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Energy Efficiency Applications in Electric Motors: A Case Study for Kastamonu Entegre Co, Adana MDF Facility

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ABSTRACT:

36% of the electrical energy consumed in Turkey is used by asynchronous motors, which are widely used in the industry. When considering industrial electricity consumption, it is observed that the share of electric motors in consumption reaches around 70%. Considering the rapid depletion of fossil fuels, which have a significant share in the energy supply, and the environmental problems caused by these sources, the efficiency and savings potential of electric motors, which use energy so intensely, is important.

In this study, according to the ISO 500 data of 2019, Kastamonu Particle Board Plant (Kastamonu Entegre Co), which ranks 46th among the largest industrial establishments in Turkey, is used in Adana MDF Facility, B1 group 18.5 kW, B2 group 15 kW and F1 group the energy saving potentials provided by the 315 kW IE2 efficiency class motors in case they are upgraded to the IE3 class are calculated and payback periods are presented. According to this, the energy saving provided by the B1 group motor is 1923 kWh/Year (119 $/Year), and the payback period is 5,01 years. In the B2 group motor, the energy saving provided is 2340 kWh/Year (145 $/Year), and the payback period is 3,95 years. On the other hand, the energy savings achieved in the F1 group motor is 18815 kWh/Year (1167 $/Year), and the payback period is determined as 8,68 years.

Keywords: *Electric motors, Energy efficiency, Efficiency class*

Elektrik Motorlarında Enerji Verimliliği Uygulamaları: Kastamonu Entegre A.Ş., Adana MDF Tesisi Örneği

ÖZET

Türkiye'de tüketilen elektrik enerjisinin %36'sı, endüstride yaygın olarak kullanılan asenkron motorlar tarafından tüketilmektedir. Sanayi elektrik tüketimine bakıldığında ise elektrik motorlarının payının %70 mertebelerine çıktığı görülmektedir. Fosil yakıtların hızla tükenmekte olması ve enerji arzında önemli bir paya sahip olan bu kaynakların neden olduğu çevresel sorunlar göz önüne alındığında, enerjiyi yoğun bir şekilde kullanan elektrik motorlarının verimliliği ve tasarruf potansiyeli önemlidir.

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Bu çalışmada, 2019 yılı ISO 500 verilerine göre Türkiye'nin en büyük sanayi tesisleri arasında 46. sırada yer alan Kastamonu Parça Levha Tesisi (Kastamonu Entegre AŞ), Adana MDF Tesisinde kullanılan B1 grubu 18.5 kW, B2 grubu 15 kW ve F1 grubu 315 kW IE2 verimlilik sınıfı motorlarının IE3 sınıfına yükseltilmesi durumunda sağlanan enerji tasarruf potansiyelleri hesaplanmış ve geri ödeme süreleri sunulmuştur. Buna göre, B1 grubu motor tarafından sağlanan enerji tasarrufu yılda 1923 kWh (119 $/Yıl) ve geri ödeme süresi 5,01 yıl olarak hesaplanmıştır. B2 grubu motorla elde edilen enerji tasarrufu yılda 2340 kWh (145 $/Yıl) ve geri ödeme süresi 3,95 yıl olarak belirlenmiştir. Diğer yandan, F1 grubu motorla elde edilen enerji tasarrufu yılda 18815 kWh (1167 $/Yıl) ve geri ödeme süresi 8,68 yıl olarak tespit edilmiştir.

Anahtar Kelimeler: *Elektrik motorları, Enerji verimliliği, Verimlilik sınıfı*

1. INTRODUCTION

36% of the electrical energy consumed in Turkey is used by asynchronous motors, which are widely used in the industry. Examining industrial electricity consumption reveals that the portion attributed to electric motors has surged to around 70%. Considering the rapid depletion of fossil fuels, which have a significant share in the energy supply, and the environmental problems caused by these sources, the efficiency and savings potential of electric motors, which use energy so intensely, is important. The present usage of electric motors predominantly comprises asynchronous motors, accounting for approximately 90% of the total. Consequently, prioritizing the use of high-efficiency motors becomes imperative in curtailing the efficiency losses inherent in industrial asynchronous motor operations [1].

Electric motors use electrical energy to generate power. The ratio of the mechanical power they produce to the power drawn from the network or system is defined as motor efficiency. Motor losses can be grouped as body losses, stator resistance, rotor resistance, friction, and other mechanical losses (Figure 1) [2].

