Multi Criteria Evaluation Based Motor Energy Saving Strategy for Small and Medium Scale Industry

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Abstract—**This paper presents investigation on multi criteria evaluation of induction motor energy saving strategy particularly applied in the small and medium scale industry. A walk-through motor energy audit is carried out in a typical type of enterprise to collect some important data. During the research, three induction motor energy saving strategies, by which energy efficient motor, variable speed drive, and capacitor bank are considered with respect to five criteria thought to influence the decision making in selecting suitable energy saving strategy for motor. With the support of economic as well as technical data required for each strategy, the multi criteria evaluation using analytic hierarchy process offers feasible solution corresponds to their inherent characteristic. It is revealed that capacitor bank is the most suitable saving strategy to the case of small and medium scale industry in this research and thus suggested to be provisioned at the first priority, followed by variable speed drive and energy efficient motor, consecutively.**

Keywords—Analytic Hierarchy Process, decision making, energy saving strategy, induction motor, small and medium enterprise

I. INTRODUCTION

Small and medium scale industry (SMI) have played a significant role in the Indonesian economy development in 2009. Of more than 40 million enterprises, 99.99% is small and medium scale and only 0.01% is corporation [1]. Millions of people engage in this productive activity and employ 97.30 % of people working in the private sector. They contribute significantly to the development as 58.17% of Gross Domestic Product comes from these enterprises. Despite the fact that SMI's is very potential for building a stable economic growth, developing SMI's is a difficult issue. The most common problems for SMI's are lack of access to market information, low quality of human resources, lack of access to capital, and technology.

As in any industrial sector, utilization of industrial motors in SMI's sector can be easily found. Electric motors contribute as major electrical equipment consuming large portion of energy during manufacturing process in SMI. The most common and simple industrial motor is induction motors, either three phase or one phase type. It has been found that several losses occurred in induction motor [2]. Therefore, energy efficiency improvement for industrial motors can be performed according to technical point of view to reduce those losses through installing certain instruments or replace standard motors with the efficient ones. Besides, a multi criteria evaluation can be added up as it reinforces the decision making in selecting the most appropriate strategy. There is lack of study on multi criteria evaluation for decision making purpose in industrial motors. Reference [3] shows a model for improving energy efficiency in industrial motor system using multi criteria analysis. However, the model might not be worked in the context of SMI due to some limitations attached to that type of industry.

Considering the inherent characteristic of SMI, the selected motor energy saving strategy could be based on the cost point of view, among another consideration. A simple approach is then carried out in this research to investigate the most appropriate energy saving technology to be decided for SMI, mainly based on multi criteria evaluation. This paper is organized as follows: the fundamental theory is presented in the next section, research method used is followed subsequently, result and discussion are presented in the subsequent section and finally conclusion is followed.

II. FUNDAMENTAL THEORY

In this section, small and medium scale industry and multi criteria evaluation based on Analytic Hierarchy Process are briefly explained. The two concepts are the focus in this research in which the analysis is performed accordingly.

Small and Medium Industry

In Indonesia, small and medium industries (SMI) are categorized as those industries having a number of employees between 5 and 99 [4]. The official statistics divides SMI into seven industrial sectors, namely food and beverages, textile, wood products, pulp and paper products (including printing and publishing), chemical products, non-metallic mineral products, such as ceramics, and fabricated metal products (including foundries). The law No. 20/2008 defines SMI into three broad size categories: micro, small, and medium enterprises. Each category is distinguished based on their net assets value and turnover. Small size industries are those having net assets value in the range of Rp. 50 million to Rp. 500 million and annual turnover of Rp. 300 million to Rp. 2.5 billion. Meanwhile, medium industries are those enterprises having net assets value of Rp. 500 million to Rp. 10 billion with annual turnover of Rp. 2.5 billion to Rp. 50 billion. In the perspective of electricity energy demand, as per other regulation issued by the Indonesian government, manufacturing factories having apparent power connection to utility distribution grid up to 200 kVA are categorized as SMI [5].

Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a mathematic based decision-making tool proposed by Saaty [6]. Until now, this method is widely used to solve various problems related to decision-making, including: resources allocation, decision analysis or cost benefit, determine the ranking of several alternatives, projections of future planning, and other complex problems. In the energy or electrical engineering field, some studies worked based on AHP can be found in [7]. AHP uses a mathematical framework in which the procedure comprises three stages: preparation of the hierarchy (decomposition), prioritization (comparative judgment), and calculating relative weights. In the first stage, attributes influencing decision making are identified and then sorted into different classes to form a decision-making hierarchy.

In the second stage, data serving as the basis for pairwise comparison judgments are gathered. In the AHP procedure, the assessment of priority will be placed in a matrix called the matrix of pairwise comparison. AHP measurement consists of 9 stages and indicated the relative importance of attributes during pairwise comparison as presented in Table 1 [7].

TABLE I
SCALE FOR PAIRWISE COMPARISON

Scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between adjacent scale values	When compromised is needed
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*.	

In the third stage, relative weights of decision-making attributes are estimated via Eigen vectors. The Eigen vector method is widely used to determine relative weights of attributes from the results of pairwise comparison. If w_i is the weight of assessment characteristic i and the relative importance of attribute j, compared to attribute i, is a_{ij}, then pairwise comparison matrix A, consisting of $a_{ij} = w_i/w_j$, is a symmetrical matrix with all factors on the main diagonal equal to 1. Consistency Ratio (CR) is a measure indicating whether ordinal rankings of the pairwise comparison data obtained from expert evaluations are reliable. If w is $(w_1; w_2; \ldots; w_n)$ and l is the Eigen value of A, the condition for matrix A to be consistent is as follows:

$Aw = \lambda w$ (1) where λ is the Eigen value of A and w the Eigen vector of A.

As pairwise comparisons of attributes are most often inconsistent, an expression using a maximum Eigen value (λ_{max}) can be re-written into a homogenous linear system of equations as given below:

$$(A - \lambda_{\max} . I)w = 0 \qquad (2)$$

Next, w, satisfying the above equation, which is not a zero vector, must be obtained. To sum up, one needs to calculate the Eigen value from the evaluation matrix and obtain the Eigen vector corresponding to the maximum Eigen value to normalize the weights so that their sum equals 1. λ_{max} in equation (1) is the estimated value of l in Eq. 1. The maximum Eigen value (λ_{max}) is always equal to or greater than the number of attributes *(n)*. The closer the maximum Eigen value obtained is to the number of attributes, the more consistent the pairwise comparison matrix. This phenomenon is measured through the following Consistency Ratio (CR), whereby a value of the CR of 10% or less, indicates the consistency of an assessment, whereas 20% or less constitutes a tolerable range

$$CR = \frac{CI}{RI} \quad (4)$$

where CI is Consistency Index and RI is Random Index.

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)} \quad (5)$$

where n is number of attributes.

Motor Energy Saving

Motor inventory audit is one of important electrical system audit section due to high portion of electricity consumption. The objectives that can be considered for a motor energy audit is stated as in [8] to identify motor energy use in an industry, to implement energy savings measures by which individual industry can conserve energy used, and as a benchmark of electric motors energy use in other industries.

There are at least three ways by that energy can be saved i.e. through the utilization of high energy efficient motors (EEM), utilization of technology, and by practicing good housekeeping [9]. Utilization of technology deals with the method of controlling motor. This option uses a variable speed drive (VSD). Another option is installation of capacitor bank. Through this option, power factor correction which is applied at motor will not only decrease energy use but also will significantly extend the life of the motor [10].

Research Methodology

Initially, factory visit to a sandals factory having 110 kVA grid connection is conducted in the form of a walk-through motor energy audit to collect motor technical data as well as operational and electricity consumption pattern. Located in Pasuruan District, East Java, the factory gets the predetermined sandals making-order from a national big-well established Sandals and Shoes Company. In this research, essential motor data based on nameplate and measurement gathered during walk-through audit is presented in Table 2.

