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Comprehensive Energy Saving Strategies in Industrial: Technical Potentials For Developing Countries

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ABSTRACT:Energy is one of the essential factors for continuous economic development and growth. The industrial sector is the largest user of energy in many developed and developing countries (e.g. Uzbekistan). An industrial sector applies more energy than any other end use sectors and nowadays this sector is consuming about 37% of the world's total delivered energy. Energy is disbursed in the industrial sector by a various group of industries including agriculture, manufacturing, construction and mining, and for a vast range of activities, such as assembly and processing, lighting, and space conditioning. Energy saving technologies, such as application of high efficiency motors (HEMs) has been reviewed. Depending on energy saving technologies results, it has been revealed that in the industrial sectors, a sizeable amount of electrical energy, different emissions and utility bill can be saved by using these technology. Additionally, studies showed a great potential for energy efficiency enhancement in motor systems in developed as well as in developing countries around the world. Particularly, system optimization accesses that regard the whole motor system's efficiency demonstrate high potential. A number of the energy efficiency investments illustrate payback times of only a few years only.

KEYWORDS: Energy, high efficient motors, electric motors, energy savings, cost-benefit, technology.

I. INTRODUCTION

A number of the developing countries moved 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. Of the different forms of energy, electrical energy is considered the highest grade of usable energy for its flexibility and quality in distribution, transmission and convertibility with minimal losses and applicability on few end use equipments. Generally, electric energy demand and supply gap are very wide despite the availability of vast and large quantities of energy resources in Uzbekistan.

Energy is a basic need for different purposes in industrial facilities of all countries around the world. Vast amount of energy needed for countries with faster economic growth. Energy is thus crucial and important factor for economic employment and competitiveness. However, global population and energy needs are increased drastically. This concern has to be addressed by the international community to overcome any shortage of energy resources in the near future.

World marketed energy consumption is planned to increase by 33% from 2010 to 2030. Total world energy usage increased from 82.919 ZW in 1980 to 116.614 ZW in 2000 year and then is expected to reach 198,654 ZW in 2030 as shown in Figure 1 (US EIA 2009).

Currently, urbanization and population has significantly widened the supply to demand gap. Other related energy challenges comprises balancing the energy supply discrepancy with the environment with respect to global warming and pollution; and the discrepancy with economics in the light of employment for greater purchasing energy taxes and power for revenue against social welfare. Concretely, the manufacturing industry, especially the automotive industry and automobile subsector in particular is negatively affected by energy demand supply gaps and is hardly investing in self-generation because of the inadequate supply of grid electric energy. Obviously, within the auto-industry, energy unavailability directly affects vehicle production, services and the movement of goods. Hence, it shortened working hours, creates unemployment and reduces business profitability.

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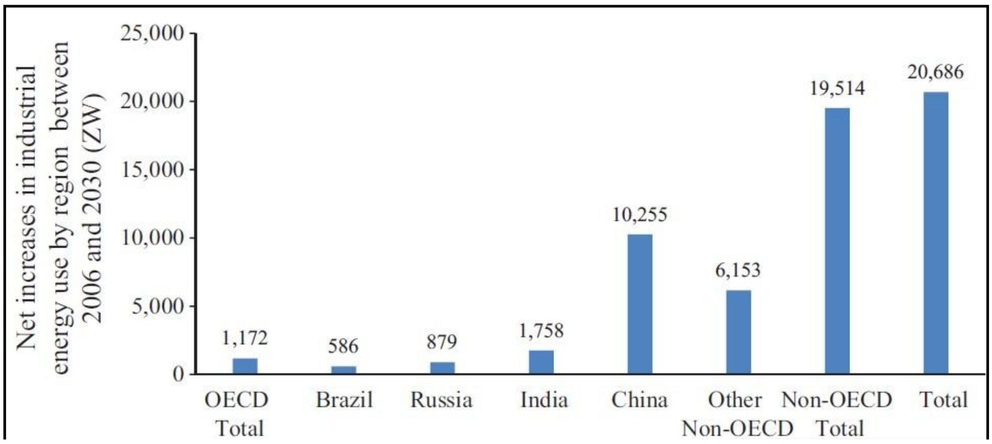

