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Analysis of Flux Density Distribution Effects on Rotor Bar Models to Improve Energy Efficiency, Environmental Sustainability, and Economic Outcomes in Induction Motors

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Abstract: Induction motors are highly favored in industrial applications for their ease of operation, compactness, lightweight, efficiency, low maintenance, and cost-effectiveness. They are widely used in conveyors, compressors, crushers, drills, fans, escalators, refrigerators, and electric vehicles. In Malaysia, industrial motors account for about 48% of energy consumption. This research introduces an improved rotor design with optimized rotor bars. Using MotorSolve (IM) software and theoretical calculations, the study found that the new design boosts energy efficiency. The new rotor bar design achieved an energy efficiency of 76.92%, compared to 74% for the current design. In terms of energy efficiency, this research found that adopting high-efficiency motors in industrial applications can save a significant amount of energy. These motors can also be used in a variety of horsepower ranges. The research suggests a maintenance plan for malfunctioning motors that attempts to reduce energy consumption, motor losses, and CO2 emissions in any apparatus. These results offer valuable insights for policymakers to refine energy policies for induction motors. In the future, real-time estimation of the motor's actual operating loss will be required to properly predict the trend in motor efficiency loss under various failure scenarios, which is consistent with the research goal of reducing energy losses in induction motors.

Keywords: Induction Motor, Energy Efficiency, Bar Type, Bar Size, Bar Conductivity, Energy Saving.

1 Introduction

THE laminated cylindrical core of the squirrel cage rotor has parallel slots running the length of its surface. There is an aluminium or copper bar within each slot. To short-circuit every bar, these copper bars—which are somewhat longer than the rotor itself—are placed into the slots and welded at both ends to copper end-rings. The bars and end-rings of medium and small motors are usually made of die-cast aluminium, which is moulded into a single, solid piece. The moulded process was introduced by [1]. Augie Hand [2] found and mention that a three-phase motor's design letter was important factor in selecting an induction motor by refers to the nameplate. In his book, a design letter can divide into four designs which is design A, design B, design C and design D as shown in Table 1.

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Table 1. The Rotor Bars Slot Design and Specifications [2]

Design of Rotor Bars Slot	Descriptions / Characteristics
A	Because of the larger rotor bars used in the design, the initial torque is mild and the initial current is considerable.
B	The design was a standard design for industrial motor. This design needs a moderate beginning current and has average initial torque.
C	▪ The design has two shapes (or two different size and types of rotor bars) that are linked together. ▪ While the deeper part of the bar lessens slide, the smaller section of the bar offers strong starting torque. ▪ This design has moderate starting current
D	The load that requires a very high initial torque but not excessive torque at maximum speed is suitable for this design.

The rotor bar designs of a 3-phase squirrel cage induction motor determine its performance and can have an impact on energy efficiency. Because rotor bar types differ in terms of efficiency and power factor, they can affect how much current and voltage are used. Known by many as "asynchronous motors," induction motors are frequently used in industrial settings where continuous speed operation is necessary. When compared to other kinds of electric motors, they are frequently less costly and require less maintenance. A rotor and stator windings make up an induction motor. The motor frame is permanently attached to the low resistance stator windings. There are two types of rotors: squirrel cage and wound. A space in the air that permits the rotor to spin freely between the stator and rotor is mentioned by [3]. The round bar design in squirrel cage rotors shows promise for boosting the efficiency of induction motors. However, the efficiency is influenced by the number of round bars used. Research by Daut found that an increase in the number of round bars leads to a reduction in motor efficiency and an increase in power loss [4].

Various research efforts have sought to determine the peak flux density in the rotor frame core material. According to [5], the flux density in core frame material can be divided into two primary components: stator core flux density (Bscm) and rotor core flux density (Brcm). The peak value for rotor core flux density is expressed in Eq. (1).

$$B_{rcm} = \frac{\Phi_m}{(D_r - D_{sh} - 2.d_{r1}).\ell_b.SF} \quad (1)$$

Where Φ_m represents the maximum flux per pole, D_r is the rotor diameter, D_{sh} signifies the shaft diameter, d_{r1} is the bar depth, ℓ_b is the rotor lamination stack length and SF stands for the stacking factor.

