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Energy Efficiency Opportunities and Savings Potential for Electric Motor and Its Impact on GHG Emissions Reduction

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ABSTRACT

Motors are the single largest users of electric power, consuming over half of all electricity and more than 60% of that used in the industrial sector. The use of energy-efficient motor technologies offers utilities the possibility of achieving substantial energy savings and reduction of GHG emissions. This paper presents a comprehensive literature review about energy efficiency opportunities and savings potential for electric motor. This paper compiles latest literatures in terms of journal articles, conference proceedings, web materials, reports, books, handbooks on electrical motor energy use, and opportunities for energy efficiency as well as energy savings strategies. Besides, present status of the efficient motor technology, market potential have been presented in this paper. Also, different energy savings strategies such as rewinding, use of variable speed drive (VSD), and capacitor bank to improve the power factor to reduce their energy uses have also been reviewed. Furthermore, cost parameters to carry out economic analysis and payback period for different energy savings strategies have been shown as well.

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1. INTRODUCTION

Electric motor is widely used in various sectors where mechanical energy is needed. It is an electromechanical device which converts electrical energy into rotary mechanical energy. This output is then further converted to ultimately provide the needed end use energy.

Electric motor systems account for about 60 to 70 percent of industrial electricity consumption depending on the industrial structure [1]. There has been extensively usage of electric motors not only in the industry sectors but also in the commercial, residential, agricultural and transportation sectors. The share of each motor system in the total electricity consumption of all motor systems in the USA as well as EU is denoted in Figure 1. This is a general pattern in most of the countries which is comparable with others with a slight variation. Pumping, compressed air and fan systems are the significant energy users where consumption of electricity is dominant. Besides, material handling and processing also consume a lot of electricity, although they are heterogeneous and differ from each other [1].

Motors are considered as one of the significant energy users. There are various methods to improve the efficiency of an electric motor. By improving efficieny, a substantial amount of energy as well as electricilty bill can be saved which can help an organization to enhance its electrical demand profile. Efficient electric motors not only set up systematic energy cost management to achieve energy cost saving but also help an organization to adopt sustainable energy management practice toassure that energy has been efficiently consumed.

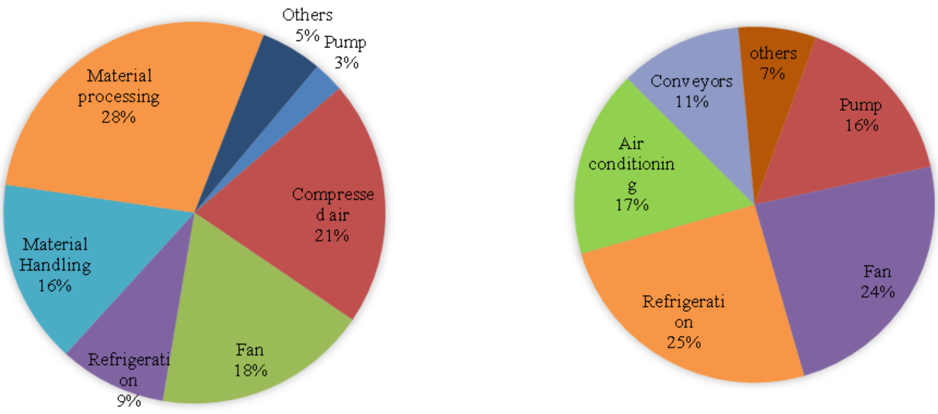

Figure 1. (a) Electric motor electricity use by type of motor system in the USA [2], (b) motor electricity consumption by end-use in the Industrial sector in EU [3]

Among the various sectors contribute to mitigate greenhouse gas (GHG) emissions, the role played by the industrial sector is considered as significant. Thus, lowering GHG emissions from the industrial sector would reduce overall GHG emissions. If energy is used as conservation means where reliance on energy imports would be less and, thus, results less GHG emissions. Energy savings and emissions reductions can be achieved by 10-30% by reducing total energy use or by increasing the production rate per unit of energy used [4]. By contrast, to reduce GHG emissions, enhance the energy efficiency is the key role to be played. Therefore, energy research organizations and governments emphasize the importance of energy efficiency of motor in the industrial sector at high priority. There should have been appropriate policy which can help to reduce GHG emissions.