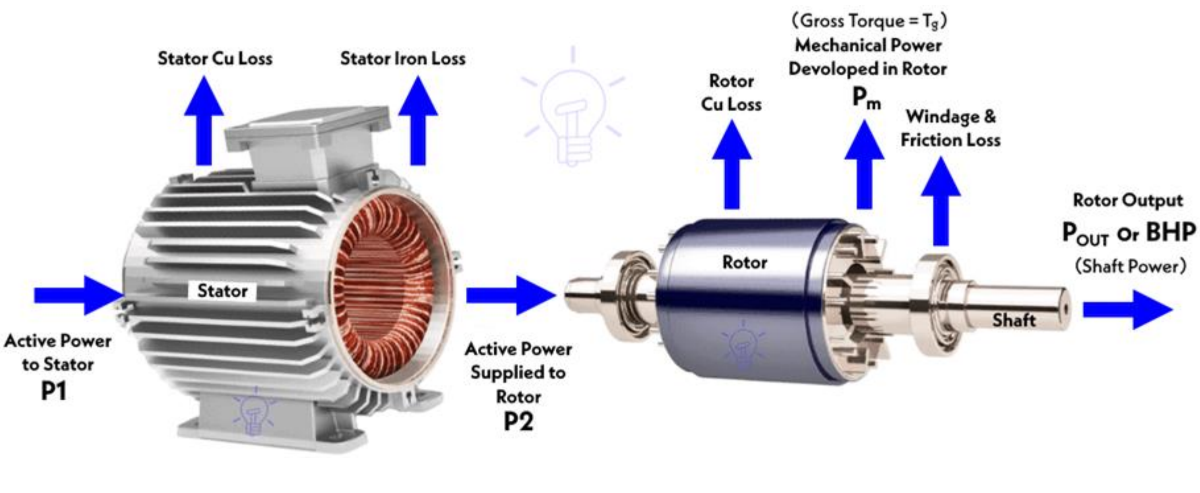

Figure 1. Losses in an Electric Motors [3]

Along with technological developments, motors used in almost every field have been developed, and the amount of lost energy in motors has been reduced and made more efficient. The use of higher-quality metal materials in the stator part, the reduction of magnetic stress, larger cores, improved bearings and fans with fewer losses, and reduced winding resistances contribute to a smaller difference between the input and output power (Figure 2).

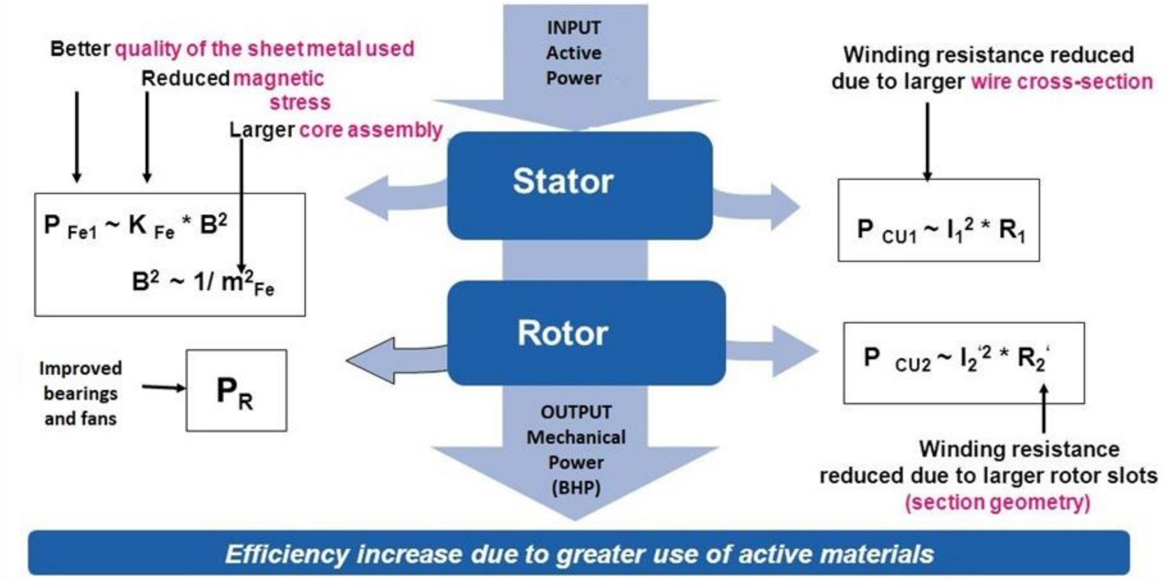

Figure 2. Efforts to increase efficiency in electric motors [4]

The European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP) and the National Electric Manufacturers Association (NEMA) have made motor efficiency classifications. Today, electric motors have been diversified to respond to different working conditions, and these products have been classified with international standards. Electric motor manufacturers offer electric motors to the market within the framework of accepted standards, and regulations are made on frame dimensions and working conditions. According to the worldwide accepted IEC 60034-30-1 electric motor standards, electric motors between 0.12 and 1000 kW brake horsepower are classified with IE codes according to their efficiency [5].

