Motor Summit 2007
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Motor Summit 2007

Comparison of Test Methods for the Determination of Measured Efficiency

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Natural Resources Canada

- **Branch of Canadian Federal Government**
  - *Responsible for energy-related initiatives*
  - *Active cooperation with Canadian electric utilities*
- **Supports Promotion of Energy-Efficient Products**
  - *Promotion of products through education/standards*
    - *Can-Most motor selection software (Motor Master)*
    - *Funding for Canadian Standards Association (CSA)*
  - *Implementation of energy performance standards*
    - *Legislation implemented in 1997 for electric motors*
    - *Certification of products and compliance with legislation*
- **Provides Funding for Evaluation of Test Methods**
  - *Support for global cooperation and harmonization*

Reasons for Harmonization

- **Common Standards for Energy Performance**
  - *Clear definitions and standards for energy performance*
  - *Adoption of accurate and repeatable test methods*
  - *Standard requirements for performance reporting (labeling)*
- **Supports Promotion of Energy-Efficient Products**
  - *Clear, concise guidelines for classification of performance*
  - *Common basis for performance regulation and enforcement*
- **Facilitates Global Compliance for Products**
  - *Elimination of duplication in testing and certification*
  - *Reduction in costs for repetitive testing and certification*
  - *Facilitates requirements of a global market place*

Comparison of Test Methods

- **CSA C390 (1998) – Pending Revision 2007/08**
  - *Indirect and Allowance Methods*
  - *Revisions to reflect "best practice" application*
- **IEEE 112 (2004)**
  - *Indirect and Allowance Methods*
  - *Direct Method (Reverse Rotation Test)*
- **IEC 60034-2 (Proposed 4th Edition)**
  - *Indirect and Allowance Methods (IEC 61972)*
  - *Direct Method (Eh-Star Test)*
  - *Direct method (Reverse Rotation Test)*

"Determination of Stray Load Losses is the Defining Difference Between Test Methodologies"

Methods for P_{LL} Measurement

- ***Indirect Test Methods for P_{LL} Measurement***
  - *CSA C390, Method 1*
  - *IEC 61972, Method 1 (included in proposed 60034-2)*
  - *IEEE 112, Method B*
- ***Direct Test Methods for P_{LL} Measurement***
  - *IEEE 112, Method E/F (reverse rotation test)*
  - *IEC 60034-2, 4th edition (reverse rotation and Eh-Star test)*
- ***Assigned Allowances for P_{LL} Losses***
  - *IEC 61972, Method 2 (% of measured input power)*
  - *IEEE 112, Method E1/F1 (% of rated output power)*
  - *CSA C390, Method 2 (% of rated output power)*

Indirect Method - IEEE/CSA/IEC

- **"Best Practice" Application of the Indirect Methods Provide Similar Results**
  - *Input/output methods with segregation of losses*
  - *Most refined test methods presently in use globally*
  - *Quality instrumentation provides excellent accuracy*
  - *Similar application of temperature measurements*
  - *Adequate thermal stabilization during test*
  - *High values of correlation (>0.99) provide repeatability*
- **Differences in Application of Indirect Methods**
  - *Differences can arise due to variances in requirements for instrumentation accuracy, temperature measurement and stabilization and specification of correlation coefficients*

Indirect Method – CSA C390

- **Further Refinement to Indirect Method Supports Improvement in Accuracy and Repeatability**
  - Inclusion of an additional requirement for “maximum uncertainty of measurement”
  - Replaces focus on accuracy at the full-scale rating of the measurement device or instrument
  - Accounts for combined error present in multiple component systems used for measurement
  - Addresses the issue of accuracy for actual measurement rather than concentrating on allowable error at the rating of the measuring device
- **Introduction of “Maximum Uncertainty of Measurement” in Pending CSA C390 (2008)**

Indirect Method - IEEE/CSA/IEC

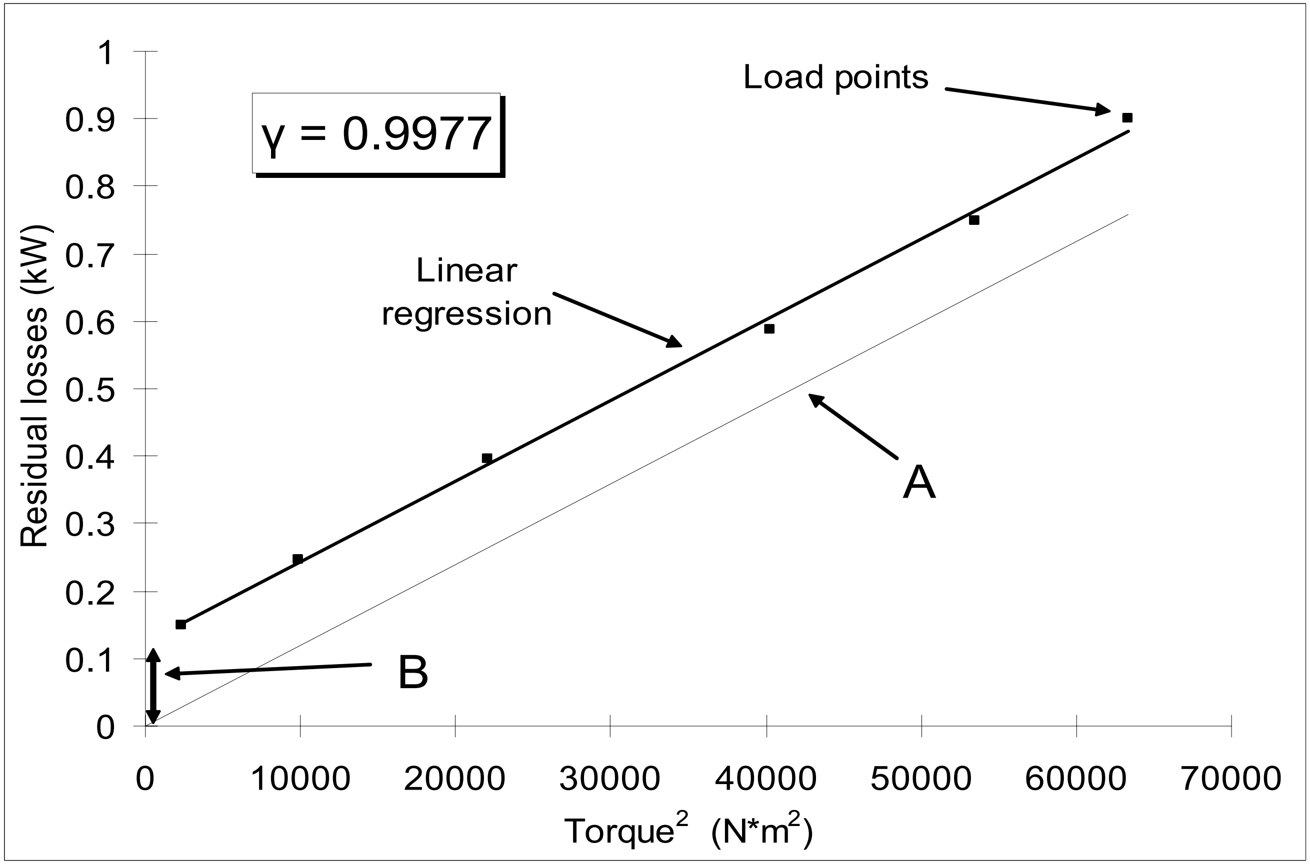
- **The Determination of Additional Losses (stray load losses) is a Critical Issue During Testing**
- **Residual Losses, P_{Lr}**
  - $P_{Lr} = P_{in} - P_{out} - P_s - P_r - P_{fe} - P_{fw}$
  - Definitions

