Analysis and Comparison Between the IEC 60034-2-1 X IEEE 112 X CSA C390 X NBR 17094-3 Standards for Calculating the Efficiency of Three-Phase Induction Motors Using the Loss Segregation Method.

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Analysis and comparison between the IEC 60034-2-1 x IEEE 112 x CSA C390 x NBR 17094-3 standards for calculating the efficiency of three-phase induction motors using the loss segregation method

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Abstract. The aim of this article is to analyze and compare the latest editions of the NBR, IEC, IEEE and CSA standards for determining the efficiency of three-phase induction motors using the loss segregation method, in order to verify their equivalence and harmonization.
To do this, the power supply requirements, instrumentation requirements and test procedures adopted are checked and compared.
Finally, the results of the efficiency determination obtained in tests performed on motors with power between 0,75 kW and 750 kW, in order to verify the variation in the efficiency of these motors when subjected to the methodologies of the different standards, in order to show the existence of equivalence of the results between them.

Keywords: Motor efficiency requirements, Induction motor efficiency, Energy efficiency, test methods, IEC 60034-2-1, IEEE 112, CSA C390, NBR 17094-3.

1 Introduction

The quest for energy efficiency has driven the industry to adopt standardized methods for assessing the performance of electric motors, with the loss separation method emerging as the preferred choice in global regulatory programs [1] and [2] for evaluating the efficiency of three-phase induction motors.

However, the diversity of internationally adopted standards for calculating motor efficiency introduces nuances that require a detailed analysis. While the loss separation method is widely accepted, differences in standards such as IEC 60034-2-1 [3], IEEE 112 [4], CSA C390 [5], and NBR 17094-3 [6] result in variations in the methodologies used to calculate losses and, consequently, motor efficiency.

In [7], [8] and [9] you can see some comparisons already made between the loss separation methods of the IEC, IEEE and CSA or the NBR and IEC, but this article intends to update this comparison of the latest current versions of these four standards, IEC, IEEE, CSA and NBR.

This article aims to investigate these methodological differences, highlighting how each standard addresses loss separation and influences the calculation of three-phase induction motor efficiency. Understanding these nuances is essential for professionals and researchers seeking to ensure regulatory compliance, optimize energy performance, and promote sustainable practices in the industry.

2 Motor Efficiency

From an energy point of view [10], we can consider the motor to be a transducer that transforms electrical energy from the input into mechanical energy at the output (shaft end). In this transformation, part of the input energy is dissipated in the form of losses, as shown in the fig. 1.

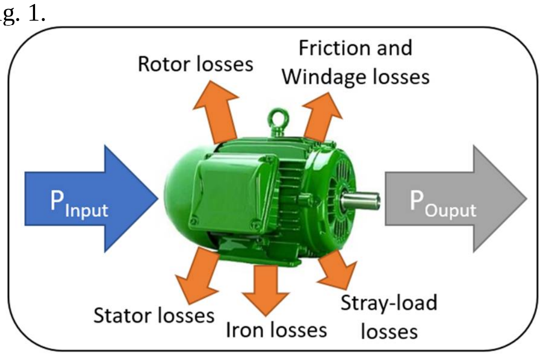

Fig. 1. Representation of the electric motor from an energy point of view.

According [3], [4], [5] and [6], as the efficiency (N%) of the motor is given by the ratio between the output energy and the input energy, it can be obtained in two ways:

- Direct method given by the ratio between the output mechanical power (Pin) and the input electrical power (Pout) according to equation (1).

$$N(\%) = 100.\frac{P_{out}}{P_{in}} \quad (1)$$

- Indirect method with segregation losses given by the ratio of the input electrical power minus summation of losses and the input electrical power according to equation (2).

$$N(\%) = 100.\frac{(P_{in} - \sum Losses)}{P_{in}} \quad (2)$$

3 Analysis of Standards Efficiency Determination

3.1 Methods NBR, IEC, NEMA and CSA evaluated

The NBR 17094-3, IEEE 112, CSA C390 and IEC 60034-2-1 standards was evaluated and, more specifically, the loss separation method used in each of them. This method was chosen because it is the preferred method used by energy efficiency regulations to determine efficiency of three phase induction motors [1], [2] having a low uncertainty and more repeatibility.

Although they use the same method, there are some particularities in the methodologies of each standard, so that the efficiency obtained ends up being slightly different.

