Invitation for Proposals

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CUSTOMER ENERGY SOLUTIONS INTEREST GROUP (CESIG)

CEATI PROJECT No. CESIG-12-02

MOTOR EFFICIENCY ESTIMATING TOOL FOR AC THREE PHASE INDUCTION MOTORS BASED ON UNCOUPLED MOTOR TESTING

CEATI International Inc. (CEATI) invites the submission of proposals to perform research work on the following topic:

TITLE

Motor Efficiency Estimating Tool for AC Three-Phase Induction Motors based on Uncoupled Motor Testing

INTRODUCTION

A.C. induction motors that have operated for years experiencing multiple failures and repairs may operate below their original nameplate ratings or assumed efficiency. Numerous investigations of new motor efficiency were conducted while very little work investigating the actual running efficiency of older motors in the field was reported. Studies have shown that repaired motors appear to operate below their nameplates and below the projections of many of the standard motor decision tools. While these studies concede the importance of motor loading on the effective operational efficiency of the motor, they do not utilize routine testing methods to determine this efficiency during motor refurbishment but rather assume original manufacturer values for their comparisons.

A draft algorithm using a series of routine motor tests (no-load power and cold resistance) which are typically conducted by motor service centres has been evaluated at BC Hydro. The BC Hydro paper is attached to this Invitation for Proposals as Appendix 1.

CESIG participants sponsoring this development assume that with hard data, the economics of motor “repair versus replace” decisions could change significantly. If true, this could appreciably boost the efficiency of the industrial motor population through increased penetration of high efficiency motors, such as the NEMA Premium™ line. At the same time, motor service centres will offer increased quality assurance for the motor repair and rewind work they are conducting by being able to estimate repaired motors efficiency by using a credible methodology not involving standard and costly dynamometer testing.

PROJECT OBJECTIVES

Develop a modified algorithm and calculator tool for modelling efficiency of repaired and rewound AC induction motors at motor service centre upon motor refurbishment using routine uncoupled and unpowered motor testing and nameplate data.

Mathematical model is to complement the recently released standard, CSA C392-11: Testing of Three-phase Squirrel Cage Induction Motors during Refurbishment in terms of methodology, instrumentation, measurement and accuracy requirements.

Basic measurement data that is currently collected during the motor repair or refurbishment process together with motor nameplate data should be the only input data required for this software. The draft algorithm inputs to be included are the following:

1. Cold resistance and temperature

2. No load power, Power Factor, and no load current as function of applied voltage (Saturation Test)
3. Mathematical model of stray load loss (SLL)
4. Name plate data details.

In addition, the following inputs could be included, along with any others suggested by the contractor:

5. Indirect measurement of stray load loss through Impedance Balance Test
6. Indirect measurement of stray load loss through Eh-star Test

Alternatively, the contractor may choose to develop their own algorithm and calculation to achieve the same results.

Motors targeted in this project are AC three-phase squirrel-cage induction motors from 200 V to 7500 V.

SCOPE OF THE STUDY

The outcome of this project will be an enhanced mathematical model and calculator application tool to more accurately assess the economic benefits of utilizing premium-efficiency industrial AC squirrel cage motors.

Tasks:

1. Improve the accuracy of the draft algorithm by using more advanced mathematical modeling;
2. Design and validation testing of the new software. Validation and calibration of the model can be done with experimental test data, such as from Hydro-Québec, or any other available motor test data;
3. Assess the effectiveness of the algorithm.
4. Evaluate the effects on motor efficiency of power supply voltage variation voltage unbalance by varying voltage by +/- 10%.

POTENTIAL BENEFITS

- New tool to assess AC three-phase squirrel-cage induction motor efficiency, primarily during refurbishment, for motors rated between 200 V and 7,500 V at much lower cost than dynamometer testing.
- New tool for users to test efficiency of new motors prior to using them in production, by sending the motor to a rewind facility to screen efficiency.
- New tool to assess efficiency of refurbished motors and enable customers to more accurately evaluate whether to repair or replace a motor in the future.
- Provides reliable efficiency data that enables improved energy-efficiency standard development for testing during refurbishment (CSA C392).

- Utility DSM programs to encourage early adoption of energy-efficient and premium efficiency motors and assurance that the investment in energy efficiency is sustained over the entire life of a motor.
- Enable further refinement of DSM programs indirectly involving A.C. induction motors.
- Enable evaluation of the effects of the Electrical Distribution Supply Optimization (EDSO) on induction motor efficiency.
- Measurement of Energy Savings during refurbishment and retrofits.
- Increases the potential for new and more efficient motor purchases
- The potential energy savings is estimated based on the avoided efficiency degradation with motor repair and accelerated adoption of new premium efficiency motors.

