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Maintenance an Opportunity for Energy Saving

Behnoush Darabnia*, Micaela Demichela

SAfeR- Centre of Studies on Safety, Reliability and Risks, DISAT- Department of Applied Science and Technology
Politecnico di Torino, 10129 Torino, Corso Duca degli Abruzzi, 24, Italy
behnoush.darabnia@polito.it

Energy saving is an important issue for the industrial sectors which is a crucial factor in energy cost, waste reduction and environmental management. Maintenance operations are fundamental in granting machineries and processes energy saving, given the capability of optimising them thanks to a predictive model. To ensure that the plant achieved the desired performance it needs a track performance on maintenance operations and maintenance results. In addition it needs the relationship between the inputs of the maintenance process and the outcomes in terms of total contribution to manufacturing performance and objectives. Deterioration of manufacturing systems' condition, and hence its capability, begins to take place as soon as the system is commissioned. In addition to normal wear and deterioration, other failures may occur especially when the equipment are pushed beyond their design limits or due to operational errors. As a result, equipment downtime, quality problems, energy losses, safety hazards or environmental pollution become the obvious outcomes. All these outcomes have the potential to impact negatively the operating cost, profitability, customers' demand satisfaction, and productivity among other important performance requirements.

The developed model in this study is an integration of a probabilistic and a deterministic model based on balanced cost and benefits. Through the adoption of this model it has been possible to support decision making for the maximization of energy efficiency by optimizing maintenance interventions and operative procedures. This is described through the application to a case study: the optimisation of maintenance operations in energy consuming equipment in the production process of bituminous materials, based on the energy consumption data from the field and a part of the results are illustrated in this work.

1. Introduction

The major challenge of maintenance optimization is to implement a maintenance strategy, which maximizes availability and efficiency of the equipment, controls the rate of equipment deterioration, ensures the safe and environmentally friendly operation, and minimizes the total cost of the operation which means the both production and energy cost. For example; industrial compressed air systems require periodic maintenance to operate at peak efficiency and minimize unscheduled downtime. Inadequate maintenance can increase energy consumption via lower compression efficiency, air leakage, or pressure variability. It also can lead to high operating temperatures, poor moisture control, excessive contamination, and unsafe working environments. Most issues are minor and can be corrected with simple adjustments, cleaning, part replacement, or elimination of adverse conditions which means preventive maintenance.

Maintenance techniques have experienced several phases, over recent years. These phases in relation of their efficiency have been evolved from break down maintenance, preventive maintenance, predictive maintenance, risk-based maintenance towards maintenance and safety integrity. The maintenance activity, its costs and its effectiveness in any type of the system depends on the correct integration of these four main, this argument was recently discussed by (Qingfeng et al., 2011).

Here was construct an energy efficiency analysis model for evaluating energy efficiency of the systems and equipment in the industrial process where as an element of novelty, the maintenance influence has been used as an optimization parameter.

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2. Maintenance, an energy efficiency opportunity

In grate energy consuming industries with high carbon dioxide emissions, are practiced various energy saving strategies such as energy saving by management, technologies and policies. The importance of energy efficiency in manufacturing industries is to reduce energy cost and consumption also environmental impacts (CO_2 emissions, wastes). Many energy efficiency measures in industry consist of improving purchasing, maintenance practices and procedures. These measures often have positive implications other than just energy savings. They can also reduce maintenance costs and increase the productivity benefits of the site, and vice versa. To achieve these results, an Energetic Efficiency Management System EEMS is needed, that will require a structure like all other industrial management systems. An EEMS scheme has been developed for this study, which also includes the decision-making procedure that allows the selection of an optimum set of maintenance and operating procedures, to achieve high performance of the system that it is shown in Figure 1.

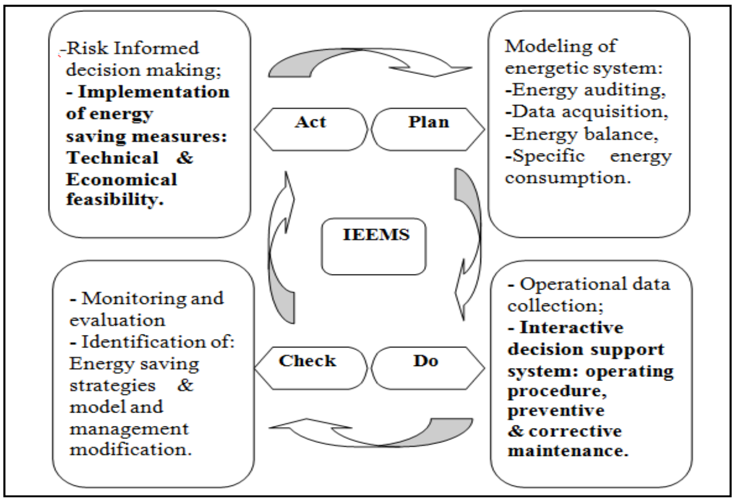

Figure 1. An Interactive Energy Efficiency Management System.