P_{in} : Input Power
P_{out} : Shaft Power (Torque * Speed)
P_s : Stator Losses
P_r : Rotor Losses
P_{fe} : Iron Losses
P_{fw} : Windage/Friction Losses

Indirect Method - IEEE/IEC/CSA

Residual losses (P_{Lr})

$$P_{Lr} = A\,T^2 + B$$



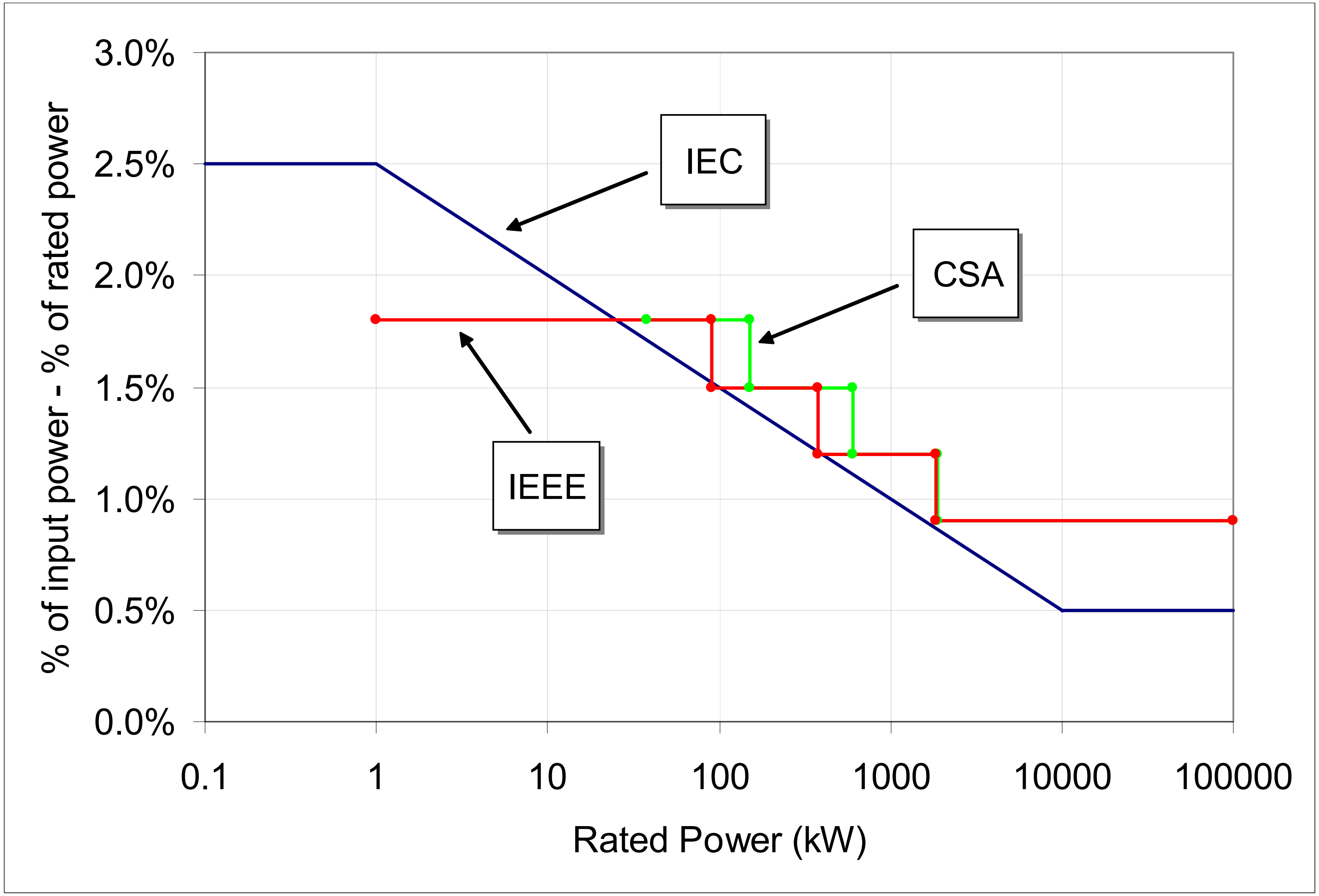
Indirect Method - IEEE/CSA/IEC

- **Specification of the Correlation Coefficient is Important to Maintain Accuracy and Achieve Repeatability in Testing**
  - *IEEE/CSA specify 0.90, IEC specifies 0.95*
- **Additional Losses, P_{LL}, Are Dependent on the Correlation Coefficient Obtained From the Regression Analysis**
  - $P_{LL} = A\ T^2$
- **A Higher Degree of Correlation is an Indicator of the Quality of the Test**

