JOURNAL OF MECHANICS OF CONTINUA AND MATHEMATICAL SCIENCES
www.journalimcms.org

ISSN (Online) : 2454 -7190 Vol.-18, No.-5, May (2023) pp 22-31 ISSN (Print) 0973-8975

ENERGY CONSERVATION BY NEW ENERGY-EFFICIENT MOTORS AND CONFIDENCE INTERVAL FORECASTS USING STATISTICAL TECHNIQUES

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https://doi.org/10.26782/jmcms.2023.05.00003

(Received: February 22, 2023; Accepted: May 04, 2023)

Abstract

As the most energy-intensive machines on the planet, induction motors are the subject of an ongoing study to increase their effectiveness. In this respect, new energy-efficient motors (NEEMs) are being developed. For increasing energy conservation, motors with efficiencies considerably higher than traditional standard motors (TSMs) and energy-efficient motors (EEMs) have been suggested. NEEMs have the potential to save a significant quantity of energy as well as operating costs. A comparative study is conducted in this paper to show how much energy and cost can be saved if TSMs in various industries in Pakistan are replaced with NEEMs, as well as their payback period. A data sample of 23 motors of different ratings has been collected in this pilot study and 90 percent confidence limits are calculated using a t-distribution. The energy conservation benefits of the NEEMs are found encouraging.

Keywords. Energy-efficient motors, energy conservation, payback, cost saving, energy saving.

I. Introduction

Since the majority of Pakistan's electricity is produced by burning fossil fuels, which have detrimental effects on the planet's atmosphere, the country has been experiencing a power deficit for more than 20 years [I]. To overcome this issue, in addition to switching to renewables, significant attention is being paid to optimizing usage and minimizing electrical power waste [II]. Consequently, the fields of research in energy-conserving devices and improving their efficiency are being extensively researched nowadays. [III]. Globally, the industrial sector usually seems to be a major consumer of a country's electric power [IV]. In Pakistan, a recent 2021 estimate shows that the country's industries use about 29% of the nation's total power, with electric motors using almost 80% of it [VI]. The breakdown of Pakistan's total electricity usage by various sectors for the years 2021 and 2022 is shown in Figure 1. Historically, almost every industry has used low-efficiency motors in the past, which are also called standard induction motors. Some efficient motors can have significant advantages over traditional ones [VII].

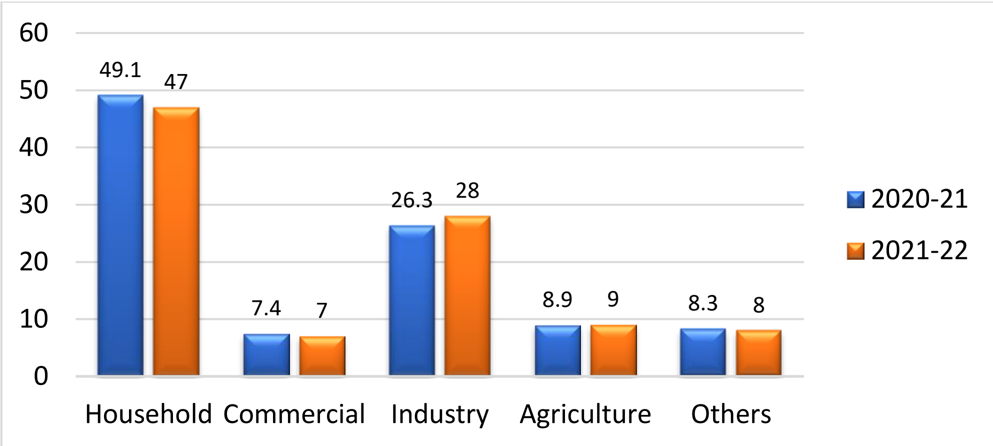

Fig. 1. Electricity Consumption by different sectors in Pakistan

Any machine's effectiveness and efficacy are significantly influenced by losses [IX]. The losses resulting from stator and rotor failures are the most frequent. Energy-efficient motors (EEMs) were frequently recommended as a replacement for conventional standard motors (TSMs) in a study to reduce electrical losses and preserve energy [VIII]. Higher-efficiency motors can result in substantial energy savings, cost savings, quick payback times, and a reduction in Pakistan's power shortage [IX].