Decision making and implementation of the energy saving measures are based on the condition of the system, so technical and economical feasibility and it's important to balance these two important facts to arrive an optimum point.

3. Cost effective energy saving

The decision-making procedure allows the selection of an optimum set of maintenance procedures, but it does not indicate the selection of the most cost effective maintenance practice. So as to deal with this issue, it needs to evaluate the equipment failure probability and the costs of maintenance and failure consequences. Then decision-making procedure, based on decision tree, can be used to select the maintenance procedure that minimizes the risk associated with the equipment failure expressed by the mean failure costs, which was also discussed by (Carazas and Souza, 2010).

Over the recent decades maintenance strategies have evolved from corrective to a preventive approach and deterministic models have been integrated or replaced by those based on reliability and risk, which are probabilistic. Approaches to obtain the optimum maintenance interval bring to minimization of total cost. Cost minimization is also one of the objectives of maintenance planning. Although, the importance of the cost effective energy saving measures in industry facilities is to reduce energy consumption of major energy using equipment. On the other hand the aim of these approaches is to achieve productivity and cost benefits in industries. Even if their purpose is not directly energy related, their benefits often are applied to energy saving too.

The conservation supply curve is an analytical tool that captures both the engineering and the economic perspectives of energy conservation, which was first introduced by (Meier, 1982). The curve shows the energy conservation potential as a function of the marginal Cost of Conserved Energy (CCE), which accounts for both the costs associated with implementing and maintaining a particular technology or measure and the energy savings associated with that option over its life time. The advantage of using a conservation supply curve is that it provides a clear, easy to understand framework for summarizing complex information about energy efficiency technologies, their costs, and the potential for energy saving. In the other words, the Cost of Conserved Energy almost includes maintenance and operation system optimization which are recently illustrated by (Worrell et al., 2003) and (McKane and Hasanbeigi, 2011) and can be calculated from Eq. (1) and (2).

$$CCE = {}^{(Annualized\ Capital\ Cost\ +\ Annual\ change\ in\ M\&O\ costs)}\!/_{Annual\ energy\ saving} \qquad (1)$$

$$Annualized\ Capital\ Cost\ = Capital\ Cost * \left[{}^{d}\!/_{1-(1+d)^{-n}}\right] \qquad (2)$$

Where, M&O is the annual maintenance and operation costs in €/y, annual energy saving is in kWh/y, annualized capital cost is in €/y, d is the discount rate and n is the life time of the energy efficiency measure in y. In our study, the real discount rate d was assumed equal to 0.75% per year, to reflect the barriers to energy efficiency investment in industry, for short payback periods about 3 y. The cost analysis is dependent on the existence of a database that relates costs to some undesirable failure events associated with process plant equipment. For the present analysis, the costs are divided into three classes: (i) Fixed operational costs; (ii) Variable operational costs, and (iii) Unavailability costs, which were also discussed by (Muchiri et al., 2011). The total maintenance and operational costs can be calculated by the sum of those costs, as shown in Eq. (3) below:

$$Total\ M\&O\ cost = Fixed\ cost + Variable\ cost + Un\ availability\ cost \qquad (3)$$

The Maintenance and Operation fixed costs are related to the process plant operation independently. Those costs include plant operator's wages, general and equipment maintenance costs, insurance and taxes. The variable M&O include costs that are dependent on the amount of production or on the equipment operation time history. Both classes of costs are dependent on the maintenance policy applied on the process plant equipment.

4. Application to a case study

The decision making model and data analysing are shown through application to a case study in an industrial production process in Bitumtec Ltd. plant, which produces bituminous materials for road paving. For this study the batch production process of modified bitumen was chosen. They produce maximum 20-21 t/h modified bitumen. For this process, they possess two mixers which alternate with each other annually. Polymer, chemical additives and bitumen enter in the primary mixer and recycled for many times that depends on the quality of the product and in the end of the process for the last time the mixture passes in to the secondary mixer and exits modified bitumen that have high quality and performances. In the next steps, there are storage, quality control of the product and transport of the materials to the customers.

Energy efficiency analysis developed model was used to estimate the potential cost-effectiveness of electrical efficiency for the motor system (as an example) or the most critical component which is the great energy consumer in the chosen process. The motor is used during production and drag the mill "Siefer" which homogenized the polymer. Objective of the study of historical data and observations was to prevent malfunctions and/or decrease the negative effects due to failures with appropriate defined efficiency measures also increase the performance of the system.

