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Energy Consumption, Energy Savings and Emission Analysis for Industrial Motors

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Abstract

Energy is one of the indispensable factors for continuous development and economic growth. The industrial sector is the largest user of energy in Malaysia. Since motors are the principle energy users, different energy savings, strategies have been applied to reduce their energy consumption and associated emissions released into the atmosphere. These strategies include using high efficient motors and Variable Speed Drive (VSD). It has been estimated that there can be a total energy savings of 1765MWh, 2703 MWh and 3605MWh by utilizing energy-efficient motors for a 50%, 75% and 100% load respectively. Similarly, it is hypothesized that a significant amount of energy can be saved using VSD to reduce speed, thus cutting energy costs. Moreover, a substantial reduction in the amount of emissions can be effected together with the associated energy savings for different energy savings strategies. It is clear that the use of VSDs and energy efficient motors leads to substantial energy savings and an enormous reduction in emissions.

Keywords
Industrial motors, Energy consumption, Energy savings, Variable speed drive, Emission reduction.

1. Introduction

Most of the developing countries shifted from agriculture to industrialization and urbanization within a process of economic growth and development over the last few decades. Energy efficiency improvement is the main objective of many national energy policies. Energy losses in a large number of industries exist, and there is evident potential for energy efficiency improvements [1]. Among the various sectors contributing to greenhouse gas emissions, the contribution of the industrial sector was significant. Previous studies have reported that implementing a few select options at little or no cost in the industrial sector could reduce GHG emissions by 10-30% of GHG emissions [2]. In Malaysia, the industrial sector was found to be major user of energy; it accounted for some 48% of total energy use in 2007 [3]. The increased use of energy raised serious concerns in the Malaysian government about the need to overcome heightened energy expenditure by promoting the end-use energy efficiency. On the other hand, improving energy efficiency is the key to reducing greenhouse gas (GHG) emissions. Therefore, energy research organizations and governments are actively engaged in developing methods of assessing energy efficiency. This assessment can provide a basis for establishing energy policy and can simultaneously reduce GHG emissions. One way to achieve more efficient use of final energy in an industry is to determine the precise amount of energy used and identifiable energy losses. Various types of equipment and devices that use energy at varying levels of efficiency depend on the characteristics and working conditions [4]. Comprehensive literature on electrical motor energy savings, policy, and technology can be found in a handbook [5]. In Slovenia, the industrial sector consumes about 52% of total electrical energy [6]. In Turkey, about 35% of total energy is used in the industrial sector [7]. Approximately half of the total generated electricity in the UK is used to drive electrical motors. This means that efficiency improvements to electrical machines can have a very large impact on energy consumption [8]. Motor-driven systems account for approximately 65% of the electricity used by industry in the European Union [9]. In Jordan, the industrial sector consumes about 31% of total energy [10]. In Malaysia, about 48% of total energy is used to drive industrial motors [11]. In many industrialized countries, more than 70% of the total energy is consumed by electric motors. Therefore, the cost of energy to operate motors has become a real concern for industry [12]. The energy consumed to drive electric motors used in industrial plants is about 65% of the total energy consumption in Turkey. Therefore, it is important to ensure placement of ‘‘high efficiency” motors in industrial plants wherever possible [13]. By introducing variable speed to the driven load, it is possible to optimize the efficiency of the entire system, and it is in this area that the greatest efficiency gains are possible [8]. By combining several of the solutions, aggregate energy savings can easily approach 30% to 35% [14]. In the existing literature, no study has quantified the details of motor energy savings in the ASEAN industrial sector. This study presents the energy savings and associated emission reductions by industrial motors for different energy savings strategies. It is hoped this study will be useful for formulating policy measures for industrial motors energy use in ASEAN and other countries. Furthermore, the results can furnish important guidelines and insights for future research and development allocations and energy projects to reduce motor energy use.

2. Methodology

2.1 Energy audit data

More than 2,500 questionnaires were distributed by mail to various industrial firms, amounting to 10% of the total Malaysian industrial sector. Based on the response received, 125 industries were selected to perform the walkthrough audit. However, audit team managed to visit and collect complete data for 91 industries. The audited factories were divided into 11 sectors according to the product they manufactured. Table 1 shows the sectors with three digit International Standard Industrial Classification (ISIC) code and the number of factories audited from each sector.

Table 1 Number of audited industrial sector with ISIC code

Sectors	Sector/ISIC code	Number of audited factories
Food products	311	9
Wood and wood products	331	8
Paper and paper products	341	13
Chemicals	352	4
Petroleum refineries	353	5
Rubber and rubber products	355	13
Plastic and plastic products	356	7
Glass and glass products	362	4
Iron and steel	371	5
Fabricated metal products	381	12
Cement	390	6
Total		91

The most important data that have been collected during the walkthrough audit are power rating and operation time for equipments/machineries using energy; fossil fuel and other sources of energy use; production figure; peak and off-peak tariff usage behavior; and power factor. It was found that the industrial motor consumes a major share of total industrial energy. Consequently, the electrical motor has been targeted to estimate energy savings and emission reduction by applying various energy savings strategies.

