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# Assessment of Energy Efficient and Standard Induction Motor in MATLAB Environment

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***Abstract****—Verification of the skin impact electrical phenomenon model is done by scrutiny the calculated current and potency at full load, with makers equipped knowledge beneath traditional conditions. The potency of the commonplace motor and the energy economical motor decreases because the order of harmonics will increase. It's found that the fifth and seventh harmonics contributed over forty fifth and twenty fifth severally of the overall rotor loss of each the EEM and remembering. the speed of drop of the EEM efficiencies is larger than the speed of drop of efficiencies for the remembering at the same load condition this implies that though the EEM could be a far better style, it's a lot of liable to harmonic as a result of the electrical phenomenon within the rotor bars. The payback analysis shows that the EEMs area unit a lot of value effective even once subjected to harmonic. However, the losses due to harmonics have to be compelled to be decreased and more analysis have to be compelled to be dedicated to the losses at the fifth and seventh harmonics.*

***Keywords****:— Harmonics in Induction motor, mat lab, Fourier Transform, energy efficient motor.*

## 1. INTRODUCTION

In induction machine, the stator winding of an induction machine is excited with alternating currents. In contrast to a synchronous machine in which a field winding on the rotor is excited with dc current, alternating currents flow in the rotor windings of an induction machine. In induction machines, alternating currents are applied directly to the stator windings. Rotor currents are then produced by induction, i.e., transformer action. The induction machine may be regarded as a generalized transformer in which electric power is transformed between rotor and stator together with a change of frequency and a flow of mechanical power [12]. Although the induction motor is the most common of all motors, it is seldom used as a generator; its performance characteristics as a generator are unsatisfactory for most applications, although in recent years it has been found to be well suited for wind-power applications [18]. The induction machine may also be used as a frequency changer. In the induction motor, the stator windings are essentially the same as those of a synchronous machine. However, the rotor windings are electrically short-circuited and frequently have no external connections; currents are induced by transformer action from the stator winding

## 2. AN ENERGY-EFFICIENT MOTOR

Until recently, there was no single definition of an energy-efficient motor. Similarly, there were no efficiency standards for standard NEMA design B polyphase induction motors [8]. As discussed earlier, standard motors were designed with efficiencies high enough to achieve the allowable temperature rise for the rating. Therefore, for a given horsepower rating, there is a considerable variation in efficiency. In 1974, one electric motor manufacturer examined the trend of increasing energy costs and the costs of improving electric motor efficiencies. The cost/benefit ratio at that time justified the development of a line of energy-efficient motors with losses approximately 25% lower than the average NEMA design B motors [10]. This has resulted in a continuing industry effort to decrease the watt losses of induction motors. Figure 1 shows a comparison between the full-load watt losses for standard four-pole, 1800-rpm NEMA design B induction motors, the first-generation energy-efficient motors with a 25% reduction in watt losses, and the current energy efficient motors. The watt loss reduction for the current energy efficient four-pole, 1800-rpm motors ranges from 25 to 43%, with an average watt loss reduction of 35%.

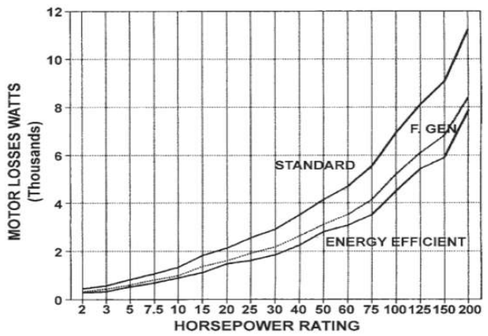


*Figure 1: Full-load losses, standard NEMA Design B 1800-rpm motors versus first-generation energy-efficient motors (25% loss reduction) and current energy-efficient motors.*

### *Analysis Objective*

The objective of this research is to study the losses due to harmonics on energy efficient motors and identify at what harmonic level these motor losses are most significant. This study also investigates the losses on standard motors under the same nonlinear load condition. Multiple motor sizes (25hp, 50hp, 100hp, 150hp, 250hp, and 300hp) were used for this study.

The efficiency of the EEM will be evaluated under this application by using the skin effect impedance model. This model accounts for the nonlinear dependence of rotor bar impedance with frequency [6].