- IE1 - Standard Efficiency,
- IE2 - High Efficiency,
- IE3 - Premium Efficiency and
- IE4 - Super Premium Efficiency
- IE5 - Ultra Premium Efficiency

The comparison of the newly determined standards with other standards is shown in Figure 3.

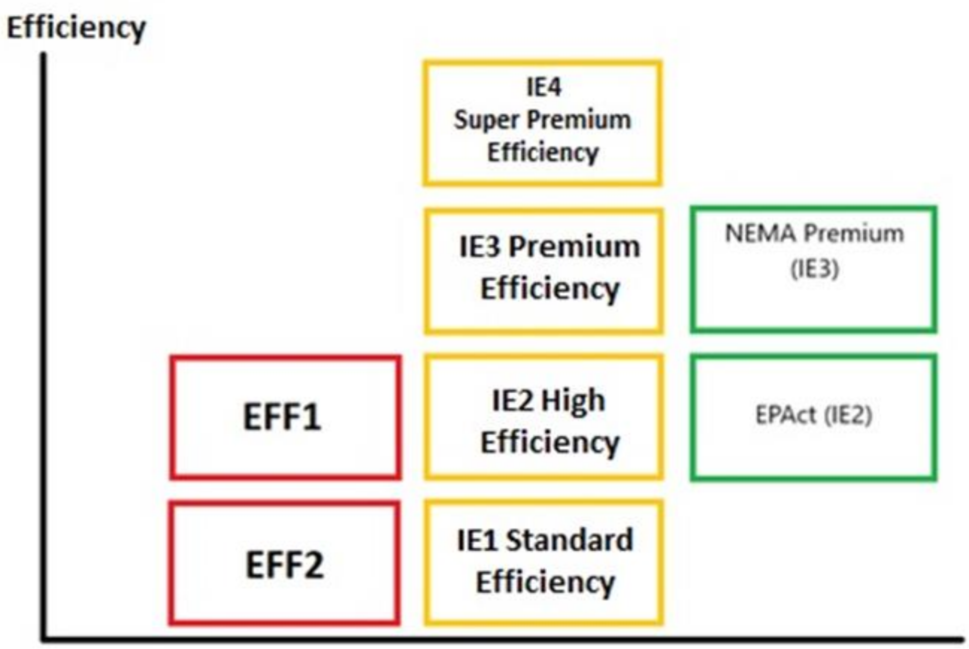

Figure 3. Comparison of electric motors Efficiency class standards

Work has been done with the National Electricity Manufacturers Association (NEMA) in preparing the Energy Stability and Safety Act (EISA) approved by the EU in 2007 and the binding provisions on energy efficiency in electric motors. In the studies, regulations have been proposed to optimize electric motors for general and private use, low-efficiency electric motor systems, and to be more environmentally sensitive [5]. The mentioned standards started to be legally implemented in Europe on all induction motors with 2, 4, and 6 poles, up to 1000 V, 50/60 Hz, 0.75 to 375 KW, as of 16.06.2011 [4].

The transition process related to reducing the negative effects of these regulations on industrial enterprises and facilitating the transition to new regulations was carried out with a certain time planning [5]. After the implementations, as of January 1, 2015, motors under IE3 efficiency class were planned to be withdrawn from the market, while the use of IE2 efficiency class motors was stipulated to be used only with adjustable speed drives [6]. In Turkey, as a result of the studies carried out, the IEC 60034-30-1 standard, published in 2009, entered into force after 2010 [7]. This standard was revised again in 2012 [8] and 2014 [9] after the updates made in the original standard and took its final form in use today.

Since the world's energy demand is predicted to double by 2050, environmental concerns have increased, and it has become inevitable to make regulations to increase energy efficiency worldwide [5]. As can be seen in Figure 4, the energy demand in Turkey has been increasing exponentially since 1970.