Brcm should not exceed 100 kiloline/in2 (1 T). The reduced area for flux flow should be considered if there is a ventilation hole through the rotor core axis. The Stacking Factor (SF) is a percentage-based numerical value less than one. Its definition is the ratio of the real core height, measured at a specific pressure, to the height of the solid magnetic material in a laminated core. The volume ratio of magnetic material to the entire geometric volume of the core is hence the SF. SF typically ranges from 0.94 to 0.97, based on the lamination material's thickness is mentioned by [5].

MATLAB will be used for theoretical calculations to validate the induction motor design further after it has been evaluated using the MotorSolve (IM) simulation technique. The goal of this theoretical method is to validate the first simulation results and design a high-efficiency squirrel cage induction motor. The stator and rotor impedance, air gap, efficiency, power factor, torque, and power loss are all calculated using the MATLAB programming technique. Making sure that the MATLAB results validate the simulation findings is crucial for designing and verifying induction motors was verified by [6].

Moreover, in some of induction motor is a great start up and procedure characteristic was accomplished based on shaped of rotor bars. This shaped of rotor bars can separate into three groups which are a double cage, a deep slot, and a typical cast aluminium rotor hole. A double cage rotor bar type has two shape bars which is outer bar (consumes extreme resistance and low leakage induction) and inner bar (consumes low resistance and high leakage inductance). The resistance of a deep slot rotor bars type will change as a function of the rotor frequency. It is because of the resistance was analysed at different frequencies. The last sheep can make the rotor resistance higher when slip was increase via the use of magnetic material for the cage winding's conducting component was proved by [7].

Most early, the theories and studies of rotor bars slot were concerned with selection of the slot number. Juha Pyrhonen [8] found that the slot number of the rotor bars Q_r was selected with special factor. The asynchronous harmonic was decreased when the number of rotor bars slot is slightly. In this book, the selection number of rotor bars slot was selected refer to the rotor characteristic and functional of motor. From the selection number of rotor bars slot, it can predict the particular harmful synchronous torque when the motor is held at stall position with positive rotation speeds position or negative rotation speeds in counter-current braking position and will make the harmful of mechanical vibrations condition. The numbers of rotor bars slot are certain in order to advantage as the best first.

Initial current and torque are not greatly affected by the round or square shape and kind of rotor bar conductors, according to Kothari, research [9]. Double-cage rotors and deep-bar conductors were developed in response to this. Deep-bar rotors are efficient for both beginning and running because of their low running resistance, high starting torque, and low starting current. The inner bars of the double-cage rotor have lower reactance and higher resistance than the outside bars, which are joined by end rings. In this study, rotor slots made of cast copper that have apertures appropriate for die cast are examined as they relate to squirrel cage motors.

According to recent study by [10], squirrel cage rotors start up consistently when the number of rotor bar slots and stator poles line up. Stronger torque is produced if the number of rotor bar slots (S2) and stator slots (S1) are equal, however this may also cause cogging, which causes the motor to have trouble starting. The magnetomotive force (mmf) wave's interaction between specific spatial harmonics affects cogging. Achieving an optimal balance between the stator and rotor slot counts can prevent problems with synchronous harmonic torque.

The MotorSolve (IM) programme includes an automated finite element module that ensures precise results for designing and analysing induction motors and generators. It allows users to customise the rotor and stator configurations. Furthermore, the results can be changed for optimal or non-optimal driving situations. The user-friendly interface makes the operation easier, with automated winding geometry and tuning options, as mentioned by MotorSolve [11]. An induction motor's fundamental losses include resistance losses in the stator and rotor cage, iron losses, friction, windage losses, and miscellaneous losses. At 20°C, the resistivity of copper and aluminum are 10.37 ohms and 16.06 ohms per circular mil-foot, respectively. Given the same current requirements, replacing aluminum with copper reduces resistance loss. This approach advocates for using copper bars in the rotor structure instead of aluminum ones. The approach was introduced by Ranganathan [12].

Many theories have been proposed to explain what type and category of rotor bars was used based on functioning characteristic of the induction motor. Stephen L. Herman [13] argued that rotors were made of different types of bars. The squirrel cage induction motor was given a code letter on their nameplate. The code letter shows the type of bars that used in the rotor. It can separate into four groups of rotor type as shown in Table 2.