PROJECT TASKS (with approximate timing for various tasks**)**

R&D activity	– 1 month
Design, testing and validation of model*	– 3 months
Sensitivity analysis of electrical distribution system impacts (distribution system voltage)	– 1 month
Analysis, documentation and technical report	– 1 month

* Using existent data from testing facilities of squirrel cage motors, including: Hydro-Québec – Laboratoires des Technologies de l'Energie – Shawinigan, Quebec; Advanced Energy – North Carolina

Expected project duration is 9 – 12 months

DELIVERABLES

- Software or equivalent tool capable of estimating motor efficiency at 100%, 75%, 50% load points (minimum) at rated/nominal voltage; Algorithm, inputs and any assumptions must be included.
- User's instructions and testing set-up and procedure;
- Description of instrumentation, accuracy and calibration requirements;
- Brief technical report with typical examples and calculations.

The successful proponent is expected to prepare a ready-to-publish report on the results of the investigation and present the results to funding consortium members. The completed report must be submitted for CEATI approval in editable, electronic format (Microsoft Word). In addition, the platform and version should be specified for any software or programs to be developed.

Progress reports will also be required on either a quarterly or milestone basis - normally these are scheduled to coincide with the completion of the identified tasks.

The successful proponent is also expected to provide the following:

- A ten to fifteen (10-15) slide Power Point Presentation. This should be composed of three main sections:
  1. The factors motivating the initiation of the work;
  2. A description of the main findings;
  3. Summary of the conclusions and recommendations for future research.

- Contents for the Project's Technical Brief. This is a summary of the report (between 1,000 and 1,500 words), which is published separately by CEATI. Proponents are not responsible for the preparation of a ready-to-print Technical Brief, but solely to provide the contents for the following 4 sections: Background, Summary, Conclusions and Recommendations, along with at least 2 relevant figures/tables.
  1. The Report Background section should be short (approximately 200 words) and should detail the reasons the work was conducted.
  2. The Summary section should be approximately 700 words. It must provide a general description of the work program.
  3. The Conclusions section should be about 150 words and should provide a general outline of the key results (do not include specifics).
  4. The Recommendations section should be about 200 words and should include a description of the potential applications of the results.

Please note that all reporting must be submitted in English. If written English is not the author's strong suit, it is recommended that a technical writer be hired to review the document prior to submission.

BUDGET AND SCHEDULE

The proposal must contain a schedule and a quote of required remuneration for the work in US or Canadian dollars. All prices shall be presumed to be in Canadian dollars (CAD) unless explicitly specified otherwise in the proposal. Proponents' responses to this section must include a full breakdown of the budget and schedule, including an indication of rates and hours and the task allocation for the key personnel by task and must correspond to any phases or milestones outlined above. (Please refer to the Proposal Template for more information).

It is expected that this project can be completed (draft final report submitted for review and approval) within 9 - 12 months of initiation.

The proposal must include the names and qualifications of the key individuals who will be involved, as well as the name of the accountable manager.

CEATI is not bound to accept any proposal but any selection will take into account technical merit, qualifications, price and schedule. A proposal may be accepted in whole or in part. A commitment to proceed with the first phase of a multi-phase project does not automatically imply that the work of the subsequent phases will be undertaken.

ALTERNATIVE WORKS

Proponents shall generally follow the above description of work, but are encouraged to offer alternative works if these alternatives will meet the objectives and provide a better end product to the utilities sponsoring this work. Alternatives shall be fully described including logistics explaining why the alternate works are being offered and the benefits to be realized by the funding utilities. Where alternatives are proposed, separate budgets shall be calculated for each alternative.

SUBMISSION OF PROPOSALS

The consideration of proposals received will be limited to those who indicate their intent to employ a suitable experienced project team and who possess proper facilities to perform the work. Receipt of this "IFP" does not necessarily constitute a prior determination by CEATI that your organization has the requisite experience and facilities.

The proposal must be properly completed and executed in accordance with the CEATI guidelines available at http://www.ceati.com/guidelines.php, and shall be submitted to CEATI as an attachment in Microsoft Word at the following website: www.ceati.com/private/submissions. Be sure to indicate project number "**CESIG-12-02**" on the submission form. For assistance, please contact us at 514-866-5377.