Energy-efficient motors have number of benefits as energy efficient motors have the features with improved manufacturing techniques and superior materials. Besides, they usually have longer insulation and bearing lives, higher service factors as well as lower waste heat output, less vibration, all of which increase reliability. Moreover, longer warranties which most motor manufacturers offer for their most efficient models.

2. STATUS OF THE TECHNOLOGY

For more than a decade, many countries have started implementing labelling and minimum energy performance standard (MEPS) schemes with an aim to phase out the least efficient motor classes by setting minimum standards for the efficiency. The idea behind its approach is to improve the efficiency of motors on the market. The labelling helps to provide the necessary information which allows for easy comparisons of motor efficiency among producers and hence contributes to transforming the motor market towards high efficiency motors.

Both labelling and MEPS have already been started in many countries like Brazil, China, USA, Europe, Mexico, Australia and Taiwan, resulting in several different national standards [5]. But due to variation in motor efficiency classes in different countries, it is difficult to make comparison and it turns out to be a considerable trade barrier. Therefore, the International Electrotechnical Commission (IEC) developed test standards and labels as well as international efficiency classification for electric motors. The classification introduced by IEC had different efficiency levels with the label IE1 for the least efficient motors and IE4 for the highest efficiency motors. The defined efficiency classes are presented in Figure 2 for 50 Hz motors. The IE4 class has not yet been defined, but is expected to demand a further 15 percent reduction of losses in comparison to IE3. According to Figure 2, it is seen that, the expected savings and differences in efficiency are particularly high for smaller motors. The gap closes with increasing motor size which only have about 2 percent difference from IE1 to IE3 for 375 kW motors.

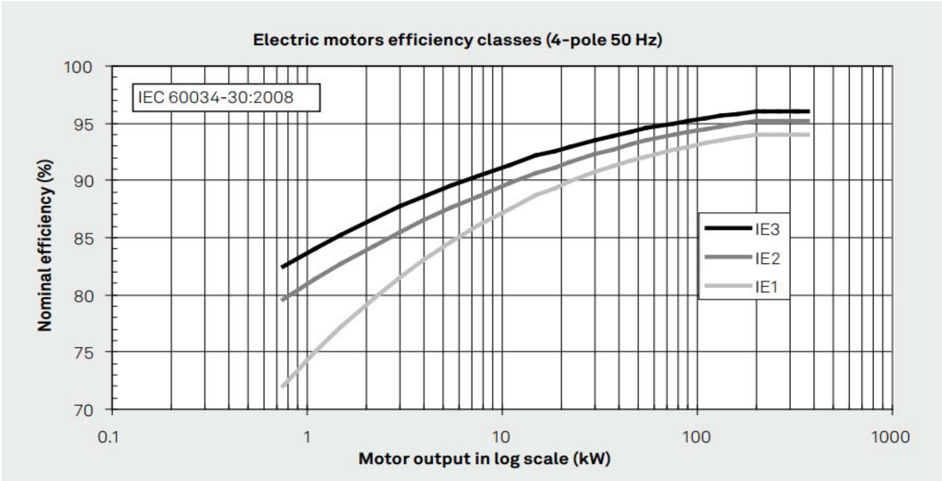

Figure 2. Efficiency classes for 50 Hz 4-Pole motors according to IEC 60034-30 [5]

United States (US) was the first country to introduce ambitious MEPS for electric motors. MEPS were passed into law as early as 1992, but it took five years to adapt to the standards and redesign their motors. This so called Energy Policy Act (EPAct) 92 standard is comparable to the international IE2. Figure 3 provides a detailed picture on implementation dates of the different standards by country. The labels IE1 and IE2 have already been applied in Australia, New Zealand, Brazil, Mexico, and China. Besides, by 2015, the implementation of IE3 class will be predominant in USA, Canada and EU countries. In South East Asia, Thailand and the Philippines are playing the leading role towards the development of national standards for energy conservation [6]. In Brazil, the first regulation of the energy efficiency act for electric motors was introduced in 2002 which established two sets of minimum efficiency performance standards (MEPS), one is the 'standard' (mandatory) and other is the 'high-efficiency' (voluntary) motor. Later, an updated regulation was launched in 2005 (Edict 553/2005) which was strongly recommended to use the previous high-efficiency MEPS as mandatory for all motors in the Brazilian market [7].