Table 2. Several Rotor Bar Slot Types: Explanations & Features [13]

Types of Rotor Bars Slot	Descriptions / Characteristics
A	With the maximum resistance, the rotor offers a low starting current and a strong starting torque.
B – E	The rotor has lower resistance, fair starting torque and low starting current.
F – V	The rotor has low starting torque, high starting current and good running torque.
Double Squirrel Cage Rotor	The rotor has two sets of squirrel cage rotor bars which are Inner and Outer squirrel cage; ▪ Inner squirrel cage has low resistance with high reactance. ▪ Outer squirrel cage has high resistance with low reactance.

According to further research conducted by the VTU e-Learning Centre [14], choosing the right ratio of rotor bar slots to stator slots is essential to preventing negative outcomes during motor startup. Incorrect combinations might cause the motor to start rough and possibly make too much noise, a phenomenon known as cogging and crawling. Furthermore, the torque-speed profile may exhibit random anomalies as a result of inadequate slot combinations. The goal of this research is to identify the best stator and rotor bar slot selection and application to produce an induction motor that is both highly efficient and has low losses.

Furthermore, past studies have shown that the diameter of the rotor bars has a considerable impact on efficiency. Increasing the diameter of the rotor bar slots minimises power losses in the induction motor due to increased conductivity. As a result, lower power loss improves motor efficiency, as mentioned by [15]. Modifying the rotor bar design can improve the efficiency of a 3-phase squirrel cage induction motor. The performance can be enhanced by changing the type of rotor bar, the total number of rotor slots, and the diameter of the bars. For various types of rotor bars, reducing steel sheet thickness reduces iron and overall losses, enhancing motor efficiency. Previous calculations show that the round bar design is 1.2% more efficient than the round outer and inner bar arrangements, as mentioned by [16].

In research, the performance of induction motors under both normal and defective conditions—such as broken rotor bars—was analysed. The impact of rotor bar model on efficacy, power factor, and torque ripple was investigated further. The balance between operational qualities and their connection to geometric parameters was investigated in a study by [17]. Furthermore, research by [18] highlighted the arrangement of rotor slots as a key component of an efficient method to optimising the pattern of a squirrel-cage induction motor. This approach makes it easier to develop and build more efficient motors in a timely manner, as mentioned by [19]. The author's earlier paper detailed a complete design technique that was shown to be effective for various capacitor-run single-phase induction motors (SPIMs) with varying power ratings and specifications, as mentioned by Chasiotis [20]. The study examines the outcome of rotor bar model on the efficiency of single-phase induction motors (SPIMs) driven by capacitors. Performance is greatly impacted by the rotor bar design, with efficiency variations ranging from 0.31% to 0.98%. Rotor bar design affects torque, starting current, losses, and other parameters in addition to efficiency. According to the findings, these SPIMs outperform IE3 (premium) and IE4 (super premium) standards in terms of efficiency. This work clarifies how to optimise the winding ratio, capacitor value, and rotor bar shape to increase the efficiency of SPIMs. This flexible design approach works well and is broadly applicable. The design approach was introduced by Ioannis [21]. This study examines and evaluates the efficiency of a squirrel cage induction motor by altering the rotor frame's size, construction, materials, and bar shape. The goal is to maximise motor efficiency. Two methods that are employed are mathematical modelling and MATLAB simulations. The induction motor is studied and evaluated using simulations. The software tools used in this investigation are MotorSolve (IM) and MATLAB. The objective is to compare the efficiency enhancement results from these two approaches.

2 Methodology

Figure 1 illustrates the specified rotor features for a 3-phase squirrel cage induction motor, as simulated using MotorSolve (IM) programme. Changes to the bars, bridges, core, and widths are part of the design and analysis. Figure 1 shows the changes in rotor properties in detail.

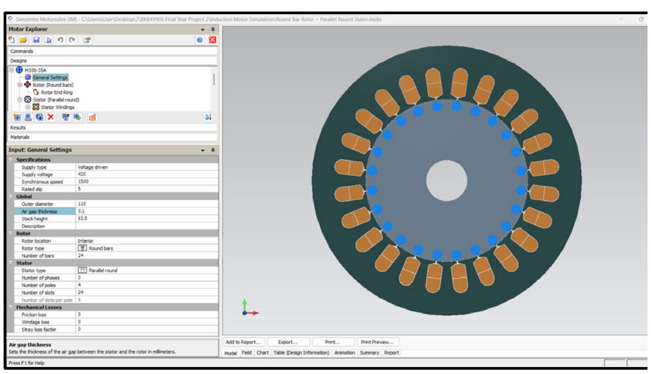


Fig 1. Determining the Rotor Properties with the MotorSolve (IM) Programme

The specification that need to be change are such as, the supply voltage, rated slip, number of bars, motor outer diameter, air gap thickness, stack length, rotor type and stator type as shown as Table 3. Table 3 displays the numerical values of the variables that characterise the standard rotor feature of the 0.5 horsepower three phase squirrel cage induction motor model.