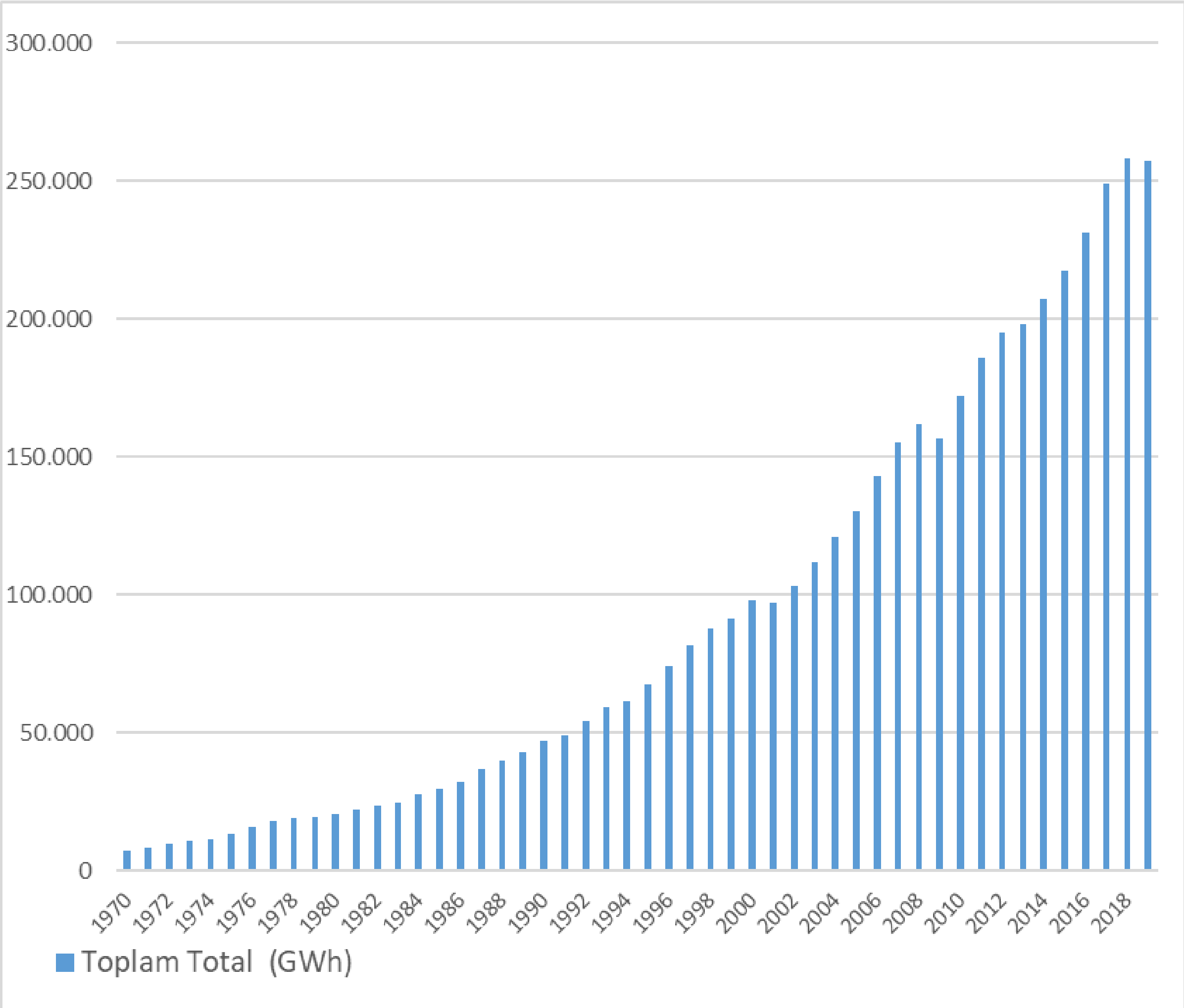

Figure 4. Türkiye Net electricity consumption by years [10]

Figure 5 and Figure 6 show the efficiency percentages of motors with different powers and pole numbers in IE1, IE2, and IE3 efficiency classes. As the rated power of the motor increases, the difference between the efficiency classes gradually decreases, but the gain should not be underestimated as the energy consumed also increases with the rated power. Due to the effort to keep the installation cost low during the establishment or overhaul of the plant, the motor efficiency class is the first to be overlooked. Although ignored, this step will return the business to a profit in the long run. Increasing electricity prices will also shorten this period.

