GREEN MOTOR INITIATIVE REWIND SAVINGS

Submitted to: The Regional Technical Forum

Dennis Bowns – Green Motors Practices Group
Erin Hope – Bonneville Power Administration

December 11, 2012

Contents

EXECUTIVE SUMMARY

The now established Green Motor Initiative (GMI) has significantly impacted the Pacific Northwest electric motor rewinding market through testing, processing and behavioral corrections. This first of a kind initiative has successfully established efficiency retaining process control and standards within participating motor service centers. The following report provides updated documentation and data for approved prescriptive electric motor rewind practices that retain motor efficiency during the rewind process. Additionally, it provides up-to-date rewind UES impact calculations, motor efficiency principles, and describes key findings and data collected during the implementation of GMI activities. The Green Motors Practices Group (GMPG) first presented documentation of these practices to the Regional Technical Forum (RTF) in May and July of 2007 originally establishing horsepower based rewinding Unit Energy Savings.

This report seeks to address the Measure Review Recommendation Memo issued by SBW, the updated Unit Energy Savings (UES) and Unit Energy Life (UEL) guidelines issued by the RTF. Updated key variables of UES and UEL requirements are:

- Hours of operation for Industrial motors updated with GMI Data;
- Hours of operation for Agricultural irrigation motors updated with Bonneville Power Administration irrigation pump test and utility billing analysis data sets;
- Agriculture irrigation motor load as a % of rated horsepower updated with Bonneville Power Administration irrigation pump test sets.

Key variables maintained from the original RTF approved Green Motors measures:

- Industrial Motor load as a percentage of rated horsepower as adopted by the RTF in July 2007;
- Efficiency retention as a percentage change in motor efficiency based on implementing efficiency retaining process controls.

Note: Studies referenced in this document support the original efficiency retention values

A requested sunset date of October 17, 2017 allows sufficient time to facilitate a broader market transformation where motor service center facilities implement ongoing efficiency retaining process control without the need for Utility incentive programs.

Due to the short time of program implementation at these facilities, without ongoing motor service center verification and training, loss of process control and behavior relapse remains a distinct possibility. Therefore, we strongly recommend the RTF approve the proposed updated Unit Energy Savings for Industrial and Agricultural motors as proposed.

MOTOR REWINDING INITIATIVE

BACKGROUND

The RTF initiated a review of all existing RTF approved UES measures to evaluate and update existing measures to the new UES specifications set by the RTF. Based on the review by SBW, the measures were determined not to meet the new UES Guideline specifications.

SUNSET DATE

The RTF has set July 06, 2014 as the sunset date for the GMI. Considering the market has taken longer to embrace the initiative than expected, and that market actor behavior relapse is a strong possibility, GMPG respectfully requests the RTF consider a sunset date extension of October 1st, 2017.

DEFINITION OF KEY TERMS, ACRONYMS AND SYMBOLS

AEMT — Association of Electrical and Mechanical Trades

Core loss – the hysteresis and eddy current losses within a motor’s magnetic core plate

EASA — Electrical Apparatus Service Association

Efficiency – one of the following ratios expressed as a percentage: output/input; (input - loss)/input or; output/(output + losses)

GMI – Green Motor Initiative (aka Green Rewind)

GMPG – Green Motors Practices Group, a non-profit Idaho Corporation

Load – all numerical values of the electrical and mechanical qualities that signify output torque demand made on an induction motor

Low voltage — electromotive force measuring 600 volts or less

Medium voltage — electromotive force greater than 600 volts but less than 6,000 volts

Motor Service Center – a company or organization actively involved in the repair and rewinding of rotating electromechanical equipment

Rotor I^2R loss – the loss in the rotor bars and end rings due to the magnitude of current and conductor resistance

Stray-load loss – the additional fundamental and high-frequency loss in the iron; strand and circulating-current losses in the stator winding; and harmonic loss in the rotor conductors under load

Stator I^2R loss – the loss in the stator winding due to the magnitude of current and conductor resistance

Third party verifier – A company or organization providing individuals suitably experienced to examine, oversee and train motor service centers participating in GMI and controlled rewind processes

Total loss – the difference between electrical input power and mechanical output power

W_t **represents** total motor losses

W_s **represents** stator I^2R (resistance) loss

W_r **represents** rotor I^2R (resistance) loss

W_c **represents** core losses

W_{fw} **represents** windage and friction loss

W_L **represents** stray losses

REQUIRED KNOWLEDGE, SKILLS, AND EQUIPMENT FOR CERTIFIED MOTOR SERVICE CENTERS

Personnel:

- Management commitment to energy-efficiency, quality, and customer service;
- Winding technicians with a minimum of five years of experience and adequate math skills to perform cross-sectional, winding conversion and watt-loss per pound calculations;
- Mechanics with the skill to precisely measure the inner and outer seating surfaces of bearings to manufacturers' tolerances;
- Technicians capable of performing core loss testing and interpreting the core loss data;
- Eight hours of professional development (training) annually.

Equipment:

- Burn-off oven with contact temperature sensing and water mist temperature control or approved alternative core stripping method;
- Core-loss tester with watts-loss per pound capability;
- Micrometers and associated verification standards appropriate to machinery and tolerance requirements encountered;
- Dynamic balancer with suitable weight capacity to test rotating equipment when encountered;
- Power supply voltage and current capable of no-load testing machinery encountered.

REQUIRED COMMISSIONING OF MOTOR SERVICE CENTERS

Annual Member Commitment: Participating motor service centers must sign and agree to complete a minimum of nine specific high-level service goals/tasks. See attachment A-1 Member Agreement sample.

Yearly On-Site Standards Verification: Participating motor service centers must have a yearly approved third party verification review pertinent to efficiency retention. Each center must remediate and correct any processes found lacking, and provide staff training as needed. Verification completion shall be by an experienced motor repair and rewinding professional with the following qualifications:

- Minimum of 10 years of motor service center employment including mechanical department lead or higher position.
- 3 years of experience participating in this or similar repair and efficiency process control program
- Completed a minimum of 6 EASA, or equivalent, technical training sessions including the following:
    - *How to Wind Three-Phase Stators;*
    - *Mechanical Repair Fundamentals of Electric Motors;*
    - *Principles of Large AC Motors.*
- Intimately familiarity with EASA's:
    - *Tech Note 16;*

- *Tech-note 17;*
- *The Effect of Repair Rewinding on Motor Efficiency – EASA/AEMT Rewind Study and Good Practice Guide to Maintain Motor Efficiency (2003).*

Verifying party will follow up to determine if the service center has performed appropriate remediation activities:

1. Verify calibration of critical tools and equipment;
2. Visually inspect burn-off oven, and observe oven settings and testing;
3. Inspect core-loss tester operation and check reported sample results within tester memory;
4. Review and critique available rewind work in progress;
5. Reference *Electric Motor Repairing Specification—2012* as needed;
6. Discuss with the service center's repair mechanics and winding personnel the center's past and present GMI-compliant versus non-compliant motor rewind/repair practices;
7. Review 10% (or up to five) of each of the following types of documents: incentive applications, rewind invoices, core loss test results, ledger entries and receipts reported incentives. The certifying official will randomly select documents for review, but not selected or those suggested by the motor service center.

MOTOR SERVICE CENTER CERTIFICATION AND VERIFICATION FINDINGS AND RESULTS

During the Motor Service Center certification and verification process, there are numerous issues and discrepancies identified that result in efficiency loss during the rewind process. The process discrepancies GMI identifies and requires correction result in maintaining or improving motor efficiency and in most cases, extending meantime between motor downtime.

In Table 1 are more significant issues identified during the certification and verification process that if not correct would negatively affect motor efficiency. These process deviations discovered during both the initial inspection and the ongoing yearly certification and verification reviews are concerning. Moreover, finding these issues during yearly inspections demonstrates that if left unchecked, a high potential that service centers will revert to minimal process controls and standards found prior to the initiative.

