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Electricity Energy Saving Assessment for Induction Motors towards Sustainable Energy Practice in Indonesian Small and Medium Industry

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Abstract. This paper presents energy saving assessment on induction motors which are particularly being utilized in the small and medium industry. A walk-through motor energy audit is carried out in a typical type of industry in Indonesia to collect some important data. Strategy for annual motor energy saving is assessed involving energy efficient motor, variable speed drive, and capacitor bank. In addition, analysis is carried out to find impact on energy efficiency indicator as well as CO_2 emission due to energy saving. It is revealed that the combination on selected motor saving strategy may lead to reduce electricity energy by around 10%, equal to around 38% CO_2 emission mitigation. Besides, energy efficiency indicators are found to be improved. Hence environment emission is significantly reduced by applying appropriate motor energy saving for small and medium industry.

Introduction

As one of industrial scale, Small and Medium Industry (hereafter "SMI's") create a significant local pollution and other environmental problems due to the nature of these industries with their inefficient use of energy and other resources. Implementation of few options at little or no cost in the industrial sector could reduce carbon dioxide emissions by 10–30% of GHG emissions, while if improved technologies and financing mechanisms such as Clean Development Mechanism introduced by the Kyoto Protocol are adopted, further reduction may be achieved [1]. More than half of the total electricity energy used in industry consumed by motor driven systems [2]. Thus, industrial motors account for a major segment of electricity energy used in industry. Several energy saving strategies commonly available may or may not be fit with respect to several factors associated to the industry scale and their inherent characteristics.

This paper proposes a technical approach to increase energy performance of SMI in Indonesia in terms of specific energy consumption (SEC) and energy intensity (EI) as well as CO_2 emission reduction by conducting induction motors energy saving assessment. Three possible strategies are considered to reduce motor energy consumption. Energy saving potential is then analyzed with respect to their economic payback.

Methodology

Motor energy can be saved through the usage of high energy efficient motors (EEM) as well as utilization of technology in which controlling motor speed uses a variable speed drive (VSD) [3]. Another option is installation of capacitor bank. This paper analyses the feasibility of using EEM, VSD, and capacitor bank for improving motor energy efficiency in the selected SMI facility.

Energy Saving Calculation. Analysis on annual energy saving (AES) by replacing standard motor with EEM can be estimated using:

$$AES = HP \times L \times 0.746 \times h \times (1/E_{std} - 1/E_{eem}) \times 100. \quad (1)$$

where: AES is annual energy saving (kWh); HP is motor rated horse power; L is load factor (%); h is operating hour; E_{std} is standard motor efficiency rating (%); E_{eem} is energy efficient motor efficiency rating (%). Annual bill saving associated with the energy saving can be calculated by multiplying AES with average electricity cost per kWh (US$ or Rupiah). Motor input power (P_{input}) and full load current (I_a) is given by:

$\eta = P_{output} / (P_{input} \text{ Cos phi})$. (2)

$I_a = (P_{output} \times 1{,}000) / (\sqrt{3} \times V_{phase\ to\ phase})$. (3)

Motor energy saving using VSD can be estimated using:

$ES_{VSD} = n \times P \times H_{avg\_usage} \times S_{SR}$. (4)

where: ES_{VSD} is energy saving using VSD; n is number of motors; P is motor power (kW); H_{avg_usage} is annual average usage hour; S_{SR} is percentage energy savings associated with certain percentage of speed reduction. Calculation on capacitors kVAR value required for power factor correction as well as the avoided monthly kVAR penalty due to average power factor lower than 0.85 are obtained using formula mentioned in other study [4].

Selection of Appropriate Measures. Among the proposed three strategies, economic feasibility of the strategies to be applied for SMI cases is determined using simple payback period. For different energy saving strategies, payback period (year) is obtained by dividing incremental cost (US$ or Rupiah) with annual monetary saving (US$ or Rupiah). Data needed to estimate energy savings thus the payback period include: motor average usage hour, average electricity cost, motor efficiency under various load condition, incremental price for VSD, and average installation cost for capacitor per kVAR.

Establishment of Energy Efficiency Indicators. Energy efficiency could be expressed in two form: energy consumed per unit physical product, or SEC and the energy intensity, or EI [5]. Several data including electricity energy consumption during a year, amount of sandals produced in term of tons, and monetary value of total sandals produced in a year are required. Both index are respectively calculated by:

SEC = TAEC / TAP. (5)

EI = TAEC / TAV. (6)

where: TAEC is Total Annual Energy Consumption (kWh); TAP is Total Annual Production (tons or unit); TAV is Total Annual Value addition (US$ or Rupiah). The indexes can indicate opportunities for improvements in energy and processes efficiencies. This could also result in adopting measures to reduce CO_2 emission.