The authors of [X] have suggested that Pakistan's industrial sector needs energy-efficient motors for improved energy conservation. High-efficiency motors minimize the loss of heat and other elements compared to motors commonly used in the business, according to the authors of [XI]. To demonstrate the advantages of high-efficiency electric motors over standard motors of comparable rating, the authors of [XII] presented statistics from 20 TSMs from the industrial sector of Pakistan. In addition to providing an overview of how energy-efficient motor technology is used for industrial operations, authors of [XIII] have shed light on Pakistan's current initiative to conserve electricity and reduce carbon footprints. The relation of motor losses with load can be seen in detail from [XV].

Several authors have already compared the benefits of the TSMs over EEMs, but in this paper, a comparison of three different types of motors is done to highlight the energy-saving, cost-saving, and paybacks in Pakistan's reference. This paper presents the analysis and benefits of the replacement of Traditional standard motors (TSMs) with new energy-efficient motors (NEEMs) and Energy efficient motors EEMs.

II. Material and Methods

The data collection framework is described here with the details of surveyed motors. Finally, based on statistical analysis, the cost-effectiveness parameters of NEEMs are shown to be more efficient than the existing motors. Based on some industries located in Karachi, Pakistan the data about already installed motors was collected through personal visits and measurements. The data include power, current rating, and voltage ratings along with hours of operation and stated efficiency.

For this pilot study at a small scale to motivate the benefits of NEEMs, 23 samples of TSMs were used, and the collected data are given in Table 1.

Table 1: 23 TSMs data

Serial Number	Power HP	Measured Volts	Measure Amperes	Power Factor	Load factor
1	1	380	2	0.81	0.821
2	2	397	2.9	0.7	0.537
3	3	378	4.6	0.8	0.632
4	3.5	455	4.64	0.79	0.667
5	4	386	6.3	0.87	0.705
6	5	378	6.8	0.83	0.577
7	5.5	393	7.6	0.81	0.605
8	7	371	9	0.82	0.498
9	7.5	380	11.3	0.78	0.598
10	8	376	11.9	0.79	0.589
11	9	455	24	0.8	1.344
12	10	385	16.4	0.85	0.716
13	15	376	22.5	0.8	0.615
14	25	394	33.5	0.82	0.585
15	30	378	44	0.84	0.635
16	35	455	41	0.83	0.607
17	40	396	49	0.86	0.556
18	42	375	58	0.86	0.624
19	50	465	53.7	0.85	0.574
20	60	390	80	0.86	0.596
21	62	396	138	0.81	0.984
22	70	455	83	0.86	0.591
23	100	395	170	0.85	0.761

These 23 motors are labeled as the traditional standard motors (TSMs) which are usually found in industries in Pakistan. On the other hand, an energy-efficient motor (EEM) assures the same shaft output power (HP) but uses less input power (kW) than a TSM besides having a smaller amount of losses and improved efficiency. Both of these types of motors were suggested in the recent past. Here, we suggest new energy-efficient motors (NEEMs) with substantial advantages the past technologies [XV]. These motors operate at higher efficiency which is due to their fewer operating losses [XVI]. NEEMs are also known as super premium efficiency motors.

They are capable of achieving efficiency levels of up to 98%, which is significantly higher than the 90-95% efficiency range typically achieved by EEMs or TSMs. This translates into lower energy consumption and reduces operating costs. However, they are typically more expensive TSMs and EEMs and may require additional infrastructure to support their operation, such as variable speed drives. They have interior permanent magnets IPMs which increase the performance by eliminating the copper losses of the rotor winding and core. NEEMs employ reluctance torque in addition to magnetic torque, which allows them to provide more output power. Comparatively, a 15HP TSM, EEM, and NEEM have efficiency readings of 82%, 84%, and 90% respectively. However, even for higher HP such difference is evident between the TSMs and EEMs and TSMs and NEEMs.