2.2 Estimating electric motor energy savings and emission reductions

Energy can be saved in different ways for different types of machinery using industrial energy, working with the different energy savings strategies. Since motors consume a substantial share of total industrial energy, energy savings through the use of energy-efficient motors and VSDs is considered.

2.2.1 Energy savings by using a high efficiency motor

A High Efficiency Motor (HEM) uses low-loss materials to reduce core and copper losses. Therefore, it generates less heat and requires a smaller and, more energy-efficient cooling fan. The most popular approach is demand-side management, one aspect of which is to improve the efficiency to offset load growth. These facts led electric motor manufacturers to seek methods for improving the motor efficiency, which resulted in a new generation of electric motors that are known as energy-efficient electric motors. Several leading electric motor manufacturers, mainly in the U.S. and Europe, have developed product lines of energy-efficient electric motors [12]. Switching to energy efficient motor-driven systems can save Europe up to 202 billion kWh in electricity use. It was reported that a reduction of 79 million tons of CO_2 emissions (EU-15), or approximately a quarter of the EU's Kyoto target, is achievable using energy-efficient motors. This is the annual amount of CO_2 that a forest the size of Finland transforms into oxygen.

Mathematical formulations to estimate energy savings using HEMs

Annual Energy Savings (AES) by replacing a standard efficient motor with a high energy-efficient motor can be estimated using methodology described [15]:

$$AES = hp \times L \times 0.746 \times hr \times \left[\frac{1}{E_{std}} - \frac{1}{E_{ee}} \right] \times 100 \quad (1)$$

Where: *hp*-Motor rated horsepower, *n*-Number of motors, *L*- Load factor, *hr*-Usage hours, E_{std}-Standard motor efficiency rating (%)and E_{ee}-Energy-efficient motor efficiency rating (%)

2.2.2 Motor energy savings using Variable Speed Drive (VSD)

Many building systems are designed to operate at maximum load conditions. However, most building systems operate at their full load only for short periods of time. This often results in many systems operating inefficiently over long periods of time. Most such inefficient operations in buildings are encountered in air-conditioning systems that are normally sized to meet peak load conditions, these occur only for short periods during the normal day. The efficiency of such systems can be improved by varying their capacity to match actual load requirements. As all these are variable torque applications, the power required (to drive the pumps or fans) varies to the cube of the speed and, therefore, large power reductions result from small reductions in speed. The most common method is to modulate the speed of the motors of pumps and fans to vary their capacity using VSDs [16]. Variable-frequency drives provide continuous control, matching motor speed to the specific demands of the work being performed. Variable-frequency drives are an excellent choice for adjustable-speed drive users, because they allow operators to fine-tune processes while reducing costs for energy and equipment maintenance in heating, ventilating and air conditioning of buildings [17-18]. VSD installations can increase energy efficiency (in some cases energy savings can exceed 50 percent), improve power factor and process precision, and afford other performance benefits such as soft starting and overspeed capability. They also can eliminate the need for expensive and energy-wasting throttling mechanisms such as control valves and outlet dampers [16].

Electric motors are over 90% efficient when running at their rated loads. However, they are very inefficient at load-following, or running at part loads. Conventional electric motors typically use 60% to 80% of their rated input energy, even when running at less than 50% load [19]. It is very important to select an electric motor of suitable power to work efficiently. In general, motors are chosen in big capacities to meet extra load demands. Big capacities cause motors to work inefficiently at low load. Normally, motors are operated more efficiently at 75% of rated load and above. Motors operated at lower than 50% of rated load, because they were chosen based on large capacity, perform inefficiently, and due to the reactive current increase, power factors are also decreased. These kinds of motors do not use the energy efficiently because they have been chosen for large motor power, not according to the needs. These motors should be replaced with new suitable-capacity motors, and when purchasing new motors, energy-saving motors should be preferred [13]. VSDs yield sizable energy savings (15-40% in many cases) and extend equipment life by allowing for gentle start-up and shutdown [5].

Mathematical formulations to estimate energy savings using VSD

There are many ways to estimate the energy savings associated with the use of VSD for industrial motors for various applications. This paper employed the methods found in [20]. Energy use of fans and pumps varies according to the speed raised to the third power, so small changes in speed can result in huge changes in energy use. A motor energy savings using VSD can be estimated as:

$$ES_{VSD} = n \times P \times H_{avg\_usage} \times S_{SR} \quad (2)$$

Where: *P*-Motor power (kW), H_{avg_usage} - Annual average usage hours, S_{SR}- Percentage energy savings associated certain percentage of speed reduction

Table 2 shows the potential energy savings associated with the speed reduction using VSD for industrial motors [20]. These data have been used to estimate motor energy savings using VSD.