The successful proponent will be required to sign the CEATI Standard Agreement upon project initiation. Proponents are encouraged to contact CEATI (projects@ceati.com) and request a copy of these terms to review prior to submitting a proposal, if they are not already familiar with this Agreement.

CLOSING DATE FOR RECEIPT OF PROPOSALS

Thursday, January 26, 2012 by 4:00 pm EDT

Appendix 1: Power Smart - Industrial

Simulation of the Motor Efficiency based on Routine Test (SMERT - 1) (Version 1)

Foreword

The first version is launched to validate the project.
Some conditions of performing required test (including required equipment) could be set up in a separate document, based on CSA or other instructions and regulation requirements currently in power in BC.
Further on this algorithm could be improved by using:

- Other types of routine tests (as no load "in hot conditions", locked rotor test, etc)
- Partial load test
- Heat run test (temperature rise test)
- Load measurements on site (application assessment)
- Data bank

Generation of a data bank is one of the important lines to be followed in order to ensure this project sustainability.

Algorithm flow of SMERT-1, @ reference temperature $T_{r,hot} = T_{r,cold} + \Delta T_{nom}$

Line	Item	Source / Method	Alternative Source/method
	Mandatory name plate details	§ 1	
	Other information on protocol		
	Measured cold resistance $R_1@T_1$	§ 2	Wheatstone bridge & thermometer
	Conversion of R_1 to $R_{r,cold}$	§ 3, (1)	$\mathbf{R_{r,cold}} = [R_1 (T_{r,cold} + k) / (T_1 + k)]$
	Performing no load test	§ 4	Table 1, Watt meters, Ampere meters, Volt meters
	Estimate No load power cold P_0	§ 5.1	$\mathbf{P_0} \rightarrow [P_0 = f(E_{L,i}) \cap E_L = E_{nom}$
	Estimate No load current cold I_0	§ 5.2	$\mathbf{I_0} \rightarrow [I_0 = \varphi (E_{L,i}) \cap I_L = E_{nom}$
	Friction & windage losses P_{mech}	§ 5.3	$\mathbf{P_{mech}} \rightarrow [P_0 = f(E_{L,i}) \cap E_L = 0$
	Stator core Iron losses P_{Fe}	§ 5.5, (4)	$\mathbf{P_{Fe}} = P_0 - P_{cu,0} - P_{mech}$
	Estimate Rated input power P_{ic}	§ 6, (5)	$\mathbf{P_{ic}} = [\sqrt{3} \times I_{nom} \times E_{nom} \times PF_{nom}] / 1000$
	Estimate Stray losses P_{LL}	§ 7, (6)	$\mathbf{P_{LL}} = \{P_{ic} [3.0 - 0.652 \log_{10} (P_{nom} / 1\ kW)]\} / 100$
	Estimate reference temperature in "hot" conditions	§ 8.1 (7)	Table 2, preferred (7.a); **NOTE:** If measured temperature rise ΔT is available, (7.b) is to be used
	Estimate line resistance "hot"	§ 8.2, (8)	$\mathbf{R_{r,hot}} = [R_1 (T_{r,hot} + k) / (T_1 + k)]$
	Stator winding copper losses $P_{cu,s}$	§ 9.1, (9)	$\mathbf{P_{cu,s}} = 1.5 \times R_{r,hot} \times I_{nom}^2 / 1000$
	Estimate Rotor copper losses $P_{cu,r}$	§ 9.3, (11)	$\mathbf{P_{cu,r}} = [(n_s - n_{nom}) / n_s] \times P_{ag}$
	Calculated output power $P_{O,c}$	§ 9.4, (12)	$\mathbf{P_{O,c}} = P_{ag} - P_{cu,r} - P_{mech}$
	Estimated motor efficiency e_c	§ 10, (13)	$\mathbf{e_c = [P_{O,c} / P_{ic}] \times 100\%}$