We follow the cost-effectiveness procedure from [XII] and use the parameters defined in equations (1)-(4) for further analysis for each TSM.

$$kW_{saved} = HP \times L \times 0.746\left[\frac{100}{\xi_{TSM}} - \frac{100}{\xi_{NEEM}}\right] \tag{1}$$

$$E_{saved} = h \times kW_{saved} \tag{2}$$

$$C_{saved} = (kW_{saved} \times 12 \times MDC) + (E_{saved} \times EC) \tag{3}$$

$$P_{simple} = \frac{LPP\ x\ DF}{C_{saved}} \tag{4}$$

Equation (1) finds the power saved, where L is the load factor and ξ denotes the efficiency of a motor at full rated load. Equation (2) finds the total energy saved per year by a NEEM over TSM in kWh/year with *h* hours of operation. The cost savings per motor annually are calculated from (3) with information on monthly demand and energy charges (MDC and EC). By dividing the difference in prices of TSM and NEEM, which is discounted list price premium (LPP*DF) by cost savings we get a payback period in years from (4).

Here, DF=0.75, EC= Rs 19.68/kWh, and MDC=Rs 400/kW/month (NEPRA's B3 type industrial supply tariff in the year 2022) were used. The efficiencies and prices were obtained from international manufacturers and Figures 2 and 3 depict the annual energy consumption and operational costs of TSMs, EEMs, and NEEMs.

III. Statistical Analysis and Future Forecasts

With a focus on three key parameters—energy savings (measured in kWh/year), cost savings, and payback times (measured in years) of substituted EEMs and NEEMs—we apply the statistical methods described in the preceding section to the data in this section. All instances in which EEMs and NEEMs have been used in lieu of TSMs make up the population under investigation. Utilizing a sample of 23 NEEMs and their computed statistics, the population, mean energy savings, mean expense savings, and mean payback period are investigated.

The mean and standard variation of the three population parameters is calculated using sample data. The 90 percent confidence intervals for the mean energy savings, mean cost savings, and mean payback period for each prospective comparable motor replacement are then displayed using student t distribution.

