Energy 109 (2016) 592–601

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Confidence bounds for energy conservation in electric motors: An economical solution using statistical techniques

Abdul Jabbar Memon [a], Muhammad Mujtaba Shaikh [b, *]

[a] Department of Electrical Engineering, Mehran University of Engineering and Technology, Jamshoro, Pakistan
[b] Department of Basic Sciences and Related Studies, Mehran University of Engineering and Technology, Jamshoro, Pakistan

A R T I C L E I N F O

Article history:
Received 29 July 2015
Received in revised form
6 March 2016
Accepted 4 May 2016

Keywords:
Energy efficient motor
Confidence bound
Student's t-distribution
Economical solution

A B S T R A C T

Power crisis is a sensitive issue which can handicap activities of any country at large. In Pakistan, industries consume the majority of energy, of which 28% is the electrical energy. About 30–80% of the electrical energy consumed by industries is due to electric motors. This study aims to promote electrical energy conservation in industries of Pakistan by presenting benefits of replacing existing standard efficiency motors through EEMs (energy efficient motors). A sample of existing SMs (standard motors) obtained by surveying some industries of Pakistan is used for statistical analysis. The benefits of EEMs are emphasized in terms of annual energy savings, cost savings and paybacks. By using t-distribution, 90% confidence bounds for these parameters are constructed. It is found that future replacements of SMs by EEMs, will achieve an average energy saving of atleast 1009.747 kWh/year and atmost 3404.047 kWh/year, and an average cost saving of atleast Rs. 10859.719/year and atmost Rs. 33550.065/year. The average payback period would be between 0.177796 and 0.265912 years. The sensitivity analysis of the results is provided. The presented confidence bounds can be used to encourage the government and financers for the large scale replacement of SMs by EEMs to conserve electrical energy sufficiently in Pakistan industries.

1. Introduction

A core issue of current times for countries facing energy crisis is sufficient generation of electrical energy and its optimal utilization to fulfill the exhaustive needs of the population and industries. In this regard, it is also necessary to study and propose ways to maximize the energy saving along with minimizing the over-all cost on the electric devices being used: be it capital, operational, etc. Such appealing situation in many developing countries demands the proposition of optimal protocol environments, the use of energy efficient devices and the utilization of renewable energy sources for energy conservation.

Electric devices and motors are generally used in majority of the applications installed at homes, commercial sites and industries [1]. According to the study [2], industrial sector of Pakistan consumes 43% of the total energy in form of electricity, gas, etc. However, the electricity consumption by industries in Pakistan is about 28% of the total, out of which 30%–80% consumption is due to electric motors. As also reported in [3], the estimates of electrical consumption in industry show that over 80% of electrical energy consumed goes to the terminals of electric motors. On the other hand, beside exhaustive applications of electric motors in various sectors there are a number of reasons of failure of motors. The one of the major reason of failure of electric motors is due to low quality of material and poor construction. If the failure is of catastrophic nature, hazards to safety and environment can often result. To avoid these dangers condition monitoring is the best way. A thorough analysis of motor faults, symptoms and detection methods is explained in Refs. [4–6].

In such situations, improvement of industrial motor efficiency can save a significant amount of valuable electrical energy. In general, a small improvement in the efficiency of the induction motors will lead to significant energy savings and environmental benefits. Accordingly as mentioned by Cao et al. [7], in the European Union, a 3% increase in the energy efficiency of the electric machines would produce electricity savings of over $2 billion per year. Hence, little enhancement in utilization of electrical energy in industries of Pakistan and use of high efficiency electric motors can result in sufficient conservation of electrical energy.

* Corresponding author. House No. 109-A, Kalhora Colony near Eye Hospital, Hyderabad, Sindh, 71000, Pakistan. Tel: +92 333 2617602
E-mail address: mujtaba.shaikh@facuty.muet.edu.pk (M.M. Shaikh).

http://dx.doi.org/10.1016/j.energy.2016.05.014
0360-5442/

Nomenclature

EE	Energy efficient
EEM	Energy efficient motor
SM	Standard motor
L	Load factor
h	Annual operating hours
ξ_{SM}	Full load efficiency of standard motor
ξ_{EEM}	Full load efficiency of energy efficient motor
LPP	List price premium
DF	Discount factor
MDC	Monthly demand charge
EC	Energy charge
E_{saving}	Annual energy saving (in kWh/year) by a replaced EEM
C_{saving}	Annual cost saving (in Rs/year) by a replaced EEM
P_{simple}	Simple payback period (in years) for a replaced EEM
$\overline{X}_E$	Mean energy saving (in kWh/year) by replaced EEMs
$\overline{X}_C$	Mean cost saving (in Rs/year) by replaced EEMs
$\overline{X}_P$	Average payback period (in years) for replaced EEMs
μ_E	Mean energy saving (in kWh/year) by replaced EEMs in future
μ_C	Mean cost saving (in Rs/year) by replaced EEMs in future
μ_P	Average Payback period (in years) for replaced EEMs in future
s_E	Sample standard deviation in energy saving of replaced EEMs
s_C	Sample standard deviation in cost saving of replaced EEMs
s_P	Sample standard deviation in Payback period of replaced EEMs
n	Size of sample
v	Degrees of freedom ($v = n - 1$)
$t_{\alpha/2}$	Value of t-statistic leaving an area of $\alpha/2$ to the right
$\hat{s}$	Standard error of estimates