Table 3. The Value of Parameters in Specifying the Model's General Characteristic for 0.5 Hp 3 Phase Squirrel Cage Induction Motor

Parameter's	Values	Parameter's	Values
Supply Voltage	420V	Number of poles	4 poles
Motor outer diameter	110 mm	Number of bars	30 bars
Air gap thickness	0.5 mm	Stack length	63.5 mm
Rotor type	Rounds Bars	Stator type	Parallel Round
Number of phases	3 Phases	Number of slots	24 slots

The parameter d_{r1} represents the rotor bar diameter in the calculations and affects the maximum flux density of the rotor core B_{rcm}. In this theoretical calculation, parameters based on real induction motor values were used, such as: V_L = 420 V, P_S = 0.5 Hp, Speed = 1400 rpm, Frequency = 50 Hz, a=1, Frame Thickness (t_f) = 0.35 mm, and P = D_f = 4.3125 inches. The highest rotor core flux density values determined by MATLAB simulations are also shown in this calculation from Eq. (2).

$$B_{rcm} = \frac{\Phi_m}{(D_r - D_{sh} - 2.d_{r1}).\ell_b.SF} \quad (2)$$

Where the rotor diameter, D_r, bar depth, d_{r1}, stacking factor, SF, Diameter shaft, D_{sh}, actual value of max flux per poles, Φ_m, and rotor lamination stack length, l_b.

There should be no more than 100 kilolines/in² (1 T) of rotor core flux density (Brcm). One must factor in a decrease in the flux flow area (bar depth) when the rotor core has axial ventilator slots. To examine the effect of flux density in the rotor core material, the peak value for rotor core flux density is simplified and expressed in Eq. (3).

$$B_{rcm} = \frac{C_1}{(C_2 - 2d_{r1})C_3} \quad (3)$$

Where; $C_1 = \Phi_m, C_2 = D_r - D_{sh,}$ and $C_3 = l_b.SF$

A Three-Phase Squirrel Cage Induction Motor's rotor core flux density is improved by raising the bar depth (d_{r1}) of the rotor bars.

3 Result and Discussion

3.1 MotorSolve (IM) Software simulation

Achievement charts were used to evaluate the rotor bar shape and compare the efficiency gains of the proposed new designs with the NEMA via MotorSolve (IM) software. With varying rotor bar parameters, Figure 2 shows the efficiency versus speed graph for both systems. With a 3.8% increase in efficiency, the suggested new design outperformed the NEMA design with an energy efficiency of 76.92% as opposed to 74%. The inverse connection between efficiency and losses which shows that lowering total losses increases energy efficiency is the cause of this gain.

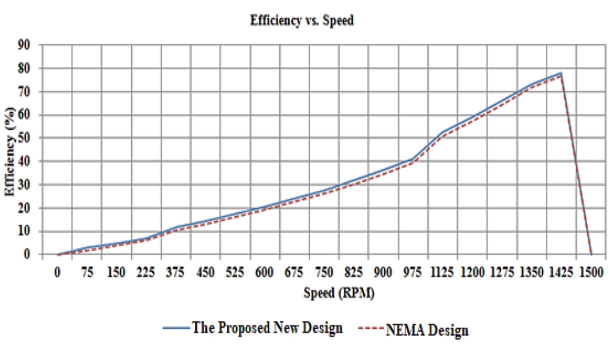


Fig 2. Plot of Efficiency versus Speed for Both Designs

3.2 Comparison of results between MotorSolve (IM) and MATLAB

Variations in core loss have an impact on the efficiency figures. MotorSolve (IM) and MATLAB were used to analyse the new recommended design for energy efficiency. The efficiency vs. speed graphs for the two simulations are presented in Figure 3.