	IE1, 50 Hz			IE2, 50 Hz			IE3, 50 Hz		
P (kW)	2 K	4 K	6 K	2 K	4 K	6 K	2 K	4 K	6 K
0.75	72.1	72.1	70.0	77.4	79.6	75.9	80.7	82.5	78.9
1.1	75.0	75.0	72.9	79.6	81.4	78.1	82.7	84.1	81.0
1.5	77.2	77.2	75.2	81.3	82.8	79.8	84.2	85.3	82.5
2.2	79.7	79.7	77.7	83.2	84.3	81.8	85.9	86.7	84.3
3	81.5	81.5	79.7	84.6	85.5	83.3	87.1	87.7	85.6
4	83.1	83.1	81.4	85.8	86.6	84.6	88.1	88.6	86.8
5.5	84.7	84.7	83.1	87.0	87.7	86.0	89.2	89.6	88.0
7.5	86.0	86.0	84.7	88.1	88.7	87.2	90.1	90.4	89.1
11	87.6	87.6	86.4	89.4	89.8	88.7	91.2	91.4	90.3
15	88.7	88.7	87.7	90.3	90.6	89.7	91.9	92.1	91.2
18.5	89.3	89.3	88.6	90.9	91.2	90.4	92.4	92.6	91.7
22	89.9	89.9	89.2	91.3	91.6	90.9	92.7	93.0	92.2
30	90.7	90.7	90.2	92.0	92.3	91.7	93.3	93.6	92.9
37	91.2	91.2	90.8	92.5	92.7	92.2	93.7	93.9	93.3
45	91.7	91.7	91.4	92.9	93.1	92.7	94.0	94.2	93.7
55	92.1	92.1	91.9	93.2	93.5	93.1	94.3	94.6	94.1
75	92.7	92.7	92.6	93.8	94.0	93.7	94.7	95.0	94.6
90	93.0	93.0	92.9	94.1	94.2	94.0	95.0	95.2	94.9
110	93.3	93.3	93.3	94.3	94.5	94.3	95.2	95.4	95.1
132	93.5	93.5	93.5	94.6	94.7	94.6	95.4	95.6	95.4
160	93.8	93.8	93.8	94.8	94.9	94.8	95.6	95.8	95.6
200-375	94.0	94.0	94.0	95.0	95.1	95.0	95.8	96.0	95.8

Figure 5. EU 640/2009 and IEC 60034-30:2008 IE European and International motor efficiency standards [11]

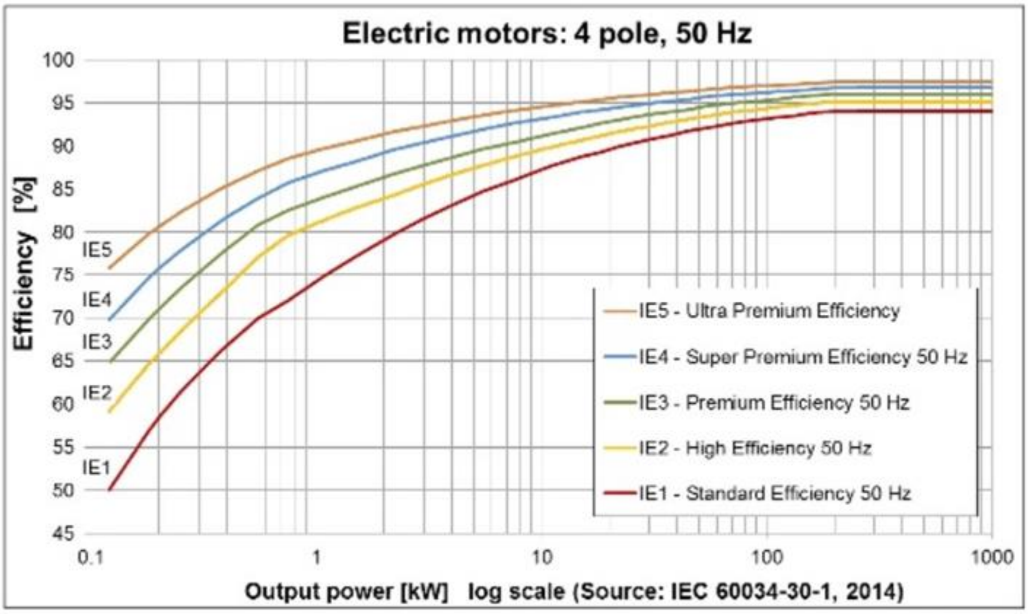

Figure 6. International standard efficiency level curves (IE-code) [9]

2. MATERIALS and METHODS

The first step in energy saving is the selection of suitable equipment. Mains values (supply voltage, number of phases, mains frequency), operation regime of the motor (such as continuous or interrupted operation), protection class of the motor, number of motor poles, rated motor power, rated torque of the motor, type of motor structure, environment according to the place to be used. The motor's physical conditions and efficiency class are the main topics to be considered in the motor selection. Each of the titles mentioned above effectively saves energy from the motor.