The methods evaluated in this article were as follows:

- **Method 2 of NBR 17094-3:** dynamometer test with indirect measurement of stray-load loss and direct measurement of stator (I2R), rotor (I2R), core and friction and windage losses.
- **Method 2-1-1B of IEC 60034-2-1:** Summation of separate losse. Additional load loss determined by the method of residual loss.
- **Method B of IEEE 112:** Input-output with segregation of losses and indirect measurement of stray-load loss.
- **CSA C390 Method:** Input-output test procedure with indirect measurement of stray-load and direct measurement of the stator winding (I2R), rotor winding (I2R), core, and windage and friction losses.

All these methods have in common the loss segregation calculation, where the respective loss components are stator winding losses, rotor winding losses, core or iron losses, windage and friction losses and additional load or stray-load losses.

3.2 Tests required to determine efficiency

The purpose of the loss segregation method is to determine the losses of the motor in order to determine its efficiency. According to test standards [3], [4], [5] and [6], for determining the losses, essentially four tests are required, Cold Resistance Test, Temperature Rise Test, Load Test and No Load Test.

Cold resistance test: used to determine the resistance of the motor when it is in thermal equilibrium with the ambient temperature (ambient motor). This resistance will be the reference for determining the temperature rise of the motor and for determining the temperature during the load and no-load tests.

Temperature rise test: In this test, rated load and rated voltage are applied to the motor until it reaches thermal equilibrium. After reaching thermal equilibrium, the motor is switched off and the hot stator resistance is quickly measured. Based on the variation between the cold resistance and the hot resistance it is possible to determine the temperature rise value of the motor winding.

Load test: This test must be performed after the temperature rise test with the motor in the hot condition. It is used to determine the losses of the motor under load. In this test, points are determined with different load percentages between 25% and 150% while keeping the rated voltage, and one of these points must be in the 100% load condition.

No load test: This test is performed with the motor running at no load and uncoupled. It is used to determine the losses of the motor at no load. In this test, points are determined with different percentages of voltage, between 125% and 20% of the rated voltage, one of which must be done in the rated voltage condition (100%).

3.3 Power supply requirements

The minimum requirements established by the test standards [3], [4], [5] and [6] for power supply for fed the motor under test are defined were verified and showed in table 1.

Table 1. Minimum power supply requirements for the motor according test standards.

Parameter	ABNTNBR	IEC	IEEE	CSA
Waveform - Max. THD (%)	-	-	+5	+5
Waveform - Max. HVF (p.u.)	+ 0,02	+ 0,015*	+ 0,03**	+ 0,03**
Max. Voltage Unbalance (%)	± 0,5	± 0,5	± 0,5	± 0,5
Max. Deviation from Rated Frequency (%)	± 0,2	± 0,1	± 0,1	± 0,1

* Voltage harmonic factor (HVF) is 0,03 for category N motors.

** Informative values from NEMA MG 1 part 30. Not mandatory requirement of this standard.

3.4 Instrumentation specification

The specification and precision of the instrumentation required by the test standards [3], [4], [5] and [6] for the loss segregation method were evaluated and showed in table 2.

Table 2. Specifications of the instrumentation according test standards.

Parameter	ABNTNBR	IEC	IEEE	CSA
CTs and PTs (%)	± 0,5 F.S.	± 0,2 R.	± 0,3 F.S. and ± 0,5 R.	± 0,3 F.S.
Voltage (%)	± 0,5% F.S.	± 0,2 R.	± 0,2 F.S.	± 0,2 F.S. and ± 0,5 R.
Current (%)	± 0,5 F.S.	± 0,2 R.	± 0,2 F.S. and ± 0,5 R.	± 0,2 F.S. and ± 0,5 R.
Power	± 0,5 F.S.	± 0,2 R.	± 0,2 F.S. and ± 1,0 R.	± 0,2 F.S. and ± 1,0 R.
Frequency	± 0,2 F.S.	± 0,1 F.S.	± 0.05 R.	± 0,2 F.S. and ± 0,05 R.
Torque	± 0,2 F.S.	± 0,2 F.S..	± 0.2 F.S. and ± 0.7 R.	± 0,2 F.S. and ± 0,7 R.
Speed	± 1 rpm	± 0,1 rpm	± 1 rpm	± 1 rpm
Resistance	± 0,5% F.S.	± 0,2 % F.S.	± 0.2 F.S.	± 1% R.
Temperature	± 1 °C	± 1 °C	± 1 °C	± 0,2% F.S. and ± 1,5 °C

F.S.: Full Scale R.: Reading

3.5 Details of Test Procedure

Each standard also has some peculiarities in the test procedure and calculation methodology applied. The table 3 shows a comparison of some of the main parameters used in the test and calculation methods according test standards [3], [4], [5] and [6].