### *3.1 Skin Effect Impedance Model*

This skin effect impedance model is an electrical machine theory which is a simplification of the skin effect electrical transient model. This model is capable of calculating the rotor bar current distribution, but neglects the electrical transients [8]. It represents the nonlinear relationship between rotor bar impedance and frequency. The fundamental frequency and successive harmonics circuits of the skin effect impedance model under steady state condition are shown in figure 2.

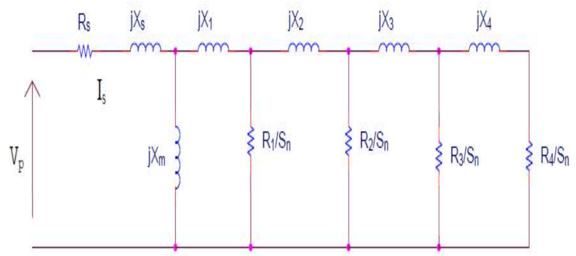


*Figure 2: The skin effect impedance model*

The different parameters of the model are calculated using the manufacturers supplied data for $r_s$, $X_s$, $X_m$, $r_r$, $r_{rstart}$ and $S_n$. The value of rotor harmonic resistance is approximated from the following linear approximation equation,

$$r_f = (r_{rstart} - r_r) * (n - s) + r_r \quad \text{……... (1)}$$

Where n is the harmonic number and $r_f$ is the rotor negative sequence resistance of the motor.

The value of internal inductance $L_{ii}$, is

$$L_{ii} = \frac{r_f^2}{r_r} \quad \text{……………………......…......… (2)}$$

The rotor bar equivalent circuit parameters $L_1$, $L_2$, $L_3$ and $L_4$ are

$$L_1 = L_{ii} * 0.1 \quad \text{……………………….....… (3)}$$

$$L_2 = L_{ii} * 0.2 \quad \ldots\ldots\ldots\ldots (4)$$

$$L_3 = L_{ii} * 0.3 \quad \ldots\ldots\ldots\ldots (5)$$

$$L_4 = L_{ii} * 0.4 \quad \ldots\ldots\ldots\ldots (6)$$

The external inductance X $_{gap}$, is found from the equation

$$X_{gap} = X_r - \frac{L_{ii}}{3} \quad \ldots\ldots\ldots\ldots (7)$$

The parameters $X_1$, $X_2$, $X_3$, $X_4$ of the skin effect impedance model are calculated by summing up the inductances [15].

$$X_1 = X_{gap} + \frac{L_1}{2} \quad \ldots\ldots\ldots\ldots (8)$$

$$X_1 = \frac{L_1}{2} + \frac{L_2}{2} \quad \ldots\ldots\ldots\ldots (9)$$

$$X_1 = \frac{L_2}{2} + \frac{L_3}{2} \quad \ldots\ldots\ldots\ldots (10)$$

$$X_1 = \frac{L_3}{2} + \frac{L_4}{2} \quad \ldots\ldots\ldots\ldots (11)$$

The constant resistance values of the models are calculated by the following Equations

$$R_1 = \frac{r_r}{0.1} \quad \ldots\ldots\ldots\ldots (12)$$

$$R_2 = \frac{r_r}{0.2} \quad \ldots\ldots\ldots\ldots (13)$$

$$R_3 = \frac{r_r}{0.3} \quad \ldots\ldots\ldots\ldots (14)$$

$$R_4 = \frac{r_r}{0.4} \quad \ldots\ldots\ldots\ldots (15)$$

These constant resistances are converted to variable resistances that vary with frequency when they are divided by respective slip, S at that harmonic order.

### *Fourier Transform*

The Fourier transform is a versatile tool used in many fields of science as a mathematical tool to alter a problem to one that can be more easily solved. The Fourier transform decomposes a signal or a function into a sum of sine and cosines of different frequencies which sum up to the original signal or function. The main advantage of the Fourier transform lies in its ability to transfer the signal from the time domain to the frequency domain which usually contains more information about the analyzed signal [11].

The Discrete Fourier Transform (DFT) is a form of Fourier transform that expresses an input functions an input function which is discrete and finite in terms of a sum of in terms of a sum of sinusoidal components by determining the amplitude sinusoidal components by determining the amplitude and phase of each component.