In this study, the Adana MDF facility, one of the 11 Kastamonu Entegre Co. that started operations in 2011, has been considered an exemplary model. Kastamonu Particle Board Plant (Kastamonu Entegre Co), established in 1969, produces wood-based boards, and with a consolidated turnover of 1.3 billion dollars, it ranks 1st in Turkey, 4th in Europe, and 6th in the world. It is the leader in the sector with its exports to more than 100 countries and ranks 46th among the largest industrial establishments in Turkey, according to the 2019 ISO 500 data [12].

In the motor efficiency calculations in the Kastamonu Entegre Co., Adana MDF facility, the instantaneous currents drawn by the motors were measured, and hourly consumption values were found, and accordingly, the load factors of the motors were determined. As the power increases in the motors, the efficiency increases, and the motor efficiency usually reaches the maximum level at 75% load. Depending on the condition of each motor, the load factor varies. Therefore, the actual consumption values of the motors used in the calculations are based on an average production capacity. For a three-phase asynchronous motor, the power can be found by the expression (1) depending on the phase-to-phase angle (φ), the mains voltage (U), and the current drawn from the mains (I).

$$P = \sqrt{3} \times U \times I \times Cos\varphi \tag{1}$$

The load factor (LF) can be obtained from the expression (2) depending on the motor nameplate power (Pm).

$$LF = \frac{P}{Pm} \tag{2}$$

The Annual Energy Savings (AES) to be obtained due to the efficiency difference between the high-efficiency motor (IE2) and the Premium-efficiency motor (IE3) are expressed with the expression (3).

$$AES = Pm \times LF \times AOH \times \left[\frac{1}{CME} - \frac{1}{NME}\right] \tag{3}$$

Here, AES represents the Annual Energy Savings (kWh/Year), Pm denotes the Motor Nameplate Power (kW), LF is the Load factor, AOH is theAannual Operating Hours (h), CME is the Current Motor Efficiency (%), and NME represents the New Motor Efficiency (%). The energy cost used in the facility is billed as 0.062 $/kWh [13], and the savings from the annual electricity bill can be obtained from the expression (4).

$$AEFV = AES \times EUP \tag{4}$$

Here, AEFV represents the Annual Energy Financial Value, AES denotes the Annual Energy Savings (kWh/Year), and EUP signifies the Energy Unit Price ($/kWh). The payback period (PP) can be determined with the help of the expression (5).

$$PP = \frac{NMP}{AES} \tag{5}$$

Here, NMP represents the New Motor Price. Figure 7, Figure 8, and Figure 9 show the characteristics of the IE2 efficiency class motors used in the Kastamonu Entegre Co., Adana MDF Facility, with a power of 18.5 kW in the B1 group, 15 kW in the B2 group, and 315 kW in the F1 group. Table 1 shows the annual energy consumption and energy costs of B1, B2, and F1 group motors.

Table 1. Characteristics of the considered IE2 motors

Motor Code	Motor Power Pm (kW)	Power Factor (Cosφ)	Motor Current (Amps)	Operating Time (hours)	Efficiency IE2	P (kW)	Load Factor	Annual Energy Consumption (kWh/Year)	Annual Energy Cost ($/Year)
B1	18,5	0,87	18	8200	90,3	10,84	0,586	88.861	5509
B2	15	0,86	16,5	8200	89,7	9,82	0,655	80.520	4992
F1	315	0,87	350	8250	95,7	210,96	0,67	1.740.400	107905