TABLE II
Essential Motor Data Based on Name Plate and Measurement

Motor name	*No. of unit*	*Per unit Power (kW)*	*Volt (V)*	*Amps (A)*	*Input Amps (A)*	*Full Load efficiency (%)*	*Cos phi*	*% Loading*
3 Ø sheet cutting motor	10	2.2	380	5	3.9	78.5	0.85	78
1 Ø drilling motor	3	0.25	220	2.4	1.5	52	0.62	62
1 Ø drilling motor	8	0.37	220	4.2	2.1	56	0.64	50
3 Ø scraping motor	12	1.5	380	3.4	1.83	81	0.83	54
3 Ø conveyor motor	3	2.2	380	5.2	4.56	84.7	0.76	87
3 Ø press motor	1	5.5	380	11.7	6.35	86.5	0.83	54.2
3 Ø glue motor	3	0.37	380	1.3	0.93	58.5	0.73	70

In this research, the appropriate approach to be implemented is mainly based on preferences in energy saving criteria. Criteria to be considered in the decision making analysis are discussed with the factory owner as priorities among the criteria were asked accordingly. Meanwhile, other findings collected during a walk-through audit are gathered as a supporting data to decision making procedure conducted via AHP analysis. As stated in the AHP's method, a decision-making hierarchy is formed considering all criteria. The complete hierarchy composed in this research is shown in Fig. 1.

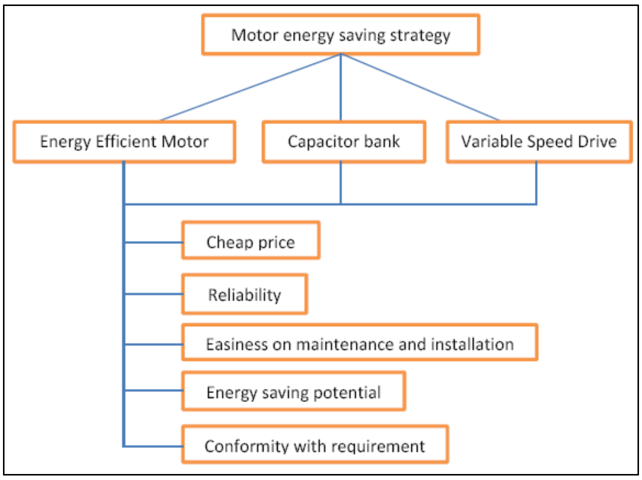

Fig.1.Three classes hierarchy used in this research

As in Fig. 1, the third class in the AHP assessment is filled with criteria, which are reliability, price, easiness on maintenance and installation, energy saving potential, and conformity with requirement; the second is placed by the energy saving strategies; which are EEM, VSD, and capacitor bank; and at the first hierarchy is the assessment goal "Motor energy-saving strategy". Following the second stage of AHP method, the criteria is then developed to perform pairwise comparison among them. A model is then generated in order to compare the relative importance with respect to goal, which is choose the most appropriate motor saving strategy.