Figure 1: World marketed energy consumption from 1980 to 2030 (ZW) (US EIA 2009)

According to International Energy Agency, electric motor systems account for about 60 percent of industrial electricity consumption and about 15 percent of final energy use in industry worldwide. As well as, following the report International Energy Agency, it is estimated that a full implementation of efficiency enhancement options could reduce worldwide electricity demand by about 7 percent. Electrical motors drive both core industrial processes, such as rolls or presses, and auxiliary systems, like compressed air generation, water pumping or ventilation. They are utilized throughout all industrial branches, though the main applications vary. With only a few exceptions, electric motors are the basic source for the provision of mechanical energy in industry. Size classes alter between motors with less than 1 kW and large industrial motors with several MW rated power. In recent years, a number of studies identified large energy efficiency potentials in electric motors and motor systems with many saving options showing immensely brief payback times and high cost-effectiveness.

II. HIGH EFFICIENCY MOTORS

The bulk of electricity consumption and application in the industrial sectors is by electric motors. Processes and activities in the industry heavily depend on electric motors including for grinding, compacting, cutting, mixing, pumps, fans, materials conveying, refrigeration and air compressors.

There are four basic types of losses in a squirrel-cage induction motor:

- Stator and Rotor losses (I^2R losses in rotor windings and stator).
- Core (Magnetic) losses - this is the sum of the hysteresis and eddy current losses of the laminated rotor and stator core.
- Friction and windage - this is the loss because of the fans and the bearing friction.
- Stray losses - this is the lump sum of all losses in the motor which can’t be ascribed to one of the other four components. It is predominantly because of electrical harmonics and stray currents in the motor.

It has to be emphasized that a standard motor is already an efficient device with efficiency above 80% over most of the working range, rising over to above 90% at complete full load. Nevertheless, motor manufacturers have been able to magnify the efficiency further with the following additional improvements: improved steel properties, increase conductor volume, thinner laminations, modified slot design, improved rotor insulation, narrowing air gap, more efficient fan design.

In 2005, the European Commission and CEMEP (the European Committee of manufacturers of Electrical Machines and Power Electronics) have devised motor efficiency classification labels – EFF1, EFF2 and EFF3 – to make it much simpler for customer to recognize energy-efficient motors in the market with EFF1 level as threshold. The motor manufacturers will label their standard motors with efficiency logos (Saidur 2010; Tripathy 1994;Saidur and Mahlia 2010).

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Vol. 3, Issue 5 , May 2016

High efficient motors proffer many benefits; some of these benefits include (Tripathy 1994):

- Less maintenance and longer life time because of lower temperature in windings and bearings.
- Higher reliability because of lower losses, including: better tolerance to thermal stresses resulting from stalls or frequent starting, enhanced ability to handle overload conditions, better resistance to abnormal operating conditions, such as over and under voltage or phase unbalance, greater tolerance to poorer voltage and current wave shapes.

Greater power factor to better the load handling of internal electrical system or prevent low factor utility penalty.
For instance, according to case study in Europe, switching to energy-efficient motor-driven systems can save up to 202 billion kWh in electricity consumption; it is equivalent to a decrease of s10 billion per year in operating costs for industry. It was reported that a reduction of 79 million tons of carbon dioxide (CO_2) emissions, or approximately a quarter of the EU's Kyoto target, is achievable using energy-efficient motors. This is the yearly amount of carbon dioxide (CO_2) that a forest the size of Finland transforms into oxygen. If industries are allowed to deal these emission reductions depending on energy saved, this would generate a revenue stream of $ billion per year (Saidur et al, 2009).