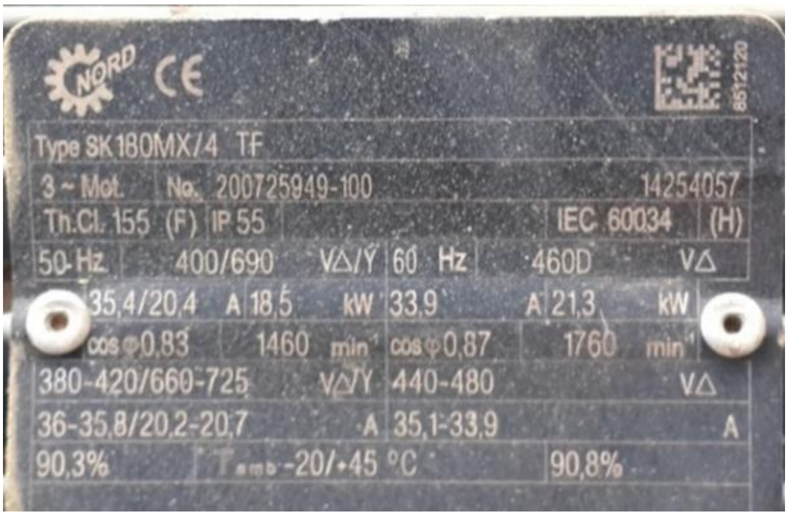

Figure 7. B1 group motor nameplate

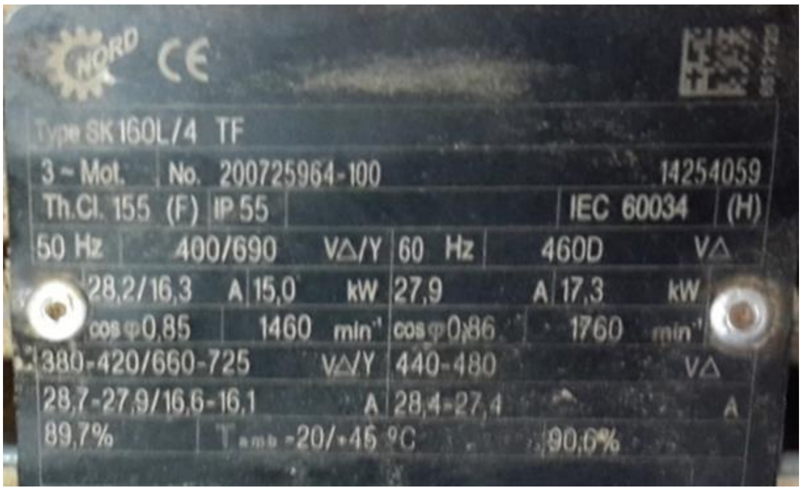

Figure 8. B2 group motor nameplate

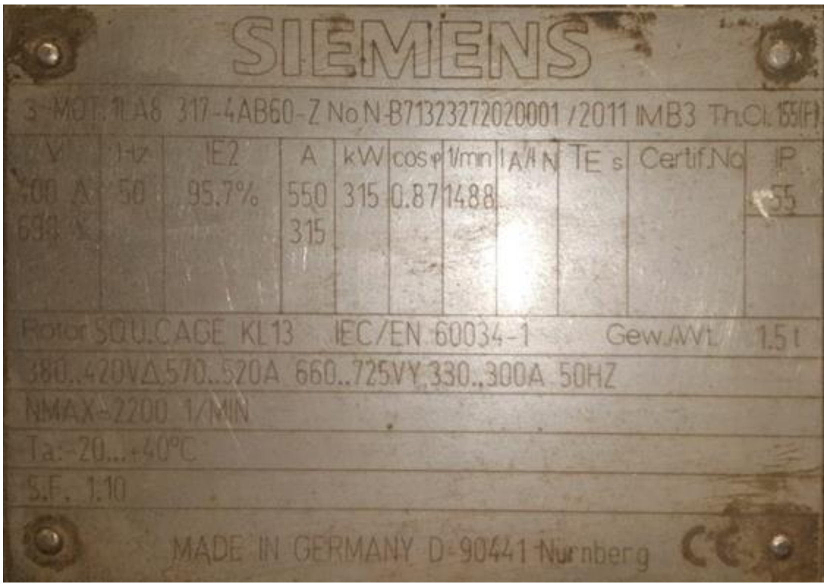

Figure 9. F1 group motor nameplate

3. FINDINGS

Most of the motors in the plant are in efficiency class IE2 and are controlled by the power control unit. The transition to motors in efficiency classes IE3 or IE4 is planned gradually. There are various motors in the facility with high powers, such as 9000 kW, 2200 kW, and 900 kW and powers such as 22.5 kW, 18.5 kW, and 0.75 kW.

The facility consists of 2 main production sections consisting of different lines. The motors considered in the study were selected from those commonly used throughout the facility. The wood chips cut into pieces in the wood shredding department are transferred to the silos where they are stored, and from there, they are transported to the fibering department in a tonnage determined according to the amount of production. This transport process is carried out by 2 conveyor belts that continue each other and two motors with 15 kW and 18.5 kW power that provide the movement of each of these belts. After the fibering process, the fibers dried with hot air are separated according to their sizes with the help of air. There are 2 fan motors with a power of 315 kW that provide airflow in this section. The current values drawn by the motors during operation at average capacity were measured, and the load factors of the motors were calculated. The gains and the payback periods of the motors whose efficiency class has been changed are shown in Table 2.