In past years, a number of studies in literature highlighted the benefits of using high efficiency motors to conserve electrical energy in industrial sector of different countries. A test procedure for applicable energy efficient motors for Malaysian industries was given in Ref. [8]. R. Saidur et al. [9] presented case study of energy conservation in electric motors in Malaysian industries. Annual energy savings, cost savings and paybacks for class high efficient motors (operating at 50%, 75% and 100% loads), variable speed drives and capacitor banks were computed to examine the resulting benefits and to improve the power factor. In Ref. [10] also, the benefits of replacing standard motors by energy efficient motors in Malaysian industries were presented. A range of 20–120 kW existing electric motors in Malaysian industries was used to show that sufficient amount of energy can be saved annually with acceptable dollar cost saving and very viable paybacks, which were less than a year. Reduction of CO_2 emission due to such replacement was also discussed. They also forecasted that in future years due to technological advances the total annual energy and cost savings will decrease and become negligible due to such replacement. In Ref. [11], general faults in electric motors were presented and the need of investment strategies to replace standard efficiency motors by high efficiency motors was discussed. Following the test procedures, the economic benefits were discussed in terms of energy savings, cost savings and payback periods for high efficiency motors operating at 50%, 75% and 100% loads. The paybacks were between 1 and 3 years.

In Ref. [12], authors discussed economic benefits of using energy efficient performance database on commercial buildings by calculating energy saving, cost saving and paybacks. The computed numbers lead to accelerate energy retrofit in such buildings. Agenor et al. [13] compared performance of motors in Brazilian industries using different standards for standard and energy efficient motors. E. C. Bortoni et al. [14] developed a model to compare the amount of savings in standard and energy efficient motors with usage of PROCEL labels for the motors in Brazil. Recently, in Ref. [15], authors compared motor performance in Brazilian industries using efficiency deviations with minimum efficiency standards. Akbaba [16] applied the strategy of replacing standard efficiency motors by high efficiency motors on motor data ranging from 5 to 300 HP from Bahrain. The energy savings, cost savings and paybacks (approximately 3 years) were discussed. The benefits of using two class of polyphase motor efficiency standards to improve energy conservation along with the statistics regarding energy saving and reduction in CO_2 emission were given in Ref. [17]. Ozkara et al. [18] investigated efficiency and total-factor energy efficiency scores of manufacturing industry of Turkey and showed the total average electricity saving potential of 26 regions, from 2003 to 2012, to be 39.7%. Peng et al. [19] presented case study of Chinese industry and identified factors influencing the energy efficiency. The solution approaches for increasing energy efficiency of machine tools on system level were discussed by Neugeebauer et al. [20].

On the other hand, some recent studies have also discussed alternate procedures and algorithms to assure energy conservation in induction motors and related systems. For example, in Ref. [21], the use of small sized induction motors was recommended instead of open full sized ones, in order to upraise energy conversion process, during balanced and unbalanced voltage operation. Kumar et al. [22] discussed model based control schemes for vector-controlled induction motors to control motor excitation w.r.t. torque and speed. Zhu et al. [23] discussed three operational plants of solar power technologies in China to highlight future reduction in cost. In Ref. [24], Yu et al. proposed a dynamic system for active energy demand management used for evaluating policy scheme effect on household energy consumption. Safamehr et al. [25] suggested an improved intelligent demand-response programming paradigm, for efficient and reliable, energy and cost management of micro-grids under some constraints related to suppliers and consumers. The use of existing model equations and new algorithms, to optimize energy consumption of double star induction motors [26], and to control speeds of induction motor supplied by wind turbines [27], were also proposed.

Beside such procedures and optimal design systems, the large amount of electrical energy can be conserved using short term investment policies by replacing standard efficiency motors in industries with energy efficient motors – which was also highlighted by Saidur [11]. Brundage et al. [28] recently emphasized the importance of investment strategy to deal with energy economics in manufacturing industry. As the energy conservation in industry requires making new/extra investment in more efficient equipment to replace old and inefficient facilities, the main aspect of energy policy in the energy conservation appears to be the use of energy efficient devices and motors. This most effective step can provide