II.1 Energy Saving by High Efficient Motors (HEM)

II.1.1 Mathematical formulations to estimate energy savings by HEM

Annual energy savings (AES) by replacing a standard efficient motor with a high energy-efficient motor can be evaluated using the following equations:

$$AEC_{BAU} = \frac{M_{Hp} \times 0.7456 \times N_{motors} \times OPH}{\eta_{stdmotor}} \quad (1)$$

$$AEC_{BAU} = \frac{PM_{Hp} \times 0.7456 \times N_{motors} \times OPH}{\eta_{efmotor}} \quad (2)$$

$$AES_{HEM} = AEC_{BAU} - AEC_{NP} \quad (3)$$

II.2 Cost -Benefit Using High Efficient Motors

II.2.1 Mathematical formulations to evaluate cost–benefit analysis

When applying high energy motors, yearly bill saving is related to the unit price of energy and yearly energy saving. The formula that connected with the above cost savings method can be calculated as:

$$ABS_{HEM} = AES_{HEM} \times UEP \quad (4)$$

Payback period is the function of the incremental cost of HEM divided by the yearly bill saving of HEM in a particular year.
Payback period can be expressed mathematically from the following equation:

$$PBP_{HEM} = \frac{IC_{HEM}}{ABS_{HEM}} \quad (5)$$

II.2.2 Cost benefit results using high efficient motors

According to Saidur et al (2009), when installing high efficient motors in the industrial motors and based on Eqs. (4) and (5), the results of total yearly bill saving and payback period are shown in Table 1.

ISSN: 2350-0328
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Vol. 3, Issue 5 , May 2016

Table 1: Bill savings and payback period for high efficient motors (Saidur et al, 2009)

HP	Load (50%)		Load (75%)		Load (100%)	
	Bill savings (RM/year)	Payback/year	Bill savings (RM/year)	Payback/year	Bill savings (RM/year)	Payback/year
0.25	43,469	7.89	65,203	5.26	86,937	3.95
0.5	21,734	5.1	32,601	3.4	43,469	2.55
0.75	37,259	3.48	55,888	2.32	74,518	1.74
1	149,035	2.9	223,553	1.94	298,070	1.45
1.5	18,629	1.94	27,944	1.29	37,259	0.97
2	124,196	1.71	186,294	1.14	248,392	0.86
3	335,329	1.06	502,994	0.7	670,658	0.53
4	2,036,814	1.67	3,055,222	1.12	4,073,629	0.84
5.5	68,308	2.08	102,462	1.39	136,616	1.04
7.5	186,294	1.98	279,441	1.32	372,588	0.99
15	93,147	1.77	139,721	1.18	186,294	0.88
20	2,483,920	1.45	3,725,880	0.97	4,967,840	0.73
25	931,470	1.62	1,397,205	1.08	1,862,940	0.81
30	372,588	1.47	558,882	0.98	745,176	0.74
40	993,568	1.32	1,490,352	0.88	1,987,136	0.66
50	620,980	1.11	931,470	0.74	1,241,960	0.56
60	1,862,940	1.17	2,794,410	0.78	3,725,880	0.59
75	465,735	1.18	698,603	0.78	931,470	0.59

III. MOTOR SYSTEM TECHNOLOGY AND OPTIONS FOR ENERGY EFFICIENCY

Electric motors are applied in many industrial systems where mechanical energy is required and needed. They convert electrical energy into rotary mechanical energy, which then is further converted to eventually provide the needed use-energy. Depending and based on the industrial structure, electric motor systems comprises for about 60 % to 70% of industrial electricity consumption. Pumping, fan and compressed air systems are some of the most electricity-consuming motor systems. Moreover, processing and material handling consume a great deal of electricity, although these systems are more heterogeneous and rather different from each other.

III.1 Component Efficiency Improvement

Due to the considerable heterogeneity of motor systems, production systems and firms in industry, the options to improve energy efficiency are diverse and manifold. Nevertheless, certain cross-cutting improvement possibilities are observable among the many of motor systems. These options also have the highest savings potential at industry level, although system-specific options might provide for greater energy savings at the individual firm-level (Almeida et al, 2008). Some of the options that have the highest potentials for efficiency improvement relate to the motor itself, the motor control and the core motor system like the use of high efficiency fans or pumps or the correct sizing of these appliances. The following options relate to the core motor system and the electric motor itself.