These properties makes the DFT ideal for processing information stored in DFT ideal for processing information stored in computers. In particular, the DFT is widely employed in signal processing and related particular, the DFT is widely employed in signal processing and related particular, the DFT is widely employed in signal processing and related fields to analyze the frequencies contained in a sampled signal fields to analyze the frequencies contained in a sampled sign al and solve other and solve other mathematical operations. As power system disturbances are subject to transient and non As power system disturbances are subject to transient and non As power system disturbances are subject to transient and non-periodic components, the DFT alone may fail to provide an accurate signal analysis. A much alone may fail to provide an accurate signal analysis. A much alone may fail to provide an accurate signal analysis. A much faster algorithm called the Fast Fourier Transform (FFT) was developed b y Cooley in was developed by Cooley in 1965. This algorithm makes the computation This algorithm makes the computation speed f or analyzing a Fourier signal analyzing a Fourier signal much faster. The computation time for computation time for the FFT is proportional to $N\log_2(N)$, where N (N), where N is the number of points in the series [11].

The sequence of N complex numbers $x_0$, ..., $x_{N-1}$ is transformed into the is transformed into the sequence of N complex numbers $X_0$,..., $X_{N-1}$ by th e DFT according to the formula:

$$X_k = \sum_{n=0}^{N-1} x_n e^{-\frac{2\pi i}{N}kn} \quad k = 0, \dots \dots \dots, N-1 \qquad \dots\dots (3.16)$$

Where e is the base of the natural logarithm and i is the imaginary unit ($i^2$=-1)

### *Harmonic Model*

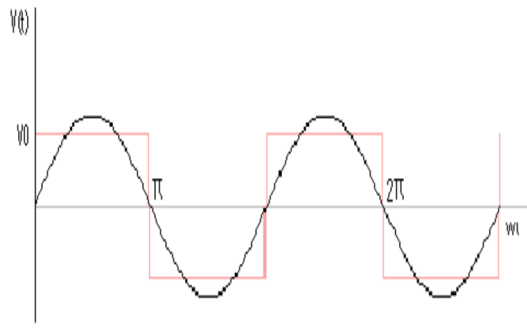


*Figure 3: Sinusoidal Wave*

Any single-valued, finite and continuous function valued, finite and continuous function V (t) having a period o, may be $\frac{2\pi}{\omega}$ expressed as the Fourier series Where $v_0$ is the fundamental voltage (peak to peak) This equation represents a function s a function in terms of the fundamental frequency and it's in terms of the fundamental frequency and its harmonics. Each frequency is an integer multiple of the fundamental Each frequency is an integer multiple of the fundamental Each frequency is an integer multiple of the fundamental system frequency as shown in Figure 3.3.

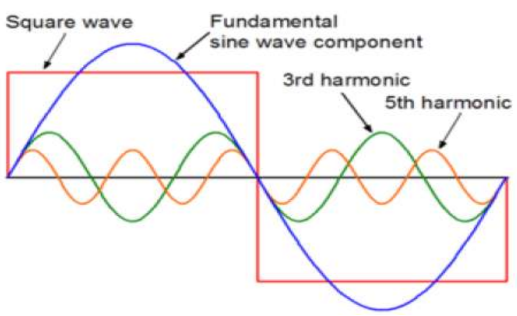


*Figure 4: Harmonic Waveform*

## 3. RESULTS AND DISCUSSION

| 50 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| EEM Stator Loss | EEM Rotor Loss | EEM Eff | EEM tLoss | STM Stator Loss | STM Rotor Loss | STM Eff | STM tLoss | LifeCost | PBP |
| 0.0233448 | 0.78667 | 93.9881 | 0.0523491 | 0.0260738 | 0.775179 | 92.3249 | 0.065396 | 438.376 | 5.03883 |
| 0.0225762 | 0.0433362 | 93.3405 | 0.0789122 | 0.0234545 | 0.0417064 | 91.5922 | 0.0871444 | 467.736 | 4.72253 |
| 0.0103893 | 0.023538 | 93.1436 | 0.0466075 | 0.0107632 | 0.0225935 | 91.3541 | 0.0550223 | 481.009 | 4.59222 |
| 0.00453622 | 0.00912837 | 93.0985 | 0.0261422 | 0.00470895 | 0.00877831 | 91.2918 | 0.0349543 | 486.2 | 4.54319 |
| 0.00308506 | 0.00674059 | 93.0707 | 0.0222649 | 0.00319806 | 0.00647367 | 91.2518 | 0.0311006 | 489.854 | 4.50931 |
| 0.00188233 | 0.00384415 | 93.0574 | 0.0181247 | 0.00195352 | 0.00369586 | 91.2313 | 0.027038 | 491.975 | 4.48986 |
| 0.00145616 | 0.00314128 | 93.0474 | 0.0169844 | 0.00150982 | 0.00301748 | 91.2156 | 0.0259047 | 493.664 | 4.4745 |
| 0.00102381 | 0.00210599 | 93.0412 | 0.0155021 | 0.0010624 | 0.00202451 | 91.2054 | 0.0244499 | 494.814 | 4.4641 |
| 0.000844579 | 0.00181014 | 93.036 | 0.0150223 | 0.000875803 | 0.00173898 | 91.1969 | 0.0239731 | 495.785 | 4.45536 |

