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Energy savings and emissions reductions for rewinding and replacement of industrial motor

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ABSTRACT

Electric motors consume 30–80% of total industrial energy around the world. This study estimates the economic viability of replacing rewound and standard motors with high efficiency motors (HEMs) in the industrial sector. The efficiency of a motor is degraded when it is rewound and it is better to rewind a larger motor compared with a smaller motor. It was found that a HEM can save on average 5.5% of energy compared with a standard motor. In addition, the payback period was found to be reasonable when a motor is operated at a 50% load. HEMs will also save a sizeable amount of energy and reduce emissions. It was estimated that 67,868 MWh/year energy and US$ 4,343,531 per year could be saved by introducing HEMs. By contrast, 44,582 tons of CO_2, 333 tons of SO_2 and 122 tons of NO_x emissions could be reduced through the aforementioned energy savings. This study found that rewound motors of a larger size and HEMs are economically viable.

1. Introduction

The industrial sector is the largest energy user around the world. The electrical energy consumption in Malaysia has increased sharply in the past few years, and modern energy efficient technologies are desperately needed for the national energy policy [1]. Industrial motors use a major fraction of total industrial energy. Electric motors have broad applications in industry, business, public service and household electrical appliances, powering a variety of equipment including wind blowers, water pumps, compressors and machine tools. In industrially developed and large developing countries, electric motors account for a considerable proportion of total national power consumption [2]. The induction motor is the main driven system in modern industrial society [3]. Electric motors consume 30–80% of total industrial energy around the world (Table 1). In Malaysia, electric motors consume about 48% of the industrial energy consumption. Electric motors are also responsible for consuming about 40% of electricity worldwide. In Malaysia, the bulk of electricity in the industrial and commercial sectors is consumed by electric motors. Activities and processes in industries are heavily dependent on electric motors for compacting, cutting, grinding, mixing, fans, pumps, materials conveying, air compressors and refrigeration. Motors are also used widely in the commercial sector for air conditioning, ventilation, refrigeration, water pumping, lifts and escalators. Energy losses in a large number of industries prevail, and potential energy efficiency improvements are imminent [4]. Among the various sectors contributing to greenhouse gas (GHG) emissions, the contribution of the industrial sector is significant. Thus, lowering GHG emissions from the industrial sector would reduce overall GHG emissions. Energy conservation means less reliance on energy imports and, thus, less GHG emissions. Previous studies have reported that the implementation of selected options at little or no cost in the industrial sector could reduce GHG emissions by 10–30% [5,6]. The instantaneous emissions associated with electricity generation vary with the demand for electricity. Indeed, the fuel mix needed for electricity generation changes with the kinds of power plants needed to supply the amount of electricity required as well as the fluctuating rate of the corresponding emissions [7]. Any reduction in carbon dioxide emissions afforded by a demand-side intervention in the electricity system is typically assessed by means of an assumed grid emissions rate, which measures the CO_2 intensity of electricity not used as a result of the intervention. This emissions rate is called the marginal emissions factor (MEF). The accurate estimation of MEF is crucial for performance assessment because its application leads to decisions regarding the relative merits of CO_2 reduction strategies

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Nomenclature

AES	Expected annual bill savings (US$)
c	Average energy cost (US$/kWh)
COEF	Emission coefficient of fuel (kg/kg or litter)
E	Motor efficiency rating (%)
EF	Emission factor (kg/kWh)
F	Amount of fuel (kg or litter)
GEN	Electricity delivered to the grid (kWh)
hp	Motor rated horsepower
hr	Annual operating hours
L	Load factor (percentage of full load)
NCV	Net calorific value of fuel
OXID	Oxidation factor of the fuel
0.746	Conversion factor from horsepower to kW

Subscripts

BM	Build margin
ee	Energy-efficient motor
i	Fuel type
j	Power plant
MEF	Marginal emission factor
OM	Operational margin
re	Rewind motor
std	Standard motor
w	Emission weighted factor
y	Year

[8]. Electricity generation has recently focused on the problems of urban air pollution, acid deposition, contamination from nuclear accidents and nuclear wastes and the increased concentration of carbon dioxide and other GHGs in the atmosphere [9]. The electricity generation sector in Korea is under pressure to mitigate GHGs as directed by the Kyoto Protocol [10]. Energy savings and emissions reductions can be achieved either by reducing total energy use or by increasing the production rate per unit of energy used. By contrast, improving energy efficiency is the key to reducing GHG emissions. Therefore, energy research organisations and governments are actively engaged in developing methods for assessing energy efficiency. This assessment can provide a basis for establishing energy policy and help reduce GHG emissions [11]. Fig. 1 presents the distribution of energy consumption by motor for various applications in a typical plant.