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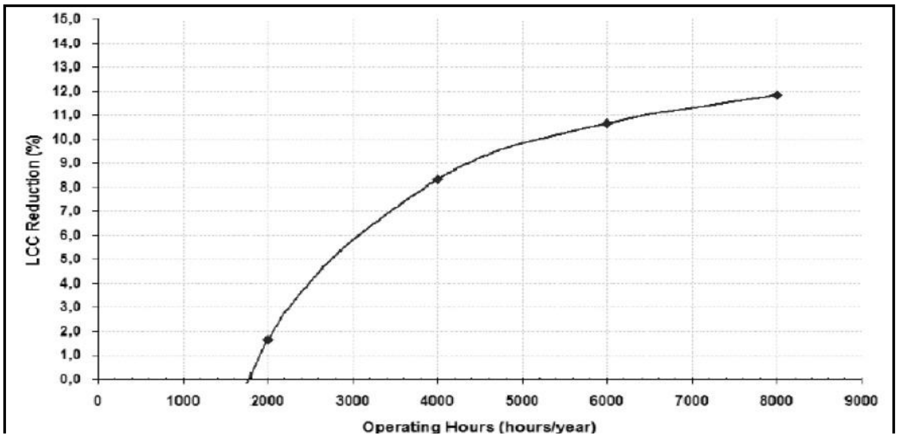

Figure 2: Lifecycle cost reduction by using an 1.1 kW energy efficient brushless permanent magnet motor instead of a standard motor (efficiency class IE1/Eff2) (Almeida et al, 2008)

Depending on efficiency and the age of the motor in place, the replacement of a less efficient motor with a high efficiency motor can have significant saving potentials with payback times of a few years only. For applications which have high annual running hours, in particular – mostly in firms with multi-shift operations – replacement can be immensely profitable. Case studies disclose that motors which are older than 20 years are still being applied in many companies – in developing as well as in developed countries. Even shorter payback times are achieved if following the breakdown of a motor, high efficiency motors are selected rather than standard ones. The price premium of a high efficiency motor of about 20 percent frequently pays off after several months. A direct comparison of the lifecycle costs of an energy efficient permanent magnet motor with a standard asynchronous motor is presented in Fig. 2 and it shows that investment in the energy efficient motor is cost-effective above 2000 h annual running time (Almeida et al, 2008). For motors with immensely great yearly running hours, the lifecycle costs can be decreased by more than 10 percent.

In case of a motor breakdown, companies frequently decide to rewind the broken motor and to thus avoid higher investments in a new one. The basic steps in motor rewinding are the dismantling of the motor and checking for damages, removal of the old or outdated windings as well as insulation and cleaning of the stator core and, eventually, rewinding with new wire and efficiency testing. According to Meyers et al (1993) rewinding is even more common in developing countries because of the relatively low labor costs and the high price of a new motor. Some motors are rewound 5 to 6 times before they are lastly scrapped.

From an efficiency point of view, rewinding can be a poor decision for two reasons. The older less efficient motor will continue to be used for a decade or two and, furthermore, rewinding frequently comes with a loss of motor efficiency of 1 to 3 percent, which is considerable for electric motors. Others debate that rewinding can actually increase motor efficiency, if, for example, the copper content of the windings is increased during rewinding by using a copper wire with a greater diameter (EASA AEMT 2003). Yet, if motor efficiency is low and can be enhanced via rewinding (through increased copper content), the motor might just be very inefficient and buying a new one might substantially improve efficiency. Moreover, good rewinding needs reliable repair work-shops that apply low temperature bake out ovens, high quality materials and a quality assurance program to ensure that motor efficiency is tested and analyzed after rewinding and that the motor was not damaged during the process (EnerWise 2005).

Consequently, (high quality) rewinding may be applied for motors in applications with low annual running hours (less than 2,000 hours per year), where motor efficiency is not as crucial. Quality assurance and capacity development for proper motor rewinding is an effective and an accurate measure to improve the efficiency of the motor stock, particularly in developing countries.