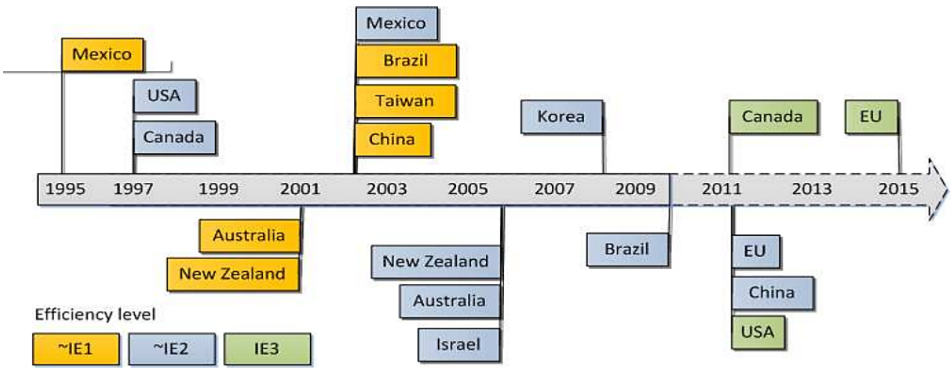

Figure 3. Implementation of mandatory MEPS for electric motors worldwide [8] and [9]

3. MARKET POTENTIAL

A look at the historic motor market data reveals that market transformation towards more efficient motors has taken place in the past. In Europe, the labelling has significant contribution to reduce the market share of the least efficient (Eff3) motors which dropped from about 68 percent in 1998 to 16 percent in 2001, and only 2 percent in 2007 [9]. However, labelling could not significantly improve the diffusion of high efficient IE2 (former Eff1) motor in EU due its high upfront cost. Moreover, the efficiency class IE1 (Eff2) has high percentage of market share (about 80 percent) in comparison to only 12 percent of IE2 (Eff1) in the EU. In the USA, NEMA premium motors (equal IE3 motors), have increased steadily since 2001 and reached close to 30 percent in 2006. In Canada, motors with IE3 or higher even accounted for 39 percent of the market in 2007. In Korea, IE1 motors had a market share of 10 percent in 2005, while 90 percent of the motors were less efficient.

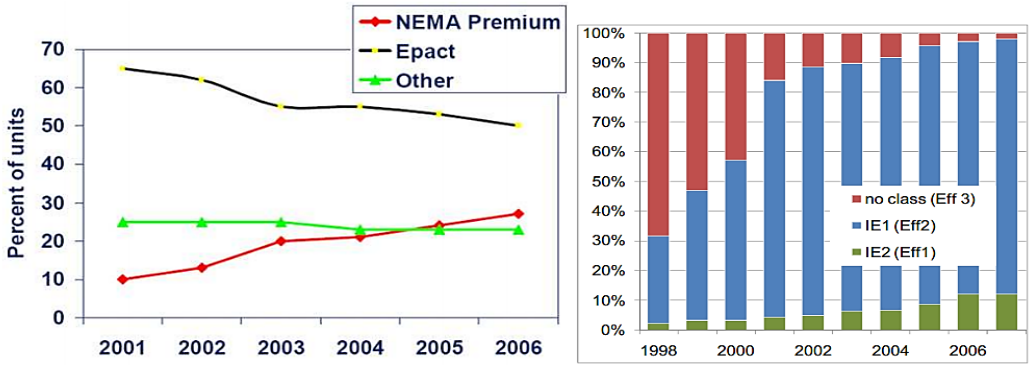

Figure 4. Market share of motors by efficiency class in the USA (left) and the EU (right) [5]

4. DESCRIPTION OF THE TECHNOLOGY

4.1. Technical Measures to Improve Motor Efficiency

Efficient electric motors achieve greater efficiency by reducing the loss which account for only 3-6% of the energy that flows through the motor. As shown in Table 1, there are five categories of losses that occurred in a motor including stator power losses, rotor power losses, magnetic core losses, friction and windage losses, and stray load losses [10]. Among them, stator power losses consume the highest percentage (37% of total energy loss) share of energy loss that a motor accounts. Besides, stray load losses which have 16% of total energy loss can be reduced by redesigning stator winding, but each design change may increase losses in other areas. Moreover, rotor power losses, magnetic core losses and friction and windage losses can be minimized by using higher quality materials and optimizing the design for larger magnetic fields and greater electricity flow [11].