Table 2 Potential savings from VSD [20]

Average speed reduction (%)	Potential energy savings (%)
10	22
20	44
20	61
40	73
50	83
60	89

2.2.3 Estimation of emission reduction

The energy savings is likely to reduce the electricity generation from power plants. As a consequence, the reduction of CO_2 and other emissions from the fuels used by the power sector can be estimated. The amount of emission that can be reduced associated with the energy savings can be estimated using the following equation [21]:

$$ER = AES \times EF \quad (3)$$

Where: *ER*-Emission reduction in kg and *EF*- Emission factor (kg/kWh)

Emission factor for per unit energy has been shown in Table 3 and has been used to estimate the amount of emission that can be reduced.

Table 3 Emission factors of fossil fuels for electricity generation [21]

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
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

3. Results and Discussions

Using Equations (1) and average usage hours 6000, energy savings as a result of using a high efficiency motor have been estimated for different motor sizes and loads. it was determined that 1765MWh, 2703MWh, and 3605MWh of total energy can be saved by using energy-efficient motors for 50%, 75% and 100% motor loading respectively.

From Table 4, 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. Using the data shown in Table 4, and Equation (3), the amount of emissions that can be reduced as a result of introducing energy-efficient motors has been estimated and is presented in Table 5. Table 6 shows the emission reduction associated with the energy savings by motors using VSD. It should be pointed out that the amount of energy and emission reductions has been estimated for only 91 industries in Malaysia. Thus, there is a tremendous potential for saving of energy and lowering electricity bills for the total number of industries in Malaysia. Along with energy savings, it will reduce emission of pollutants released into the atmosphere as well.

Table 4 Motor energy savings with VSD for different % of speed reduction

Motor power (HP)	Energy savings (MWh)					
	10% speed reduction	20% speed reduction	30% speed reduction	40% speed reduction	50% speed reduction	60% speed reduction
0.5	57	114	158	190	215	231
1	391	782	1084	1297	1475	1582
2	325	650	901	1078	1226	1315
3	880	1761	2441	2921	3321	3561
4	5341	10,682	14,809	17,723	20,151	21,607
15	251	502	696	833	947	1016
20	6519	13,038	18,075	21,631	24,594	26,372
25	2437	4874	6758	8087	9,195	9860
30	975	1950	2703	3235	3678	3944
40	2600	5199	7208	8626	9808	10,517
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

Table 5 Emission reductions (ton) associated with energy savings for energy efficient motor

CO_2	SO_2	NO_x	CO
27,140	162	77	17
40,707	244	115	25
39,562	311	128	19

Table 6 Emission reductions associated with energy savings by VSD

Motor power (HP)	Emission reductions (kg) for 20% speed reduction				Emission reductions (kg) for 40% speed reduction				Emission reductions (kg) for 60% speed reduction			
	CO_2	SO_2	NO_x	CO	CO_2	SO_2	NO_x	CO	CO_2	SO_2	NO_x	CO
0.25	1,140,634	6828	3217	694	1892,415	11,328	5337	1151	2,307,191	13,811	6506	1403
0.5	570,194	3413	1608	347	946,003	5663	2668	575	1,153,346	6904	3252	702
0.75	978,003	5854	2758	595	1622,596	9713	4576	987	1,978,233	11,842	5579	1203
1	3,911,026	23,411	11,029	2379	6,488,748	38,842	18,298	3947	7,910,939	47,355	22,309	4812
1.5	489,371	2929	1380	298	811,911	4860	2290	494	989,864	5925	2791	602
2	3,258,531	19,506	9189	1982	5,406,200	32,361	15245	3288	6,591,120	39,454	18,587	4009
3	8,799,809	52,676	24,815	5352	14,599,683	87,394	41171	8880	17,799,614	106,548	50195	10,826
4	53,445,435	319,924	150,716	32,507	88,670,836	530,783	250,052	53,932	108,105,540	647,119	304,858	65,753
5.5	1,794,361	10,741	5060	1091	2,977,008	17,820	8395	1811	3,629,502	21,726	10,235	2208
7.5	4,886,319	29,249	13,779	2972	8,106,847	48,528	22,861	4931	9,883,690	59,164	27,872	6012
15	2,439,463	14,603	6879	1484	4,047,291	24,227	11413	2462	4,934,369	29,537	13,915	3001
20	65,170,629	390,111	183,781	39,639	108,123,998	647,230	304,910	65,764	131,822,409	789,089	371,739	80,178
25	24,443,914	146,321	68,932	14,868	40,554,676	242,760	114,364	24,667	49,443,372	295,968	139,430	30,073
30	9,787,422	58,587	27,601	5953	16,238,223	97,202	45,792	9877	19,797,286	118,506	55,828	12,041
40	26,060,366	155,997	73,490	15,851	43,236,517	258,814	121,927	26,298	52,713,014	315,540	148,651	32,062
50	16,312,370	97,646	46,001	9922	27,063,705	162,003	76,320	16,461	32,995,476	197,511	93,047	20,069
60	48,907,541	292,760	137,919	29,747	81,142,057	485,716	228,821	49,353	98,926,617	592,174	278,973	60,170
75	12,197,316	73,013	34,396	7419	20,236,456	121,135	57,067	12,308	24,671,844	147,686	69,575	15,006