Number of Member Service Centers

1. Ninety-six originally identified, contacted, and invited to participate;
2. Seventy-three service centers initially certified for participation in GMI;
3. Sixty on-site-verified service centers currently participate;
4. Twelve service centers have either elected to exit the Group or been excused since 2009.

Tables 1 and 2 summarize significant corrections made by the certified service centers to their test and process equipment, process controls, and to on-site technician behaviors during the certification process and following verification inspections. These corrections have prevented potential individual motor efficiency losses from 0.01% to 2%.

Table 1 Correction to On-Site Testing and Process Equipment

Test and Process Equipment Correction	Qty.	Value	Effecting	Repairing Specification—2012 Section
Added core testing	8	High	Core loss	2.1.2 Core Loss
Added second core test	37	High	Core loss	2.1.2 Core Loss
Purchased new or repaired core tester	5	High	Core loss	2.1.2 Core Loss
Purchased new burn-off oven	4	High	Core loss	2.1.3 Burn Out
Corrected burn-off temperature above 750° F	19	High	Core loss	2.1.3 Burn Out
Added water suppression to burn-off oven	4	High	Core loss	2.1.3 Burn Out
Corrected inoperable oven water	9	High	Core loss	2.1.3 Burn Out
Added oven water check with each batch	14	Moderate	Core loss	2.1.3 Burn Out
Calibrated core loss baseline	25	Moderate	Core loss	5.2.3 Ref. tool stator
Calibrated core tester	4	Moderate	Core loss	5.2.1 to 5.2.4 Procedure
Calibrated burn-off oven	26*	High	Core loss	3.1.1 Cal., 4.2 Procedure
Calibrated measuring devices	12	Moderate	Windage/Friction	3.1.1 Calibration, 6.2.1 Procedure
Calibrated electrical meters	4	Moderate	Winding Resistance	3.1.1 Calibration

*Of the 26 service centers adding burn-off calibration, three reported temperature errors of over 100° F. See attachment A-3 for Motor Repairing Specification – 2012.

Table 2 Corrections to Onsite Technician Behavior

Behavior Issue	Qty.	Value	Impacts	Repairing Specification—2012 Section
Smearing lamination	6	High	Stray load losses	2.2.2.1 Grinding
Splaying core teeth	16	High	Stray load losses	2.1.4 Winding Extraction
Lengthening coil extensions	1	High	Winding Resistance	2.3.3 Stator Coil Extensions
Applying open flame to laminations	4	High	Core and stray losses	2.1.3 Burn Out
Using excessive grinding	46*	High	Core losses	2.2.1 Iron Damage , 2.2.2.1 Grinding
Over-lubricating bearings	5	Moderate	Windage/Friction	2.8 Reassembly
Reducing cross sectional area	1	High	Winding Resistance	2.3.2 Conductors

*All participating service centers often times rewind motors that have excessive damage, or are too expensive, or difficult to replace.

ELIGIBLE ELECTRIC MOTORS

- Low and medium-voltage random wound and form coil three phase A.C. squirrel cage induction motors rated from 15 to 5,000 horsepower reported in sizes as listed in Tables 3 and 4;
- Rewound as per Electric Motor Repairing Specification – 2012 (see attachment A-03);
- Kilowatt or metric rated motors meeting bullets one and two are eligible provided converted to horsepower and rounded down to the nearest horsepower rating as listed in Tables 3 and 4 when reported.

DATA COLLECTION

Key motor information for each unit processed through GMI is accomplished using the *Green Rewind Incentive Application*. The application is a one-page document that certified motor service centers fill out for each motor for which the center is claiming a utility incentive. This data allows program requirement verification, clearly identifies HP, application, hours operated, core-loss testing for future GMI evaluation of key UES variables. Most data collected is self-explanatory and listed in Attachment A-2, for less clear data the following definitions are included:

"SC ID – Motor Tag No" SC ID is the "service center identification number", an account number assigned by GMPG to each participating member service center. The "Motor Tag No." is a unique tracking number assigned to each motor by the member service center to identify motors repaired by their service center meeting UES requirements. The combination of the two numbers allows easy field identification of which service center completed the rewind and the individual motor;

"Number of shifts motor runs" provides Initiative confirmation of hours rewound motors operate. Choices: 1shift weekdays only; 1 shift with Saturday; 2 shifts weekdays only; 2 shifts with Saturdays; 3 shifts weekdays only; 3 shifts with Saturdays or; 24/7 (This field represents the data source used in Table 4, *Industrial Motor Annual Hours of Operation*, GMI Data 2009 to 2012;

"Beginning Watts/lb. and After Stripping Watts/lb." describes core-loss test results before and after burn-off, stripping magnet wire and slot insulation from a motor cores to be wound (Reference: *Electric Motor Repairing Specification – 2012, 2.1.2 Core Loss*, page 2 of 8);

"Estimated Annual Operation Cost" is a calculator that uses application entries and service center additions of **"% of Full Load"** and **"Cust. Cost Per kWh"** The calculator estimates the annual motor energy consumption to aid service centers and end-use customers in repair/replace decision making.

A second set of data collected as part of GMI is the *Non-Compliant Motors Rewound.* This dataset of 435 non-compliant motors, constitutes data collected for motors excluded from the program due to failure event efficiency reductions but the motor owner choose to have them rewound instead of replaced. The damaged motor data collection, commissioned by Bonneville Power Administration and reported to GMPG by participating motor service centers, provides unit specifics, costs and disposition. The data set is included as Attachment A-5.

Unit Energy Life (UEL)

Based on the RTF UEL guidelines, we suggest updating the UEL for industrial and agricultural motors to 10 years for all horsepower ratings. The UEL is based on the default UEL tables and UEL checklist. This will establish UELs across all HP ranges consistent with other motor based measures in those sectors.

UNIT ENERGY SAVINGS CALCULATION (UES)

UES calculations for all sectors and rated horsepower use the same energy equation, only some key variables change depending on sector and rated horsepower. Because the energy savings vary based on original nominal efficiency values, small differences occur in UES calculation for various HP groups

$$\textit{Unit Energy Savings} = \left[\frac{\textit{HP x 0.746 x OP x ML}}{\textit{Pre Eff.}}\right] - \left[\frac{\textit{HP x 0.746 x OP x ML}}{\textit{Post Eff.}}\right]$$

Where:

- UES - Unit Energy Savings is the annual energy savings of the motor in kWh by retaining original efficiency utilizing rewind process control (see Attachment A-3)
- HP - Horsepower obtained from standardized horsepower ratings
- 0.746 converts horsepower to kilowatts
- OP - Operating hours is the annual operating hours of the motor
- ML - Motor loading is the percentage of the standardized horsepower rating required to drive equipment
- Pre Eff. – Nameplate motor nominal efficiency
- Post Eff. – Reduce nameplate motor nominal efficiency without process control as follows:

15 to 25 HP less 1%	40 HP less 0.8%	60 HP less 0.6%
30 HP less 0.9%	50 HP less 0.7%	≥ 75 HP less 0.5%

There are three changing key variables dependent upon **sector** and **rated horsepower**:

- **Annual hours of operation** (OP)**;**
- **Percentage of nameplate horsepower (motor load) required by driven equipment** (ML)**;**
- **Motor rewind efficiency *Pre Eff* and Post *Eff* resulting in retention or loss.**

PERCENT OF EACH EFFICIENCY RANGE PROCESSED BY GMI

15HP to 500 HP: The UES is a weighted average of the energy savings from each motor efficiency group (e.g. 15 to 200 HP uses Pre-EPACT, EPACT, and NEMA Premium® and 250 to 500 HP uses Non-NEMA Premium® and NEMA Premium®) based on the percent of those motors historically processed by the program.