| 100 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| EEM Stator Loss | EEM Rotor Loss | EEM Eff | EEM tLoss | STM Stator Loss | STM Rotor Loss | STM Eff | STM tLoss | LifeCost | PBP |
| 0.0141648 | 0.78409 | 95.4425 | 0.0401639 | 0.0148027 | 0.765835 | 92.9505 | 0.0606511 | 1284.96 | 1.31212 |
| 0.0180179 | 0.046585 | 94.8095 | 0.0794675 | 0.014934 | 0.0363303 | 92.4293 | 0.0791686 | 1242.47 | 1.35699 |
| 0.00838641 | 0.025625 | 94.606 | 0.0485701 | 0.00702967 | 0.0202115 | 92.2358 | 0.0549053 | 1242.5 | 1.35695 |
| 0.00363151 | 0.00984447 | 94.5593 | 0.0278294 | 0.00301936 | 0.00770187 | 92.182 | 0.0382202 | 1247.61 | 1.35139 |
| 0.00248384 | 0.00731568 | 94.5298 | 0.0241162 | 0.00207672 | 0.00575571 | 92.1455 | 0.0353026 | 1252.16 | 1.34648 |
| 0.00150841 | 0.00415016 | 94.5156 | 0.0199338 | 0.00125538 | 0.00325015 | 92.1263 | 0.0319424 | 1255.2 | 1.34322 |
| 0.00117133 | 0.00340573 | 94.5047 | 0.0188415 | 0.000978476 | 0.00267716 | 92.1112 | 0.031084 | 1257.79 | 1.34046 |
| 0.000820839 | 0.00227485 | 94.4979 | 0.0173453 | 0.000683477 | 0.00178239 | 92.1014 | 0.0298824 | 1259.61 | 1.33852 |
| 0.000679066 | 0.0019615 | 94.4922 | 0.0168857 | 0.000567008 | 0.0015412 | 92.093 | 0.0295211 | 1261.2 | 1.33683 |

| 150 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| EEM Stator Loss | EEM Rotor Loss | EEM Eff | EEM tLoss | STM Stator Loss | STM Rotor Loss | STM Eff | STM tLoss | LifeCost | PBP |
| 0.0124085 | 0.773336 | 95.7073 | 0.0367373 | 0.0158301 | 0.797382 | 93.6255 | 0.055728 | 1594.14 | 1.52457 |
| 0.00698558 | 0.0144315 | 95.6115 | 0.0337476 | 0.0118406 | 0.0258495 | 93.3242 | 0.0636517 | 1758.98 | 1.38169 |
| 0.0034228 | 0.00834087 | 95.5739 | 0.0239978 | 0.00565722 | 0.0145942 | 93.2061 | 0.0460387 | 1823.87 | 1.33253 |
| 0.00142785 | 0.00309286 | 95.5638 | 0.0166826 | 0.00240378 | 0.00550333 | 93.172 | 0.033571 | 1843.17 | 1.31858 |
| 0.00100189 | 0.00235563 | 95.5568 | 0.0155078 | 0.00166562 | 0.00414287 | 93.1485 | 0.0314514 | 1856.5 | 1.30911 |
| 0.000595743 | 0.00130962 | 95.5531 | 0.0140411 | 0.00100074 | 0.00232544 | 93.1361 | 0.0289443 | 1863.63 | 1.3041 |
| 0.000470554 | 0.00109247 | 95.5502 | 0.0136954 | 0.000783862 | 0.00192481 | 93.1261 | 0.0283206 | 1869.32 | 1.30014 |
| 0.000324903 | 0.000719397 | 95.5484 | 0.0131715 | 0.00054519 | 0.0012761 | 93.1196 | 0.0274244 | 1873.05 | 1.29755 |
| 0.000272239 | 0.000627973 | 95.5468 | 0.0130259 | 0.000453963 | 0.00110745 | 93.1141 | 0.0271619 | 1876.21 | 1.29536 |

