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)	$\mathbf{P_{nom}}$	kW
- *Rated speed	$\mathbf{n_{nom}}$	rpm
- *Rated voltage	$\mathbf{E_{nom}}$	Volts
- *Rated current	$\mathbf{I_{nom}}$	A
- *Rated efficiency	$\mathbf{e_{nom}}$	%
- *Rated power factor	$\mathbf{PF_{nom}}$	decimal
- *Class of insulation	options: B, F, H	
- *Motor rated winding temperature rise	$\mathbf{\Delta T_{nom}}$	°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:

$\mathbf{R_1 \ @ \ T_1}$ Ohms, °C

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

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

$k = 234.5$

$T_{r,cold} = 25$ °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)	$\mathbf{E_{L,i}}$	Volts
- Various values of measured absorbed no-load power	$\mathbf{P_{0,i}}$	kW
- Various values of measured no-load line current (average)	$\mathbf{I_{0,i}}$	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 $I_0 = \varphi(E_{L,i})$

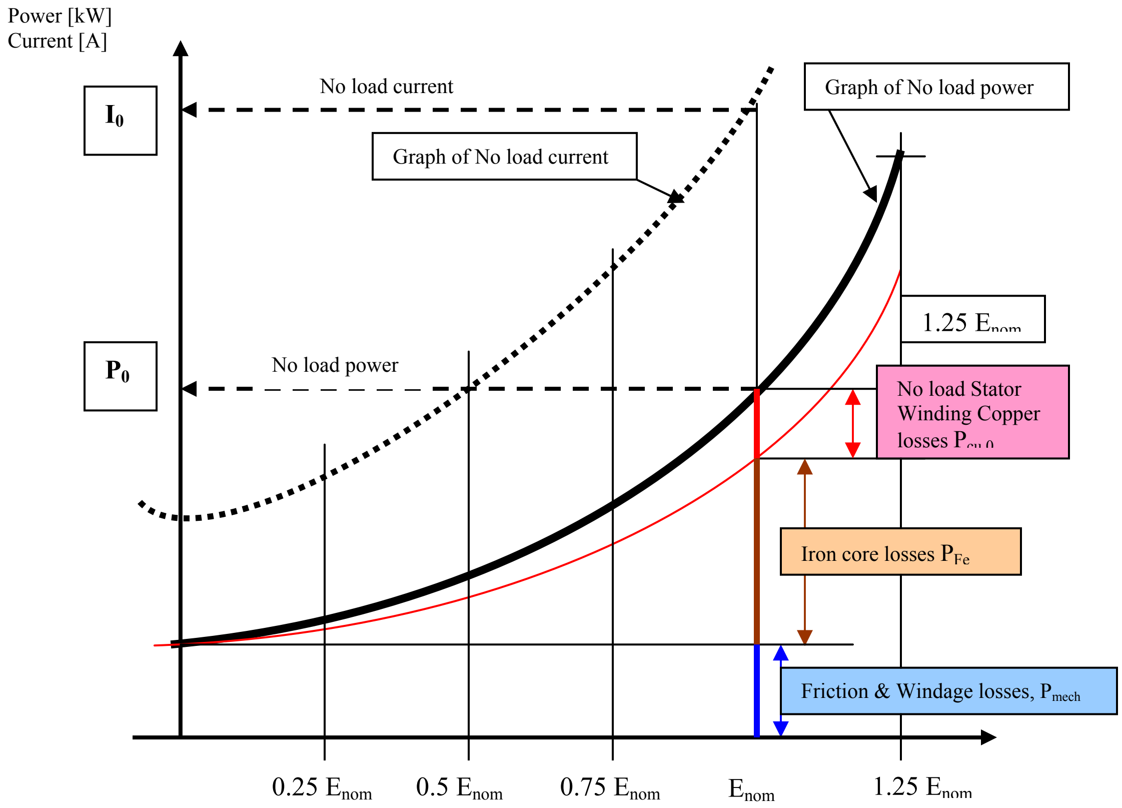

Figure 1. Losses separation after performing a No Load test

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, $P_{cu,0}$

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

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

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

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

$$\mathbf{P_{cu,r}} = [(n_s - n_{nom}) / n_s] \text{ x } P_{ag} \tag{11}$$

9.4. Estimating $\mathbf{P_{Oc}}$ = Output power calculated

$$\mathbf{P_{O,c}} = P_{ag} - P_{cu,r} - P_{mech} \tag{12}$$

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

$$\mathbf{e_c = [P_{O,c} / P_{ic}] \text{ x } 100\%} \tag{13}$$