The proposed framework with flowing steps are introduced:

- Identification of the most critical component.

Particularly, in this work was addressed the electrical motor (160 kWh) "Siefer".

- Life time and energy consumption data collection and observation, also related maintenance (corrective and preventive) activities and failures data collection.
- Estimated costs of maintenance and the economic evaluation of maintenance policies (based on balanced cost and risk of inefficiency).
- Maintenance optimization (in terms of probability and consequences).
- Estimated operating costs of the system.
- Analysis of energy efficiency through maintenance optimization and operating procedures, by using of bottom-up energy efficiency supply curve model, where it was introduced:

Expert inputs (based on the information from the expert of the system), and data assumption.

• Definition of scenarios and efficiency measures (in this case, were defined three levels of base case scenarios with their relative potential for recovery of electricity: low, medium and high) and were proposed solutions to increase the efficiency based on the maintenance activities, operating procedures and the conditions of the system.
• Determination of the impact of these measures on the performance.
To determin the impact of the energy efficiency measures also was asked the expert of the system to provide his opinion on energy savings likely to result from implementation of each measure expressed as a % improvement for each of the Low, Medium and High base cases. The percentage efficiency improvement by the implementation of each measure decreases as the base case moves from Low to High. Here by using our developed model, are estimated annual saved energy and annual potentilal of CO_2 reduction for any efficiency level, as is shown by Table 1.

Table 1: Cost-effectiveness and environmental benefits for each base case scenario.

Efficiency base case scenarios	Characteristics	Potential recovery efficiency %	Average annual energy consumption kWh	Average energy price €/kWh	q	Annual saved energy kWh/y	Annual potential CO_2 reduction $kgCO_2/y$
Low	Maintenance is limited to what is required to support operation	15	300000	0.15	0.922	45000	22500
Med.	Maintenance is a routine part of operations and includes some preventive actions	10	300000	0.15	0.922	30000	15000
High	Both routine and predictive maintenance are commonly practiced	5	300000	0.15	0.922	15000	7500

That should be noted, Studying the historical data has been noted that the old motor was broken after 8000 h working, on July 2010, fortunatley they had also a new motor in the stock, so they have had only 10 h of stop working and loss of production (time to remove old motor and instal the new one). Therfore, in 2010, in addition to preventive (ordinary) maintenance for the motor system, they have also had corrective maintenance. Here was also estimated CCE for each three base case scenarios for the years 2010, 2011 and 2012 as is shown In the Figure 2. It should be emphasized, our industrial case study was in the medium level.

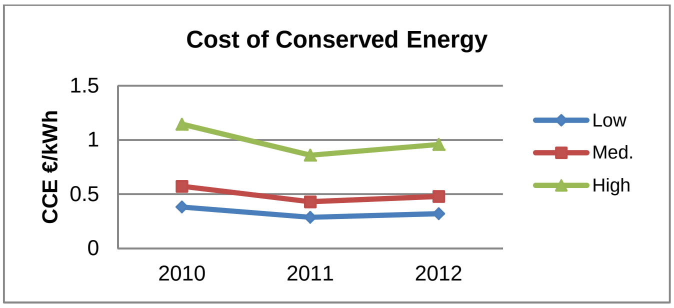

Figure 2. Cost of conserved energy €/kWh.

Decision making was made in the base of efficiency level, therefore were established and proposed solutions to increase the efficiency based on the maintenance activities, operating procedures and the conditions of the system, here also were estimated through our developed model, cunmmulative annual energy saving and cumulative annual potential of CO_2 reduction for a medium level base case scenario which are showed by Table 2.

Table 2: Energy efficiency measures for the motor system (case study).

Energy efficiency measures for motor system	Base case efficiency scenarios: Low (Up to15%)	Med. (Up to 10%)	High (Up to 15%)	Cumulative annual energy saving kWh/y	Cumulative annual potential CO_2 reduction $kgCO_2/y$
	Possibility of energy recovery %			For Med. level	For Med. level
Upgrade system maintenance					
1. Fix leaks, damaged seals and packing	3.0	2.0	1.0	4.696	2.348
2. Remove sediments from mixer	7.0	5.0	3.0	15.668	7.834
3. Replace Motor with more energy efficient type	14.0	7.0	5.0	29.413	14.706
4. Use of new technologies and more efficient devices, like: New belts(higher power transition and maintenance free)	1.0	1.0	1.0	31.240	15.620
5. Initiate predictive maintenance program (maintenance optimization)	7.0	5.0	2.0	39.917	19.959
6. Use of inverter (o Variable speed drive)	*not economical convenient for the case study.			43.189	21.595

*Management consumption of the motor, to minimize peaks during start of the work is economic alternative for measure 6, by starting motor only one time a day, and turned off motor only at the end of the daily work.