Table 3: Number of Motors Processed From Each Efficiency Range						
HP	**Pre-EPact Motors**		**EPact**		**NEMA Premium®**	
	N =	**% of Total**	**N =**	**% of Total**	**N =**	**% of Total**
15	82	50%	25	15%	57	35%
20	115	69%	32	19%	19	11%
25	75	72%	21	20%	8	8%
30	77	76%	14	14%	10	10%
40	88	73%	20	17%	13	11%
50	71	69%	17	17%	15	15%
60	61	82%	10	14%	3	4%
75	191	82%	30	13%	13	6%
100	127	76%	21	13%	19	11%
125	85	75%	15	13%	13	12%
150	141	81%	28	16%	6	3%
200	230	81%	44	15%	10	4%
250	123	93%			9	7%
300	127	94%			8	6%
350	75	91%			7	9%
400	106	96%			4	4%
450	31	94%			2	6%
500	39	100%			0	-
Total	2337		277		216	

600HP to 5,000 HP UES reflects a single efficiency value for each HP rating in this range. Motors 600 HP and larger are not covered by NEMA Premium® published standards or by Department of Energy minimum efficiency standards. NEMA Premium® Table 12-13 (see attachment A-8) show that the majority of form-coil wound medium voltage motors 250 to 500 HP have 95% nominal efficiency expect 2 pole ODP motors. In 2009 when BPA applied for GMI UES to 5,000 HP the 95% efficiency came from this NEMA table. To provide more accurate nominal efficiencies, the published efficiency for motors 600 to 5,000 HP from two of the larger manufactures of motors in this HP range (Siemens and General Electric) were compiled. The average published nominal efficiency used to calculate the updated UES are as shown in Table 4.

Table 4 Average of Two Manufacturers' Published Efficiencies for Motors 600 Through 5,000 HP

HP	Efficiency	**HP**	Efficiency	**HP**	Efficiency	**HP**	Efficiency
600	94.2	**1,000**	94.8	**2,000**	95.5	**3,500**	96.3
700	94.4	**1,250**	95	**2,250**	95.8	**4,000**	96.3
800	94.5	**1,500**	95.1	**2,500**	95.9	**4,500**	96.4
900	94.6	**1,750**	95.3	**3,000**	96.2	**5,000**	96.5

ANNUAL HOURS OF OPERATION

In the review of documents used by the RTF to establish the annual hours of operation impacted by the rewind initiative, SBW Consulting, Inc. suggested referencing a Northwest Motors Survey completed by Oregon State University (Attachment A-7). GMI added annual hours of operation for industrial motors to the incentive application in 2008 (Attachment A-2). The reported hours did not affect the incentive amounts received for the motor so they are considered unbiased. The NW Motor survey data contains motors with both very low and very high annual operating hours and represents the average motor found in an industrial facility. The data does not fully represent motors processed through GMI because, motors with lower operating hours and load factors typically extends motor meantime between motor downtime limiting the need for rewinding. Based on this, GMI reported operating hours are more representative of motors processed by the initiative.

Table 5 compares this source of data and two others: the RTF's currently approved data and GMI Incentive Application information.

Table 5 Industrial Motor Annual Hours of Operation

HP	Current RTF-Approved Data[1]	Motor Units N=	GMI Data 2009 to 2012	Motor Units N=	NW Motors Survey Data
15 to 20	3,391	302	5,331	4,120	5,561
25 to 50	4,067	301	5,608	5,199	5,681
60 to 100	5,329	832	5,804	2,365	5,990
125 to 200	5,200	522	5,982	1,370	6,113
250 to 500	6,132	486	6,513	563	5,914
600 to 1,000	7,186	54	7,342	87	6,435
1,250 to 5,000	7,436	39	7,164	36	5,520

Industrial Hours of Operation used for UES calculations: The *GMI Data 2009 to 2012* column as used in the Industrial UES calculations.

AGRICULTURAL HOURS OF OPERATION

The average operating hours for agricultural irrigation pumping motors is based on two data sets from BPA's Ag Irrigation program (Attachment A-9). The first data set represents two years of billing data from irrigation pumps with a dedicated utility meter collected by Mr. Tom Osborn, BPA, for billing analysis. The data covers utilities in central Washington and central and eastern Oregon. The second data set represents three years of billing information contained in pump tests and system evaluations conducted by Mr. Dick Stroh, BPA. This data covers utilities in

---

[1] United States Industrial Electric Motor Systems Market Opportunities Assessment, Published by US Department of Energy December 1996, Motor Challenge, Section I, page 42

southern Idaho and northern Nevada. The test report documented average annual operating hours based on system logs, utility data, and interviews with system operators.

Table 6 Agricultural Motor Annual Hours of Operation

HP	Motor Units N=	Average	Min	Max	Std. Deviation
5 to 20	7	2,221	1,039	3,410	713
25 to 50	14	2,691	841	7,745	1,630
60 to 100	101	2,357	814	6,886	1,268
125 to 200	98	2,198	822	4,878	912
250 to 500	50	2,674	834	5,673	1,269
600 to 1,000	4	2,124	1,831	2,567	360
1,250 to 5,000	-	2,124*			
Total	334				

***Operating Hours for motors 1,250 to 5,000 HP based on the 600 to 1,000 HP average.**

Agriculture Hours of Operation used for UES calculations: The calculation of UES for agricultural motors relied in part upon BPA operating hours.

PERCENT OF NAMEPLATE HORSEPOWER NECESSARY TO DRIVE THE LOAD

Measuring motor load is difficult. On-site safety is of primary concern when measuring electrical power to the motor, and may require a licensed or at least qualified electrical technician. Connecting into the electrical feed usually requires a process shutdown. Further, since most operating loads vary, the measurement necessitates a kW data-logger to produce an average. Considering the complexity and difficulty of measuring in-situ motor load data we have had difficulty locating reliable sources. In addition, in most cases end-user maintenance staff and GMI member service centers do not have access to accurate motor load data.

As suggested by SBW Consulting the following table compares the existing Industrial RTF approved motor load percentages with those in the overall averages from Northwest Motors Survey data:

Table 7 Industrial Percentage of Horsepower Utilized to Drive Loads

HP	Current RTF-Approved	GMI Data	Motor Units N=	Northwest Motor Industrial (only) Survey Averaged
15 to 75	60%	N/A	10,854	69%
100 to 5,000	70%	N/A	2,886	70%

The NW Motor survey contains data of lightly or fully unloaded motors that appear inaccurate based on lower than typical minimum loads (e.g. air compressors, fans, and pumps). In a few cases, the motor loads stated were less than the load expected for a motor with no connected load or uncoupled shaft. Because of these issues, data filtering removed motors with a stated load less than 40% (Attachment A-7). GMI Industrial UES motor load is consistent with the methodology used for the RTF *Standard Savings Estimation Protocol for Premium Efficiency Motors* (November 2012) as shown below.

Table 8 NW Motor Survey Average Industrial Motor Loading

HP Range	Ave Motor Load
5 to 20 HP	79%
25 to 50 HP	80%
60 to 100 HP	78%
125 to 200 HP	80%
250 to 500 HP	82%
600 to 1,000 HP	82%
1,025 to 5,000 HP	82%

Industrial Percentage of horsepower to drive loads: The load data from the RTF *Standard Savings Estimation Protocol for Premium Efficiency Motors* (October 2012) is used to calculate the Industrial UES.