Table 1. Measures to reduce energy loss in electric motors, by type of loss [10]

Type of loss	% of total energy loss	Technical difficulty of reducing loss	Measures to reduce loss
Stator power loss	37	Prohibitive	♦ Theoretically, there is little possibility to reduce the loss of stator power without also decreasing the power available to create the magnetic field.
Rotor power losses	18	Moderate	♦ Increase conductor material (e.g. magnet wiring in the stator winding, or aluminium in the rotor) ♦ Increase in flux across the air gap ♦ Use permanent magnets to eliminate rotor power losses ♦ Use semiconductor power switch systems to eliminate rotor power losses
Magnetic core losses	20	Moderate	♦ Increase the length of the magnet structure ♦ Use thinner laminations in the magnetic structure ♦ Use silicon-grade electrical steel
Friction and windage losses	9	Moderate	♦ Reducing these heat-producing losses can also save energy by requiring less use of the ventilation system
Stray load losses	16	Prohibitive	♦ These losses can be addressed through re-design of the stator winding, but major reductions are difficult because each design change may actually increase losses in other areas.

4.2. Rewinding

The most common practice in industry is to rewind burnt-out motors which exceed 50% of the total number of motors in some industries. It is a technique which can maintain motor efficiency at previous levels. But careful measures should be taken care ofto rewind the motors as in most cases it can result in efficiency loss. The effect of rewinding can reduce the motor efficiency such as winding material, winding and slot design insulation performance, and operating temperature. For example, when the windings are got heated, there can have damage to the insulation between lamination which further raise the eddy current losses. However, if proper measures are taken regarding using wires of greater cross section, slot size permitting, would result a reduction of stator losses and thereby increasing efficiency. However, original design and structure of the motor should be remained same during the rewind, unless there are specific load-related reasons for redesign [12].

4.3. Power Factor Correction by Installing Capacitors

Capacitors are often used to improve the power factor which is connected in parallel (shunted) with the motor. The capacitor itself will not responsible to improve the power factor of the motor but of the starter terminals where power is generated or distributed. The benefits of power factor correction include reduced I^2R losses in cables upstream of the capacitor (and hence reduced energy charges) reduced kVA demand (and hence reduced utility demand charges), reduced voltage drop in the cables (leading to improved voltage regulation), and an increase in the overall efficiency of the plant electrical system [12].

4.4. Variable Speed Drives (VSD)

Electric motors have traditional control methods using mainly two states; stop and operate at maximum speed. Motors are sized to provide the maximum power output required in most motor installation. In order to provide the maximum designed load, the rotational speed is kept constant at its maximum value and to match with the load the power input to the motor also remains constant at the maximum value. However, in order to have significant energy savings, rotational speed of the motor should be decreased when load decreases. Nevertheless, the majority of motors are operated only at 100% speed for short periods of time which often results systems operating inefficiently and significant energy losses during the operation time. To match the speed of the motor with the related load, VSD technique has become a very popular choice now-a-days. The speed of a motor or generator can be controlled and adjusted to any desired speed by using VSD. In addition, VSD can also keep an electric motor speed at a constant level where the load is variable [4].