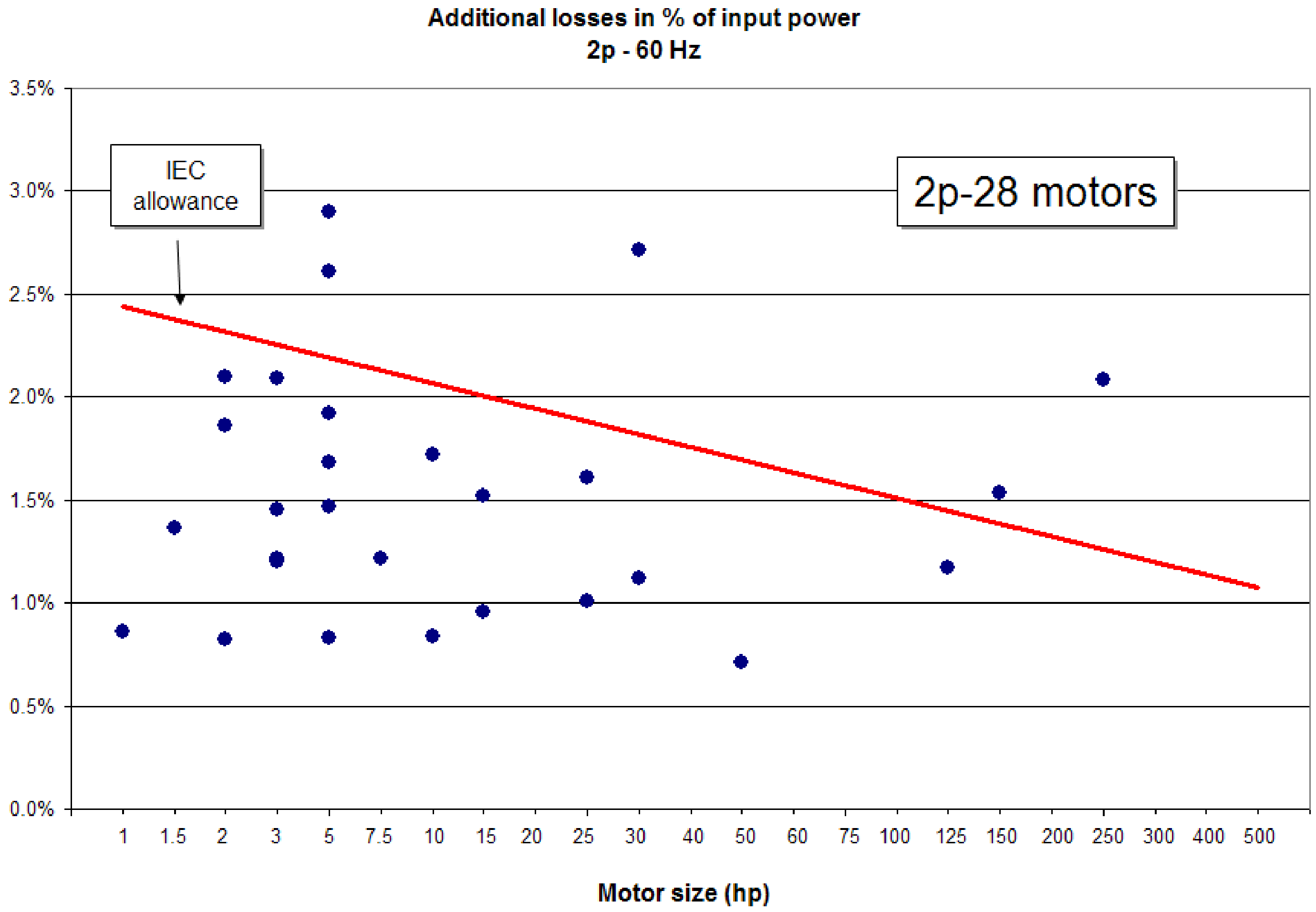
Assigned Allowance Methods

- **Allowance Methods are Subjective Approximations Based on Assumption That**
  - Induction machines have similar ratios of losses
  - Segregation of losses can be defined by ratings
- **Ratios for Stray-Load Loss Allowances**
  - Computed as a percentage of rated output power (CSA, IEEE) or percentage of measured input power (IEC)
  - IEC 61972 (proposed for 60034-2, edition 4) provides for a more rigorous application of allowances than IEEE/CSA

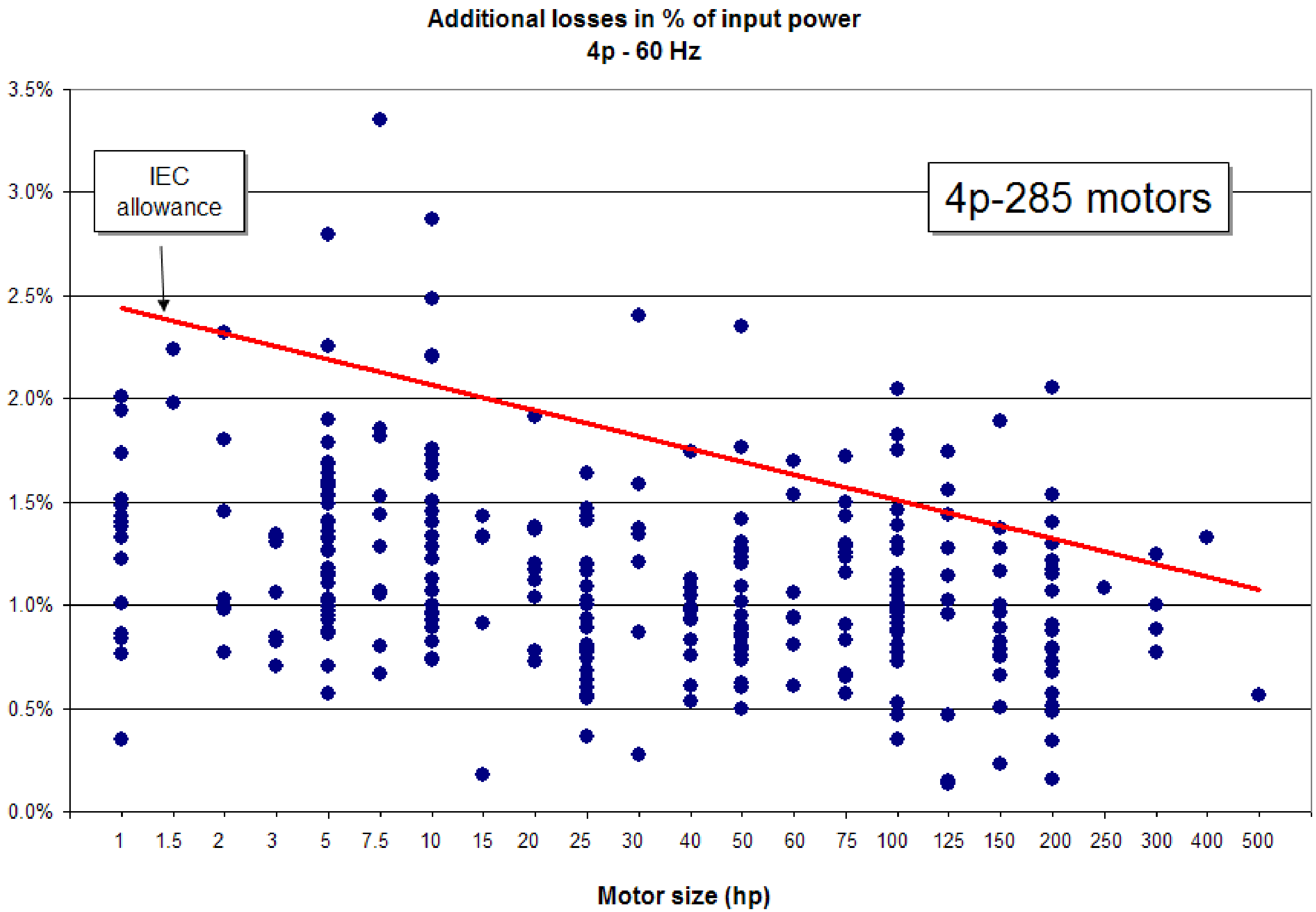
Assigned Allowance Methods



Additional Losses (Comparison)



Additional Losses (Comparison)