Agricultural motor load is based on data BPA compiled of actual motor loads measured during irrigation pump testing conducted between 2006 and 2012 for motors less than 1,000 HP, and from 2002 to 2006 for motors greater than 1,000 HP (Attachment A-10). The "Averaged Motor Load," captured during pump tests, is a byproduct of determining motor and overall system efficiency. The following data includes actual measured motor load collected from 608 pump tests commissioned or completed by BPA Energy Efficiency audits:

Table 9 BPA Agriculture Pump Test Motor Loading

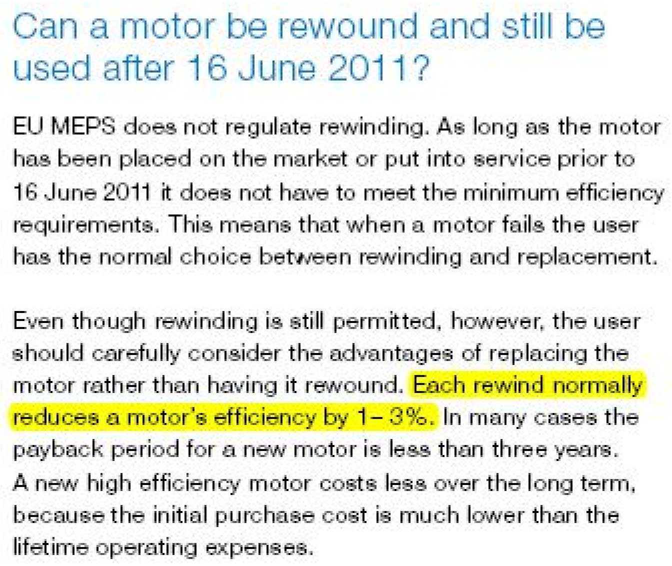
HP Range	N=	Ave Motor Load	Min	Max	Std. Deviation
5 to 20 HP	23	91%	40%	115%	0.22277
25 to 50 HP	107	92%	44%	115%	0.214956
60 to 100 HP	109	94%	52%	115%	0.191014
125 to 200 HP	96	93%	46%	113%	0.200607
250 to 500 HP	100	97%	42%	114%	0.182192
600 to 1,000 HP	70	115%	63%	143%	0.186733
1,025 to 5,000 HP	25	96%	78%	134%	0.133899

Table 9 motor loading data contains some measured loads greater than nameplate service factors. For consistency, motors were scrubbed from15 to 500 HP with less than 40% or greater than 100% load from the data set. Based on discussions with Mr. Tom Osborn and Mr. Dick Stroh both of Bonneville Power Administration, medium voltage irrigation motors (600 to 5,000 HP) when rewound are, if possible and as needed, reengineered to a higher horsepower accommodating loads far exceeding service factor. To accomplish this rewinding task, it is necessary to have core-plate and wire slot space proportionally available to the desired horsepower and approved by the equipment owner. If not originally manufactured to the higher horsepower, nomenclature would likely not reflect the internal changes, can increase the operating time between maintenance cycles in harsh operating conditions, may slightly improve efficiency and allow the motor to drive increased loads.

Agricultural Percentage of horsepower to drive loads: The load data based upon the BPA's Agricultural Pump Test Motor Loading to calculate the Agricultural UES.

MOTOR REWIND EFFICIENCY LOSSES AND RETENTION

During the original RTF motor rewind introduction in May of 2007, some attendees commented that 1% or 2% to even 3% is an accurate rewind degradation percentage. That same erroneous conventional wisdom expressed by the RTF in 2007 persists today as demonstrated by ABB Electric Motors and Generators on their Website page entitled "*EU MEPS for low voltage electric motors, Frequently Asked Questions*", page 4 as follows:



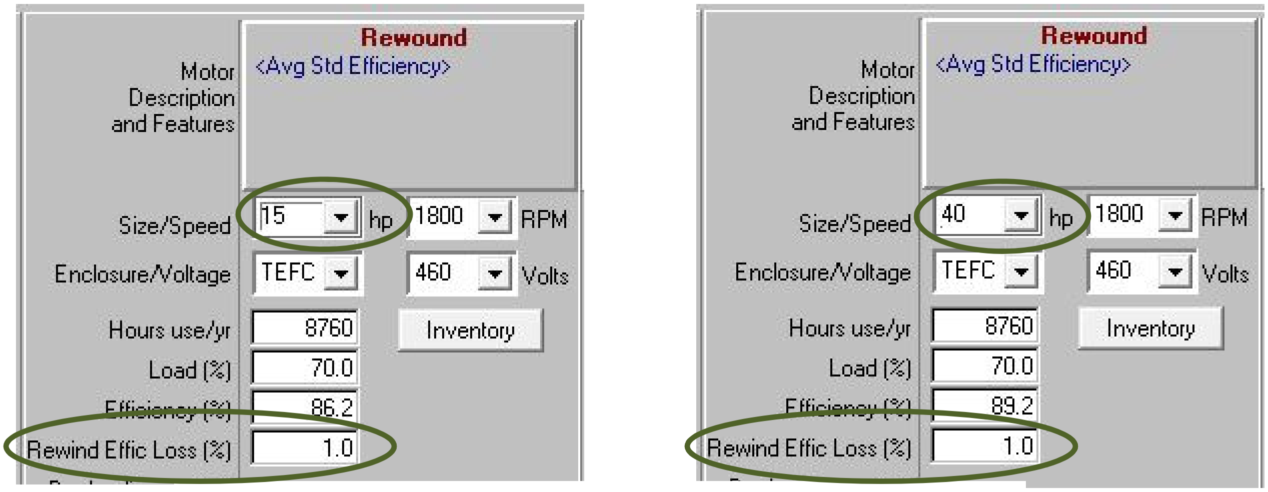
Can a motor be rewound and still be used after 16 June 2011?

EU MEPS does not regulate rewinding. As long as the motor has been placed on the market or put into service prior to 16 June 2011 it does not have to meet the minimum efficiency requirements. This means that when a motor fails the user has the normal choice between rewinding and replacement.

Even though rewinding is still permitted, however, the user should carefully consider the advantages of replacing the motor rather than having it rewound. Each rewind normally reduces a motor's efficiency by 1– 3%. In many cases the payback period for a new motor is less than three years. A new high efficiency motor costs less over the long term, because the initial purchase cost is much lower than the lifetime operating expenses.

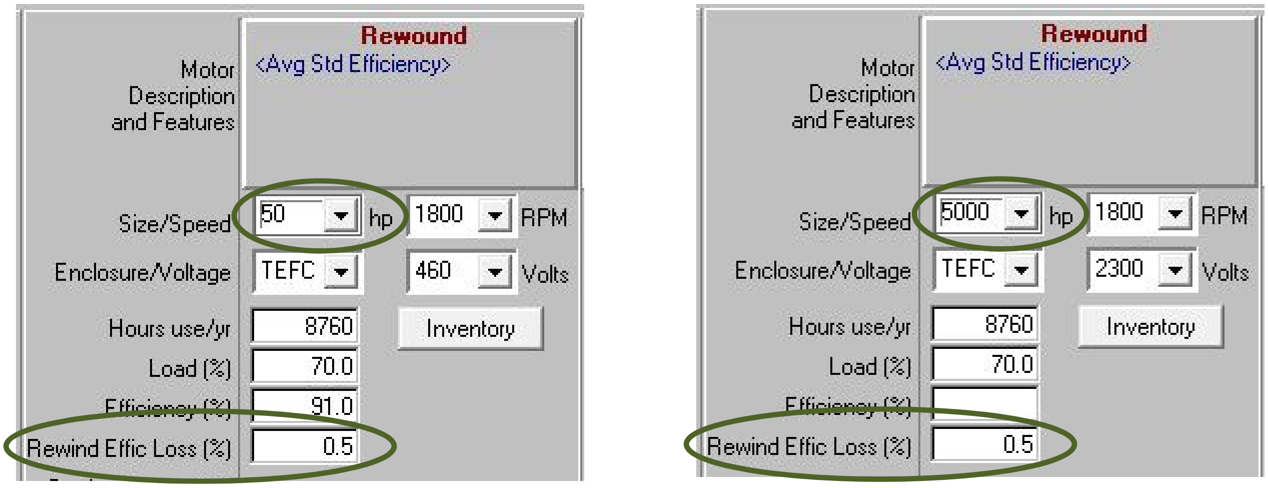
For the complete document go to ABB Website location:
http://www05.abb.com/global/scot/scot234.nsf/veritydisplay/1be8c5c047ae5937c12578b5002d7e3d/$file/eu%20meps%209akk105072%20en%2005_2011%20low_res.rev%20b.pdf