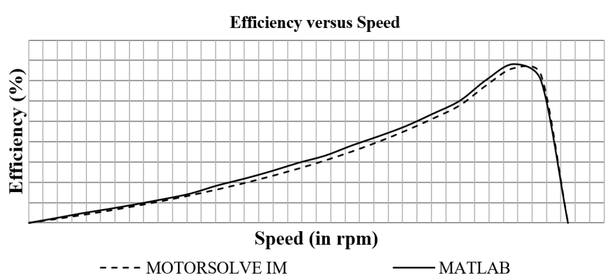
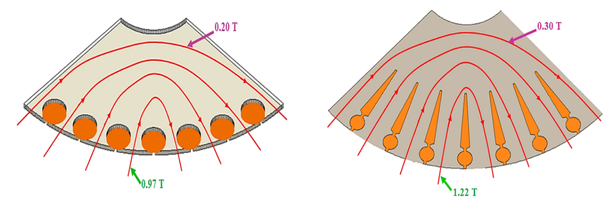


Fig 3. Plot of Efficiency versus Speed for Two Simulate Software

Figure 3 shows that the total energy efficiency for the new design that is being proposed is 72.99% according to MATLAB and 76.92% according to MotorSolve (IM) at a speed of 1425 rpm. This implies that the new design, with predicted values ranging from 76% to 77%, exhibits greater energy efficiency.

3.3 Flux Density

MATLAB simulation was used to evaluate the flux density in the rotor core, with a particular emphasis on Brcm. While the NEMA design measured 1.22 T, the proposed new design obtained a flux density of 0.97 T. To avoid excessive flux leakage through the axial ventilation hole in the rotor core shaft, the ideal rotor core flux density is to stay below 1 T. Since it maintains a more favourable flux density, the data show that the new design that has been suggested performs better than the NEMA model.



(a) Bar Configuration in Proposed New Design *(b) Bar Configuration in NEMA Design*

Fig 4. Flux Distribution in (a) New Design and (b) NEMA Design Bar Forms

The flow distribution for both kinds of rotor bar configurations is shown in Figure 4. The graph indicates that the flux density near the shaft area (rotor frame inner diameter) is lower in the new design that is being suggested—it measures 0.2 T as opposed to 0.97 T at the rotor bars area. On the other hand, flux densities of 1.22 T at the outer rotor bars and 0.3 T close to the inner shaft are displayed in the NEMA design. Increased length and reluctance cause a decrease in magnetic flux and flux density, which accounts for this fluctuation.

The three-phase induction motor's rotor bar types are shown in Figures 5 and 6. The highest rotor core flux density values determined by MATLAB simulations are also shown in this calculation from Eq. (2) and summarize in Figure 5 and 6. There should be no more than 100 kilolines/in² (1 T) of rotor core flux density (Brcm). One must factor in a decrease in the flux flow area (bar depth) when the rotor core has axial ventilator slots. A Three-Phase Squirrel Cage Induction Motor's rotor core flux density is improved by raising the bar depth (dr1) of the rotor bars.

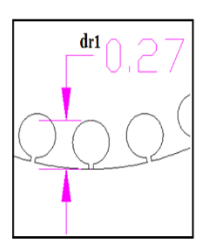


Fig. 5 Bar Configuration in Proposed New Design

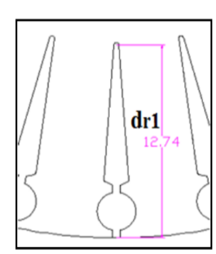
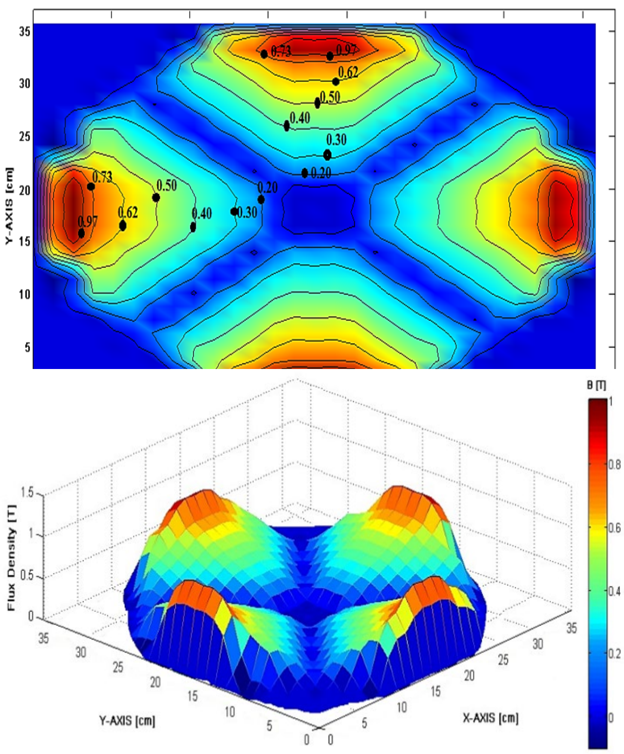


