

Electric Motor Power Consumption Characteristics and Energy Savings: Revisited

S. T. Yusuf^{1,*}, W. N. Dansarki², J. S. Mboli³, D. T. Agbu⁴

^{1, 2, 3, 4}Department of Electrical & Electronics Engineering, Taraba State University, Jalingo. Nigeria.
theophylussimon@gmail.com

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ABSTRACT

Almost every mechanical movement that we see around us is accomplished by an electric motor. This paper revisits electric motor energy consumption, and discusses efficiency and energy saving strategies. Losses in different design of motors have been identified, and ways to overcome these losses are explained. Energy saving methods such as capacitor bank, speed drive and high efficient motor strategy were considered to reduce energy consumption.

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Introduction

Electric motors have broad range of applications in public and private industries, household electrical appliances and many more. Power consumption statistics for most developed nation identify that electric motors consumes about 40% of overall power consumption [1]. The speed of electrical motors can be regulated by variable speed drive which also controls the rotational force of the motors. Mechanical equipment such as fans, pumps, conveyors and compressors also integrate the variable speed drive technology. At the moment, a lot of industries are manufacturing the variable speed drive technology to help in reducing the losses in the mechanical equipment [2]. Obviously the use of variable speed drive helps to preserve the energy consumption, boost the power factor and enhances the energy efficiency. Also, it results in a smooth start up, process precision and over speed capability. The energy savings reduce greenhouse gas emissions to a certain level. The frequency convertor and the automatic control system, which can be used in the multi-drive electromechanical systems with a few induction motions [3]. There are paramount components of automation that aim to enhance the process whilst lessening the investment costs, energy consumption and cost as well as the greenhouse gas emissions [4].

In practice, most industries use standard motors in place of high-efficiency motors which are more efficient. As a result, various approaches are being used to reduce the energy consumption in the appliances. One of these approaches is to utilize standards which are energy efficient for electric motors.

Brazil has introduced an efficient policy for electric motors with the aim of reducing electricity consumption. These results have shown that in relation to the average current electricity tariffs, efficient motors are more preferred economically to standard motors [5, 6]. This can be validated based on energy conservation calculations of both the efficient and standard motors.

A good strategy for analyzing energy efficient enhancement in industries is presented in [7]. An alternative approach is to join together premeditated acquiescent and levy which trims down a consequential quantity of energy as well as the emission levels by industry [8]. Seventy five percent of the total industrial electricity is being consumed by electric motors. For that reason, the key focus is to conserve a chunk of electricity in a cost effective manner. These provide a major reduction in the impact on the environment [9]. The use of energy in industries in Europe is shown in figure 1.

However, the electric motor's efficiency is dependent on existing technology while the choice of electric motor is determined by the level of development and economy as well as the life cycle cost analysis [10, 11]. Energy efficient programs have their limitations. These limitations are discussed in [12]. In order to have efficient use of energy in industries, the energy losses and energy used have to be resolved. Various categories of motors and contrivances utilize different levels of energy efficiency based on their working conditions and characteristics [13, 14]. The use of energy saving and efficiency are presented in [15, 16]. Industries make use of about 51% of total electrical energy [17] in Slovenia and 36% in Turkey [18]. In EU countries,

motor-driven systems use up about 66% of the electricity [19]. In other countries like Jordan and Malaysia, their industrial motors utilize about 32% of total energy [20] and 49% of total energy respectively [21, 22].

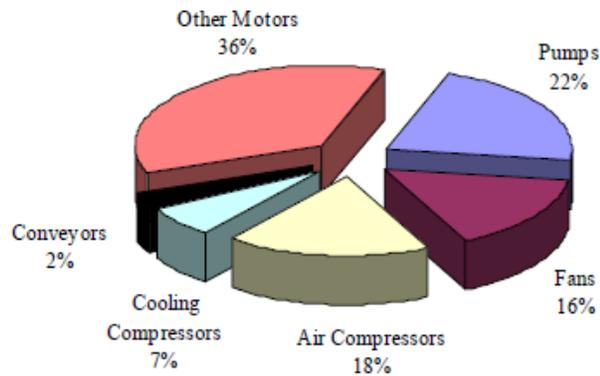


Figure 1. Industrial motor energy use in Europe [9]