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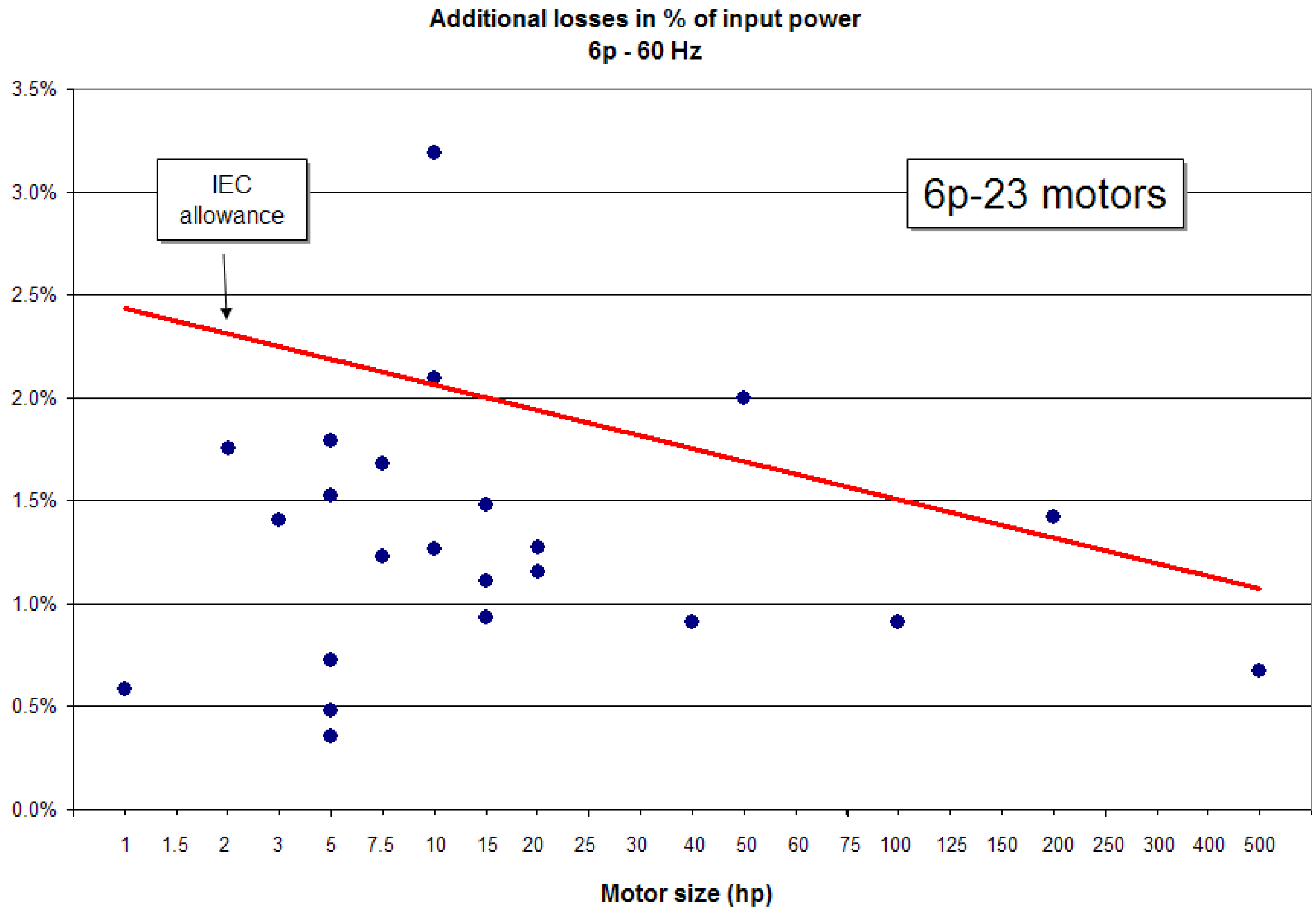
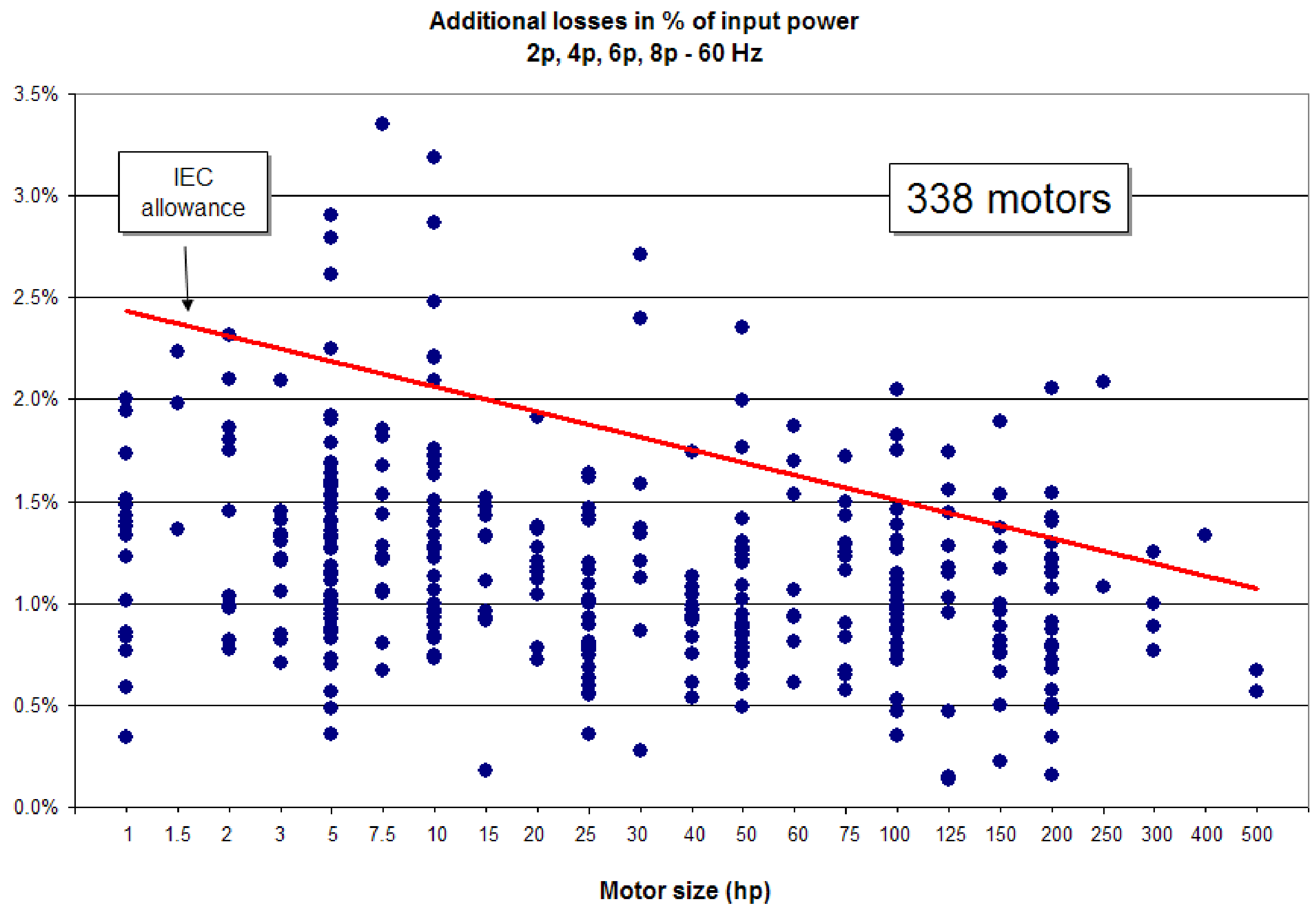


Additional Losses (Comparison)



Direct Methods

- **Enable Additional (Stray-Load) Losses to be Evaluated Without Requirement for Loading**
- **Risk of Substantial Variation in Stray-Load Loss Measurement**
  - *Reverse rotation test method (IEEE 112, Method E/F)*
  - *Eh-Star test method (Proposed IEC 60034-2,4^{th} Edition)*
- **Accuracy and Repeatability Have NOT Been Adequately Demonstrated in Laboratory**
  - *Substantial stray-load loss variation using indirect methods*
  - *Selection of resistance, Reh, can require multiple tests*
  - *Impact of temperature not adequately defined*

Reverse Rotation Test (RRT)

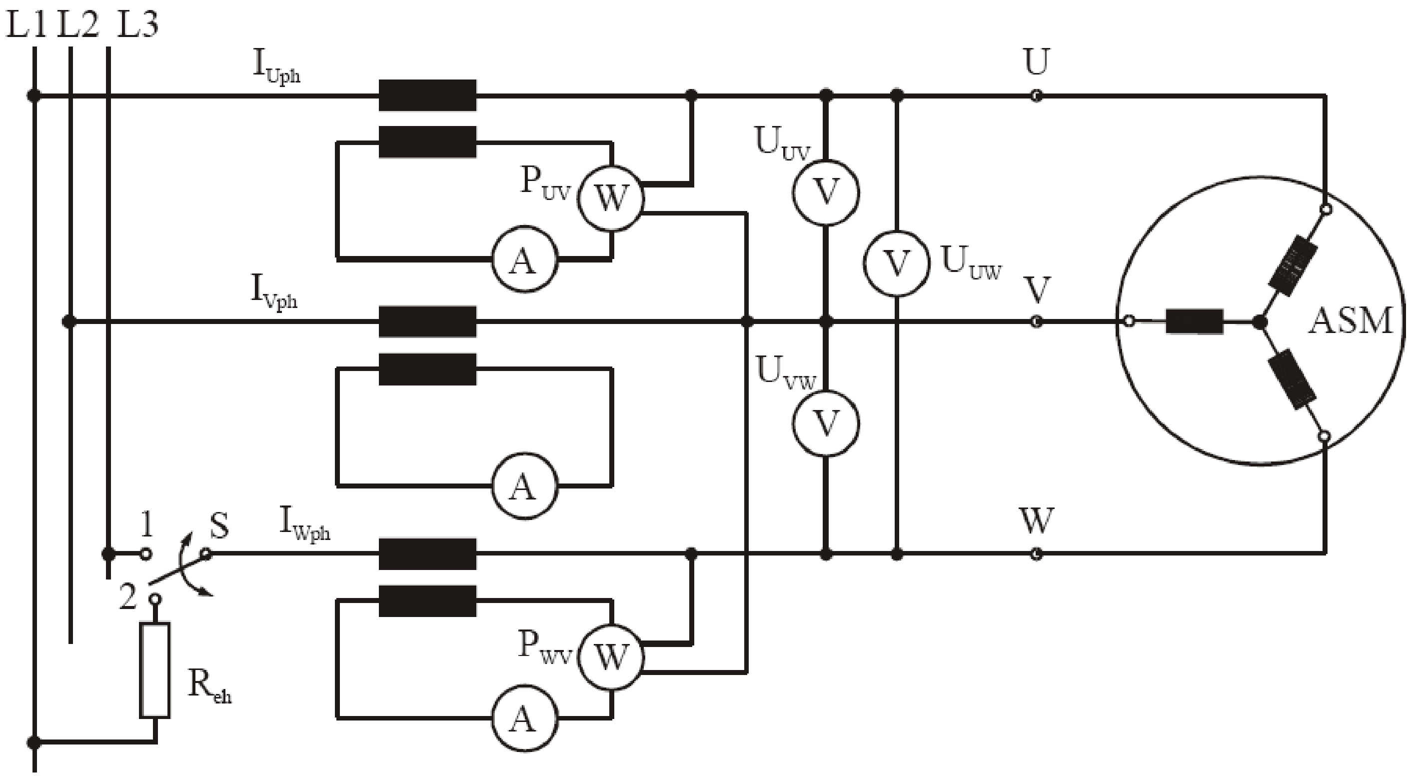
- **Additional Losses at Fundamental Frequency**
  - *Rotor has to be removed from motor*
- **Additional Losses at Higher Frequency**
  - *Inverse rotation of motor required*
  - *Mechanical means required for rotor rotation*
  - *Wattmeter requires high accuracy at low power factor*