Fig. 6 Bar Configuration in NEMA Design

Based on simulation and theoretical through MATLAB, the contour graph of local modification of the flux density for The Proposed New Design was shown in Figure 7 (a). For both design rotor bars, it shows that the flux density was increase from the inner to the outer of the rotor core. This is due to the outer of rotor core was enclosed to the rotor surface and the flux density was increase until it saturates at the width of rotor bars and slots. Based on the contour graph for the proposed new design, the flux density was increase from 0.2 T to 0.97 T. Based on Figure 7 (b), the mesh graph shows the flux line that consistent at the both rotor bar design. These flux lines were decrease towards the inner area of the rotor core (frame). The mesh graph was connected to the contour graph. The flux line strength was increased from the outer region to the inner region of the rotor core.



(b)

Fig. 7. (a) The Contour & (b) The Mesh Graph of Flux Distribution for The Proposed New Design

3.4 Energy Efficiency Analysis

Table 4 shows the comparison of Energy Efficiency between the proposed new design and NEMA design as refer to the National Electrical Manufacturers Association (NEMA) Standard.

Table 4. The Comparison of Energy Efficiency for Both Rotor Bars Design as per NEMA Standards

	Energy Efficiency
NEMA Design	74.0 %
The Proposed New Design	76.9 %

Based on Table 4, it shows the increasing in energy efficiency at full load for 0.5Hp induction motor for both rotor bars design. Consequently, if full load condition was operating not required at all the time, the proposed new design gives improved saving over than NEMA design. Design criteria such as rotor copper loses, bar size and bar type to accomplish the maximum energy efficiency.

3.5 Strategy to Improve Energy Efficiency

The Proposed New Design (Round Bar) was selected in order to improve the motor efficiency. The strategy to improve the motor efficiency such as below:

3.5.1 Replace the conductivity (with higher conductivity) from aluminium to copper

Table 5 show the comparison of energy efficiency between the proposed new design and NEMA design by replacing the conductivity from aluminium to copper bars. Table 5 shows that electrical energy efficiency is increased when copper is used instead of aluminium in the "squirrel cage" structure of the induction motor rotor. Energy losses are minimised by the higher electrical conductivity of copper when compared to aluminium.

Table 5. The Comparison of Energy Efficiency for Both Rotor Bars Design by Replacing the Conductivity

Energy Efficiency	Aluminium	Cooper
NEMA Design	66.9 %	74.0 %
The Proposed New Design	68.4 %	76.9 %

3.5.2 Changing the diameter of rotor bar slot

Table 6 shows comparison of energy efficiency between the proposed new design and NEMA design by replacing the diameter of each slot that will be altered. Based on table 6, the Proposed New Design was showed high energy efficiency which is 79.6 %. This slot shape is appropriate for motors with high-conductivity rotor cage materials because it has a separate "starting bar" that is separated from the main conductor bar by a "leakage slot." This rotor bar design also offers increased slip and locked rotor torque. It is mostly utilised in highinertia load applications, such punch presses, elevators, and hoists that have flywheels.

Table 6. The Comparison of Energy Efficiency for Both Rotor Bars Design by Changing the Diameter

Design A	Diameter (d)	Efficiency
	12.8 mm	76.8 %
	14.8 mm	79.6 %
	16.8 mm	77.9 %
Design B	Diameter (d)	Efficiency
	12.7 mm	70.9 %
	14.7 mm	74.0 %
	16.7 mm	72.4 %

3.6 Economic and Environment Aspect

The normal industrial rate in Malaysia is regulated by Tenaga Nasional Berhad (TNB) at 38.0 sen/kWh, with a minimum monthly price of RM7.20 for use exceeding 200 kWh. The following formula Eq. (4) is used to determine the annual energy savings (AES) from using a new rotor bar structure:

$$AES = hp \times L \times 0.746 \times \left[\frac{100}{E_{STD}} - \frac{100}{E_{CR}}\right] \quad (4)$$

Where Annual energy savings are represented by AES. HP stands for horsepower. The letter L represents load factor. The total operational hours in a year are denoted by hr. The efficiency of the current rotor (%) is shown by E_{std}. The new rotor design's efficiency (%) is indicated by the letter E_{ee}.