Motor Design

Motors are design based on their applications. The advancement of high speed motors for hybrid electric plug in have been by [23] Motor design are complex. A design of a liquid cooled motor has certain important features which are a novel channel of coolant that reduces the effect of the coolant on the aluminum housing structural properties. As a result of thermal analysis, liquid cooling will handle the thermal load [23] presents cylinder like robots that are locomotive by means of either rolling or jumping on the ground. The robot is described to explicate the mechanism for enabling rolling and jumping by utilizing only one DC motor. Second, the robotic design is analyzed in terms of energy efficiency and compared to a couple of hybrid mobile robots. In [24], a power rating of 12 kW at 12000 rpm of a motor is given. The evaluation of the thermal and loss performance of the optimized design is carried out. A low weight DC permanent magnet motor is used in the propulsion of an ultra-light aircraft in [25].

A motor with 16poles and 18 slots gives a low mass and high torque density with active components. A novel design of a permanent magnet motor (brushless) was designed in [26]. The magnets distribution of the current is reduced with the configuration of the fixture and magnetizing current. The spindle motor induced voltage level with a magnetized magnet is somewhat equal with the ideal motor. Although the motor possesses a low cogging torque and harmonics, it is magnetized by an alternative fixture. A genetic algorithm was utilize to optimizes the efficiency of transverse flux permanent magnet machine [27], the genetic algorithm (GA) is made up in other to obtain the parameters (geometric) of the stator and rotor so as to reduce the loss of power in the winding and iron. This presents

an efficient method to the efficiency of the motor [28]. The proposed motor which functions with brushless electrical DC motor has a torque and speed property which depicts that the DC series motor characteristics and the motor speed is controlled by altering the voltage. These characteristics make the proposed model of motor suitable for electrical conveyances or other variable-speed applications.

The hysteresis and eddy current losses in the stator make up the magnetic core losses; these losses are dependent on the input voltage and the material and geometry of the magnetic core. The friction in the bearings of the motor and aerodynamic losses connected with rotating components in the equipment results in loss (friction and windage).

An electrical motor experiences several losses [29]. The motor efficiency is determined by the intrinsic losses which can be lowered by a change in the transmutations of the motor design. Considering losses in motors design [30] the disunion of losses of single-phase induction motors has been shown to be a challenging process. This is partly due to the need to account for losses in the rotor due to the reverse field and also due to supplemental tests required to determine parameters of the motor in order to calculate efficiency. It has been shown that the direct input–output method seemed to produce consistent results. This may be due to rectification techniques for input power and output torque that appear to offset or minimize the variability in the system. Several advantages are experienced by reluctance motors which single phased and switched [31] for energy efficient fractional power loads. Poorly efficient motors result in fractional power loads which makes the drives inefficient.

An additional advantage is the controllable speed ability of the motor. An approach to decreasing torque Motors and high speed rotor iron losses are analyzed in [32]. A reduction in rotor loss can be achieved by making use of a rotor material whose B (H) curve has a low level of saturation; however this loads to a heavier rotor.

The induction motor losses are composed of the stator winding and rotor cage resistance loss, stray loss and windage loss. Copper has a resistivity for circular mil per foot at 20°C is 10.37 while that of aluminum is 16.06. Hence when copper is substituted for aluminum it yields a 34.4% resistance loss reduction [33]. As a result a copper bar can be utilized in the rotor in place of aluminum bar. Over the past years, the manufacturers have observed that the replacement of aluminum with copper in the induction motor squirrel cage yields a substantial reduction in losses [34, 35].