CO_2 Emission Analysis. In this paper, the CO_2 emission by SMI is estimated as the annual indirect emission since the factory only relies on grid electricity supply as :

Annual indirect emission = $(EC \times CEF) / \eta_{TD}$. (7)

where: EC is the annual electricity consumption by the factory (kWh); CEF is CO_2 emission factor due to electricity generation; and η_{TD} is transmission and distribution efficiency. Meanwhile, the specific CO_2 emission from the factory can be estimated by dividing total annual emission (tons of CO_2) with total annual production (tons of product). Another method that can be applied to estimate the amount of emission reduction (in kg) associated with the energy savings is by multiplying annual energy saving with emission factor (kg/kWh). In the case of Indonesia, CO_2 emission factor is estimated to be 0.787 kg/kWh, referring to average grid emission factor for Java-Madura-Bali interconnection in 2008 [6].

Walk-through Motor Audit. The selected research observation site is a sandals factory located in Pasuruan district, East Java. Referring to the SMI's classification, this factory can be classified into medium size enterprise due to the amount of labor, which is approximately 150 people, and having a 3-phase 110 kVA power connection into the PLN grid. The electricity is entering the factory via a main distribution panel (MDP) located inside the factory. Required data in terms of technical as well as operational and electricity consumption pattern is collected through a walk-through motor energy audit. Located in Pasuruan District, East Java, the factory is getting the contract on sandals making-order from a national big-well established Sandals and Shoes Company. The factory runs 290 days a year and the daily working hour is 9 hours. The factory monthly electricity bill is about 10 million Rupiah. The factory is equipped with standard 3 Ø and 1 Ø induction motors. Essential motor information as seen in the motor nameplate and based on field measurement is shown in Table 1.

Table 1. Motor data based on nameplate

Motor name / application	No. of unit	Power (kW)	No. of poles	F.L. speed (rpm)	Volt (V)	F.L. current (A)	Input current (A)	F.L. eff (%)	Cos phi	Loading (%)
3 Ø sheet cutting	10	2.2	6	950	380/220	5/8.8	3.9	78.5	0.85	78
1 Ø drilling	3	0.25	2	1,400	220	2.4	1.5	52	0.62	62
1 Ø drilling	8	0.37	2	1,400	220	4.2	2.1	56	0.64	50
3 Ø scraping	12	1.5	2	2,850	380/220	3.4/5.8	1.83	81	0.83	54
3 Ø conveyor	3	2.2	4	1,420	380/220	5.2/8.9	4.56	84.7	0.76	67
3 Ø press	1	5.5	4	1,435	380/220	11.7/20.2	6.35	86.5	0.83	54.2
3 Ø glue	3	0.37	4	1,450	380/220	1.3/3.5	0.93	58.5	0.73	70

Required motor data for analysis is obtained mixed from motor name plate, field measurement, and calculation. Motor volt and Amperage are found in the nameplate. Motor input amperage or running current is obtained by the measurement during field visit. Full load efficiency is taken from the references. Hence, motor input power and can be calculated using equation in the methodology chapter. From the calculation taken into account motor input power, full load efficiency, power factor (Cos phi), motor percentage loading can be determined as the ratio between motor running current and motor full load input current (I_a) multiply with 100%.

Result and Discussion

Measurements are taken as indication and consider as average value for the estimates analysis purpose whereas motor full load efficiency is taken from the references. All motor are running for 9 hours per day for 290 days in a year, except only 4 hours per day for glue motors. From table 1, we can see that motor power factor changes against its load. Power factor is minimum at no load and increases as additional load is applied to the motor.

Assessment for EED, VSD, and Capacitor Bank. Standard existing motor to be replaced with EEM are those with low efficiency or considerably having low loading. Table 2 presents replacement recommendation on existing motor with EEM in terms of technical with impact on their economic. Replacement strategies can be appeared in the form of motor downsizing or same motor size with improved performance. Taking into account the off-peak energy charge applied by the Utility for I-2 class, which is 800 Rupiah/kWh, the annual monetary saving for all sheet cutting motors would be 4,236,000 Rupiah. For saving using a different motor size, power saving is obtained simply from the different size of new motor against the old one, in this case for scraping motor and press motor.

Table 2. Replacement option of existing motors with EEM

Motor name / application	Power (kW)	Amps (A)	F. L. Eff (%)	Cos phi	Loading (%)	Unit Price (Rp.000)	Total AES (kWh)	Total Saving (Rp.000)	Estimated payback (year)
3 Ø sheet cutting	2.2	4.7	86	0.82	83	3,915	5,295	4,236	9.24
1 Ø drilling	0.25	1.8	59	0.99	83	2,262	468	374	18.2
1 Ø drilling	0.37	2.5	64	0.95	84	2,410	1,449	1,159	16.6
3 Ø scraping	1.1	2.35	84	0.89	78	3,028	9,772	7,818	4.6
3 Ø conveyor	2.2	4.7	86	0.82	97	3,915	411	329	35.6
3 Ø press	4	8.4	88.5	0.81	76	5,203	3,130	2,504	2.07
3 Ø glue	0.37	1.05	71	0.73	88	1,653	922	738	6.71

