ISSN 2320-9984

Volume 11 Issue 1 | March 2023

ISSN: 2320-9984 (Online)

International Journal of Modern Engineering & Management Research

Website: www.ijmemr.org

Impact of Harmonics on Performance 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, Fourier Transform, energy efficient motor Induction motor, Fourier series, Matlab, losses of induction motor.*

1. INTRODUCTION

The largest portion of electricity consumed is employed by induction motors. Over of all electrical energy consumption in the India is by electric motors and over 2 third of electricity utilized by business is electrical motor [11]. Raising the potency of electrical motors is of high priority. within the last 20 years, vital effort has been created by makers of electrical motors in the technique of construction of energy efficient motors (EEM). This effort has resulted in improvement in full-load efficiencies of electrical motors. The Energy Policy Act (EPACT) of 1992 that was enforced in 1997 needs that each one general purpose point in time single speed squirrel-cage induction motors factory-made within the North American nation rated from 1 – two hundred horse power (hp) should meet minimum potency levels. Motor potency standards have succeeded in remodeling the motor marketplace, leading to vital energy savings and carbon reductions. As a results of the standards that was enacted as a part of the EPAct-92 [10]. The importance of this investigation is to more explore area wherever energy economical motors are still vulnerable to vital losses once subjected to non- curving supply such as harmonics. It has been established that harmonics considerably impact the operation of normal motors however their impact on energy economical motors has not been totally investigated, additionally the harmonics order at that these losses area unit most vital has not be documented.

2. STANDARD MOTOR EFFICIENCY

During the period from 1960 to 1975, electric motors, particularly those in the 1- to 250-hp range, were designed for minimum first cost. The amount of active material, i.e., lamination steel, copper or aluminum or magnet wire, and rotor aluminum, was selected as the minimum levels required meeting the performance requirements of the motor [1]. Efficiency was maintained at levels high enough to meet the temperature rise requirements of the particular motor. As a consequence, depending on the type of enclosure and ventilation system, a wide range in efficiencies exists for standard NEMA design B polyphase motors. Table 1 is an indication of the range of the nominal electric motor efficiencies at rated horsepower. These data are also presented in Figure 1. The data are based on information published by the major electric motor manufacturers. However, the meaning or interpretation of data published prior to the NEMA adoption of the definition of nominal efficiency is not always clear. In 1977, NEMA recommended a procedure for marking.

Table 1: Full-Load Efficiencies of NEMA Design B Standard Three-Phase Induction Motors

HP	Nominal Efficiency range	Average Nominal Efficiency
1	68-78	73
1.5	68-80	75
2	72-81	77
3	74-83	80
5	78-85	82
7.5	80-87	84
10	81-88	85
15	83-89	86
20	84-89	87.5
25	85-90	88
30	86-90.5	88.5
40	87-91.5	89.5
50	88-92	90
60	88.5-92	90.5
75	89.4-92.5	91
100	90-93	91.5
125	90.5-93	92
150	91-93.5	92.5
200	91.5-94	93
250	91.594.5	93.5

The three-phase motors with a NEMA nominal efficiency. This efficiency represents the average efficiency for a large population of motors of the same design [6]. In addition, a minimum efficiency was established for each level of nominal efficiency. The minimum efficiency is the lowest level of efficiency to be expected when a motor is marked with the nominal efficiency in accordance with the NEMA standard. This method of identifying the motor efficiency takes into account variations in materials, manufacturing processes, and test results in motor-to-motor efficiency variations for a given motor design. The nominal efficiency represents a value that should be used to compute the energy.

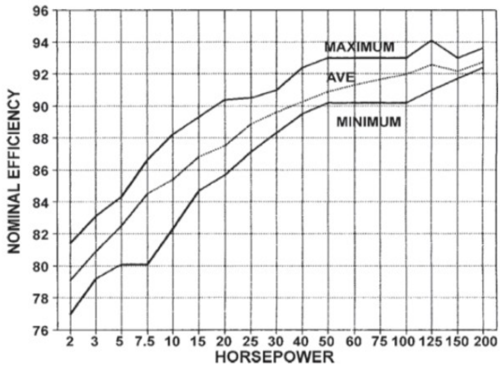

Figure 1: Nominal efficiency range of standard open NEMA design B 1800-rpm polyphase induction motors.

Consumption of a motor or group of motors. Table 1 shows a wide range in efficiency for individual motors and, consequently, a range in the electric motor losses and electric power input

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].

Motor Losses

The losses associated with these motors can be categorized into five major types. The first type of loss is the primary I^2R loss which is the copper loss that is due to the stator windings. The secondary I^2R loss is considered the second type of induction motor loss [5]. This loss is due to the rotor bars and end rings of the motor. The third type of induction motor loss is the losses in the iron core of the motor. Friction and windage loss in the induction motor which is caused by the friction in the bearings of the motor and aerodynamic losses associated with the ventilation fan and other rotating parts are considered the fourth type of motor loss. The fifth and most elusive is the stray load loss [7]. The stray load losses arise from variety of sources and are very difficult to identify or measure. At each of the harmonic levels these losses are calculated and are used to calculate the efficiency of the motor. However, since the no load loss provided by the motor vendor can represent the friction, windage and iron core losses of the motor, they are considered constant regardless of the harmonic level. The skin effect impedance model equivalent circuits of a three-phase induction motor are shown in Figure 2.