However, EASA and the Department of Energy, through Washington State University Extension Program, agreed that a 1% loss of efficiency for motors less than 50 HP, and a 0.5% loss of efficiency for motors of 50 HP or more, accurately reflect the efficiency losses resulting from a non-process controlled motor rewinding. DOE adopted and published these loss percentages as the default in their Motor Master+ motor management software. The following are DOE's Motor Master+ screen shots located under the software's compare button:


Rewound
<Avg Std Efficiency>
Motor Description and Features
Size/Speed: 15 hp 1800 RPM
Enclosure/Voltage: TEFC 460 Volts
Hours use/yr: 8760
Load (%): 70.0
Efficiency (%): 86.2
Rewind Effic Loss (%): 1.0

Rewound
<Avg Std Efficiency>
Motor Description and Features
Size/Speed: 40 hp 1800 RPM
Enclosure/Voltage: TEFC 460 Volts
Hours use/yr: 8760
Load (%): 70.0
Efficiency (%): 89.2
Rewind Effic Loss (%): 1.0

1 thru 40 HP rewind efficiency default degradation established at 1%


Rewound
<Avg Std Efficiency>
Motor Description and Features
Size/Speed: 50 hp 1800 RPM
Enclosure/Voltage: TEFC 460 Volts
Hours use/yr: 8760
Load (%): 70.0
Efficiency (%): 91.0
Rewind Effic Loss (%): 0.5

Rewound
<Avg Std Efficiency>
Motor Description and Features
Size/Speed: 5000 hp 1800 RPM
Enclosure/Voltage: TEFC 2300 Volts
Hours use/yr: 8760
Load (%): 70.0
Efficiency (%):
Rewind Effic Loss (%): 0.5

50 to 5,000 HP rewind efficiency default degradation established at 0.5% or ½ of 1% of motor efficiency

To download Motor Master + software, go to the DOE's Office of Industrial Technology Website at: http://www1.eere.energy.gov/manufacturing/tech_deployment/software_motormaster.html.

In addition to Motor Master+, EASA/AEMT's *The Effect of Repair/Rewinding on Motor Efficiency, 2003 Study*[2] and the *AEMT Good Practices Guide*[3] further substantiate rewind non-process controlled rewind degradation illustrated in Table 14 page 20. Presented later in this document are illustrations and calculations of various potential rewind losses and improvements. For further reference concerning refurbishment and rewinding please consult Canadian Standards document C-392-11.[4]

The RTF approved GMI efficiency degradation percentages. After the introduction in May 2007 of data on efficiency losses from inadequate rewind practices, the RTF "smoothed" the change in efficiency loss reported for different sizes of motors. In Motor Master + the change stepped abruptly from 0.5% loss

---

[2] *The Effect of Repair/Rewinding on Motor Efficiency*, EASA/AEMT Rewind Study, pages 2-4

[3] Good Practices Guide, The Repair of Induction Motors Best Practices to Maintain Energy Efficiency Pg. 34

[4] CSA, C392-11, Testing of three-phase squirrel cage induction motors during refurbishment, Pgs. 8-38

for motors of 60 HP or more, up to 1% loss for 50 HP or less. The RTF directed to spread the 0.5% increase linearly over more horsepower sizes. GMPG responded as shown in the fourth column in the following table. GMI does not begin the increase in efficiency loss until the motor size changes from 25 to 30 HP. The efficiency loss then decreases by an increment of 0.1% with each change in HP until reaching 75 HP and efficiency loss of 0.5%. The efficiency loss is constant at 0.5% from 75HP to 5,000 HP.

Table 10 Potential rewinding losses on averaged efficiency

HP	Avg.	Core & Stray Loss	Inadequate Rewind	New Efficiency	HP	Avg.	Core & Stray Loss	Inadequate Rewind	New Efficiency
15	91.7	2.9%	1.0%	90.7	125	95.0	1.8%	0.5%	94.5
20	92.2	2.7%	1.0%	91.2	150	95.3	1.6%	0.5%	94.8
25	92.8	2.5%	1.0%	91.8	200	95.6	1.5%	0.5%	95.1
30	93.0	2.5%	0.9%	92.1	250	95.7	1.5%	0.5%	95.2
40	93.5	2.3%	0.8%	92.7	300	95.7	1.5%	0.5%	95.2
50	93.9	2.1%	0.7%	93.2	350	95.8	1.5%	0.5%	95.3
60	94.4	2.0%	0.6%	93.8	400	95.9	1.4%	0.5%	95.4
75	94.4	2.0%	0.5%	93.9	450	96.0	1.4%	0.5%	95.5
100	94.8	1.8%	0.5%	94.3	500	96.0	1.4%	0.5%	95.5

The following Table provides the current RTF-approved Unit Energy Savings (UES) for the Industrial and Agricultural sectors of the Green Motor Initiative (GMI).

Table 11 Existing RTF-Approved Deemed UES

Motor HP	Industrial kWh Saved	Agricultural kWh Saved	Motor HP	Industrial kWh Saved	Agricultural kWh Saved
15	274	145	**500**	8,732	2,848
20	363	192	**600**	12,584	12,584
25	535	237	**700**	14,682	14,682
30	575	254	**800**	16,708	16,708
40	672	297	**900**	18,737	18,737
50	729	322	**1,000**	20,754	20,754
60	971	328	**1,250**	26,695	26,695
75	1,009	341	**1,500**	31,867	31,867
100	1,558	585	**1,750**	37,035	37,035
125	1,891	727	**2,000**	42,355	42,355
150	2,254	867	**2,250**	47,468	47,468
200	2,987	1,149	**2,500**	52,450	52,450
250	4,397	1,434	**3,000**	63,071	63,071
300	5,269	1,718	**3,500**	73,392	73,392
350	6,147	2,005	**4,000**	83,919	83,919
400	7,005	2,285	**4,500**	94,213	94,213
450	7,859	2,563	**5,000**	104,681	104,681

The below Table provides **recommended** RTF Unit Energy Savings (UES) for Industrial and Agricultural sectors participating in the Green Motor Initiative (GMI). For calculation detail see Attachment A-6.

Table 12 Proposed RTF- Deemed Weighted UES

Motor HP	Industrial kWh Saved	Agricultural kWh Saved	Motor HP	Industrial kWh Saved	Agricultural kWh Saved
15	603	289	**500**	11,118	5,400
20	806	387	**600**	15,265	6,193
25	1,056	582	**700**	17,734	7,195
30	1,137	627	**800**	20,224	8,205
40	1,324	730	**900**	22,704	9,211
50	1,423	785	**1,000**	25,120	10,192
60	1,470	720	**1,250**	30,509	10,590
75	1,513	740	**1,500**	36,534	12,681
100	1,997	977	**1,750**	42,444	14,732
125	2,625	1,121	**2,000**	48,304	16,766
150	3,121	1,333	**2,250**	54,001	18,744
200	4,130	1,764	**2,500**	59,876	20,783
250	5,638	2,738	**3,000**	71,402	24,784
300	6,731	3,269	**3,500**	83,129	28,854
350	7,847	3,811	**4,000**	95,005	32,976
400	8,900	4,323	**4,500**	106,658	37,021
450	9,993	4,853	**5,000**	118,263	41,049

Rewind Studies Using Standard and Controlled Processes

There are two studies cited below both with uncontrolled and controlled motor rewind process. EASA/AEMT 2003 Study, originally cited in the RTF submittal in 2007, and an earlier AEMT study focusing on 5.5 kW (7.5 HP) motors exposed to varying burn-off temperatures during rewind process. In addition, Canadian Standards Association completed a new rewinding Standard C-392-11 establishing motor testing and calculations for determining process rewinding's impact on motor efficiency.