Based on the review of motor design, losses arise owing to air resistance and friction bearing. These losses which account for 8–12% of total losses are not dependent on the load of the motor however they result from the windage and circulatory air through the motor [36]. The stator and rotor losses generate heat which is

thereby reduced by employing a smaller fan. As current (I) flows through the stator winding which offers some resistance R , stator losses (I^2R loss) occur. In other words, as current flows through the conductors of the rotor and stator heat losses occur this is referred to as I^2R losses. This is a huge loss since it accounts for about 55–60% of the total losses. Rotor losses can be tackled by increasing the conductive bars size and terminating the rings to yield lower rotor losses. Power losses are referred to as slip losses due to their large but not fully-dependence on the motor slip degree being exhibited. The flux leakage (I) which goes through the stator winding with resistance (R) when the motor functions under load results in stray load loss. Hence, these losses may vary with respect to the square of the load current, and may result from the induced leakage flux from the lamination load currents, which accounts for 4 – 5% of total losses. As the load in the motor is increased the stray losses, stator as well as rotor I^2R losses increases also.

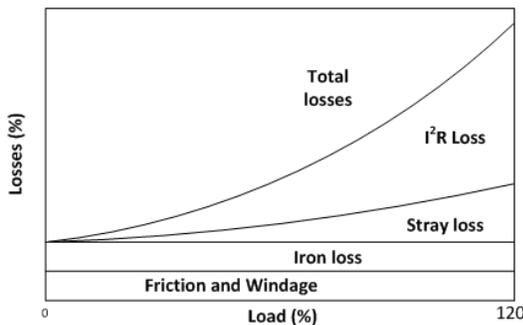


Figure 2 Motor losses with load [36]

Motor Efficiency

Energy efficient electrical motor has the ability to decrease energy consumption and manage operational cost over its lifetime. References [37-39] pointed out that, using copper instead of aluminum in die cast rotor of an induction motor can significantly improve motor efficiency. Reference [40] presented an economic evaluation between copper and aluminum squirrel cages of electric motor. The utilization of this material is one technique that enables electric motor efficiency to be incremented as much as 1.5% – 3%. This efficiency is expected to be higher on small motors, decrementing value on more sizably voluminous designs. Paramount efficiency improvement might be attributed to integrating additional copper to the windings. Furthermore, [41] reviewed design and production techniques for motor efficient. The level of effectiveness is improved primarily by decrease in load loss and core loss as well as several decreases in friction and windage losses. It has been confirm that the material jointly with optimized laminations could greatly help to achieve efficiency. Decreasing windage loss will significantly improve the efficiency of the motor, temperature raise in the coil

winding; will lead towards increase in the stator resistance loss. Designers should find a balance solution among the diverse losses so that the whole motor performance is optimized.

Mechanical and electrical problems in electric motors can be detected either directly or indirectly depending on the technique used. Directly, many parameters can be monitored to give utilizable suggestion of incipient faults. It is showed that mechanical defects are detectable through variations in the vibration of the stator core [42]. Design of DC motors that draws high power for it consumption [43] has tendency of incipient mechanical faults. Analysis of magnetic field created in electric motor with strong magnetic materials (NdFeB) [44] has demonstrated analytically, the consequence of eddy currents induced in electromagnets. An advanced improvement of electric switched reluctance motor for automotive function were presented by [44] the efficiency and peak torque characteristics of switched reluctance system, coalesced with its typical low cost construction make this technology unique. However, a combine optimization was conducted on the design and control for a compact high torque gain motor aimed at application in full hybrid conveyances. Efficiency through control technique has the benefit of idealizing good system performance and ascertains that a certain lowest level is achieved as shown in figure 3.

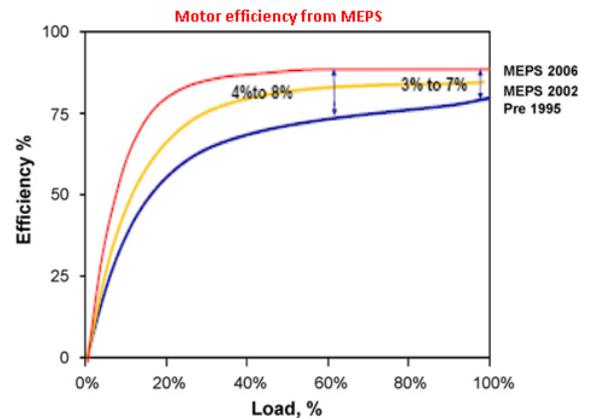


Figure 3. Efficiency level. Source: [45]

Improving the performance of electric motor require the use of high energy density permanent magnet materials, this actually reduces losses developed in the motor [46] the system has an energy efficient solution which is valid with no risk of harm to the controller under investigation. To improve performance of a brushless DC motor, an investigation and Simulation of Single and two phase axial flux motor was implemented by [47], two phase motor produce more torque and reaches higher efficiency than the single phase motor. On the other hand, the benefit of using a single phase version is simpler with cheaper converter

which the motor is supplied from. The structure of both motors depends on the type of coil design.