Abbreviations **Units**

e_c	= estimated (calculated) motor efficiency	%
e_{nom}	= rated efficiency	%
f	= fundamental frequency	60 Hz
n_{nom}	= rated speed	rpm
n	= measured (actual) speed	rpm
n_s	= synchronous speed (n_s = 120 f / 2p)	rpm
p	= poles number of the motor	
p.u.	= relative units	
s	= slip ($s = n_s - n_{nom}$)	rpm
E_L	= Line voltage	V
$E_{L,i}$	= Various values of measured Line voltage	V
E_{nom}	= Rated voltage	V
I_{nom}	= Rated current	A
I_L	= Line current	A
$I_{L,i}$	= Various values of measured Line current	A
I_0	= No load current @ E_{nom}	A
$I_{0,i}$	= Various values of measured no load current	A
P_0	= No load power @ E_{nom}	kW
$P_{0,i}$	= Various values of measured no load power	kW
P_{ag}	= Air gap power	kW
$P_{cu,0}$	= No load stator winding copper losses	kW
$P_{cu,s}$	= Stator winding copper losses	kW
$P_{cu,r}$	= Rotor copper losses	kW
P_{Fe}	= Stator core (iron) losses	kW
PF_{nom}	= Rated power factor	decimals
P_i	= Absorbed Input power (measured)	kW
P_{ic}	= Rated Input power calculated	kW
P_{LL}	= Stray losses	kW
P_{mech}	= Friction and windage losses	kW
P_{nom}	= Rated output power (HP x 0.746)	kW
P_{Oc}	= Output power calculated	kW
R_1	= Measured Line resistance of the stator winding "cold" (@ temperature T_1)	Ohm
$R_{r,cold}$	= Line resistance of the stator winding at reference temperature, "cold" $T_{r,cold}$	Ohm
$R_{r,hot}$	= Line resistance of the stator winding at reference temperature, "hot" $T_{r,hot}$	Ohm
R_2	= Measured Line resistance of stator winding "hot" (@ temperature T_2	Ohm
T_a	= Ambient temperature	°C
T_1	= Measured Average temperature of the stator winding denominated as "cold"	°C
$T_{r,cold}$	= Reference temperature in "cold" conditions	°C
$T_{r,hot}$	= Reference temperature in "hot" conditions	°C
ΔT_{nom}	= Motor rated temperature rise	°C
ΔT	= Measured (actual) temperature rise of the motor	°C

1. Basic data to be recorded for the test protocol

Mandatory name plate details

- *Rated output power (HP x 0.746) — P_{nom} — kW
- *Rated speed — n_{nom} — rpm
- *Rated voltage — E_{nom} — Volts
- *Rated current — I_{nom} — A
- *Rated efficiency — e_{nom} — %
- *Rated power factor — PF_{nom} — decimal
- *Class of insulation — options: B, F, H
- *Motor rated winding temperature rise — ΔT_{nom} — °C

Other information regarding the motor

- Motor type, Frame, enclosure, Mounting, Rating, Duty, Service factor
- Motor manufacturer
- Serial Number
- Year of manufacturing
- Customer Identification
- Customer Motor Identification (TAG)
- Motor Identification at repairer
- Application data:
  - Type
  - Duty
  - Starting (numbers, procedure, time duration)
  - Estimated load
- How long the motor has been in service
- How many repairs
- Type of previous repairs (a list to be provided)
- Cause of failure (a list to be provided)
- Type of current repair (a list to be provided)
- Intermediate tests and results during repair procedure

2. Basic measurement to be performed and recorded

Cold LINE resistance measurements at ambient temperature by average:

R_1 @ T_1 Ohms, °C

3. Conversion of the line resistance to the reference temperature in “cold” situation:

$$R_{r,cold} = [R_1 (T_{r,cold} + k) / (T_1 + k)] \quad (1)$$

k = 234.5

$T_{r,cold}$ = 25 °C

4. Performing No-load test of the motor in "cold" situation at rated frequency and variable voltage

The scope of the no-load test is to obtain losses separation of the Friction & windage and Iron losses.

No-load test of the motor in "cold" situation at variable voltage, recording for minimum five recommended points (as p.u. of E_{nom}) :

- Line Voltage values (average) **$E_{L,i}$** Volts
- Various values of measured absorbed no-load power **$P_{0,i}$** kW
- Various values of measured no-load line current (average) **$I_{0,i}$** A

Table 1. Recording No load test of the motor in "cold" situation

Recommended $E_{L,i}$ [p.u. of E_{nom}]	1.25	1.0	0.75	0.5	0.25	Obtaining Estimated Values @ E_{nom}
$P_{0,i}$						$\mathbf{P_0} \rightarrow [P_0 = f(E_{L,i}) \cap E_L = E_{nom}$
$I_{0,i}$						$\mathbf{I_0} \rightarrow [I_0 = \varphi(E_{L,i}) \cap I_L = E_{nom}$

Based on data obtained from the test recorded on table 1, the following graphs will be available:

- No load power variation function of the line voltage: $P_0 = f(E_{L,i})$
- No load line current variation function of the line voltage $I_0 = \varphi(E_{L,i})$

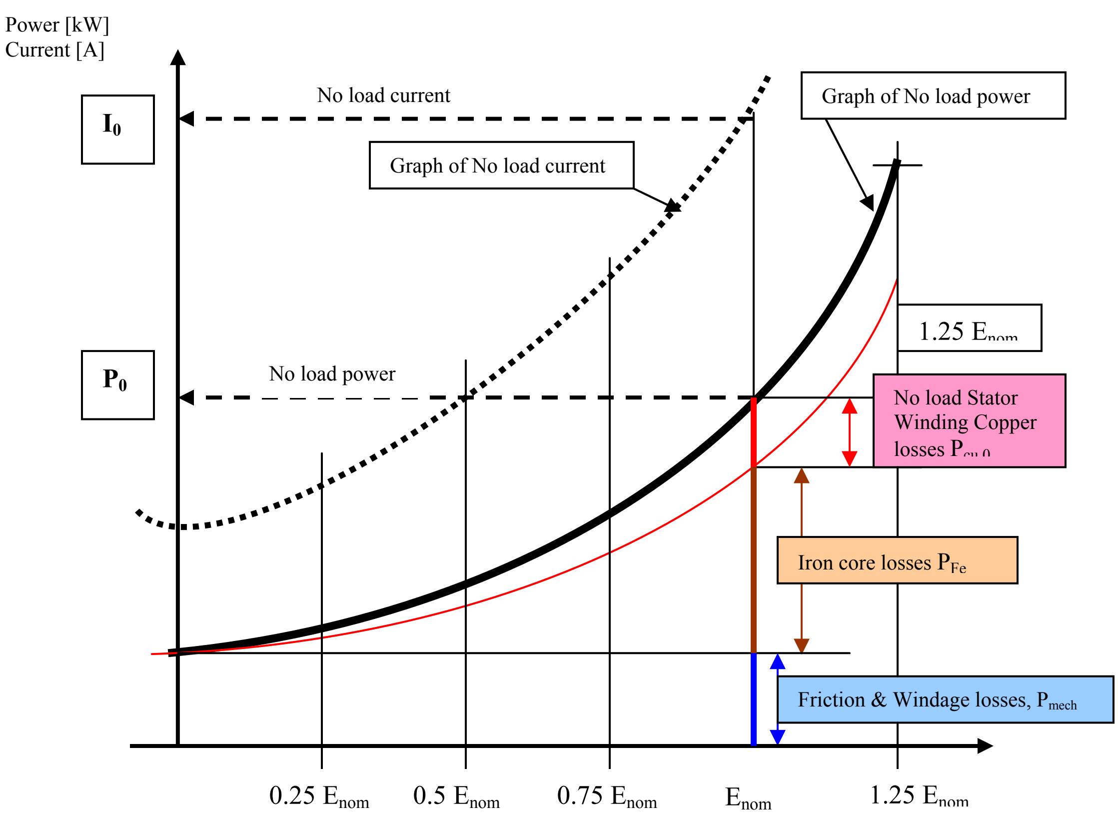

Figure 1. Losses separation after performing a No Load test

The graph of No load power: $\mathbf{P_0 = f\ (E_{L,\,i})}$ is a parabolic function of $E_{L,i}$

$$P_0 = A \cdot E_{L,i}^{2} + B \cdot E_{L,i} + C$$

A, B, C constants are obtainable from test data recorded as per table 1 with values of $E_{L,i}$ around those recommended in the first row of the table 1 (as p.u. of E_{nom}).

The graph of No load current: $\mathbf{I_0 = \varphi\ (E_{L,\,i})}$ is a parabolic function of $E_{L,i}$

$$I_0 = D \cdot E_{L,i}^{2} + E \cdot E_{L,i} + F$$

D, E, F constants are obtainable from test data recorded as per table 1 with values of $E_{L,i}$ around those recommended in the first row of the table 1(as p.u. of E_{nom}).