Statistical Evaluation

Based on the AEMT and EASA/AEMT studies, Table 13 demonstrates the sample size and the average annual motors reported to the Green Motor Initiative. The sample size and the average motors reported to the program exceed the 80% confidence and 20% precision required by UES guidelines.

Table 13 GMI Three Years Average (N=582) Versus AEMT plus EASA/AEMT Motor Study Events (N=72)

GMI reported motor rewinds with process control	Events **without** process control (two studies)	**Percent of GMI rewinds**	Events **with** process control (two studies)	**Percent of GMI rewinds**	Total events (two studies)	**Percent of GMI rewinds**
582	20	**3.4%**	52	**8.9%**	72	**12.4%**

EASA/AEMT – *The Effect of Repair/Rewinding on Motor Efficiency, 2003Study*

During the original May and July 2007 RTF presentations of rewinding as an energy efficient measure, EASA/AEMT's *The Effect of Repair/Rewinding on Motor Efficiency, 2003 Study* reference proves process-controlled rewinding[5] can and does retain motor efficiency. To address uncontrolled rewinding processes the EASA/AEMT Study presented six motors in Group A[6] as essentially a "blind study." The rewind and re-assembly of these motors (multiple times totaling **11 "events"**) were done in a conventional service center manner, meaning that no specific efficiency retention practices were implemented. Subsequently, lamination teeth flaring due to excessive force during winding removal increased stray load losses, and over-lubrication increased friction losses for an average total efficiency loss of 0.6%. This study illustrated the potential consequences of not following good process control practices.

AEMT - *GOOD PRACTICES GUIDE*

The *AEMT Good Practices Guide* published in the United Kingdom 1996, *Appendix 2, Burn-out Ovens and Their Effect on Stator Core Losses*[7] provide evidence that uncontrolled excessive heating of motor laminations does cause increases in core losses. There were 34 motors in the burn-off study. All were 5.5 kW (7.5 HP) and all used variations of semi-processed steel for laminations. Differences among the 34 were as follows:

Group 1: Thirteen used "Newcor," low-carbon silicon-free steel with blue/back oxide microfilm insulation;
Group 2: Thirteen used "Losil," low-carbon low-silicon steel with blue/black oxide microfilm insulation and;
Group 3: Eight used undisclosed semi-processed steel with a microfilm of an inorganic insulation known as "L3."

The 34 motors received one event (or test) each. They were tested in three groups shown above in burn-off ovens at temperatures increasing in 20° C increments from 300° C (570° F) to 500° C (930° F). Below are test results for the 26 motors in Groups 1 and 2 (all manufactured with a microfilm of blue/black oxide inner-laminar insulation);

- Seventeen were tested in burn-out ovens where temperatures were maintained at less than 400° C (750° F); they showed essentially no core loss degradation;
- The remaining nine exposed to temperatures of 400° C (750° F) to 500° C (930° F); their core losses ranged from 20% to 275%, mirroring the temperature increase (refer to Table 13 in this document for impact).

By contrast, among the eight motors in Group 3 treated with "L3" inner-laminar inorganic insulation (new at the time of the study), core losses were virtually unaffected by temperature changes over the test range.

---

[5] Defined as a rewind of a motor that follows the GMI's *Electric Motor Repairing Specification – 2012*
[6] *The Effect of Repair/Rewinding on Motor Efficiency*, EASA/AEMT Rewind Study, pages 2-4
[7] Good Practices Guide, The Repair of Induction Motors Best Practices to Maintain Energy Efficiency Pg. 34

Table 13, page 16 shows a comparison between (1) the number of events from the EASA/AEMT study plus the number of events from the AEMT guide, and; (2) an average number of motors that were rewound annually with process controls in place and subsequently incentivized. GMPG calculated the average annual rewinds based on three years of data.

Canadian Standards Association (CSA) C392-11

CSA published the C392-11 Standard, "*Testing of three-phase squirrel cage induction motors during refurbishment*" in 2011. The Standard's scope[8]covers, *"Integral horsepower, three-phase, alternating current, squirrel cage induction motors rated 200 to 13,200 volts at 60 Hz."* The Standard also covers motors operating on variable frequency drives. Based on the aforementioned study scope, with the exception of fractional horsepower ratings, C392-11 is **unlimited in horsepower**, RPM, or enclosure.

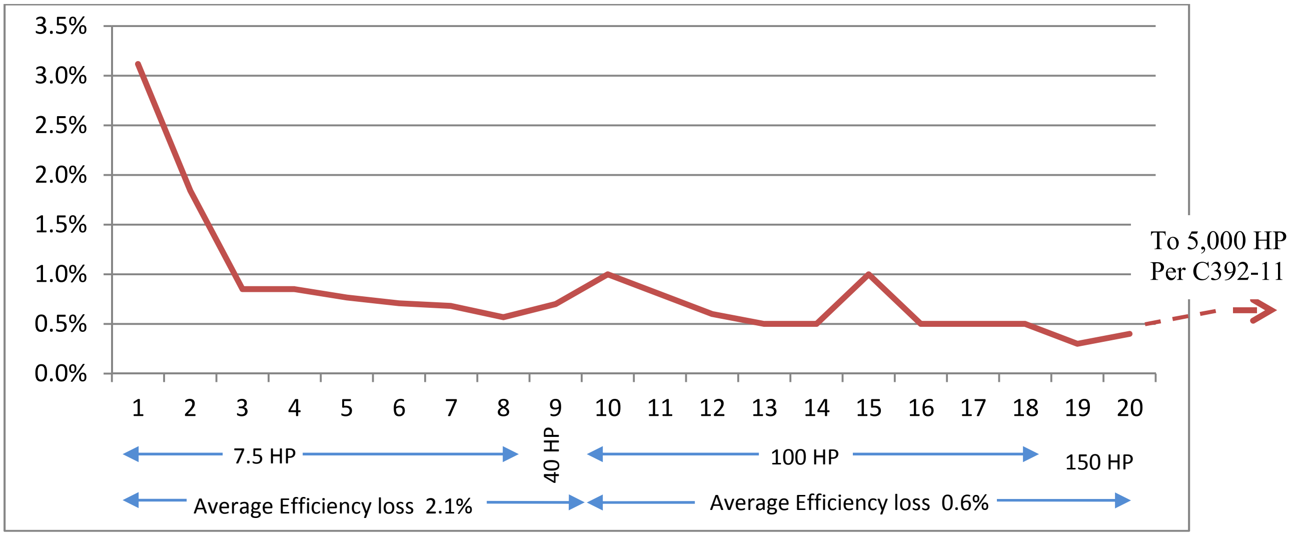
C392-11's Foreword[9] states, "*This Standard provides guidance to electric motor service centers in verifying that the refurbishing process has maintained or enhanced the electric motor (hereafter motor) efficiency. It is also intended to provide a reliable evaluation of changes in the condition of the motor, with respect to its efficiency that might have resulted from its failure*…"

By totaling C392-11's potential motor efficiency losses attributable to rewinding, we find a potential for losses of 1.2 to 3.6%. Motors experiencing such substantial losses in efficiency would experience significant pre-mature and repeated failure typically resulting in motor replacement. This is why GMI calculates motor efficiency losses of 0.5% to 1.0% losses.