"Results obtained typically show twice the value of losses obtained via indirect method"

Eh-Star Test Method

- ***<u>Method Allows for Evaluation of Additional Losses without Dynamometer Loading</u>***
- ***Asymmetric Supply Using a Variable, Single-Phase AC Supply and a Resistor, R_{eh}, Connected to the Motor Winding***
- ***The Asymmetrical Supplied Motor is Considered as Two Machines***
  - *One component is fed by the positive sequence*
  - *One component is fed by the negative sequence*

Test Configuration



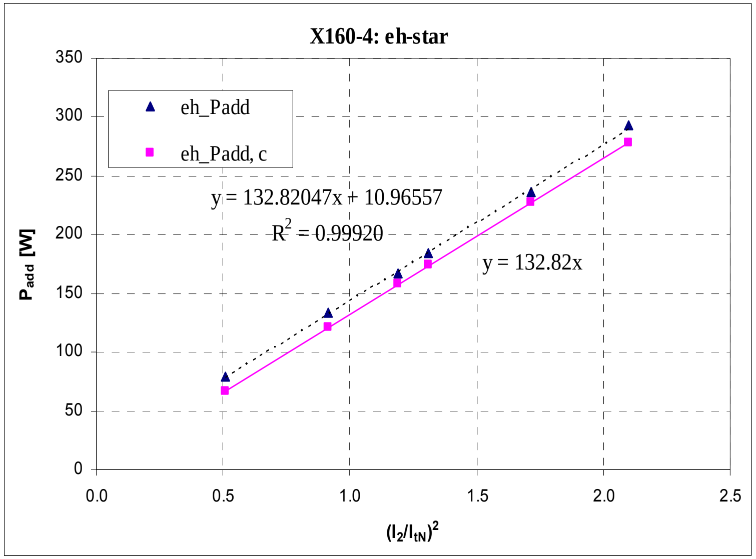
Source: IEC 60034-2 Ed. 4

Computation

Evaluation of eh-star-test, guideline, Version 1.3 X160-4
Algorithm written by A. Binder/Darmstadt University of Technology 13.07.2005

		load point	1	2	3	4	5	6
	rated line- line voltage	U_N [V]	**400.0**	**400.0**	**400.0**	**400.0**	**400.0**	**400.0**
	rated line current	I_N [A]	**21.62**	**21.62**	**21.62**	**21.62**	**21.62**	**21.62**
	no-load line current	I_0 [A]	**10.92**	**10.92**	**10.92**	**10.92**	**10.92**	**10.92**
	frequency	f [Hz]	**50**	**50**	**50**	**50**	**50**	**50**
Input	number of poles	2p	**4**	**4**	**4**	**4**	**4**	**4**
	line- line voltage	U_{UV} [V]	**152.48**	**140.23**	**125.01**	**120.12**	**107.16**	**82.7**
	line- line voltage	U_{VW} [V]	**166.26**	**152.81**	**136.26**	**130.89**	**116.76**	**89.94**
	line- line voltage	U_{WU} [V]	**47.49**	**42.82**	**37.33**	**35.56**	**30.95**	**22.3**
	phase current	I_{Uph} [A]	**27.267**	**24.719**	**21.688**	**20.706**	**18.245**	**13.807**
	phase current	I_{Vph} [A]	**32.549**	**29.452**	**25.787**	**24.609**	**21.661**	**16.397**
	phase current	I_{Wph} [A]	**22.361**	**20.134**	**17.488**	**16.622**	**14.437**	**10.371**
	input pow er	$P_{e,in}$ [W]	**2456.7**	**2050.5**	**1600**	**1469.4**	**1155.42**	**684.81**
	speed	n [rpm]	**1467.5**	**1466.7**	**1466.4**	**1466.3**	**1465.3**	**1461.3**
data	phase resistance @ 20°C	$R_{s,\ 20°C}$ [Ω]	**0.362301**	**0.362301**	**0.362301**	**0.362301**	**0.36230067**	**0.36230067**
	line- line resistance @ 20°C	$R_{VW,\ 20°C}$ [Ω]	**0.710781**					
	line- line resistance @ begin	$R_{VW,\ begin}$ [Ω]	**0.73749**					
	line- line resistance @ end	$R_{VW,\ end}$ [Ω]	**0.770816**					
	core losses	P_{FeN} [W]	**312.41**	**312.41**	**312.41**	**312.41**	**312.41**	**312.41**
	friction & w indage losses	P_{fwN} [W]	**71.38**	**71.38**	**71.38**	**71.38**	**71.38**	**71.38**

	eh-resistance (operating)	R_{eh} [Ω]	2.1238	2.1268	2.1346	2.1393	2.1438	2.1502
	w inding temperature	temp [°C]	29.58	32.98	37.01	38.30	41.54	41.54
	positive sequence current	I_1 [A]	5.8784	5.3657	4.7681	4.5856	4.1404	3.4453
Output	negative sequence current	I_2 [A]	27.0377	24.4424	21.3614	20.3620	17.8526	13.2873
	ratio (positive/negative)	I_1 / I_2	0.2174	0.2195	0.2232	0.2252	0.2319	0.2593
	rated test current	I_{tN} [A]	18.6595	18.6595	18.6595	18.6595	18.6595	18.6595
	stray load losses	P_{add} [W]	**292.8050**	**236.1909**	**184.0135**	**167.4715**	**133.6884**	**79.5636**
	check of real pow er	P_{kont} [W]	2457.53	2051.23	1600.59	1469.95	1155.86	685.05
data		(I_2/I_{tN})^2	2.0996	1.7159	1.3106	1.1908	0.9154	0.5071
	stray load losses @ I_{tN}	*Intercept B*	10.9656		*Slope A*	**132.8205**	Correlat. Fact	0.99960
	corrected stray load losses	$P_{add,\ c}$ [W]	278.872	227.904	174.070	158.163	121.581	67.350