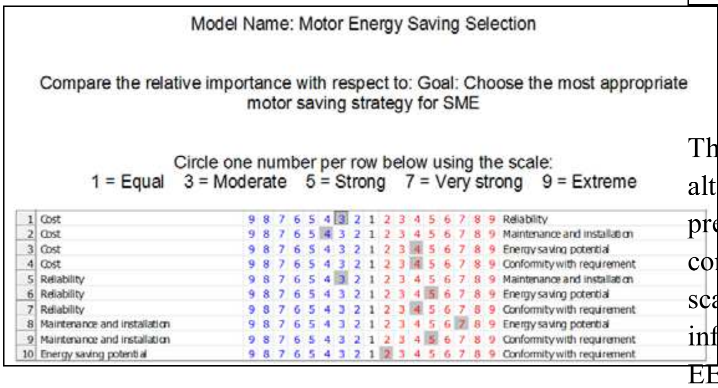

Fig.2. Pairwise comparison among all criteria

Assessment over all criteria is conducted then after by selecting the scale representing an attribute relative importance over another. As in Fig. 2, cost is assumed moderate importance when it is compared to reliability as number three is chosen. Interpretation should then be made in the same way for other comparison. The scale is determined based on relevant supporting information such as energy saving technology price, service life approximation, and other technical as well as economical parameters. The required cost of energy of capacitor bank is 720,000 Rupiah/kVAR, accounted for a total estimated cost Rp. 21,500,000. The proposed cost for EEM could be 2,130,000 Rupiah/kW, accounted for 85,648,000 Rupiah whereas the cost for VSD is 2,590,000 Rupiah/kW, accounted for all VSD for 17,100,000 Rupiah [11].

IV. Results

Based on the analysis performed by AHP, the weight resulted from the pairwise comparison is revealed as presented in Fig 3. In this case, the result reflects that the decision maker assumes "conformity with requirement" is the most important criteria toward the goal, followed by "energy saving potential" and "cost" in the second and third sequence, respectively.

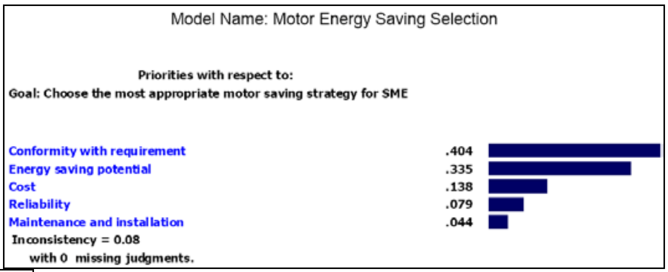

Fig.3. Synthesis result for weighting of all criteria

The next step is related to the comparison between alternatives to the criteria. In this regards, all preferences, i.e. EEM, VSD, and Capacitor bank are compared each other with respect to each criteria. The scale of comparison is chosen considering measurable information analyzed separately above. For instance, EEM is compared with Capacitor bank with respect to "Cost". The rest criteria are treated in a similar manner as previously done. Finally, weighting for all alternatives with respect to the desired goal is summarized in Fig. 4.

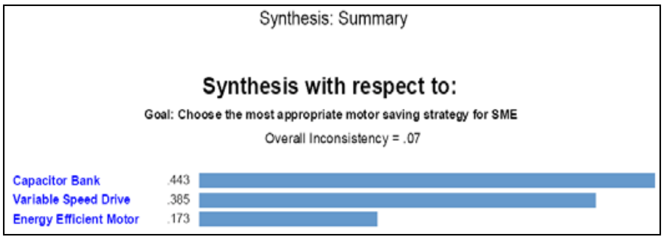

Fig.4. Synthesis summary on weighting of all alternatives

The weighting summary presented in Fig. 4 is composed of all alternatives weighting with respect to all criteria. Capacitor bank gains the highest trust level with respect to cost and conformity to the requirement. VSD is superior with respect to energy saving potential, whereas EEM is a priority with respect to reliability and maintenance-installation. From the summary given in Fig. 4, we can infer that capacitor bank is the most suitable saving strategy to the case of a SMI in this research. Hence, capacitor bank is suggested by the AHP model to be provisioned at the first priority to the factory, followed by VSD and EEM.

V. Conclusions

In this research, energy saving opportunities for induction motor applied in SMI is analyzed. In this research, a sandals factory is chosen as a case study. Decision making in selecting appropriate technology for motor energy saving is made based on multi criteria evaluation using AHP. In viewing to the inherent characteristic of SMI, Capacitor bank shall be in the highest rank among two others technologies i.e. VSD and EEM. The result obtained in this study is likely to be suited for other typical plant condition. Future paper shall report combination between techno-economic analysis and AHP that will enhance the decision making analysis, along with assessment to emission mitigation potential.

VI. References

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