Saidur identified the following losses occurring in induction motors [2]. The efficiency of a motor is determined by intrinsic losses that can be reduced only by changing the motor's design. There are two types of intrinsic losses: fixed losses, and variable losses. Fig. 2 shows the various losses in the motor. Fixed losses are independent of motor load and consist of magnetic core losses and friction and windage losses. Magnetic core losses consist of eddy current and hysteresis losses in the stator. Variable losses are dependent on load and consist of resistance losses in the stator and rotor and miscellaneous stray losses. Resistances to current flow in the stator and rotor result in heat generation that is proportional to the resistance of the material and the square of the current. Stray losses arise from a variety of sources and are difficult to either measure directly or calculate, but are generally proportional to the square of the rotor current [2]. A motor's function is to convert electrical energy to mechanical energy for performing useful work. Even though standard motors operate efficiently in the typical range of 83–92%, energy efficient motors perform significantly better. An efficiency gain to only 92–94% results in a 25% reduction in losses. Motor energy losses can be segregated into five major areas, each of which is influenced by design and construction [29–33].

A common cause of motor failure is a problem with the motor windings, and the solution often is to rewind the old motor. Because it is economical in terms of initial cost, rewinding motors is common, particularly for motors with a higher horsepower. However, the motor rewinding process often results in a loss of motor efficiency. It is generally cost effective to replace motors under 20 horsepower with new high efficiency motors (HEMs) rather than rewind them. When deciding whether to buy a new motor or rewind the old one, it is wise to consider the cost difference between the rewound and a new HEM as well as the relevant energy costs to operate them. A paperboard plant with 485 motors, where an average of three motors were repaired per month, of which about 70% required rewind or replacement [35]. The facility operated 8000 h/year. Collected motor information is shown in Table 2.

A robust and efficient induction motor usually converts 90–95% of input electrical power into mechanical work. However, because of the huge amount of energy such motors use, a minor change in efficiency will have a major impact on operating cost. A HEM uses specific materials to reduce core and copper losses. Therefore, it generates less heat and requires smaller and more energy efficient cooling fans [36]. Future energy challenges and the environmental crises such as fossil fuel emissions and global warming are urging the world to focus on energy saving programs more than ever. An effective way to face these challenges is to improve the efficiency of

Table 1
Electric motor energy use by country.

Country	Motor energy usage (%)	Reference
US	75	[13, 14]
UK	50	[15]
EU	65–72	[16, 17]
Jordan	31	[18]
Malaysia	48	[19]
Turkey	65	[20]
Slovenia	52	[21]
Canada	80	[22]
India	70	[23]
China	60	[24]
Korea	40	[25]
Brazil	49	[26]
Australia	30	[27]
South Africa	60	[28]

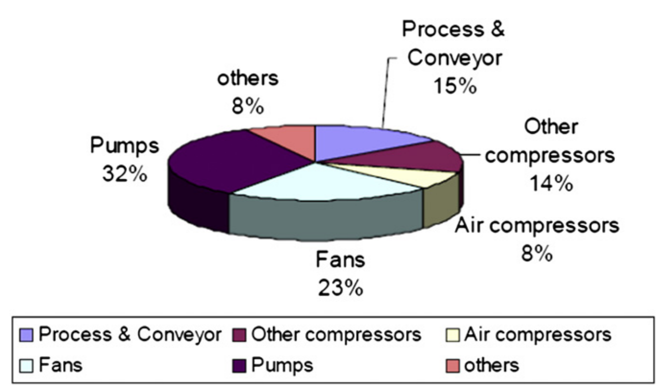

Fig. 1. Energy consumption by motor for various applications in a typical plant [12].