Table 3. Details of the tests and calculation methodology according test standards.

Parameter	ABNT NBR 17094 Method 2	IEC 60034-2-1 Method 2-1-1B	IEEE 112 Method B	CSA C390
Calculation of motor load points resistance	Measure Stator Resistance before and after test	Measure Stator Resistance before and after test	Resistance based on detector temperature	Resistance based on detector temperature

	Rstator average	Rstator linear		
Calculation voltage drop to iron losses	No	Yes	Yes	Yes
Correlation coefficient of stray-load losses	0,95	0,95	0,90	0,95
Winding material factor	234,5 Cu 225 Al	235 Cu 225 Al	234,5 Cu 225 Al	234,5 Cu 224.6 Al
Correction of losses to reference amb. Temp.	Yes (25°C)	Yes (25°C)	Yes (25°C)	Yes (25°C)
Stabilization of no-load losses	Yes*	No	Yes	Yes
No-load test points	**	8	6	6
Load test points	6	6	6	6

* It does not need to be done if the no-load test is performed after the temperature rise test.
** It does not define the number of points, only that it must vary from 110% Un to the point of lowest voltage at which the current begins to increase in order to obtain the extrapolation graph, normally use a minimum of 6 points.

4 Results of the Tests performed

Tests were performed on 117 motors with power ratings ranging from 0.75 kW to 750 kW to determine efficiency using the methods evaluated in the standards.

The tests required to determine efficiency were performed on each motor. After the test, the efficiency using the four methods evaluated was determined. The table 4 and figures 2, 3 and 4 show the average performance results obtained in the tests according to each standard.

Table 4. Efficiency comparison obtained according to standards.

Power (kW)	ABNT NBR	IEC	IEEE	CSA
0,75	80,99	81,37	81,19	81,13
1,5	86,33	86,59	86,44	86,41
3,0	88,40	88,57	88,47	88,43
7,5	90,65	90,79	90,73	90,73
15	92,23	92,34	92,27	92,27
30	93,63	93,66	93,61	93,61
75	95,53	95,56	95,53	95,53
150	96,20	96,21	96,18	96,18
300	96,60	96,60	96,59	96,66
370	97,06	97,07	97,08	97,07
560	97,38	97,41	97,40	97,40
750	97,37	97,38	97,38	97,38

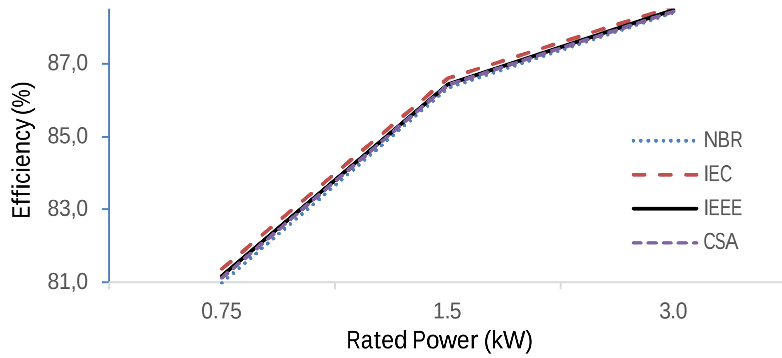

Fig. 2. Graph of efficiency comparison according to standards from 0,75 up to 3 kW.

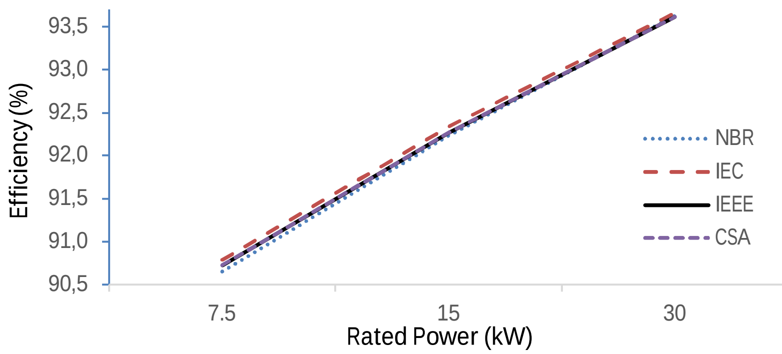

Fig. 3. Graph of efficiency comparison according to standards from 7,5 up to 30 kW.

