91	0.91	0.9	0.89	0.84	0.68
Index of income removal - IAR (%)	-	-	-24	-	-	-

Source: Authors, (2020).

The Brazilian standard NBR 17094-3 for motor testing determines a methodology for acceptance of the results of the test performance uncertainty of electric motors of an informative nature, where the test compliance tolerance limits vary according to the performance range of the electric motor which is defined by the results deviation index, which represents how the electric motor tested is far from the declared value of the electric motor. The tolerance applied to the performance evaluation is represented as a zone of acceptable values. Its border limits are called the lower limit of tolerance (LIT) and an upper limit of tolerance (LST). Electric motors that exhibit their characteristics within these limits must be considered approved. The uncertainty of the performance should be considered.

And for the efficiency's located in the uncertainty zone, the electric motor tested may or may not respect the established tolerance. In this case, it is recommended to test the sample, review the uncertainty or the tolerance applied in the measured range.

Motors with efficiency within the rejection zone should be reproved in this test. Figure 5 shows the results for the electric motor tested in this work where its data are within the acceptance zone with an IAR of -24%.

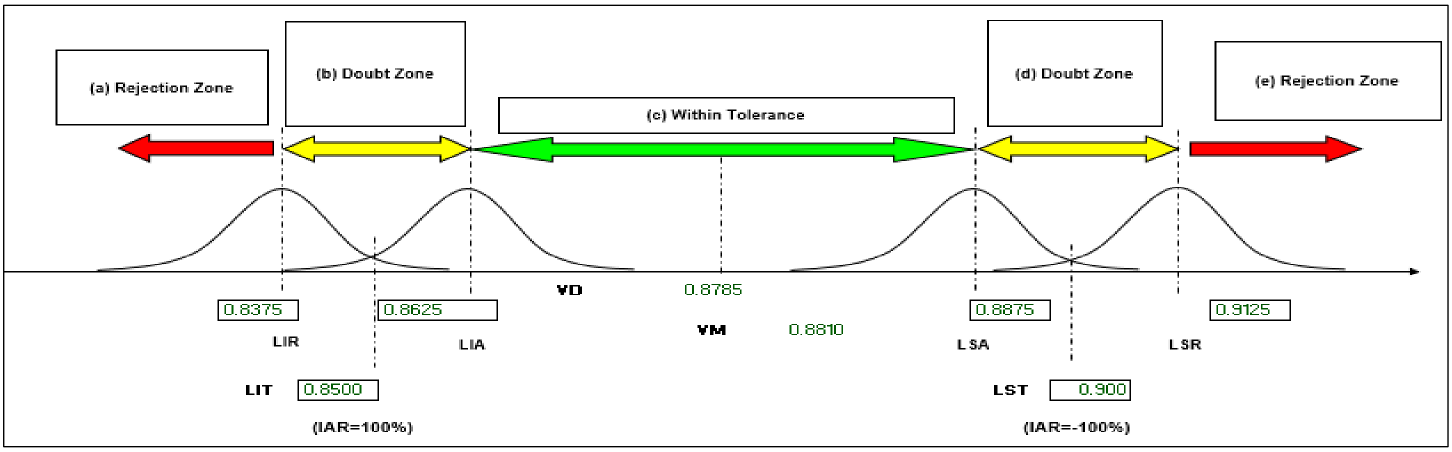

Figure 5: Compliance Zone.
Source: Adapted from [22].

At where:
LIT - Lower Limit of Tolerance;
LST – Upper Limit of Tolerance;
IM – Measurement Uncertainty;
LIA – Lower Limit of Acceptance;
LSA – Upper Limit of Acceptance;
LIR – Lower Rejection Limit;
LSR – Upper Limit of Rejection.

IV. COMPARISION BETWEEN THE MAIN STANDARDS

The energy efficiency of the electrical equipment is today one of the main factors that influence the competitiveness between industries. The convenient choice and dimensioning of the equipment are therefore one of the challenges that the industries in general face. To do this, it is important that strong regulation that establishes national procedures to determine the efficiency of electric motors are implemented.

IV.1 MAIN STANDARDS

The efficiency values provided by the manufacturers are determined according to the specifications of minimum efficiency values through the different energy efficiency standards of three-phase induction motors adopted by each country in the world. This work highlights:

- IEEE 112 (Institute of Electrical and Electronics Engineers) - method B (American standard);
- IEC 60034-2-1 (International Electrotechnical Commission) - (International standard);
- JEC 37 (Japanese Electrotechnical Commission) - (Japanese standard);
- NBR 17094-3 (Brazilian standard).