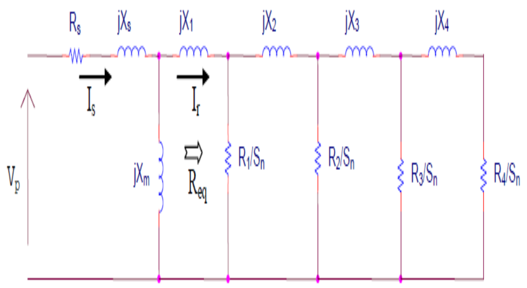

Figure 2: The skin effect impedance model

Where R_s and X_s refer to the stator resistance and reactance respectively, X_m is the magnetizing reactance, I_s and I_r are the stator and the rotor current. S_n is the slip of the motor which is dependent on the harmonic. R_{eq} is the equivalent motor impedances looking into the rotor as shown in Figure 3.

Calculating Motor Losses:

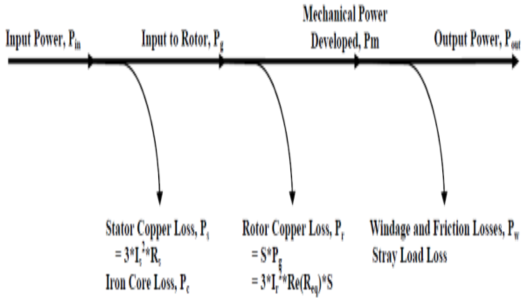

Figure 3: Power Flow in an Induction Motor

Input Power

The total electrical power input can be calculated as shown in 1....

$$P_{in} = \sqrt{3} * V_p * I_s * \cos\theta \quad \text{.................. (1)}$$

Where V_p, I_s, and Cos) θ are the fundamental voltage, stator current and the power factor of the motor respectively.

Stator Loss

The formula to calculate the stator loss of the motor is given by…

$$P_s = 3 * I_s^2 * R_s \quad \text{…....…….............. (2)}$$

Where, R_s is the stator resistance.

Rotor Loss

The power transferred across the air gap, P_g which is also known as the rotor input power is first calculated as shown below. The rotor resistance loss is then calculated based on the slip of that harmonic order as shown…

$$P_g = 3 * I_s^2 * R_g \quad \text{…………………...……. (3)}$$

Where R_g is the real part of the parallel combination of jX_m and R_{eq}…………………

$$P_r = S * P_g \quad \text{…………………………...……. (4)}$$

The rotor loss can also be calculated using equation 5…

$$P_r = 3 * I_r^2 * Re(R_{eq}) * S \quad \text{…...…...…….. (5)}$$

Stray Losses

Stray loss cannot be easily calculated. It is actually the sum of several smaller losses that are dependent on the motor operation. For this study, the stray loss is assumed to be 0.5% of the total input power at each harmonic order based on International Electro technical Commission, IEC standard. So,…

$$P_{strayLoss} = 0.005 * P_{in} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

3. RESULTS AND DISCUSSION

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. All values displayed on the graph are in per unit, (p.u), and percentages.

Table 2: Compares the characteristic behavior of these motors (EEMs and STMs) at the fundamental frequency and at different orders of harmonics

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

Graphical Reports

The graphs shown in Figures 4-9, obtained from the computer analysis for this of the 250hp motors [8]. Each of the graphs show the overall analysis of this study based on their corresponding rating. The graphs include, the total cumulative loss of both the STM and EEM in per unit, the associated secondary ohmics loss (rotor loss) in per unit, the percent increase in rotor loss in percentage, the associated primary ohmics loss (stator loss) in per unit, the percent increase in stator loss in percentage, the efficiencies of EEM and STM in percentage, percentage decrease in efficiencies for each motor, the yearly savings (Rs), percent increase in yearly savings in percentage and the payback period in year(s).