Source: A. Binder, M'hamed Aoulkadi, Dept. of Electrical Energy Conversion, Darmstadt University of Technology, Germany

Motors Tested

hp	460 V	575 V	50 Hz	60 Hz	2P	4P	6P	Wye	Delta
2	●			●		●		●	
5	●			●			●	●	
5		●		●		●		●	
10	●			●		●			●
10		●		●	●				●
20		●		●		●			●
50		●		●		●			●
75 / 55 kW	●	●	●	●	●				●
125 / 90 kW	●	●	●	●			●		●
150		●		●		●			●
200		●		●		●			●

Motors Tested

Size	Poles	Freq.	Enclosure	Nameplate Efficiency	EPACT/ CSA	Measured Efficiency
(hp)	(#)	(Hz)	()	(%)	(%)	(%)
2	4	60	TEFC	84.0	84.0	84.7
5	6	60	TEFC	87.5	87.5	88.7
5	4	60	TEFC	87.5	87.5	86.7
10	2	60	TEFC	89.7	89.5	91.0
10	4	60	TEFC	90.2	89.5	89.7
20	4	60	TEFC	93.0	91.0	93.2
50	4	60	TEFC	93.8	93.0	92.8
75 / 55 kW	2	60 / 50	TEFC	93.0 / 92.5	93.0 / 93.0	93.0 / 92.5
125 / 90 kW	6	60 / 50	TEFC	94.1 / 93.6	94.1 / 94.1	94.8 / 93.7
150	4	60	TEFC	95.8	95.0	95.9
200	4	60	TEFC	95.0	95.0	95.9

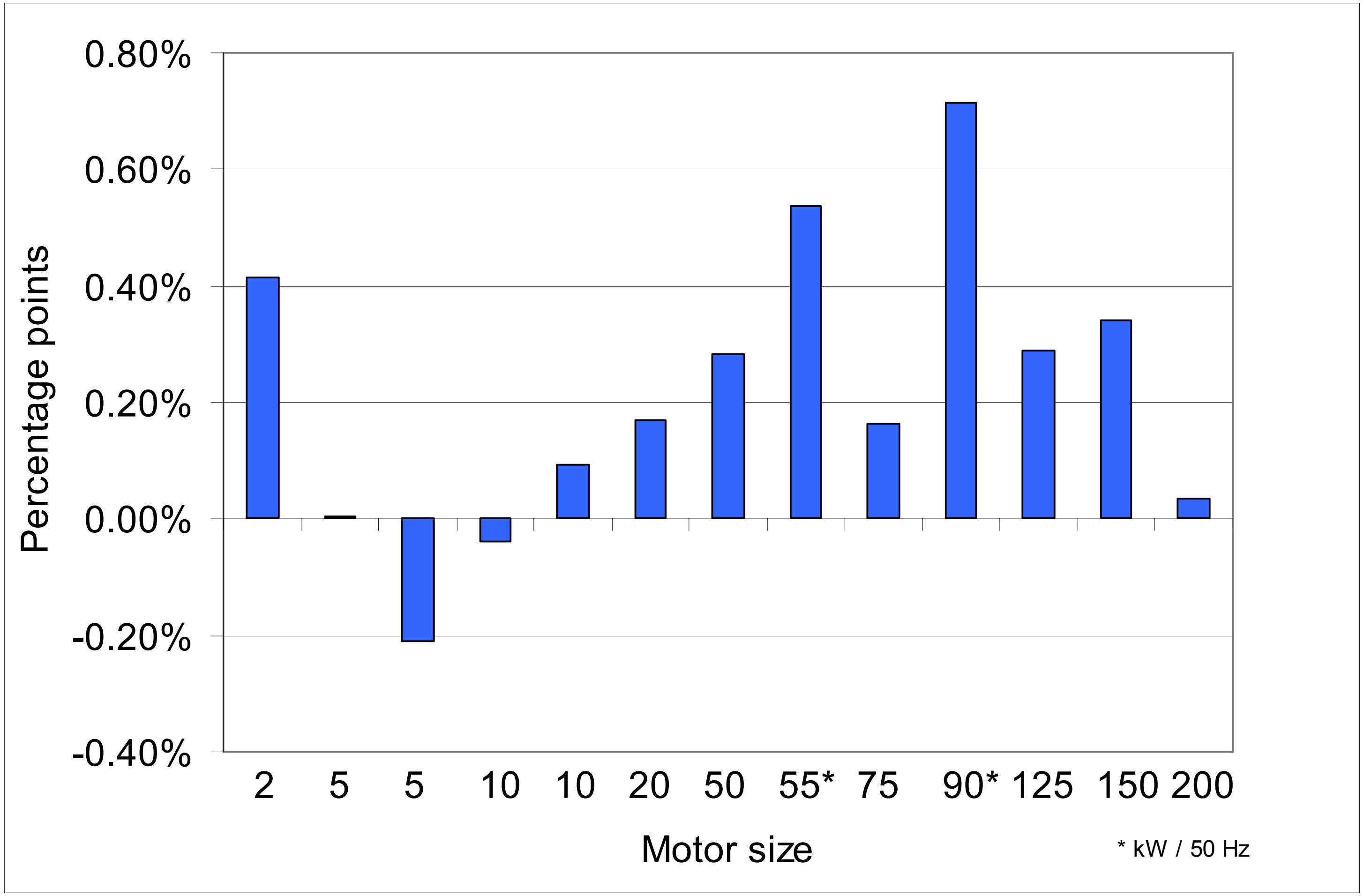
Comparison of P_{LL} Measurements

	Size	Poles	P_{LL} indirect	P_{LL} Eh-star	P_{LL} / Total	P_{LL} / Pin	Eh-star / indirect
	(hp)	(#)	(W)	(W)	(%)	(%)	(%)
	2	4	25	16	9.2%	1.4%	-35%
	5	6	31	31	6.5%	0.7%	-1%
	5	4	49	60	8.6%	1.1%	21%
	10	4	133	137	15.5%	1.6%	3%
	10	2	69	61	9.3%	0.8%	-12%
	20	4	224	195	20.7%	1.4%	-13%
	50	4	487	365	16.8%	1.2%	-25%
<	55 kW	2	1182	840	26.7%	2.0%	-29%
	75	2	948	843	22.7%	1.6%	-11%
<	90 kW	6	1822	1095	30.0%	1.9%	-40%
	125	6	1294	995	25.2%	1.3%	-23%
	150	4	1080	667	22.7%	0.9%	-38%
	200	4	1267	1211	19.8%	0.8%	-4%