IV.2 TESTS METHODS

There are currently some standards for testing electric machines, and for three-phase induction motors. Different electric motor test methodologies leads to significantly different efficiency values. This is due to the fact that different considerations and treatment were given to the losses that occur during the energy conversion process inside the electric motor. The IEEE 112 standard test method A, B, and C determines the motor efficiency directly from electrical power input measurements and mechanical output power under load operating conditions. The IEEE 112, E and F test method and the JEC standard use different techniques to determine the input and output power, or both, when a direct measurement is not available. The main difference between the different methods is the treatment of dispersion losses under load. The IEEE 112 method E and F requires a separate test for the on-load dispersion losses while the old IEC 34-2 assumes a percentage value at full load for these losses, where the current standard 60034-2-1 already performs a test to determine dispersion losses. The JEC standard 37 uses a circular diagram as the main method for calculating efficiency and does not include a direct measurement of on-load dispersion losses. Since the load dispersion losses are about 8-15% of all the loss, the accuracy in dispersion losses computations can be compromised in these methods [27].

There are several procedures for conducting tests in electric motors, which establishes the methods to be adopted during the tests so that the characteristics of the motors can be determined and the minimum values for their acceptance. The test methods can be divided into two groups, named by Direct Method and Indirect Method.

In the direct method, both input and output mechanical power is measured. In the indirect method, one or both are not measured directly. Within the same norm, it is difficult to compare the values obtained by the direct and indirect methods, since they start from different hypotheses.

In addition, the choice between several methods depends on factors such as equipment availability, cost and time to perform the tests, the precision required, the amount of power involved, etc. Analyzing in terms of energy conservation, it is important that the method chosen it's the one that more accurately assesses the actual electric motor performance. The input-output with loss segregation method, described by IEEE-112 - Method B, is the most suitable for this. This is because of the estimation of dispersion losses that are difficult to quantify. One of the main differences between these procedures is in the form of how the dispersion loss in charge is determined. The test methods of the abovementioned standards are given.

IV.3 IEEE 112-METHOD B

It is the most important standard in the industrial field because polyphase squirrel cage induction motors with power in the range of 0.16 to 370 kW are tested on the horizontal axis. Method B requires three tests:

- Temperature rise test - The machine operates at nominal load until the main motor winding temperature stabilizes), measurements are taken every 30 minutes, where the machine is considered stabilized if the measured value of the temperature does not exceed 1 °C within 1 hour, this test is performed to establish the temperature at which stator and rotor losses will be corrected. At the end of this test, the stator winding resistance must be measured.
- No-load test - The no-load test must be carried out in an uncoupled machine immediately after the load test. Six different voltage values are applied, including the nominal voltage. The suggested voltage are: 125%, 100%, 80% and 60% 40% and 20% of the nominal voltage. This test aims to determine the iron losses and friction and ventilation losses. The test should be performed as soon as possible with the readings performed in descending voltage sequence. The winding resistance is measured and after the test. The validity of this test depends on the difference observed between the first and second measure of the winding resistance.

The maximum allowable difference for machines up to 15kW is 3.5%. Machines with power higher than 15kW the maximum allowable difference is 3.0%.

- Variable load test under nominal conditions - Four load points are applied approximately equally spaced between 25% and 100% (including 100%) and two equally spaced values above 100% and not exceeding 150% of the rated load. Classification and partial load application tests are performed from the highest load to the lowest in descending order. These tests should be performed as soon as possible to minimize electric motor temperature changes.

The maximum allowable difference for machines up to 15kW is 3.5%. Machines with power higher than 15kW the maximum allowable difference is 3.0%. It is necessary to add to this test a specific point with the dynamometer turned off to determine the dynamometer correction.

IV.4 IEC 60034-2-1

This test method is similar to [22]. Temperature rise test – After performing the resistance measurement with the cold machine is initiated to the temperature elevation test. The motor is driven in a continuous regime with nominal load until it reaches the thermal stability, so get the temperature for which the stator and rotor losses will be corrected. The thermal equilibrium is achieved, when in the interval of 30 min, the temperature does not vary more than 1°C then the power supply is switched off and the measurement of the winding resistance is done.