Significant efficiency differences exist for the electric motor as well as for the fan, the pump or the compressor. Radgen et al (2007) reported that the efficiency of today's fans varies by up to 25 percent within one fan class. They revealed an improvement potential of 8 percent (centrifugal backward curved fans) to 33 percent (axial fans) in comparison to the typical product of each product type. This illustrates that by focusing on energy efficiency when designing a product, large efficiency gains can be realized.

Similar observations are made for pumps (AEA 2008). Consequently, when choosing a fan or pump, its energy efficiency should be a significant decision factor which it frequently is not.

ISSN: 2350-0328
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III.2 Reduction in Direct Energy Consumption

The energy efficient electric motor systems' direct energy consumption is the energy which is consumed during the production cycle. It is the energy needed and required to do work. Improvements in this area require improvements and modifications to the drive systems and machinery selected. In industrial machines the selection of energy saving equipment or facility is basically done during the design phase but in many cases can be retrofitted later onto aging machinery (technologies).
One of the most direct ways to reduce energy consumption is to only run motors while the operation is in cycle. Industrial machines using mechanical or hydraulics systems driven by induction motors require stored energy to help them in executing the work. Since these systems cannot switch on and off rapidly and are not easily controlled, they are forced to remain on frequently at constant speed. The large power output of a synchronous motor allows for the motor to be inactive when not in process considerably reducing the power consumption (MMS 2007). Replacing inefficient induction motors or hydraulic systems with contemporary permanent magnet synchronous motors is often the first step.
Implementation of power source regeneration is another superior and an affordable means of reducing the power consumption of an electrical motor system. Upon deceleration of an electrical motor it will act as generator and energy is get back into the system. Energy is sent to a discharge resistorin a conventional system. A discharge resistor dumps that electrical energy in the form of thermal heat. That waste heat is non-recoverable or non-usable. By contrast power source regeneration reverts electricity to the supply line to be applied by other equipment. The electrical energy is recovered and waste heat is highly reduced.

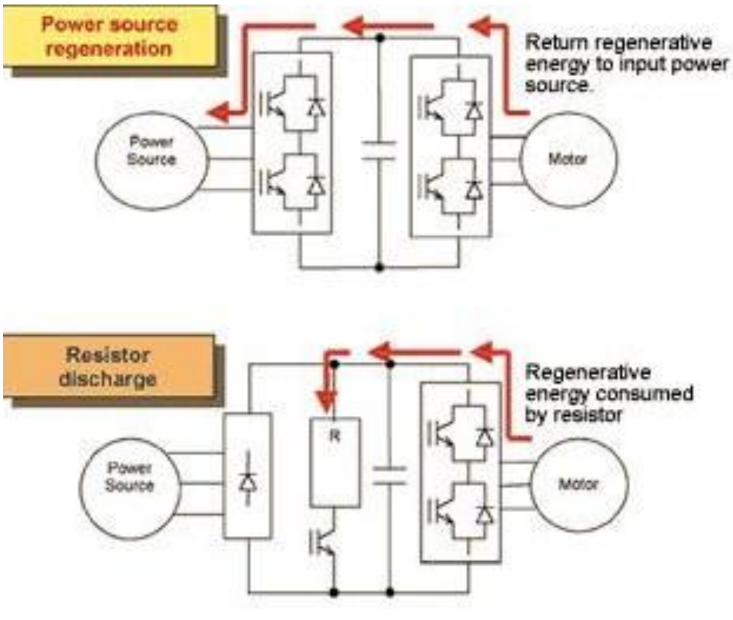

Figure 3: Reduction of electrical energy by power source regeneration (MMS 2007)

Power source regeneration requires a drive system with an intelligent power module that can be able to sense the flow of current and switch accordingly. Implementation of a servo driven system utilizing drive accelerators with power source regeneration can cause to savings of 30% to 40% in electrical power consumption (MMS 2007).