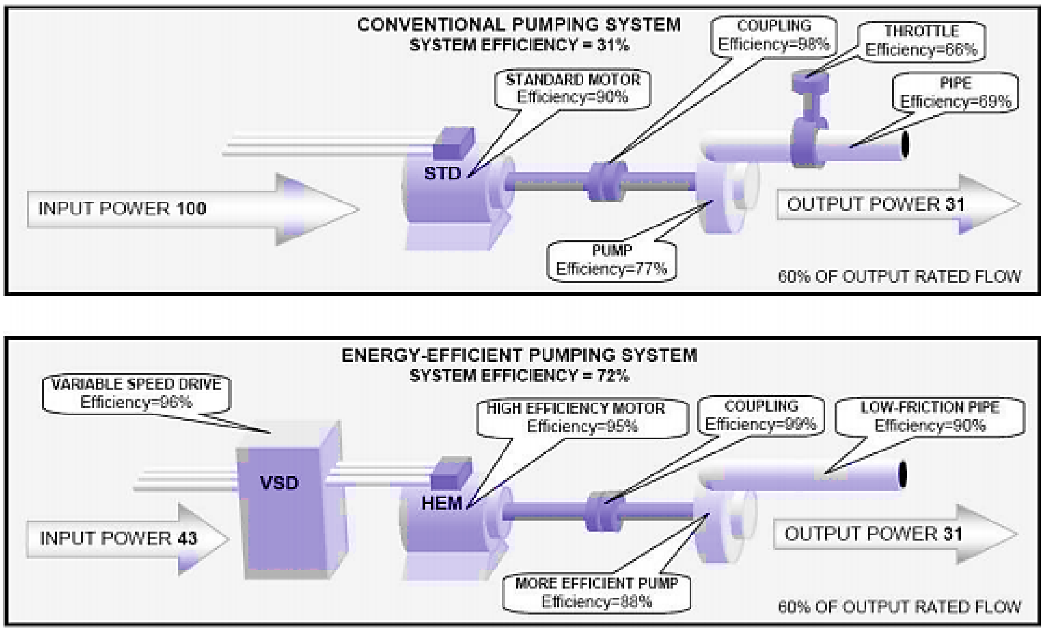

Figure 5. Comparison of a typical and an energy efficient pump system [13]

5. SUCCESSFUL IMPLEMENTATION

This section illustrates how energy efficient motors have become successful to make contribution in terms of significant energy savings and short payback period. Table 2 explains some of the case studies in different countries where efficient motor technology is effectively implemented in companies and, moreover, gives an idea of the energy savings that can be realized.

Table 2. Successful implementation of these technologies in few countries [1]

Project	**Country**	**Energy efficiency improvement**	**Cost effectiveness**
Optimization of cooling water system in a pharmaceutical company by installing two new pumps, applying variable speed control and minimizing friction losses in the ductwork system	China	Reduction of electricity demand of cooling water system by 49%	Payback about 1.8 years (investment of US$ 145,000 and annual savings of US$ 80,000).
Installation of 34 variable speed drives in a petrochemical company	China	28% electricity demand reduction per ton of crude oil refined	0.48 years static payback time.
Installation of 102 **variable speed drives** in one company	Mexico	20% reduction of electricity demand of equipped motors	1.5 years static payback and in-vestment of around US$ 400,000.
Electric motor replacement in aluminum production plant	India	Annual Electricity savings of 263 MWh (75%) reduction of electricity for cooling water pump)	Annual electricity savings of US$ 13,900 and investment of US$ 375 (payback time less than two weeks).
Replacement of inefficient reciprocating compressors by **screw compressors** for compressed air generation in a pulp and paper mill	India	24% of electricity for compressed air generation.	About 1.5 years' payback time and US$ 19,150.
Installation of **efficient screw compressors** with evaporative condensers for refrigeration in a chemical plant	India	60% of electricity for refrigeration (2,238 MWh/a)	Investment of US$ 250,000 and annual savings of US$ 195,000
Reduction of air leaks and intake air temperature in **compressed air system**	Thailand	22% of compressed air electricity consumption or 130 MWh/year	US$ 1,500 investment and payback time of 2.5 months
Compressed air system optimization in textile manufacturing plant	USA	4% reduction of com-pressed air electricity demand and further reliability benefits	The total investment of US$ 529,000 had a payback time of 2.9 years
Installation of 15 variable speed drives in a ventilation system in a textile plant	USA	59% reduction of ventilation system's electricity demand	1.3 years static payback time and US$ 130,000 investment.
Pump impeller size reduction, throttle replacement and motor replacement	UK	More than 30% of pump electricity reduction	11.5 weeks (investment of £2780)

6. FINANCIAL REQUIREMENTS AND COST

To compare motor options, a simple approach has been proposed based on the purchase price of the motor and the present value of the losses [14].

$$LCC = PP + EF\,(KWe) \quad (1)$$

Where, LCC = Life-cycle cost (in $), PP = Motor purchase price (in $), EF = Evaluation factor(in $/kW), KWe = Evaluated loss (in kW)

The evaluation factor, EF, is defined as,

$$EF = C(N)(PWF) \quad (2)$$

Where, C = Power cost (in $/kilowatt-hour), N = Operating time each year (in hours), PWF = Cumulative present worth factor.