Figure 3 shows the conservation supply curve for the electric motor system (presented case study), that presents the energy saving potential as a function of the marginal Cost of Conserved Energy CCE, which accounts for the costs associated with implementing of each measure (Table 2) that includes maintenance and operation costs M&O. Must be mentioned, the energy efficiency measures that are below the energy cost line (in this study the energy price is 0.15 €/kWh, so annual electrical energy cost is about 45000€), are both technical and economic feasible so are cost-effective and the efficiency measures that are above the energy cost line are not cost effective, so in this study measure 6 is technically feasible, but is not economic.

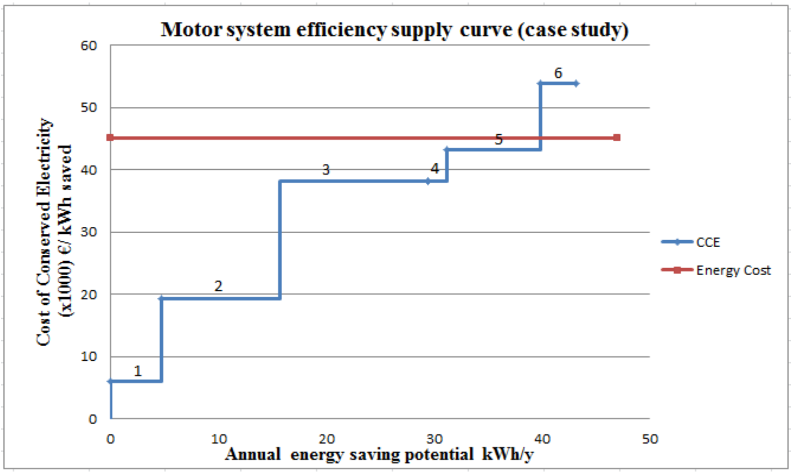

Figure 3.The conservation supply curve for electric motor system (case study).

Results have also demonstrated that even only through maintenance optimization like; upgrade system maintenance, use of new technologies and initiate a predictive maintenance program, it is possible to increase the performance of the system up to 10%, for a medium base case scenario, as is shown in Figure 4.

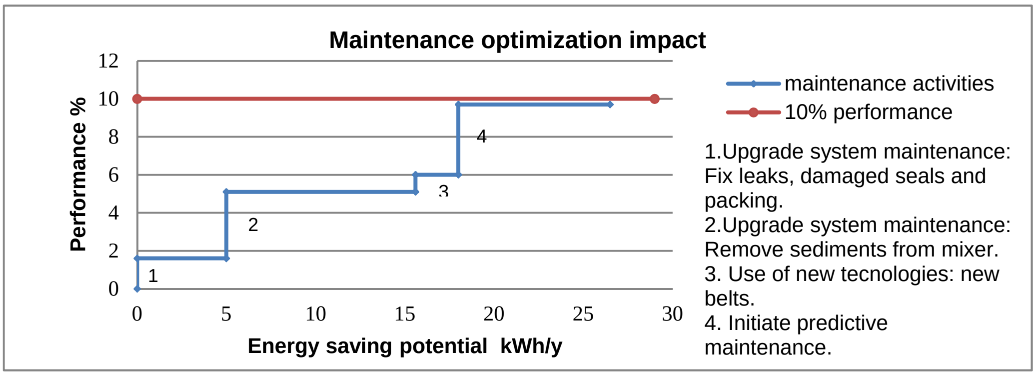

Figure 4. Maintenance optimization impacts (case study).

5. Conclusion

Analysis has demonstrated the importance of optimizing maintenance activities and operating procedures to increase the performance of the system. Using the developed efficiency analysis model, it's possible to quantify the impact of maintenance and operating procedures, in terms of energy savings or cost-effectiveness, and can be calculate the cost of conserved energy CCE, also it is possible to estimate the potential reduction of greenhouse gas emissions (CO_2). In this work, energy saving was evaluated for three different base case scenarios; low, medium and high, with their relative potential energy recovery, also were estimated their relative performance and environmental benefits. Further, based on analysis of historical data, expert inputs and analysis of the economic impacts (balanced cost), were determined the efficiency measures and solutions to achieve high efficiency of the motor system (case study). The implementation of energy saving measures, for our case study was based on both technical and economic feasibilities. Must be added, thanks to the cooperation by the company, the analysis and the results were validated by the experts of the system, which a part of the results are illustrated in this work.

Acronyms

CCE Cost of Conserved energy, €/kWh
d Discount rate
EEMS Energy Efficiency Management System
M&O Annual change in Maintenance and Operation costs, €
n lifetime of the conservation measure, y
q Capital recovery factor

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