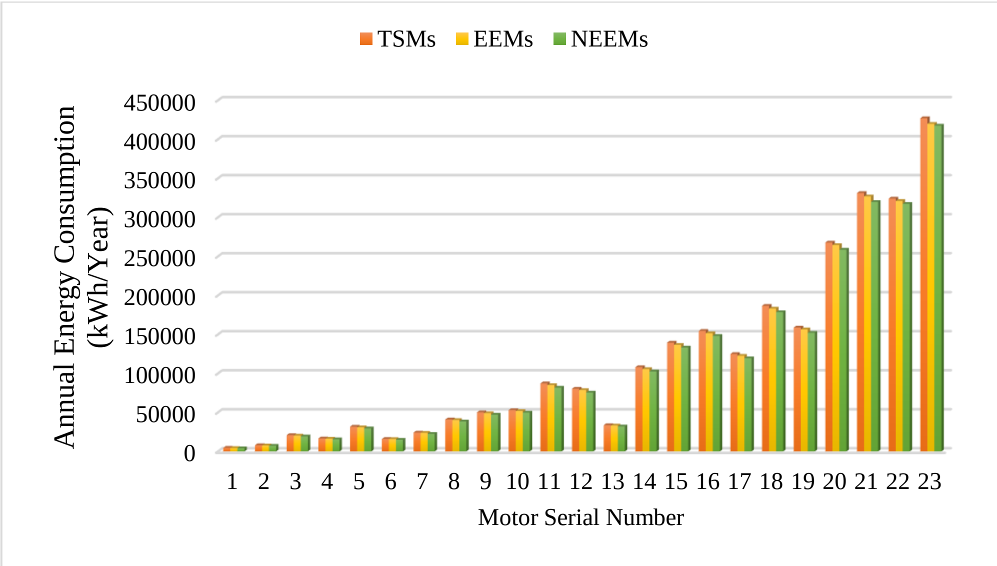

Fig. 2. Comparison of annual energy consumption of NEEMs, EEMs, and TSMs

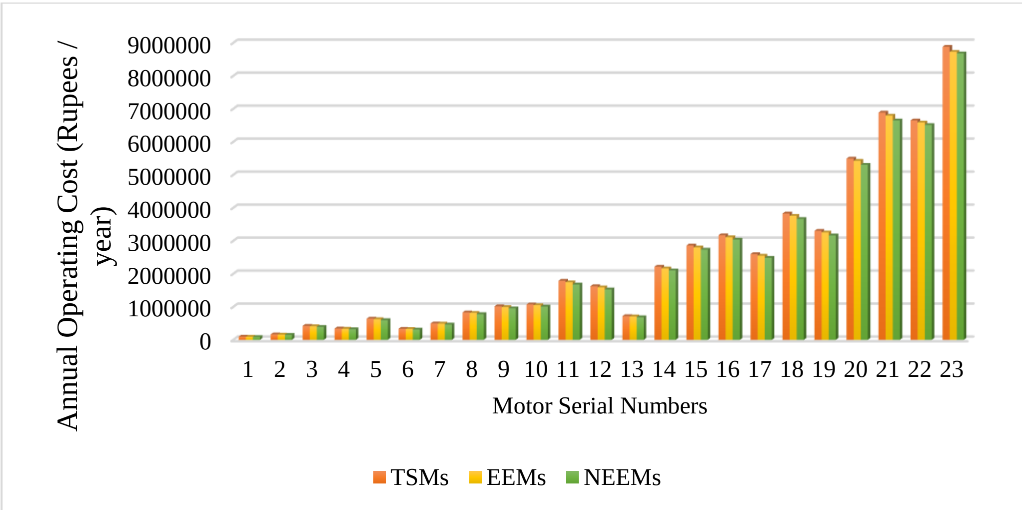

Fig. 3. Comparison of annual operating cost of NEEMs, EEMs, and TSMs

III.i. Descriptive statistical analysis

The sample means of the motors that were taken into consideration for the sample must be computed to pinpoint the center of the trend of the energy-saving, cost-saving, and payback of NEEMs in future replacements. It results in understanding the future forecasts about major indicators through single numbers - the means - as given in Table-2 in pairs.

Table 2. Comparison of pair-wise sample mean values

Sample Mean	NEEMs Vs TSMs	NEEMs Vs EEMs	Units
Energy saving	4577.225	2643.528	kWh/Year
Cost saving	93800.559	54137.891	Pkr / Year
Payback period	0.244	0.241	Years

Therefore, it is an approximate estimate that whenever TSMs are replaced by NEEMs in the future, the replaced motors will save an average of 4577.225 kWh and an amount of 93800.559 rupees per year. Additionally, the additional funds expended on NEEMs would be reimbursed in 0.244 years. The accuracy of the material must also be ascertained. The degree to which the data deviates from the mean, or the center of the data, is taken into consideration for this [XVII] {XVIII]. To help set confidence limits, we provide point estimates for the variability in three population characteristics.

The mean values from Table-2 lead to the sample variations in terms of standard deviations in Table-3. These serve as the amount of average dispersion in forecasted mean numbers for the three indicators.

Table 3. Comparison of pair-wise sample dispersions in terms of standard deviations

Standard Deviation	NEEMs Vs TSMs	NEEMs Vs EEMs	Units
Energy saving	4577.225	2643.528	kWh/Year
Cost saving	93800.559	54137.891	Pkr / Year
Payback period	0.244	0.241	Years

III.ii. Future forecasts

A lot of the time, the group chosen does not accurately reflect the population's characteristics [33]. When comparing different samples with the same mean, standard deviations are metrics that can be used to gauge their dependability [XIX]. Generally speaking, it is difficult and time-consuming to test out numerous examples. To address this, the sampling distribution is used.

One can estimate limits for population parameters, i.e., set confidence bounds, by applying the Central limit theorem and the sampling distribution afterward [XX]. As the considered sample of motors is of size: $n_{\frac{\alpha}{2},22}$ and variances (as well as standard deviations) of three population parameters are unknown, so t-distribution can be used with v = n-1 = 22 degrees of freedom. For our case, Central limit theorem states that

"If all random samples of size 23 are selected from a vast population with mean "m" and sample standard deviation "s," then the sampling distribution of the sample mean X is nearly normally distributed with mean $u_{\bar{x}} = u$ and standard deviation $\sigma_{\bar{X}} = \frac{s}{\sqrt{23}}$

Hence $t = \frac{\bar{x}-\mu}{s\sqrt{23}}$ is the value of t statistics "[XXI]-[XXII]

The Probability density function fort-distribution can be utilized with the fact that areas under it can be obtained by integrating the function within a range, to get the probabilities associated with the t-statistic within those ranges.