5. NO Load losses separation (COLD Situation)

Estimating No load power, P_0 @ E_{nom}

It results from intersection of the graph $P_0 = f\ (E_{L,i})$ with ordinate $E_L = E_{nom}$

Estimating No load current, I_0 @ E_{nom}

It results from intersection of the graph $I_0 = \varphi\ (E_{L,i})$ with ordinate $E_L = E_{nom}$

Estimating Friction & Windage losses P_{mech}

It results from intersection of graph $P_0 = f\ (E_{L,i})$ with ordinate $E_L = 0$

$$\mathbf{P_{mech} = C} \qquad \mathbf{(2)}$$

Estimating No load stator winding copper losses, $P_{cu,0}$

$$\mathbf{P_{cu,0}} = [1.5 \text{ x } R_{r,cold} \text{ x } I_0^{2}] / 1000 \qquad \mathbf{(3)}$$

I_0 = No load current, from table § 5.1

$R_{r,cold}$ = Line resistance of stator winding from § 3.

Estimating Stator core (iron) losses P_{Fe}

$$\mathbf{P_{Fe}} = P_0 - P_{cu,0} - P_{mech} \qquad \mathbf{(4)}$$

P_0 obtained from § 5.1

$P_{cu,0}$ obtained from § 5.4

P_{mech} obtained from § 5.3

6. Estimating Electrical Rated Input Power P_{ic} from name plate data

$$\mathbf{P_{ic}} = [\sqrt{3} \text{ x } I_{nom} \text{ x } E_{nom} \text{ x } PF_{nom}] / 1000 \qquad \mathbf{(5)}$$

P_{ic} = Rated Input power calculated, kW

I_{nom} = Rated line current

E_{nom} = Rated line voltage

PF_{nom} = Rated Power factor

7. Estimating Stray losses by assigned allowance (to IEC 61972) P_{LL}

$$\mathbf{P_{LL}} = \{P_{ic}\,[3.0 - 0.652\,\log_{10}(P_{nom} / 1\text{ kW})]\} / 100 \qquad \textbf{(6)}$$

P_{nom} = Rated output power [kW]

8. Estimating motor parameters in hot conditions

This estimation is used when performing a no load cold test, or an efficiency test i.e. the temperature rise at rated load has not been measured (to IEC 61972)

Estimating Reference temperature in "hot" conditions $T_{r,hot}$

The line resistance of the stator winding should be corrected to the reference temperatures $T_{r,hot}$ function of the designed temperature rise to the class of insulation of the motor, or related to the motor rated or actual temperature rise ΔT_{nom}, as specified in table 2

Table 2. Reference temperatures and Temperature rises function of Class of insulation design

Class of insulation system	Reference temperature $T_{r,hot}$ [°C]	Rated temperature rise ΔT_{nom} [°C]	Measured (actual) temperature rise ΔT [°C]
B	95	80	
F	115	105	
H	135	125	

Use one of the following:

$$T_{r,hot} = T_{r,cold} + \Delta T_{nom} \qquad \textbf{(7.a)}$$

$$T_{r,hot} = T_{r,cold} + \Delta T \qquad \textbf{(7.b)}$$

$$T_{r,hot} = \text{value from column 2 of Table 2} \qquad \textbf{(7.c)}$$

The **(7.a)** is preferred.

If measured (actual) temperature rise ΔT [°C] is available**, (7.b)** will be preferred.

If no data availability, then **(7.c)** is to be used

Estimating Line resistance of the stator winding $R_{r,hot}$ @ reference temperature, "hot" $T_{r,hot}$

$$\mathbf{R_{r,hot}} = [R_1\,(T_{r,hot} + k) / (T_1 + k)] \qquad \textbf{(8)}$$

k = 234.5

R_1 @ T_1, from § 1

9. Estimating the power flow in "hot conditions" @ reference temperature $T_{r,hot}$

Estimating $P_{cu,s}$ = Stator winding copper losses

$$\mathbf{P_{cu,s}} = 1.5 \times R_{r,hot} \times I_{nom}^2 / 1000 \qquad \textbf{(9)}$$

Estimating P_{ag} = Air gap power

$$\mathbf{P_{ag}} = P_{ic} - P_{cu,s} - P_{Fe} - P_{LL} \qquad \textbf{(10)}$$

Estimating $P_{cu,r}$ = Rotor copper losses

$$\mathbf{P_{cu,r}} = [(n_s - n_{nom}) / n_s] \times P_{ag} \quad \textbf{(11)}$$

9.4. Estimating P_{Oc} = Output power calculated

$$\mathbf{P_{O,c}} = P_{ag} - P_{cu,r} - P_{mech} \quad \textbf{(12)}$$

10. Estimating the motor efficiency at calculated output power and reference temperature

$$\mathbf{e_c = [P_{O,c} / P_{ic}] \times 100\%} \quad \textbf{(13)}$$