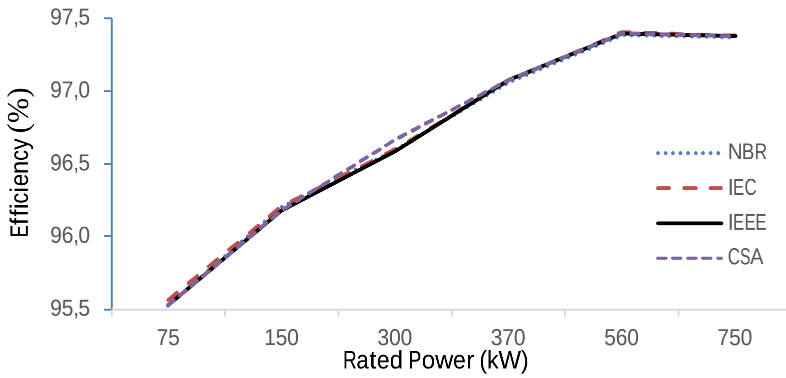

Fig. 4. Graph of efficiency comparison according to standards from 75 up to 750 kW.

It was fixed the average of the methods as a reference and calculated the difference in performance between the methods in relation to the reference. It was set a limit to check that the methods were equivalent, setting the acceptance limit at ± 1/10 of the efficiency tolerance range of the standards (± 15% of loss). The results are shown in table 5 and figure 5.

Table 5. Difference od Efficiency calculed between Standards in relation to reference.

Power (kW)	IEC	NBR	IEEE	CSA
0,75	0,204	-0,179	0,018	-0,043
1,5	0,149	-0,111	-0,005	-0,032
3,0	0,102	-0,066	-0,001	-0,034
7,5	0,066	-0,072	0,002	0,002
15	0,060	-0,041	-0,009	-0,009
30	0,031	-0,001	-0,015	-0,015
75	0,027	-0,012	-0,008	-0,008
150	0,017	0,010	-0,014	-0,013
300	-0,013	-0,016	-0,024	0,052
370	0,001	-0,011	0,007	0,004
560	0,010	-0,011	0,001	0,001
750	0,006	-0,009	0,000	0,001

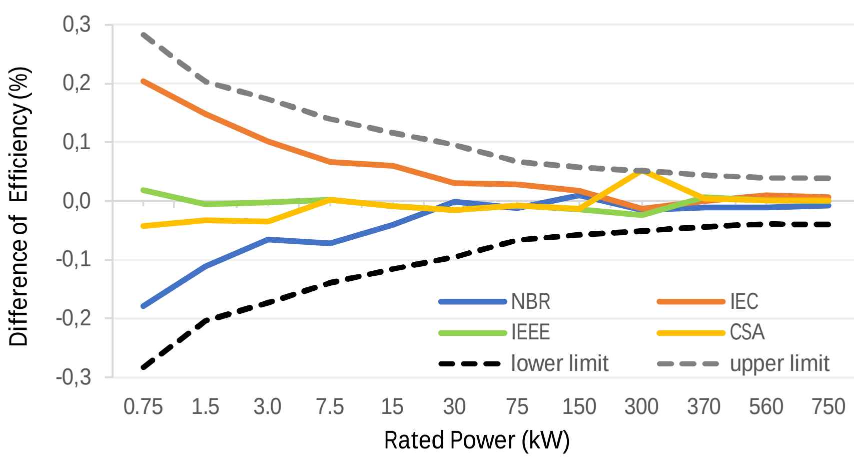

Fig. 5. Graph of Difference of Efficiency calculed between Standards.

5 Conclusion

The main conclusion of this study is that the determination of efficiency by the loss segregation method of the IEEE, IEC, CSA and NBR standards for induction motors from 0,75 kW to 750 kW, even with small differences in the test procedures, the power supply requirements and the instrumentation specification, results in very close efficiency values, all inside ± 1,5% of the losses, so it is possible to conclude these standard methods, although their peculiarities, may be considered as equivalent.

Through a meticulous examination of power supply requirements, instrumentation specifications, test procedures, and efficiency determination methods, we aimed to ascertain the equivalence and harmonization of these standards.

Finally, this study contributes to the body of knowledge surrounding motor efficiency assessment methodologies and provides valuable insights for professionals and researchers in the field.

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