REWIND LOSSES REGARDLESS OF HORSEPOWER

The following table tracks efficiency loss changes from both the AEMT study, starting at 5.5 kW (7.5 HP), and the EASA/AEMT study of six larger motors that underwent multiple rewinds and re-assemblies totaling 11 events. From the two studies a projection to 5,000 HP is established based on CSA's C392-11.

Table 14



---

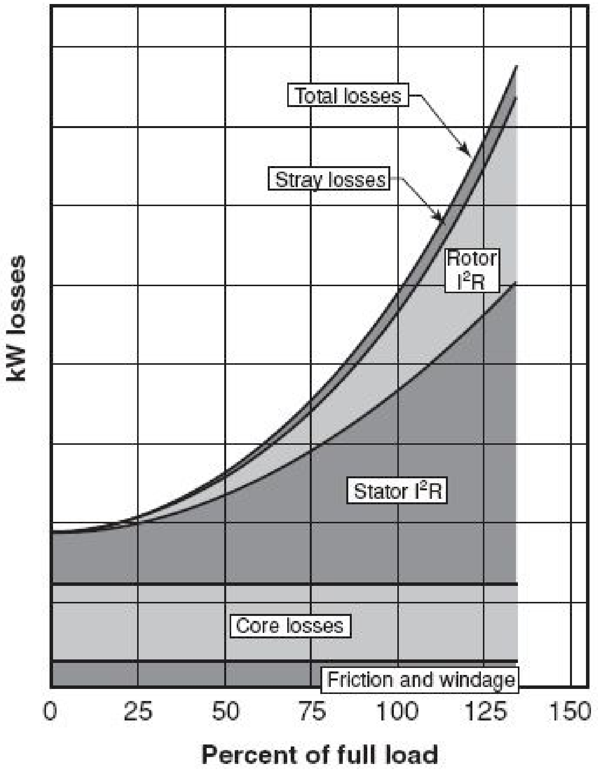
[8] CSA C392-11, 1 Scope, Page 1

[9] CSA C392-11, 0 Foreword, Page 1

It is noteworthy that from the AEMT study's 26 motors with inner-laminar insulation comprised of a "blue/black oxide microfilm" that motors 100 HP and over are seldom replaced and therefore are more likely **to not** have "L-3" insulation. Therefore, larger motors are more susceptible to efficiency losses when subjected to temperatures exceeding 750^{O} F than smaller newer motors. Very often medium voltage motors over 500 HP have additional room to accept a greater magnet-wire cross-sectional area resulting in a slight efficiency improvement above the original manufactured operational characteristic.

RELATIONSHIP OF MOTOR LOAD AND OTHER PROTOCOLS

Table 15



Typical loss components plotted against motor load. Source EASA/AEMT *The Effect of Repair/Rewinding on Motor Efficiency*[10]

Depicted graphically to the left are the five typical electric motor loss groups. Of the five motor loss groups, Core and Friction/Windage losses remain unchanged regardless of load. Stator I^2R losses dynamically change but still represent a significant loss contributor from 50 to 125% of load. Rotor I^2R losses represent the third largest contributor but in a repair/rewind scenario it is pass/fail. To prioritize these elements by order of rewinding practices impact on efficiency we have arranged them in the following order:

1. Core loss
2. Stator I^2R
3. Stray losses
4. Friction/Windage losses
5. Rotor I^2R losses (pass/fail only)

It is notable that in many instances a **failure event may have more impact on motor efficiency losses than the repair/rewind** process or repair technicians' procedures.

By adding a pulse width modulated variable frequency drive (VFD) to motor control, efficiency losses may increase only slightly through approximately 3% depending on the load and characteristics of a given motor. Generally, motor efficiency losses from VFD application occur in the context of four of the five loss elements. When operating as designed, Friction and Windage losses are unaffected and decrease with speed and load, as do other losses.

MOTOR EFFICIENCY LOSSES

Motor efficiency equals (input power- losses) divided by input power; where input power is a given dependent upon load requirement and motor loss totals. Loss calculation is as follows:

---

[10] The Effect of Repair/Rewinding on Motor Efficiency, EASA/AEMT Rewind Study, page 2-4

$W_t = W_s + W_r + W_c + W_{fw} + W_L$[11]

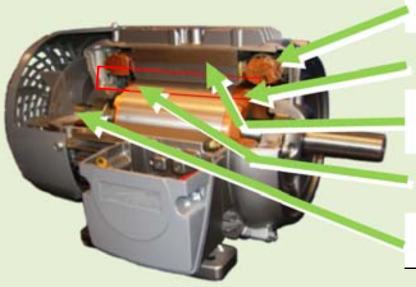
Where do motor efficiency losses go? The following two tables break down losses into five groups and assign each a percentage of total losses.

Table 16 Types of Motor Efficiency Losses as a Percentage of Total Potential Motor Efficiency Loss

Losses	2 Pole average	4 Pole average	Description of factors affecting losses
Core (Wc)	19%	21%	Electrical steel, air gap, saturation, supply frequency, condition of inter-laminar insulation
Friction/windage (Wfw)	25%	10%	Fan efficiency, lubrication, bearings, seals
Stator I^2R (Ws)	26%	34%	Conductor area, mean length of turn, heat dissipation
Rotor I^2R (Wr)	19%	21%	Bar end ring area and material
Stray load (WL)	11%	14%	Manufacturing processes, slot design, air gap, condition of air gap surfaces and end laminations
Total Motor Losses (W_t)	100%	100%	

[12]Source EASA/AEMT Effect of Repair/Rewinding on Motor Efficiency and CSA 392-11

Table 17 Four Pole, 86.5% and 95% Efficiency Loss Distribution[9]



Losses	4 Pole Losses	% of Input @ 86.5% Eff.	% of Input @ 95% Eff.
Stator I^2R (W_s)	34%	4.6%	1.7%
Rotor I^2R (W_r)	21%	2.8%	1.05%
Core (W_c)	21%	2.8%	1.05%
Stray (W_L)	14%	1.9%	0.7%
Windage/friction (W_{fw})	10%	1.4%	0.5%
Total Motor Losses (W_t)	100%	13.5%	5.0%

Source EASA/AEMT Effect of Repair/Rewinding on Motor Efficiency and CSA 392-11

---

[11] CSA C392-11, A.4.5.2, page 35

[12] EASA/AEMT Effect of Repair/Rewinding on Motor Efficiency page 2-4

[13] EASA/AEMT Effect of Repair/Rewinding on Motor Efficiency page 2-4

When rewinding, core losses (tied for second place in losses in the preceding two tables), represent a likely suspect to adversely affect efficiency when uncontrolled rewind processes are present. The following table reproduced from CSA's C392-11[14] provides levels of change and quantifiable efficiency impacts.