| 200 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| EEM Stator Loss | EEM Rotor Loss | EEM Eff | EEM tLoss | STM Stator Loss | STM Rotor Loss | STM Eff | STM tLoss | LifeCost | PBP |
| 0.0111703 | 0.789618 | 95.9502 | 0.0349407 | 0.0135421 | 0.807953 | 94.5631 | 0.0479255 | 1398.64 | 2.11967 |
| 0.00626502 | 0.0146974 | 95.8625 | 0.0320826 | 0.0118516 | 0.0284305 | 94.2544 | 0.0619055 | 1628.3 | 1.8207 |
| 0.00306749 | 0.0084959 | 95.8282 | 0.0225898 | 0.00565624 | 0.0160462 | 94.1377 | 0.0431402 | 1714.44 | 1.72922 |
| 0.00128032 | 0.00314973 | 95.8192 | 0.0153853 | 0.0024053 | 0.00605201 | 94.106 | 0.0297626 | 1738.24 | 1.70555 |
| 0.000898044 | 0.00239915 | 95.813 | 0.0142411 | 0.00166576 | 0.00455519 | 94.0843 | 0.0275039 | 1754.41 | 1.68983 |
| 0.000534157 | 0.00133371 | 95.8098 | 0.0127975 | 0.00100128 | 0.0025572 | 94.0731 | 0.0248148 | 1762.84 | 1.68174 |
| 0.000421808 | 0.00111262 | 95.8072 | 0.0124607 | 0.000783993 | 0.00211641 | 94.0642 | 0.0241502 | 1769.53 | 1.67539 |
| 0.000291306 | 0.000732629 | 95.8056 | 0.0119452 | 0.000545456 | 0.00140325 | 94.0584 | 0.023189 | 1773.86 | 1.6713 |
| 0.000244044 | 0.00063955 | 95.8042 | 0.0118034 | 0.000454059 | 0.0012177 | 94.0535 | 0.0229092 | 1777.53 | 1.66785 |

| 250 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| EEM Stator Loss | EEM Rotor Loss | EEM Eff | EEM tLoss | STM Stator Loss | STM Rotor Loss | STM Eff | STM tLoss | LifeCost | PBP |
| 0.0107013 | 0.813871 | 96.1464 | 0.0340064 | 0.0126813 | 0.805525 | 94.2708 | 0.0503298 | 2366.48 | 1.38606 |
| 0.00870185 | 0.0224611 | 95.9763 | 0.0437727 | 0.00926754 | 0.0212707 | 94.0579 | 0.0556554 | 2430.37 | 1.34962 |
| 0.00421047 | 0.0128689 | 95.9132 | 0.0295483 | 0.00448488 | 0.0121846 | 93.9702 | 0.0416481 | 2465.3 | 1.33051 |
| 0.00177261 | 0.00480023 | 95.8974 | 0.0189368 | 0.00188792 | 0.00454567 | 93.9445 | 0.0313099 | 2479.07 | 1.32311 |
| 0.00123604 | 0.0036402 | 95.8868 | 0.0172232 | 0.00131655 | 0.00344683 | 93.9264 | 0.029623 | 2489.26 | 1.3177 |
| 0.000738779 | 0.00203089 | 95.8815 | 0.0150956 | 0.000786849 | 0.00192316 | 93.9168 | 0.0275491 | 2495.08 | 1.31462 |
| 0.000581107 | 0.00168924 | 95.8773 | 0.0145913 | 0.00061895 | 0.00159954 | 93.9091 | 0.0270526 | 2499.85 | 1.31211 |
| 0.000402695 | 0.00111515 | 95.8746 | 0.0138313 | 0.000428899 | 0.00105599 | 93.9041 | 0.0263117 | 2503.05 | 1.31044 |
| 0.000336369 | 0.000971326 | 95.8723 | 0.013619 | 0.000358271 | 0.000919754 | 93.8998 | 0.0261028 | 2505.8 | 1.309 |