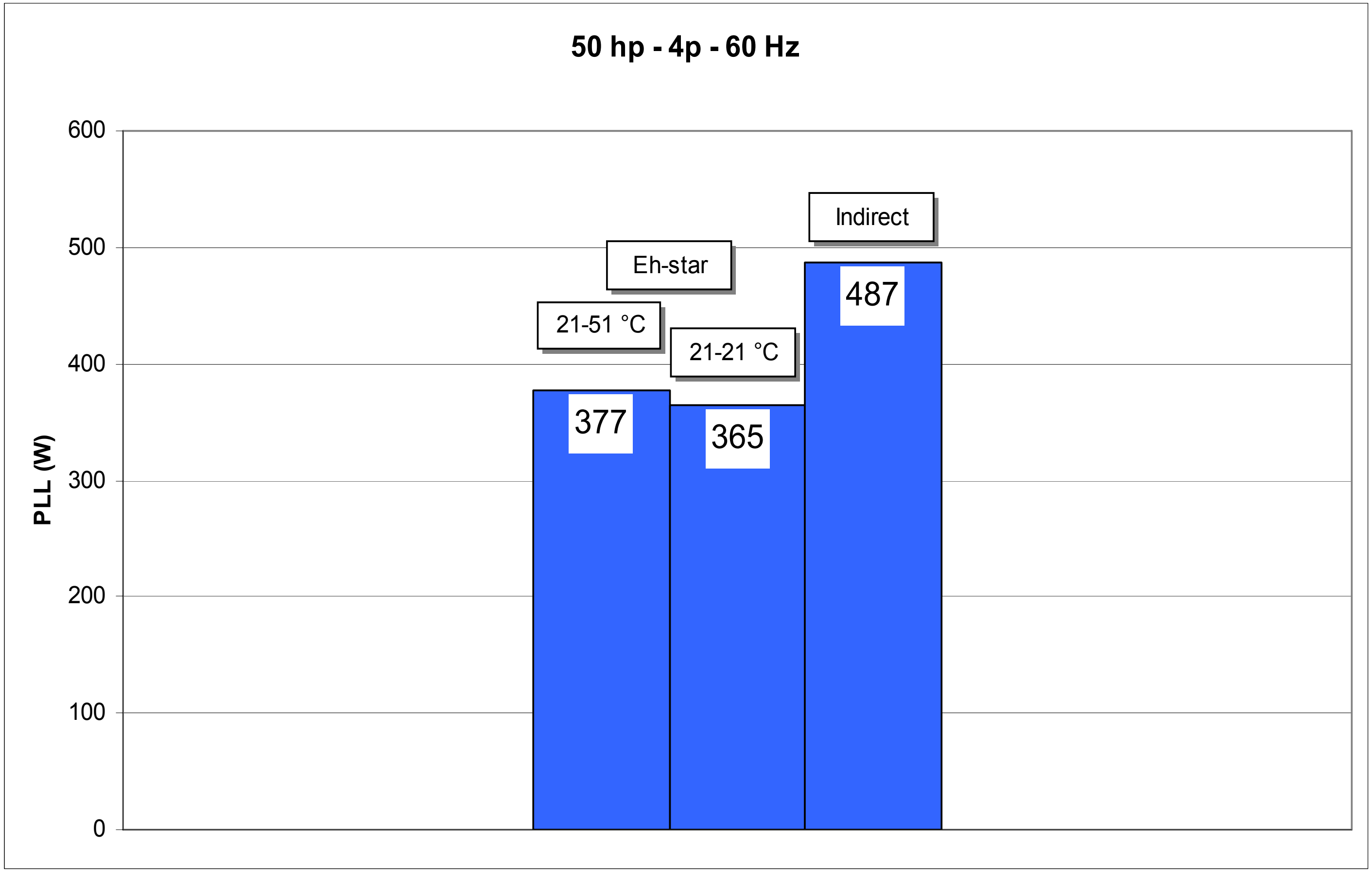
Impact on Measured Efficiency

Size	Efficiency with indirect method	Efficiency with Eh-star method	Difference in percentage points
(hp)	(%)	(%)	(p.p.)
2	84.7%	85.1%	0.42%
5	88.7%	88.7%	0.00%
5	86.7%	86.5%	-0.21%
10	89.7%	89.6%	-0.04%
10	91.0%	91.1%	0.09%
20	93.2%	93.4%	0.17%
50	92.8%	93.1%	0.28%
55 kW	92.5%	93.1%	0.54%
75	93.0%	93.2%	0.16%
90 kW	93.7%	94.4%	0.71%
125	94.8%	95.1%	0.29%
150	95.9%	96.3%	0.34%
200	95.9%	95.9%	0.03%