[48] Design a Brushless DC Motor for an Automotive Application. This motor has more advantage than the brushed motor. For most electrical rotating machines, the bearings may be considered to be hard, but [49] has shown that on large machines, foundation flexibility will influence transverse vibration behavior. An innovative configuration with low down price rate to attain the perfect commutation was presented [50] using the idea of phase locked loop to harmonize the coil current. As the back EMF and the coil current overlap with each other, the motor will gain the optimizing driving efficiency. The phase locked loop circuit can achieve the optimizing efficiency rapidly and automatically simply by means of some hardware Integrated circuit and components. An electric motor for was design by [51] to achieved low speed operation at high efficiency, the system is connected in series and energized by half the number of inverters. The torque is abridged to approximately 10% of the original model. High efficient technique was use by means of bypass controller. The operational low speed of the motor improves the efficiency at about 4%.

A survey of technologies on improving better energy efficient air conditioning [52] Knowing fully that Air conditioning is vital for sustaining comfort in indoor environments, particularly for hot and humid climates. The electric load, heat load and cooling load of the micro combined cooling can be synchronized to meet exact requirements. Having other outputs, such as symbiotic grouping is able to comprehend generally for thermal and electrical efficiency of more than 70%. Low cost efficiency measures require sophisticated technology which will definitely lead to large energy saving. The waste can be reduced by switching off the equipment when it is not being used. The European economic saving potential in industry is shown in figure 4.

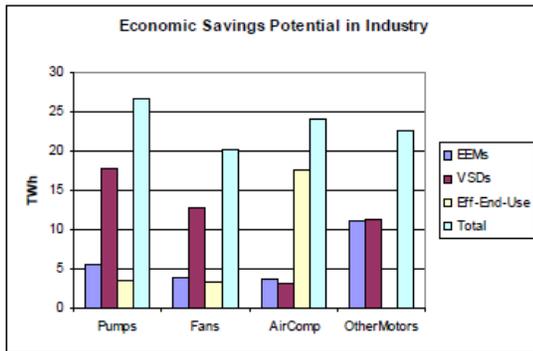


Figure 4 Energy saving potential in industry by 2015: [53]

An electric motor fan for cooling engine purpose was presented by [54], by regenerative capability, the efficiency of the

motor depends on the speed. In other to encourage the system reliability and reduce the overall cost, a sensor less control strategy has also been implemented. Reference [55] developed a new brushless DC motor of low cost energy efficient single phase. The design was carryout using Genetic Algorithm (GA). By using Genetic Algorithm for the optimization, constant trapping is reduced at the upper and lower level.

The efficiency, at which the motor is functioning, depends on the loading curve figure 5. The value of efficiency is equivalent to the highest value only when the motor functions at loading values of 75% and above. Preferably, the most advantageous functional region of motors is between 55% and 95% of the rated load; when the motor is operating at full load [56].

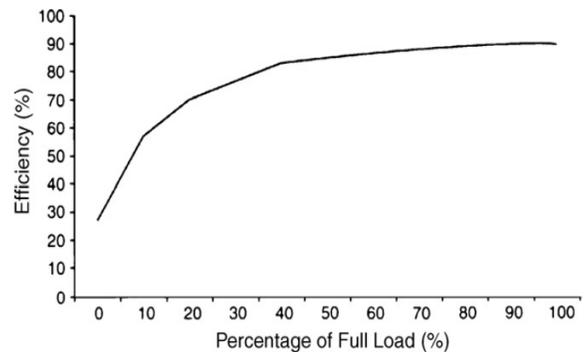


Figure 5. Motor efficiency and load relationship [57]