Table 18 Core Damage Impact on Core-Losses

Levels of Damage	Change in Wc, %	Levels of Damage	Change in Wc, %
None to slight	not measurable	**Significant**	80% increase
Threshold of measurement	20% increase	**Major**	100% increase
Moderate	40% increase	**Excessive**	>100% increase
Consequential	60% increase	**Catastrophic**	>200% increase

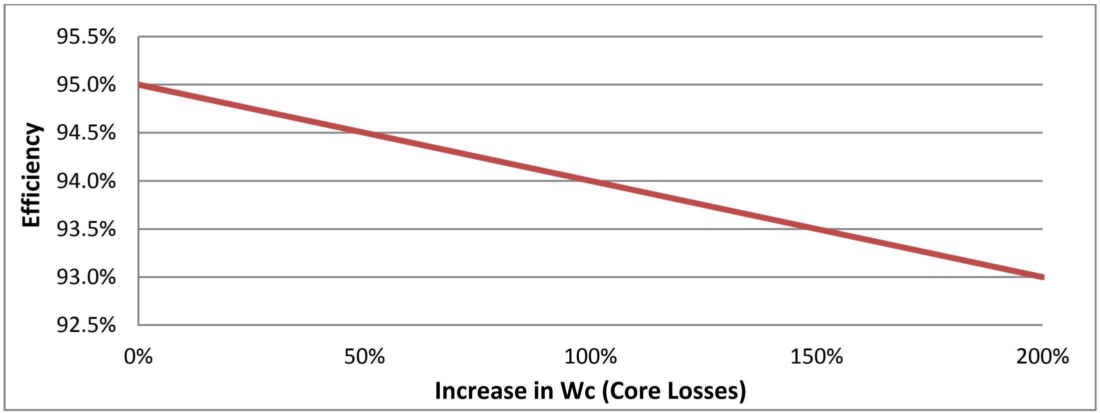
Source CSA 392-11

Calculation example to determine core loss impact on a 95% efficient motor:

W_t = 100% - efficiency or 100% - 95% = 5%

From Table 17 the average core loss of a 4 pole motor in the EASA/AEMT study was 21%. Hence W_c = 21% x 5% = 1%. From Table 18, moderate core damage causes a 40% increase in core losses or 1.4 x 1% = 1.4%. The new estimated losses are (5% - 1%) + 1.4% = 5.4%. Thus, the new estimated motor efficiency is 100% - 5.4% = 94.6%.[15]

Table 19



[16]Source EASA/AEMT Effect of Repair/Rewinding on Motor Efficiency and CSA 392-11

Stator I^2R or W_s

Stator wire resistance losses (or gains) occur in several ways:

- Mean length of turn (MLT) or overall length of the magnet wire coil
- Cross-sectional area of the conductor (e.g. slot fill)

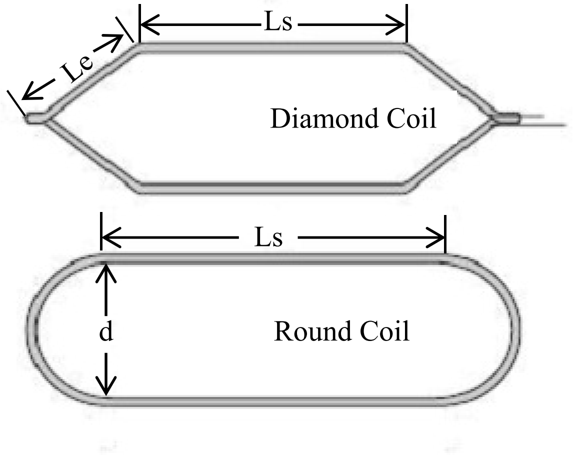
---

[14] CSA 392-11, Table A.3, Evaluation of core damage and its impact on core losses, page 31

[15] CSA 392-11, Equation 10, page 36

[16] EASA/AEMT Effect of Repair/Rewinding on Motor Efficiency page 2-4

In the following example, coil design or shape can produce MLT changes of almost 10%.



Calculation:
Diamond Coil MLT = (2 x Ls) + (4 x Le)
Round Coil MLT = 2(Ls) + πd

MLT = Mean length of turn
Ls = Straight length of coil
Le = Coil extension[17]

Table 20 Diamond Versus Round MLT

Calculation Example	Ls in.	Le in.	d in.	MLT	Change
Diamond Coil	11.0	5.5		44.0	
Round Coil	11.0		8.0	47.1	7.0%

Table 21 Effects of Coil Length Changes[18]

HP	Poles	End Turn Length	FL Efficiency	FL Efficiency Change	Total Losses	Change in Total Losses
50	4	10% short	93.1	0.1	2746	2.28
		Nominal	93		2825	
		10% long	92.8	-0.2	2911	-3
100	4	10% short	94.9	0.1	4020	2.6
		Nominal	94.8		4129	
		10% long	94.6	-0.2	4243	-2.8
200	4	10% short	95.6	0.1	6921	2.5
		Nominal	95.5		7099	
		10% long	95.3	-0.2	4243	-2.5
50	2	10% short	92.7	0.2	2935	2.9
		Nominal	92.5		3024	
		10% long	92.3	-0.2	3122	-3.2
100	2	10% short	93.9	0.2	4881	3.3
		Nominal	93.7		5047	
		10% long	93.5	-0.2	5212	-3.3
200	2	10% short	95.1	0.1	7697	2.3
		Nominal	95		7875	
		10% long	94.9	-0.1	8075	-2.5

---

[17] EASA Currents, June 2008, Applying the Best of Repair Practices, by Tom Bishop, pages 3, 4 and 5
[18] CSA C392-11, Table A-1, pages 25 and 26

Table 22 Effects of Increasing Cross-Sectional Area of a Conductor in a Four Pole Motor Winding[19]

ODP Motor Type	HP	Space Factor	Stack Length	Full-load Efficiency	Nameplate Nominal Efficiency	EPAct Efficiency Reference
Original pre-EPAct	75	48%	6.500	92.7%	92.4%	94.1%
Rewound pre-EPAct	75	59%	6.500	93.7%	93.8%	
Original pre-EPAct	100	39%	8.250	92.7%	92.4%	94.1%
Rewound pre-EPAct	100	60%	8.250	94.1%	94.1%	
Original pre-EPAct	125	43%	10.250	93.4%	93.0%	94.5%
Rewound pre-EPAct	125	59%	10.250	94.3%	94.1%	
Original pre-EPAct	150	58%	8.000	93.9%	93.6%	95.0%
Rewound pre-EPAct	150	63%	8.000	94.1%	94.1%	
Original pre-EPAct	200	55%	9.500	94.1%	94.1%	95.0%
Rewound pre-EPAct	200	63%	9.500	94.4%	94.4%	

The above table indicates Full-Load Efficiency increases (Rewound versus Original) of 0.2% to 1.4%.

---

[19] CSA C392-11, Table A-2, page 27

REFERENCES

AEMT	*Good Practices Guide, The Repair of Induction Motors Best Practices to Maintain Energy Efficiency*
CSA	*390-10 Test Methods, Marking Requirements and Energy Efficiency Levels for Three-Phase Induction Motors* *C392-11 Testing of Three-Phase Squirrel Cage Induction Motors During Refurbishment*
EASA	*ANSI/EASA AR 100-2010 Recommended Practice for the Repair of Rotating Electrical Apparatus*
EASA/AEMT	*The Effect of Repair Rewinding on Motor Efficiency – EASA/AEMT Rewind Study and Good Practice Guide to Maintain Motor Efficiency (2003); Stator Core Testing (Tech Note 17)*
IRCG	Indian River Consulting Group, *The State of the EASA Industry*, 2003 by Michael Marks
NEMA	*Standard MG-1:2009, Motors and Generators*
USDOE	Office of Industrial Technology, *Model Repair Specification for Low Voltage Induction Motors*
USDOE	Advanced Manufacturing Office, *Motor Master Plus 4.01.01* Database Software, download Website location: http://www1.eere.energy.gov/manufacturing/tech_deployment/software_motormaster.html

ATTACHMENTS

GMPG	A-1 Member Annual Agreement
	A-2 Incentive Application Form
	A-3 Electric Motor Repairing Specification—2012
	A-4 Spreadsheet of reported motor rewinds 2009 to 2011
	A-5 Spreadsheet of Non-Compliant motors
	A-6 Updated UES Calculations
OSU	A-7 Oregon State University Pacific Northwest on-site motor study spreadsheets as filtered by GMPG
NEMA	A-8 NEMA Premium® Table 12-13
BPA	A-9 Agriculture operating hours
	A-10 Motor load analysis

ACKNOWLEDGMENT

Bonneville Power Administration (BPA) commissioned this study
Peer Review provided by the Green Motors Practices Group 2012 Board of Directors