If "a" is the level of significance and "$1-\alpha$" is the level of confidence, then " $(1-\alpha) \times 100\,\%$ confidence interval for the mean "μ" of an infinite population with sample size "n" is given as:

$$\bar{x} - \frac{s}{\sqrt{23}} t_{\alpha/2\,,22} < \mu < \bar{x} + \frac{s}{\sqrt{23}} t_{\frac{\alpha}{2},22} \tag{5}$$

where $t_{\frac{\alpha}{2}23}$ is the t-value with 23 degrees of freedom, leaving an area of $^{\alpha}/_{2}$ to the right (III).

On the other hand, the increment/decrement defined in Eq (6) is defined separately as the standard error of estimates:

$$\hat{s} = \frac{s}{\sqrt{23}} t_{\alpha/2\,,22} \tag{6}$$

The confidence boundaries for mean annual energy savings, mean annual cost savings and average payback may be calculated using sampling distributions, specifically the student's t-distribution, which is named after a prominent statistician "W. S. Gosset" who presented it in his research articles under the pseudonym "Student" [XXIII]. In relation to (5), the average confidence limits for mean energy savings, mean cost savings and mean payback by NEEMs in future TSM replacements can be computed. The width of the confidence interval plays a key role in determining the degree of significance. If the size (or length) of the matching confidence interval is not excessive, it is preferable to choose a confidence level.

IV. Results and discussion

For $\alpha = 10$ and 22 degrees of freedom, the corresponding value of the t-statistic is: $t_{0.05,\ 22} = 1.729$. [XIV]. This setting leads to 90% confidence intervals for desired parameters. Equations from, (5)-(6) give the following 90% confidence bounds for mean annual energy saving, mean annual cost saving, and average payback by NEEMs in any future replacement for TSMs as in Table 4.

Table 4. Comparison of energy conservation potential of NEEMs vs TSMs and EEMs

	NEEMs VS TSMs			NEEMs VS EEMs			
Savings	**Lower Bound**	**Upper Bound**	**Mean**	**Lower Bound**	**Upper Bound**	**Mean**	**Units**
Energy	3436.99	5717.46	4577.23	2017.69	3269.37	2643.53	kWh/Year
Cost	70285.00	117316.12	93800.56	41251.02	67024.77	54137.89	Pkr/year
Payback	0.2049	0.2835	0.2442	0.1898	0.2941	0.2420	Years

In the future, whenever current TSMs are replaced by NEEMs, there will be an average annual energy savings of at least 3436.99 kWh/year and a maximum of 5717.23 kWh/year as a result of such replacement. This is statistically possible to predict with 90% confidence. Additionally, such change will save at least 70285 and as much as 117316.12 rupees annually on average in costs. The extra money spent on an average replacement NEEM would pay for itself in a payback period of between 0.204 and 0.283 years. As a result, significant yearly energy savings result in much quicker paybacks. The cost of NEEMs may be the primary barrier to replacing current TSM stock with them. Government policymakers and other financiers can be urged to take part in the acquisition and replacement of NEEMs in Pakistani sectors, given the quick paybacks of NEEMs in future replacements and the additional confidence boundaries outlined in this research. By doing so, one could undoubtedly lessen problems associated with the purchase of NEEMs in general and promote energy conservation in electric vehicles. In Pakistan's manufacturing sector, switching from TSMs to NEEMs appears to be a practical way to reduce energy costs.

V. Conclusion

Most people associate electricity with illumination, but half of the energy used worldwide is for electric motors. Your refrigerator, air conditioner, car, conveyor lines, and many other objects contain motors. But a sizeable amount of the energy used by engines is wasted. So long as we make the most of every watt of energy and power, it will be lucrative. This study's goal is to highlight the benefits of new energy motors (NEEMs) over traditional standard motors (TSMs), which are used in Pakistan's various industries. This study's cost-effectiveness portion covers yearly energy savings, cost savings, and NEEM payback times. In addition, the average payback period of replacement NEEMs in the future to replace existing TSMs is detailed, along with 90% confidence bounds for mean annual energy savings, mean annual cost savings, and average payback period. The data analysis produced promising results for switching from TSMs to NEEMs, which would surely help Pakistan and the rest of the world reduce unnecessary energy loss in motors and lessen carbon footprints.

Conflicts of Interest:

There is no conflict of interest regarding the paper.

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