4. Conclusion

The study found that a substantial amount of energy and utility bills can be saved if high efficiency motors and VSD are used for industrial motors. The study also estimated that emissions can be substantially reduced by applying energy-savings strategies to industrial motor. It was also found that more energy can be saved at levels of higher speed reduction (i.e. speed reduction above 40%).

References

1. Mohsen, M.S., Akash, B.A., 1998. Energy analysis of the steel making industry. *International Journal of Energy Research,* 22, 1049–1054.
2. Ghaddar N, Mezher T. 1999 Modeling of current and future energy intensity and greenhouse gas emissions of the Lebanese industrial sector: assessment of mitigation options. Applied Energy, 63, 53–74
3. EC, 2007, Statistics of electricity supply in Malaysia, Energy Commission Malaysia.
4. Chan D. Y.L, Yang K. H, Hsu C. H, Chien M. H, Hong Gui. B, 2007. Current situation of energy conservation in high energy-consuming industries in Taiwan, *Energy Policy*, 35, 202–209
5. Nadel, S., R.N. Elliott, M. Shepard, S. Greenberg, G. Katz, and A.T. de Almeida. 2002. Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities. Second Edition. Washington, D.C.: American Council for an Energy-Efficient Economy.
6. Al-Mansour F, Merse S, Tomsic M, 2003, Comparison of energy efficiency strategies in the industrial sector of Slovenia, Energy 28, 421–440
7. Onut S, Soner S, 2007, Analysis of energy use and efficiency in Turkish manufacturing sector SMEs, Energy Conversion and Management 48 (2007) 384–394
8. Mecrow B.C.,.Jack A.G, 2008, Efficiency trends in electric machines and drives, Energy Policy 36 (2008) 4336–4341
9. Anon, 2004. Variable Speed Driven Pumps, Best Practice Guide, Automation instrumentation & control laboratory technology, www.gambica.org.uk, downloaded on 31/12/08
10. Al-Ghandoor A., Al-Hinti I., Jaber J.O., Sawalha S.A., 2008, Electricity consumption and associated GHG emissions of the Jordanian industrial sector: Empirical analysis and future projection, *Energy Policy* 36 (2008) 258–267
11. Saidur R., Rahim N.A, Masjuki H.H., Mekhilef S..Ping H.W,.Jamaluddin M.F. 2009, End-use energy analysis in the Malaysian industrial sector. Energy, Volume 34, Issue 2, February 2009, Pages 153-158.
12. Akbaba M, 1999, Energy conservation by using energy efficient electric motors, *Applied Energy* 64 (1999) 149-158
13. Kaya D, Alptekin Yagmur E., Suleyman Yigit K., Fatma Canka Kilic, Salih Eren A., Cenk Celik,2008, Energy efficiency in pumps, Energy Conversion and Management 49 1662–1673
14. Nakahoma, 2008. “Power Factor Correction at the Residential Level – Pilot Project” Report to the LDC Tomorrow. http://www.nakahoma.com/Res%20App%20Power%20Co.pdf, Downloaded 18/01/09
15. Garcia A. G. P, Alexandre S. Szklo, Roberto Schaeffer, Michael A. McNeil, 2007, Energy-efficiency standards for electric motors in Brazilian industry, Energy Policy, 35, 3424–3439
16. Beggs C., 2002, Energy Management and Conservation, Elsevier Ltd.
17. Jayamaha L, 2006, Energy efficient building systems, McGraw Hill Publisher.
18. Teitel M, Zhao A.L.Y, Barak M, Eli Bar-lev, Shmuel D, 2008, Energy saving in agricultural buildings through fan motor control by variable frequency drives, Energy and Buildings 40 953–960
19. Bouzidi F, 2007, Energy savings on single-phase induction motors under light load conditions, MS thesis, University of Nevada Las Vegas, USA.
20. Anon, 2008.Ways to Save on Motor Energy Costs, 2008, https://www.aps.com/main/services/business/WaysToSave/BusWaystoSave_16, Downloaded on 28/11/2008
21. Mahlia, 2002. Emissions from electricity generation in Malaysia. Renewable, Energy 27, 293–300.