Load test - This test should be performed immediately after the temperature rise test with the motor at the operating temperature. A controlled load is applied to the machine in different six points. It is suggested to use loading points close to 125%, 115%, 100%, 75%, 50% and 25% of the nominal load. These tests should be performed as quickly as possible to minimize the temperature changes in the machine during the test and it is necessary to measure the winding resistance (before and after the test). The procedure aims to determine the stator and rotor losses.

No-load test – The no-load test must be carried out immediately after the load test. Eight different voltage values are applied, including the nominal voltage. The suggested voltage is: 110%, 100%, 95% and 90% of the nominal voltage. These values are used for the determination of the iron losses; the values of approximately 60%, 50%, 40% and 30% of the nominal voltage are used for the determination of friction and ventilation losses; the test should be performed as soon as possible with the readings performed in descending voltage sequence.

The winding temperature is determined by direct measurement in the nominal load test using the shortest time possible by the extrapolation procedure. After the lowest loading point is processed, another reading the winding temperature is recorded. Both readings are used to predict winding resistances for all other loads. Alternatively, the winding temperature can also be measured with temperature sensors, similar to IEEE procedures.

IV.5 JEC 37

This standard is less restrictive than that of the USA and Europe. The evaluation of efficiency by the Japanese standard can be considered as an indirect method. JEC 37 neglects parasitic load losses. For this reason, the efficiencies obtained are generally higher. In addition, no thermal correction of Joule losses is specified. Since it is very difficult to find the measurement procedures used in the Japanese standard, it is practical to evaluate the efficiency of the machine using the test results required by the other standards.

V. CONCLUSIONS

In this manuscript, standards NBR 17094-3, IEEE 112-B, IEC 60034-2-1 and JEC 37 were considered for the evaluation of the efficiency of the induction motor. Differences in the prescribed procedures of each standard were discussed. This work also supports the evaluation of the insertion of three-phase induction motors in the Brazilian market in front of the national standard.

Previous studies according to reference [24] have verified the efficacy of IEC 60034-2-1, which may offer similar efficiency values to IEEE method B, provided that the procedures are followed strictly. It can also be said that the IEC 60034-2-1 standard is well aligned with the IEEE 112 due to the values presented. However, the two standards present some distinctions in procedures adopted to determine stator conductor loss, core loss, and load losses. However, there are no differences in the determination of rotor conductor loss, friction and ventilation losses. The differences in conductor stator losses are virtually within tolerance measurement, while those in core loss and parasitic head loss are relatively significant.

Compared to IEEE 112 method B and NBR 17094-3, the IEC standard can provide more accurate but smaller loss values and thus higher values of dispersion load loss. Clearly, the nominal efficiency values for the two standards are approximately the same.

Direct Methods (IEEE 112-B) consider that speed measurement is a relatively simple procedure requiring equipment to achieve accurate results (± 1 RPM), torque measurement requires elaborate setup and much more expensive equipment to provide accurate results. Torque measurement usually requires the coupling of the motor to a dynamometer, which has the possibility of creating a controllable variable load, equipped with a torque transducer.

It is important to highlight that if the instruments used are not correctly calibrated the tests may show significant deviations due to instrumentation errors, then it is concluded that for this analysis the reason of discrepancies could be caused by wrong procedures or mistaken readings of some equipment.

In the Japanese standard JEC 37, the error is greater, since the load losses are totally ignored in the indirect measurement of the efficiency. Due to the way the losses are evaluated, the tests to determine the characteristics of the induction motor generate efficiency values that can be several points above the measured values with direct efficiency methods.

The electric motor tested had a higher efficiency than the minimum required by standard NBR 17094-1 for class IR2, 5CV, 2 poles, with efficiency of 88.1% where the efficiency standard of the induction motors determines 87.5% for this type of engine, even with a results deviation index of -24%, the project showed itself within the conformity zone, approving the lot to be marketed.

Finally, comparing the no-load test of IEC 60034-2-1 with NBR 5383-1, it is observed that the procedures present differences in the application of the variation of percentages of nominal voltage but according to [28], and the comparative analysis of the standards can be observed that the final result of efficiency undergoes small variations.

The goal of this article was to present a comparison of the test methods of the mentioned standards in order to determine the best procedure to be applied for the three-phase induction motors tests, the results show that ABNT NBR 17094-3: 2018 and IEC 60034-2-1 present advantages compared to JEC 37 because their final result of efficiency levels is more accurate.

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