The evaluation loss, kW is defined as,

$$kW_e = L(h_p)(0.746)\left[\left(\frac{S_e}{S_b}\right)^x - 1 + \left(\frac{100}{E_{op}}\right) - 1\right] \quad (3)$$

Where, L = Load factor = (driven-load rated hp)/(motor nameplate hp), hp = Motor nameplate horsepower, S_e = Rated full-load speed of evaluated motor, r/min, S_b = Rated full-load speed used as the basis for the evaluation, r/min, E_{op} = Motor nominal efficiency at the rated driven-equipment shaft load, %, $(S_e/S_b)^x$ -l = represents the control valve loss,$(l00/E_{op})$-1 = represents the motor internal losses.

Table 3. Data for Life Cycle Cost(LCC) Comparison Example [13]

Parameter	Standard Efficiency motor	Premium efficiency motor
Nameplate Output	25 hp	25 hp
Rated Load speed	3510 r/min	3540 r/min
Rated Load Efficiency	84%	93%
Motor purchase price	$1500	$1900

Assuming power cost of $0.06/kWh, operating hours of 8000 hrs/year, cumulative present worth factor equals to 4, LCC cost for standard efficiency motor is $6530 and for premium efficiency motor is $4300 by using the above equations.

7. ENERGY SAVINGS AND PAYBACK PERIOD

By using energy-efficient motors for 50%, 75% and 100% motor loading, 1765, 2703 and 3605 MWh of total energy can be saved respectively [4]. The result is calculated based on performing the walkthrough audit in 91 industries of Malaysia. Similarly, associated bill savings for the estimated amount of energy savings are US$115,936, US$173,019 and US$230,693, respectively. It also has been found that the payback period for using energy-efficient motors ranges from 0.53 to 5.05 years for different percentages of motor loading. These payback periods indicate the introduction/implementation of energy-efficient motors would seem cost effective, as their payback periods are less than one-third of the motor life (if average motor life 20 years is considered) in some cases.

The annual energy savings (AES) attained by replacing standard efficient motorswith high energy efficient motors can be estimatedby using the following equation

$$AES = h_p \times L \times 0.746 \times h_r \times \left(\frac{1}{E_{std}} - \frac{1}{E_{ee}} \right) \times 100 \quad (4)$$

where, AES = Annual energy savings, hp = Motor rated horsepower, hr = Annual operating hours, L = Load factor (percentage of full load), E_{std}= Standard motor efficiency rating (%), E_{ee}= Energy-efficient motorefficiency rating (%).

The annual bill savings associated with the above energy savings can be calculated as-

Annual bill savings (US$) = AES × c (5)

where, c = Average energy cost (US$/kWh)

A simple payback period for different energy saving strategies can be calculated by using the following equation,

Simple payback period (years) = Incremental cost/ Annual dollar savings (6)

Table 4. Efficiency of standard and high efficiency motors at different loads [16]

Motor power	Load (50%)		Load (100%)	
(hp)	E_{std}	E_{ee}	E_{std}	E_{ee}
1	70.05	75.28	77.0	80.97
2	77.20	80.02	81.00	83.55
3	77.78	82.44	81.50	85.96
4	81.07	83.69	82.90	85.96
5.5	81.15	84.35	85.30	87.75
7.5	84.70	85.51	86.61	89.50
15	84.90	88.32	87.94	90.44
20	86.03	88.51	88.95	91.64
30	88.43	90.89	90.36	92.85
40	88.15	90.39	90.36	92.85
50	89.63	91.16	92.06	93.38
60	87.89	90.07	91.78	93.00
75	88.77	90.86	92.44	93.02

Table 5. Energy savings and payback period for high efficient motor in Malaysia [4]

Motor power (hp)	Quantity (No.)	Incremental price (US$)	Load (50%)			Load (100%)		
			Energy savings (MWh)	Bill savings (US$/year)	Payback (years)	Energy savings (MWh)	Bill savings (US$/year)	Payback (years)
1	3968	24	24	4730	1.59	127	8158	1.19
2	1653	25	28	1814	1.19	71	4562	0.89
3	2976	27	122	7798	0.71	232	14873	0.53
4	13556	60	393	2169	2.04	827	52900	1.53
5.5	331	65	16	1022	2.71	16	1056	2.04
7.5	661	91	19	1194	3.77	33	2131	2.83
15	165	147	21	1351	1.24	41	2609	0.93
20	3306	197	404	25888	1.26	1081	69177	0.94
30	331	257	11	682	1.62	110	7014	1.21
40	661	231	140	8938	1.95	164	10469	1.46
50	331	281	58	3721	0.95	203	12994	0.71
60	827	574	257	16,417	2.89	173	11,060	4.29
75	165	518	60	3862	2.22	141	9018	0.95