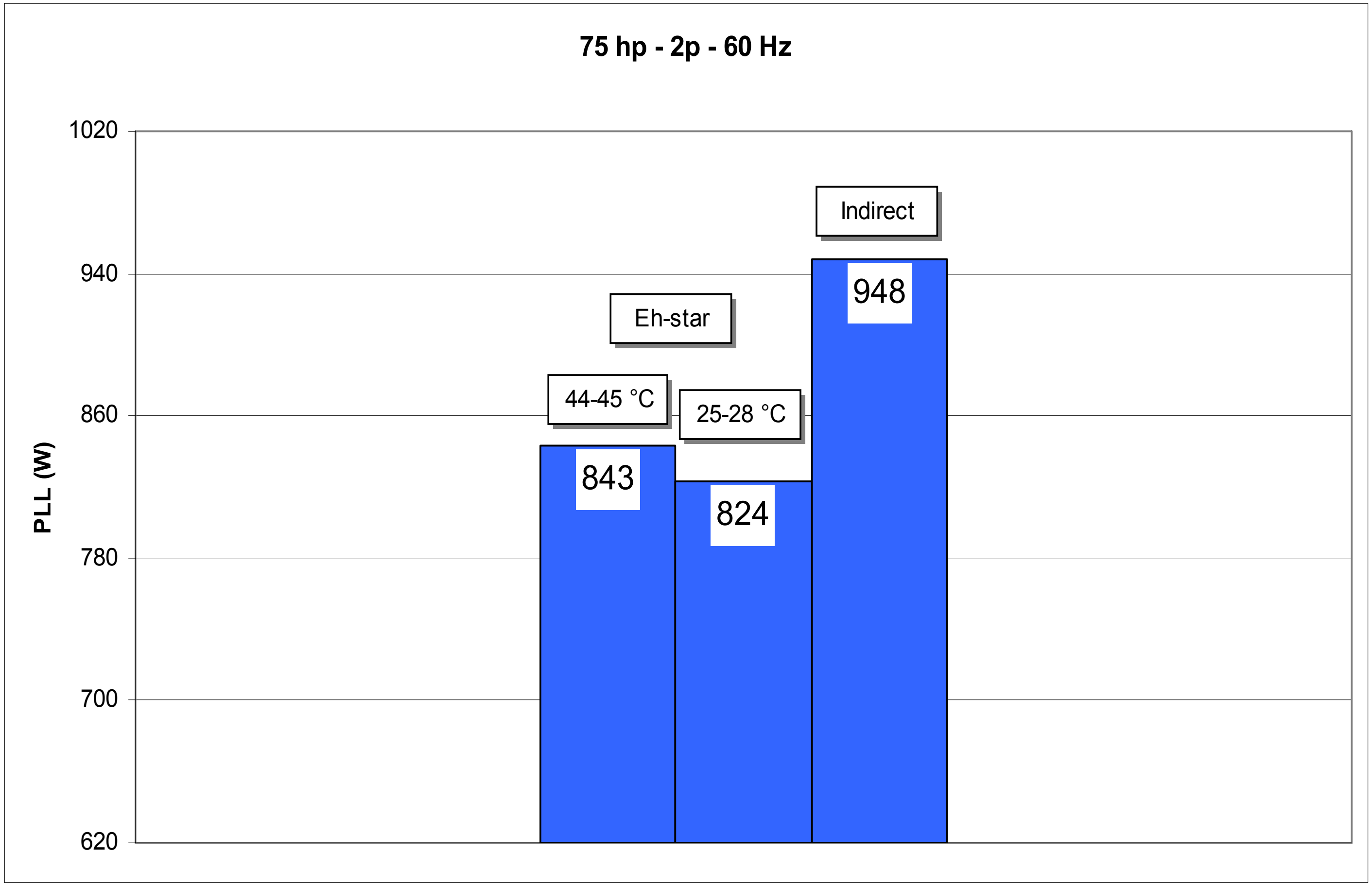
Impact on Measured Efficiency



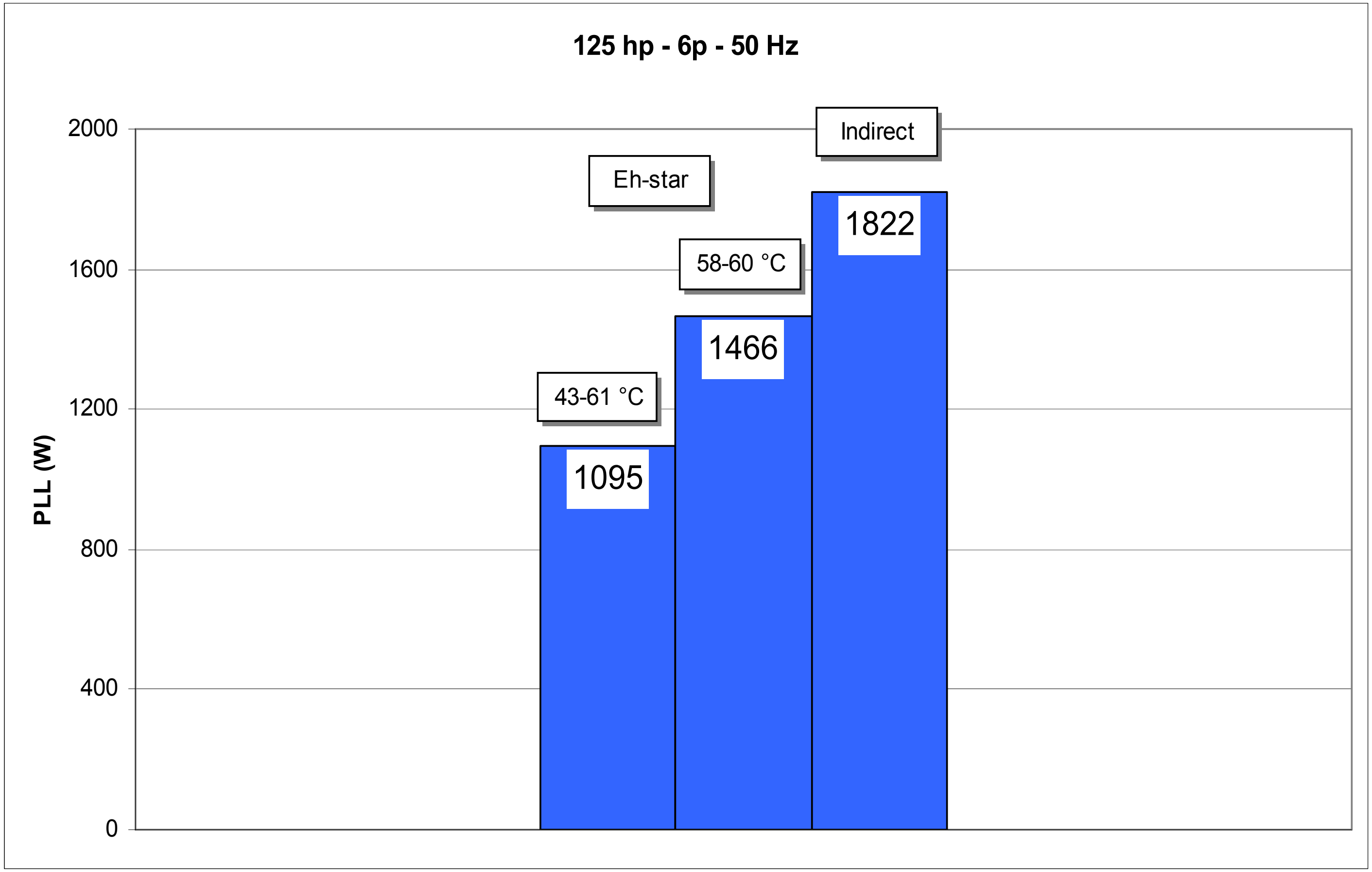
Impact of Motor Temperature



Impact of Motor Temperature



Impact of Motor Temperature



Impact of the Value of R_{eh}

- **R_{eh} selected to be approximately equal to the short circuit impedance of the motor**
  - *Approximately 20 percent of rated impedance of the motor*
  - *Represents starting point for the first test*
- **R_{eh} may require adjustment through multiple tests under the following conditions**
  - *Ratio of positive to negative sequence is greater than 30%*
  - *Rotational speed drops below the rated speed of the motor*
- **Impact of motor temperature on selection of R_{eh} not adequately addressed by standard**

Impact of the Value of R_{eh}

Reh meas./ Reh opt.	Corr. Coeff.	Ratio pos/neg	Temperature variation	Nom. Speed	Speed variation	P_{LL} eh-star	P_{LL} indirect
()	()	()	(°C)	(RPM)	(RPM)	(W)	(W)
0.92	**0.9918**	**0.30 - 0.60**	**66 - 83**	**3564**	**3551 - 3479**	**995**	**948**
1.07	**0.9966**	**0.27 - 0.46**	**21 - 64**	**3564**	**3570 - 3529**	**808**	**948**
1.60	**0.9963**	**0.22 - 0.37**	**21 - 60**	**3564**	**3575 - 3558**	**793**	**948**
2.13	**0.9928**	**0.19 - 0.32**	**46 - 66**	**3564**	**3583 - 3567**	**791**	**948**
2.13	**0.9959**	**0.20 - 0.32**	**21 - 53**	**3564**	**3583 - 3567**	**788**	**948**
2.13	**0.9994**	**0.19 - 0.29**	**43 - 45**	**3564**	**3584 - 3575**	**843**	**948**
2.13	**0.9995**	**0.19 - 0.32**	**23 - 28**	**3564**	**3585 - 3570**	**824**	**948**

Impact of Instrument Error

Eh-star method	Impact on P_{LL} of measurement error for each parameter (%)							
Parameter	U_{UV}	U_{VW}	U_{WU}	I_{uph}	I_{vph}	I_{wph}	$P_{e,in}$	n
Measurement error (%)	± 1	± 1	± 1	± 1	± 1	± 1	± 1	± 1_{rpm}
5 hp / 6p / 60 Hz	± 10	± 10	± 3	± 13	± 26	± 29	± 10	± 0
125 hp / 6p / 50 Hz	± 2	± 7	± 2	± 17	± 16	± 24	± 9	± 0
150 hp / 4p / 60 Hz	± 4	± 9	± 3	± 28	± 26	± 44	± 11	± 0

Comments on Eh-Star Method

- ***Three-Lead Delta Inter-Connected Motors Can Not Be Tested with the Method***
  - *Limited to Wye or Delta (six or more leads) motors*
- ***Obtaining Correct Value for R_{eh} Can Require Repetitive Tests (impacts motor temperature)***
- ***Initial Temperature and Temperature Rise During the Test Impact the Final Result***
  - *Proposed standard requires test to be conducted as quickly as possible to limit temperature variation, but does not specify acceptable temperature range or define "quickly"*
  - *Temperature range during test should be defined by the standard to ensure higher accuracy and repeatability*

Comments on Eh-Star Method

- **Instrumentation Accuracy Should Be Specified to Ensure the Highest Accuracy**
  - *Limit the variation of P_{LL} computed, specifically the current measurements*
- **A Minimum Value of the Correlation Coefficient Should Be Specified**
  - *A minimum correlation coefficient should be specified to improve the accuracy and repeatability of the test*
- **Proposed Application of the Eh-Star Method Allows for Substantial Variation in Results**
  - *Repeatability is a problem that must be addressed*
  - *Testing demonstrates the importance of this aspect*

Potential for Harmonization

- **Indirect Methods Provide Common Platform**
  - Basic methods similar between test standards
  - Improvements to accuracy and repeatability available
  - Latest improvements to CSA C390 further refinement
- **Allowance Methods Have Minimal Potential**
  - Based on subjective assumptions, not based in reality
  - Do not provide the basis for comparison and evaluation
- **Direct Methods Require Further Refinement**
  - Accuracy and repeatability not adequately proven
  - Compliance testing requires the ability to repeat results
  - Anticipated reductions in testing costs not realized

Questions ?