The total operating hours multiplied by the designated load yielded the annual bill savings (kWh savings), as indicated in Eq. (5) below.

$$kWh_{savings} = AES \times hr \quad (5)$$

Where the expected annual bill savings (RM), $kWh_{savings}$, the annual energy savings, *AES,* and $hours\ for\ 24 \times 336$ working days, *hr*.

Total Cost Savings (TCS) can be calculated with the following formula, found in Eq. (6):

$$TCS = (AES \times 12 \times Monthly\ Demand\ Charge) + (kWh_{savings} \times Energy\ Charge) \quad (6)$$

Eq. (7) can be used to estimate the decrease in emissions brought about by the previously described energy savings:

$$Emission\ Reduction, ER = AES \times EF \quad (7)$$

Where AES stands for Annual Energy Savings (kWh), EF is for Emission Factor (kg/kWh), and ER stands for Emission Reduction (kg). The Emission Factor for Malaysia is 0.73159 $kgCO_2/kWh$.

The amount of money can be saved depends on motor size, annual hours of use, efficiency improvement, and the serving utility's charges. Table 7 shows the comparison of Economic and Environment Aspect for both rotor bars design. Table 7 indicates that there could be an RM 2.14 million reduction in utility bills if the induction motor rotor is designed using the new design instead of the NEMA design. It shows that the proposed new design of induction motor has better performance in terms of energy efficiency, losses reduction, economic and environment aspect.

Table 7. The Comparison of Energy Efficiency, Economic & Environment Aspect for Both Rotor Bars Design

	The Proposed New Design	NEMA Design
Annual Energy Saving (AES)	486.3 kWh	431.4 kWh
Total Cost Saving (TCS)	RM 190.00	RM 168.60
Monthly Demand Charge	RM 7.20	RM 7.20
Monthly Energy Charge	38.00 sen/kWh	38.00 sen/kWh
Saving for 100,000 motors	RM 19,000,000.00	RM 16,860,000.00

3.7 Policy Implication

Less than 0.75 kW electric motors are widely employed in a variety of household and industrial uses, making up a modest portion of the overall power consumed by electric motors. Present rules focus more on bundled systems than individual motor parts, and there are gaps in some sectors' legal protections. Two important tactics for reducing energy use are: (i) using energy-efficient motors that are the right size; and (ii) using adjustable-speed drives when necessary to match the motor's torque and speed to the system's mechanical load demands.

Without policy contribution, it is difficult to realize this savings in the current market situation. In an uncontrolled market, buyers tend to lack invest in higher efficiency selections and select low-cost electric motor systems. These studies offer insights into energy efficiency and savings prospects for electric motors, which is beneficial information for manufacturers, energy managers, motor designers, and operators. During the planning and design stages, they support designers in making well-informed decisions on design options and concepts. The results may also aid government organisations in evaluating and improving current electric motor energy regulations.

4 Conclusions

This study examined the advantages and difficulties of applying the novel design in industrial uses while simulating the possible energy savings from employing high-efficiency motors. High-efficiency motors can result in significant energy savings, as the research showed. Reduced motor losses resulted from the proposed new rotor bar design's 3.8% efficiency gain over the NEMA configuration. With an error margin of less than 6%, the theoretical findings closely match the simulation outputs from the MotorSolve (IM) programme simulations for the new design, as demonstrated by MATLAB calculations. The suggested new rotor bar design, with a thickness of 0.35 mm, has the potential to save RM 2.14 million (87%) on utility expenses when compared to the NEMA design. Additionally, the design of this energy efficient motor is valid for any scale of motor horsepower. The goal of the suggested maintenance plan for broken motors is to drastically cut CO_2 emissions, energy use, and motor losses. This method works with a variety of machinery kinds. Future research should concentrate on improving real-time assessments of actual operation inefficiencies and precisely forecasting efficiency decreases under various malfunction situations.

Conflict of Interest

The authors declare no conflict of interest.

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