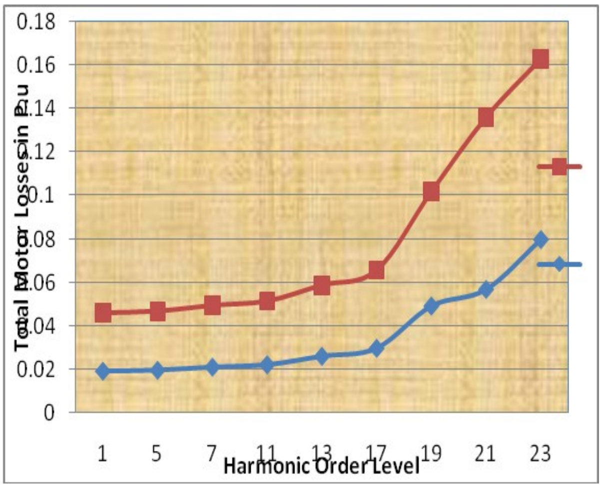

Figure 4: Cumulative Total Losses for 25HP Motors

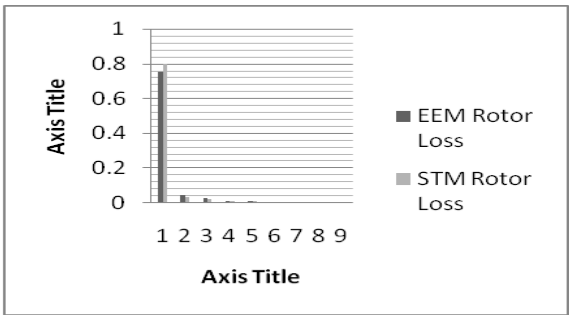

Figure 5: Rotor Losses for 25HP Motors vs. Harmonic Order

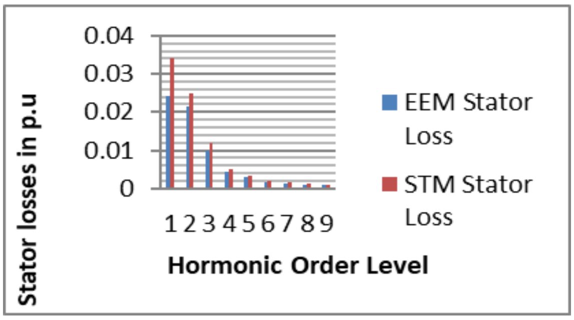

Figure 6: Stator Losses for 25 HP Motors vs. Harmonic Order

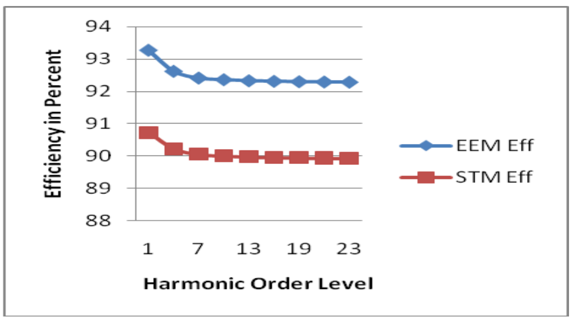

Figure 7: Efficiencies for 25 HP Motors vs. Harmonic Order

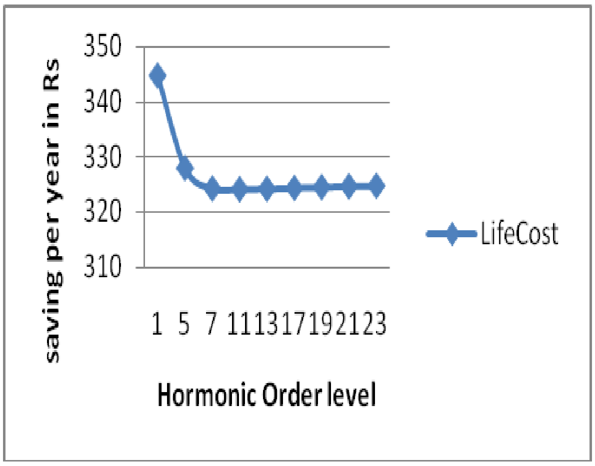

Figure 8: Yearly Savings for 25 HP EEM over STM vs.

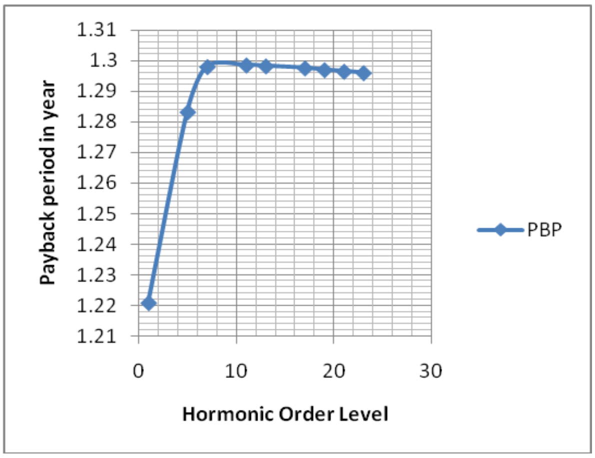

Figure 9: Payback Time for 25 HP Motors vs. Harmonic

4. CONCLUSION

In this study, the behavior of the energy efficient and the standard motors when subjected to harmonic conditions were investigated and compared. The skin effect impedance model was used in the analysis of this study. Computer program was used to simulate the characteristic of the motors. The losses due to harmonic were calculated and documented; the efficiencies of the motors and its economic impact on these motors were well understood. In addition, the harmonic orders that contributed the most loss to the motors' total losses were identified. The methodology adopted in this study supported the overall objective of this research. It was determined and verified that energy efficient motor is more cost efficient even under harmonic load.

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