Generally, by lowering the rotational speed of electric motor, the efficiency (effectiveness) reduces, and this action diminished the power factor. Typically, electric motors efficiencies is approximately 75% when it is fully loaded. An oversized electric motors exhibits higher power factor rectification. Over sizing of motors additionally raises the cost of the switch and electric wiring that are use electric motor design [57]. Electric motors with significant higher rating compare to the load it is running on, the motor is commonly operating at partial load. During this process, there will be reduction in the effectiveness of the motor. Usually, over sizing electric motors that uses lightly loaded experience both efficiency and power factor decrease consequence [58]. The effectiveness of the motors is normally 85% of full load. To emphasize more, oversized electric motors in general function at lower efficiency. In other words, if electric motors are not utilized at full load and they are extra-large, it is possible that wasted energy from the motor will be identified. The best solution to conquer this intricacy is by utilizing computer software tools (Advance Motor Master+). It allows the user to determine the efficacy of the motor intended for a particular function [59].

Motor Energy Savings

The economic development of any nation depends greatly on its technological improvement in energy sector. Energy savings can be achieved in public and private sector using different ways and strategies. These strategies are application of technology, using regulations and housekeeping (switching off, maintenance and reduce standby losses).

For the purpose of saving energy and protection, the new brushless DC motor [60] is designed with 8 poles and 12 slots for ceiling fan. At least 50% of the energy is saved. [61] [62] [63] Reported that five motors with new high-efficiency motors. Show that energy savings using with high efficient electric motors as shown in Table 1 has better performance. Advance technology have proven the use of variable speed drive as an improved way of energy saving.

Table 1. High Efficient Energy Saving Motors [62]

Motor HP	Energy savings (kWh/year)
1	111
5	301
20	10,20
50	1604
100	7141
200	5213
500	25,880

Industrial electric motor energy consumption is about 75%. Any raise in energy effectiveness of such motor will produce an essential savings. Using variable control speed can save up to 41% energy use in industries, which is economical over conventional motors. An electric motor with 15% decrease in shaft speed results in 30% decrease in power consumption [64]. [65] Reviewed the variable speed drive in a system application to reduce energy uses. This can be utilize to vary the speed for ventilating and heating for buildings. For instant, controlling the speed flow of air using adjustable technique is an energy efficient method of the system control [66].

Yu and Chan [67] Design a load-predicated speed controller intended for chiller (all-variable speed) plants to optimize their environmental performance. This reduces the yearly sum of electricity use by 20.3% and yearly water utilize by 16.1% relative in the direction of the matching constant speed plant. Having 13,500W of power consumption, it can be reduced to 365W by utilizing variable speed drive. [68] Analyze energy saving methods for electric motors. It was found that energy utilization for selected industries gives a more better performance as shown in Table 2.

Table 2. Energy Saving Potential by the Year 2015 for Public and Private Division [68].

Industry type	Savings (TWh) by VSDs
Basic chemistry	15.5
Food, beverage, and tobacco	8.0
Iron and steel	6.3
Machinery and metal	6.4
Non-metallic mineral	7.4
Paper and cardboard	15.4
Other industries	11.9
Total industry in EU	71.0
Total services	24.6

Capacitor bank power factor can be used for motor energy saving. The ratio of the apparent power to the real power is the power factor and this represents how much the power of equipment is utilized. In other words, it is a gauge of how effective the power is being utilized. Usually, about 85-95% of the apparent power is been converted into functional work. The left over power is utilize to set up an electromagnetic field in the motor [69].

Conclusion

Electrical motors are not exploit at full capacity load and in most cases they are oversized which encourage wastage of energy. An outstanding solution to overcome this difficulty is to use Advance Motor Master+ for design and implementation.

Based on the discussion, utilizing high-efficient motors can reduce energy consumption and environmental pollutions. This paper could be helpful to operators, energy managers to understand the significant of energy savings and improve maintenance strategies for suitable operation of the motor. It could be utilizable for designers to review causes of motor overheating, losses, and adopt appropriate design options on how to reduce losses.

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