| 300 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| EEM Stator Loss | EEM Rotor Loss | EEM Eff | EEM tLoss | STM Stator Loss | STM Rotor Loss | STM Eff | STM tLoss | LifeCost | PBP |
| 0.0106447 | 0.84153 | 96.4836 | 0.0317684 | 0.0116711 | 0.827215 | 94.9354 | 0.0451874 | 2319.56 | 1.31664 |
| 0.00815951 | 0.0208855 | 96.3466 | 0.0395929 | 0.00831444 | 0.0207982 | 94.7548 | 0.0509329 | 2392.75 | 1.27637 |
| 0.00396027 | 0.0120002 | 96.2962 | 0.0263776 | 0.0040274 | 0.0119232 | 94.6812 | 0.0376393 | 2430.87 | 1.25636 |
| 0.00166355 | 0.00446743 | 96.2841 | 0.0164498 | 0.00169421 | 0.004446 | 94.6602 | 0.0277308 | 2445.17 | 1.24901 |
| 0.00116177 | 0.00339258 | 96.2759 | 0.0148575 | 0.00118201 | 0.00337251 | 94.6454 | 0.0261293 | 2455.7 | 1.24365 |
| 0.000693513 | 0.00189058 | 96.2719 | 0.0128675 | 0.000706173 | 0.00188114 | 94.6376 | 0.0241424 | 2461.65 | 1.24064 |
| 0.000546061 | 0.00157401 | 96.2687 | 0.0123988 | 0.00055566 | 0.00156498 | 94.6313 | 0.0236711 | 2466.52 | 1.23819 |
| 0.000378071 | 0.00103824 | 96.2667 | 0.0116881 | 0.00038494 | 0.00103296 | 94.6273 | 0.0229613 | 2469.77 | 1.23656 |
| 0.000316043 | 0.000904968 | 96.265 | 0.0114908 | 0.000321625 | 0.000899856 | 94.6238 | 0.022763 | 2472.57 | 1.23517 |

A thorough investigation of the impact of harmonics on the operation of energy efficient motors and the standard motors was conducted with the aid of computer programs using Matlab software and using the data supplied by the motor manufacturer [15]. The computer program compares the characteristic behavior of these motors (EEMs and STMs) at the fundamental frequency and at different orders of harmonics. The manufacturer supplied data used is given in Appendix A. All values displayed on the graph are in per unit, (p.u), and percentages.

Each of the EEM and STM were analyzed utilizing the computer program developed. The result of the analysis as shown in the graph section shows that the STM has more total loss than the EEM. This conclusion is expected since the EEM is better designed to compensate for this loss; hence the focus is on the secondary ohmics loss, the rotor loss. The rotor loss is dependent on the speed and the frequency at which the motor is operating and due to this understanding and the discussion of the electrical impedance model, the rotor loss of the EEM is much greater than that of the STM. Each STM and EEM followed trend of higher rotor losses. For the 25hp motors, the rate of increase of rotor loss for the STM motor is 7% while that of the EEM motor is 10.7%. For the 50hp motors, the rate for STM and EEM are 10.6% and 10.4% respectively. The rate of increase in rotor loss for the 100hp STM is 9.38% and that of the EEM is11.43%. However as the rating of the motor increases, it was observed that the rate of increase in the rotor for the STM became slightly higher or about the same. For the 150hp the rate of increase in rotor loss for the STM is 6.64% as against 3.97% for the EEM. Likewise for the 200hp, the rate of increase in rotor loss for the STM is 7.17% as against 3.96% for the EEM. The rate of increase for 250hp for the STM and EEM are practically the same at 5.51% and 5.54% respectively. Likewise the rate of increase of the 300hp for the STM and EEM are 5.31% and 5.28%. These differences for the higher rating EEMs might be due to possible differences in rotor bar and end rings design as well as the motor's composition. In all, the largest percentage increase in rotor loss for the EEM is 11.43% at 100hp and for the STM is 10.41% at 50hp. The smallest percentage increase in rotor loss for the EEM is 3.96% at 200hp and that of the STM is 5.31% at 300hp. The largest cumulative rotor loss in per unit for the STM and EEM are 0.8703 and 0.8952 at 200hp and 250hp respectively while the smallest summation of rotor loss per unit for the STM and EEM are 0.8451 and 0.8053 at 100hp and 150hp respectively.

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