From Table 5, it is evident that a huge amount of energy can be saved for different percentages of speed reductions. More energy can be saved for higher speed reductions. Along with energy savings, a substantial amount in expense can be saved and associated emission reductions can be achieved using VSD for industrial motors in Malaysia.

There are many ways to estimate the energy savings associated with the use of VSD for industrial motors for various applications. Mathematical formulations to estimate energy savings using VSD is

$$ES_{VSD} = n \times P \times H_{avg\text{-}usage} \times S_{SR} \quad (7)$$

Where, ES_{VSD} = Energy saving with the application of VSD (MWh), n = number of motors, P = motor power (kW), $H_{avg\text{-}usage}$ = Annual average usage of hours, S_{SR}= percentage energy savings associated certain percentage of speed reduction.

Table 6. Motor energy savings with VSD for different % of speed reduction in Malaysia [4]

Motor power (hp)	Energy savings (MWh)					
	10% speed reduction	20% speed reduction	30% speed reduction	40% speed reduction	50% speed reduction	60% speed reduction
1	391	782	1084	1297	1475	1582
2	325	650	901	1078	1226	1315
3	880	1761	2441	2921	3321	3561
4	5341	10682	14809	17723	20151	21607
5.5	179	357	496	593	674	723
7.5	487	975	1352	1617	1839	1972
15	251	502	696	833	947	1016
20	6519	13038	18075	21631	24594	26372
30	975	1950	2703	3235	3678	3944
40	2600	5199	7208	8626	9808	10517
50	1625	3250	4505	5391	6130	6573
60	4904	9808	13,597	16,272	18,501	19,839
75	1256	2511	3481	4166	4737	5079

8. GHG EMISSIONS REDUCTION

Efficient electric motor has the potential to reduce emissions associated with the energy savings by motors using VSD. Table 8 shows the estimation of emission reductions for only 91 industries in Malaysia.

The energy savings is likely to reduce the electricity generation from power plants. As a consequence, the reduction of GHG emissions (CO_2, CO, NOx, SO_2) from the fuels used by the power sector can be estimated. Each of the GHGs has their own emission factor which is shown in the table 7.

Table7. Emission factors of fossil fuels for electricity generation [15]

Fuels	Emission factor (kg/kWh)			
	CO_2	SO_2	NO_x	CO
Coal	1.18	0.0139	0.0052	0.0002
Petroleum	0.85	0.0164	0.0025	0.0002
Natural Gas	0.53	0.0005	0.0009	0.0005
Hydro	0.00	0.000	0.0000	0.0000
Others	0.00	0.000	0.0000	0.0000

The amount of emission that can be reduced associated with the energy savings can be estimated using following formula [14].

$$ER = AES \times EF \quad (8)$$

Where, ER = Emission Reduction, EF = Emission Factor

Table 8. Emission reductions associated with energy savings by VSD [4]

Motor power (hp)	**Emission reduction (kg) for 20% speed reduction**				**Emission reduction (kg) for 40% speed reduction**			
	CO_2	SO_2	NO_x	CO	CO_2	SO_2	NO_x	CO
1	3,911,026	23,411	11,029	2,379	6,488,748	38,842	18,298	3,947
2	3,258,531	19,506	9,189	1,982	5,406,200	32,361	15,245	3,288
3	8,799,809	52,676	24,819	5,352	14,599,683	87,394	41,171	8,880
4	53,445,435	319,924	150,716	32,507	88,670,836	530,783	250,052	53,932
5.5	1,794,361	10,741	5,060	1,091	2,977,008	17,820	8,395	1,811
7.5	4,886,319	29,249	13,779	2,971	8,106,847	48,528	22,861	11,413
15	2,439,463	14,603	6,879	1,484	4,047,291	24,227	11,413	2,462
20	6,170,629	390,111	183,781	39,639	108,123,998	647,230	304,910	65,764
30	9,787,422	58,587	27,601	5,953	16,238,223	97,202	45,792	9,877
40	26,060,366	155,997	73,490	15,851	43,236,517	258,814	121,927	26,298
50	16,312,370	97,636	46,001	9,922	27,063,705	162,003	76,320	16,461
60	48,907,541	292,760	137,919	29,747	81,142,057	485,716	228,821	49,353
75	12,197,316	73,013	34,396	7419	20,236,456	121,135	57,067	12,308