Pulse width modulated (PWM) accelerators or amplifiers provide an excellent control method for electric motors in automation equipment. Quick acceleration with accurate speed and current control is possible but there are always switching losses when applying a PWM drive system. These losses transfers into waste heat generation. Using the latest generation of power devices will enhance controllability and reduce the heat loss. Reduction in heat loss directly equates to electrical energy savings.
Having drive software and amplifiers features matched to the motors and mechanical system selected also contribute to the direct reduction in electrical energy consumption. When utilizing an induction motor an advanced control system

can effectively optimize the firing angles as the optimum torque is produced for a given current. Matching the current contributing of torque and magnetizing will reduce heat losses within the motor but requires dynamic control. Application of rapid switching transistors and an increased pulse width modulated rate will reduce iron losses in both induction motors and permanent magnet. Comprehensive reduction in heat and other losses within the motors by using the latest control systems and power devices positively contribute to increased performance and reduced electrical energy consumption.

III.3 Future Technology

Although electric motors are a mature technology, certain improvements of energy efficiency are still expected. Currently, a new generation of motors with copper die cast rotors is being produced which will increase efficiency by some percentage points in comparison to standard technology (Doppelbauer et al, 2005). The permanent magnet motor shows potential for even higher efficiencies, particularly for smaller motors up to several kW.
In the very long-term, superconductivity may reduce losses in electric motors even more and thus reach efficiency levels of around 99 percent. Nevertheless, this technology will only be cost-effective for very large motors or generators in applications with high annual running hours.

IV. CONCLUSION

The environment and production do not need to be at odds. Advancements in electric motor design and the associated drive system in contemporary automation equipment can be extremely energy efficient. Much of the time the most energy efficient machine will also have the efficient and the highest performance but there is normally an upfront cost connected with the efficiency and performance. That added cost related with selecting energy efficient equipment can be easily returned as lowered energy costs, reliability and high performance. Too frequently inefficient machines are chosen based on purchase cost without proper concern for the lifecycle cost. As energy prices continue to magnify the total lifecycle cost of ineffective machinery will come to the surface. Environmental laws continue to reinforce; disposal costs will grow and recycling of the final resources gain importance. It is time to look attentively at equipment efficiency and environmental impact as part of the decision making process.
It has been revealed that energy saving technologies for instance application of high efficient electric motors to match load requirement have been found to be cost-effective energy saving measure to decrease energy consumption of main energy using equipment in the industrial facilities or sectors. These savings strategies revealed to be economically viable in most cases. Along with energy savings, sizeable amount of emission can be reduced by application of various energy savings strategies.
Developing countries with high growth rates and a fast growing industry can, in particular, benefit from policies for energy efficient motor systems. Using high efficiency components and system optimization tools for the construction of new production plants is the least costly and most efficient option to improve energy efficiency. Many of the components have lifetimes of up to 20 years and not choosing energy efficient components would manifest an inefficient production for a long period of time and make future optimizations more costly. This is an advantage of developing countries have in comparison to developed countries, where a – sometimes several decades old and less efficient – technological production structure is established and energy efficiency improvements are frequently more expensive, because they require substantial system changes or can't be realized because they would require an interruption of the production process.

NOMENCLATURE

ABS_{HEM} - Annual bill saving when using high efficient motors (kWh/year)
AEC_{BAU} - Annual energy consumption without variable speed drive (kWh/year)
AES_{HEM} - Annual energy saving when using high efficient motors (kWh/year)
AEC_{NP} - Annual energy consumption with variable speed drive (kWh/year)
IC_{HEM} - Incremental cost of high efficient motors (RM)
M_{Hp} - Motor horsepower (Hp)
N_{motors} - Number of motors

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Vol. 3, Issue 5 , May 2016

OPH - Operating hours in year (h/year)
PBP_{HEM} - Payback period of high efficient motors (years)
P - Pressure (kPa)
UEP - Unit energy price (RM/kWh)
$\eta_{std\ motor}$ - Efficiency of standard motor
$\eta_{ef\ motor}$ - Efficiency of efficient motor
0.7456 - Conversion factor from horsepower to kilowatt

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