From Table 2, we can see that some options are likely to be unfavorable in term of payback period, such as for drilling motors and conveyor motors, whereas for other motors are considered to be accepted for application considering the service life of induction motor, of which 15 to 20 years. Moreover, the payback period is likely to be longer than any other EEM application since the motor running period is considerably short in a day, i.e. for only 9 hours. On the other hand, several factors affecting unreasonable payback period for drilling and conveyor motors are: the efficiency difference for drilling and conveyor motors between existing and proposed motor efficiency is not significant, the price for the proposed motor is relatively high compared to their annual energy saving resulted by small efficiency difference. Hence, standard motor replacement to EEM is likely inappropriate for 1 Ø drilling motors as well as 3 Ø conveyor motors. In this regards, energy saving opportunity for both drilling motors and conveyor motor shall be assessed using VSD and capacitor bank. The total motor's power factor before compensation is found 0.814. Therefore, total reactive power required to compensate power factor into 0.96 would be 24.01 kVAR or equivalent to a capacitor bank rated in 30 kVAR. The cost is estimated of 21,500,000 Rupiah, or 720,000 Rupiah/kVAR, taken into account all auxilliary capacitor bank's components. Here, annual monetary saving occurred due to excessive kVARh penalty avoided would be 12,160,000 Rupiah. Thus, payback period is obtained for 1.7 years.

The proposed VSD in which appropriate for the conveyors application on the research site is characterized by: I_{2N} (continuous base current with 110% overload for 1 min/10 min): 6.9 A, I_{2hd} (continuous base current with 150% overload for 1 min /10 min): 5.4 A, P_N (nominal power for 4-pole motor): 2.2 kW. The VSD corresponding to the above characteristics is available with the price around 5,700,000 Rupiah. For each conveyor, the total annual estimate saving is calculated based on 2,610 hours of operation running at 60% - 80% motor speed. Based on VSD saving calculation, the associated power saving would be in the range of 48% - 78%, or equivalent with 1,484 kWh – 3,518 kWh usage each conveyor, annually. Hence, monetary saving would be 2.624,000 – 4,210,000 Rupiah lead to payback period of 1.3 – 2.1 years.

Improvement on Energy Efficiency Indicators. AEC can be derived from total motors power input multiply with their loading factor before applying saving strategies, which is 115,500 kWh, or 84%. The average sandals production capacity are calculated 48,000 pair/day or 13,920,000 pair/year, based on the number of sheet cutting machine multiply each machine capacity/day, which is 10 machines multiply with 4,800 pair. Converting the product unit from pair into tons, we get 3,480,000 tons sandals, provided 1 pair is equal to 0.25 kg. The monetary value of final product - in pair - produced is determined based on the production fee, which is 600 Rupiah/pair. Hence, SEC and EI before applying motor energy saving strategies is 9.96 kWh/Thousand pair and 16.59 kWh/Million Rupiah, respectively. With regards to motor input power, SEC and EI will be 8.29 kWh/Thousand pair and 13.83 kWh/Million Rupiah, respectively. Since the saving strategies are selected based on potential energy saving and economic consideration, the saving strategies will be mixed of capacitor bank, VSD for conveyors, and selected EEM. The most appropriate configuration to give optimum saving exclude efficiency improvement obtained by installing capacitor bank is presented in Table 3.

Table 3. Annual saving obtained by applying VSD and EEM

Motor name / application	Annual kWh before saving	Anual kWh after saving	kWh saving	Recommended Saving option	Estimated payback (year)
3 Ø sheet cutting	73,080	55,410	17,670	EEM	9.24
3 Ø scraping	57,994	31,998	25,996	EEM	4.6
3 Ø conveyor	15,457	4,452 to 10,550	11,000 to 4,907	VSD	1.3 to 2.1
3 Ø press	16,600	8,952	7,648	EEM	2.07
3 Ø glue	2,204	1,590	614	EEM	6.71

CO_2 Emission Mitigation. The annual indirect emission for the factory before applying motor energy saving strategies is 122,551.82 kg or 122 tons, provided annual electricity consumption 115,500 kWh, CO_2 emission factor for 0.787 kg/kWh, and transmission/distribution efficiency 89%.

Meanwhile, the specific CO_2 emission from the factory can be estimated for about 0.035 ton of CO_2/thousand tons of product. Based on Eq. 7, the amount of emission that can be reduced after applying energy saving strategies is at least 47.13 tons CO_2 reduction.

Conclusion

Analysis and recommendation on how motor energy can be saved in SMI through by conducting integrative analysis based on technical as well as economic aspect is presented in this paper. The important findings include a 10% reduction in total annual kWh exclude losses minimization getting from the installation of capacitor bank, a reduction on SEC and EI, and threefold on emission reduction obtained at least 47.13 tons of CO_2. In turn, those improvement will enable SMI to prioritize and select the appropriate strategy based on their inherent characteristics.

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