9. CONCLUSION

Efficiency improvement in electric motor is one of the most important energy saving options. There are various methods to improve the efficieny of the electric motor. By introducing efficient electric motor in the industrial sectors, a significant energy could be saved which would further reduce emissions. This review paper could be useful for motor designers, operators, energy managers and motor manufacturers to fully understand energy saving opportunities in electric motors and further to take proper energy saving measures to enhance energy efficiency in industries as well as residential and agriculture sectors. They could help designers adopt proper design options and concepts in the decision-making process during the initial planning and design stages (i.e. how to reduce losses) and help operators to use advanced control algorithms in practical operations to reduce the global energy consumption in electric motors and enhance control stability and environmental sustain-ability. Also, it could be useful for the government to evaluate the current electric motor energy policies.

REFERENCES

[1] Uniter Nations Industrial Development Organization (UNIDO) working paper. “Energy efficiency in electric motor systems: Technology, saving potentials and policy options for developing countries”, 2011.
[2] International Energy Agency (IEA). “Tracking Industrial Energy Efficiency and CO2 Emissions”, Paris, 2007.
[3] AT Almeida, P Fonseca, P Bertoldi. “Energy-efficient motor systems in the industrial and in the services sectors in the European Union: characterization, potentials, barriers and policies”. *Energy*, vol 27, pp. 673-690, 2003.
[4] R Saidur, NA Rahim, HW Ping, MI Jahirul, S Mekhilef and HH Masjuki. “Energy and emission analysis for industrial motors in Malaysia”. *Energy Policy*. 2009; 37: 3650–3658.
[5] R Boteler, C Brunner, A de Almeida, M Doppelbauer and W Hoyt. “Electric Motor MEPS Guide”. Zürich, 2009.
[6] PAA Yantiand TMI Mahlia. “Considerations for the selection of an applicable energy efficiency test procedure for electric motors in Malaysia: lessons for other developing countries”. *Energy Policy*. 2009; 37: 3467–74.
[7] AGP Garcia, AS Szklo, R Schaeffer and MA McNeil. “Energy-efficiency standards for electric motors in Brazilian industry”. *Energy Policy*. 2007; 36: 3424–39.
[8] AT Almeida, F Ferreira, J Fong and P Fonseca. “EUP Lot 11 Motors, Preparatory study for the Energy Using Products (EuP) Directive”. Coimbra, 2008.

[9] C Brunner and N Borg. "From voluntary to mandatory: policy developments in electric motors between 2005 and 2009". 2009.
[10] A Emadiand CA John. "Energy-Efficient Electric Motors (3rd ed. rev. and expanded)". New York: CRC Press, 2005.
[11] FK Kreithand DY Goswami. "Handbook of energy efficiency and renewable energy". CRC Press, 2007.
[12] Bureau of Energy Efficiency (BEE). "Ministry of Power, India. Components of an Electric Motor". 2005. Available at www.energymanagertraining.com/equipment_all/electric_motors/eqp_comp_motors.htm
[13] H De Keulenaer, *et al.* "*Energy Efficient Motor Driven Systems can save Europe 200 billion kWh of electricity consumption and 100 million tonne of greenhouse gas emissions a year, Motor Challenge*". Brussels: European Copper Institute, 2004
[14] PS Hamer, DM Lowe and S Wallace. "*Energy-efficient induction motors-performance characteristics and life-cycle cost comparison for centrifugal loads*". The Institute of Electrical and Electronics Engineers Incorporated Industry Applications Society 43rd Annual conference. 1996: 209-217.
[15] Mahlia. "Emissions from electricity generation in Malaysia". *Renewable Energy*. vol 27, pp. 293–300, 2002.
[16] AGP Garcia *et al*. "Energy-efficiency standards for electric motors in Brazilian industry". *Energy Policy*. 2009; 35: 3424–3439.

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