Table 2. The gains and payback periods provided by the motors whose efficiency class has been changed

Motor Code	Motor Power Pm (kW)	Operating Time (hours)	Efficiency IE3	Load Factor	Annual Energy Savings (kWh/Year)	Annual Savings ($)	IE3 Motor Price ($)	Payback Period for Current Working Conditions (Years)	Payback Period for 75% Load Factor Conditions (Years)
B1	18,5	8200	92,1	0,586	**1.923**	**119**	598	**5,01**	**3,91**
B2	15	8200	92,1	0,655	**2.340**	**145**	573	**3,95**	**3,45**
F1	315	8250	96,7	0,67	**18.815**	**1.167**	10122	**8,68**	**7,75**

Figure 10 shows that after the B1 group 18.5 kW electric motor is replaced with IE3 motor, it will provide an annual energy saving of 1923 kWh, and the payback period will be 5,01 years. After the B2 group 15 kW electric motor is replaced with an IE3 motor, it is seen that it will save 2340 kWh annually, and the payback period will be 3.95 years. It is seen that after the replacement of the 315 kW electric motor of the F1 group with the IE3 motor, an annual energy saving of 18815 kWh will be achieved, and the payback period will be 8.68 years. The replaced motors' scrap costs were not considered in the calculations.

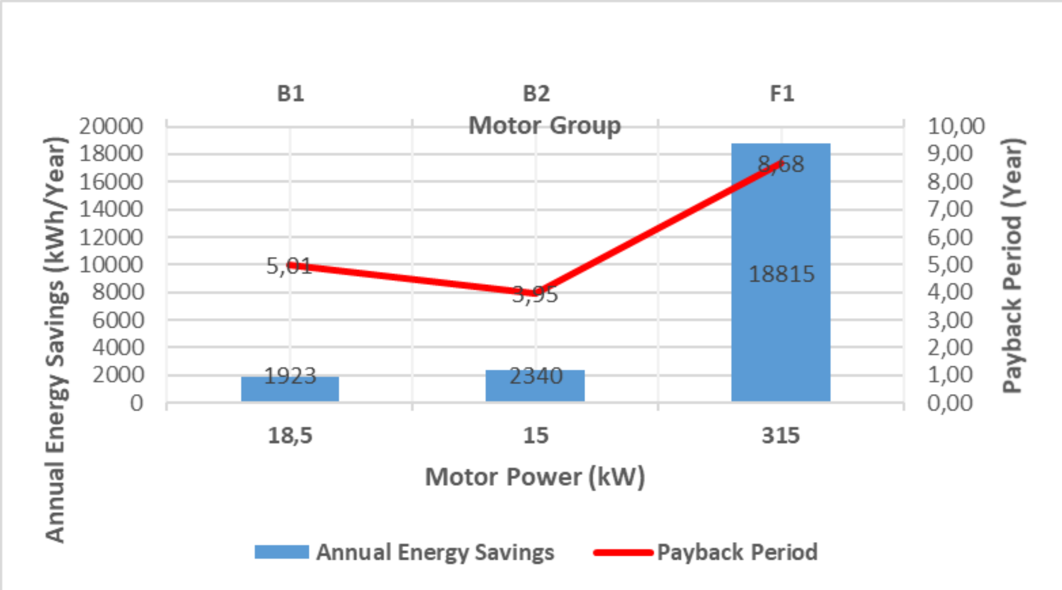

Figure 10. Energy savings and payback periods of motors replaced with IE3 efficiency class

As an alternative scenario, if these calculations are made by considering the 75% load factor, The payback period of the B1 group (18.5 kW) electric motor will be 3,91 years, the B2 group (15 kW) electric motor will be 3,45 years, and the F1 group (315 kW) electric motor will be 7,75 years, respectively.

4. RESULTS

In this study, 2 belt motion motors were examined for an energy efficiency project example, and the amount of savings, financial compensation, and payback periods were calculated for each motor.

Suppose the B1-coded motor with IE2 efficiency class is replaced with an IE3 efficiency class motor. In that case, the energy saving is 1923 kWh/Year, its financial equivalent is 119 $/Year, and the payback period is 5,01 years. The energy saving in the B2-coded motor is 2340 kWh/Year, its financial equivalent is 145 $/Year, and the payback period is 3,95 years. In the F1-coded motor, the energy saving is 18815 kWh/Year, the financial equivalent is 1167 $/Year, and the payback period is 8,68 years. While calculating the payback periods, the replaced scrap pumps' profit is not considered.

Notably, the amortization periods are longer when compared to the studies conducted for different conditions in the literature. Although periods longer than 5 years are not preferred for depreciation periods, it can be evaluated that this situation results from both the change in the efficiency of the motors depending on the load factors and the decrease in the efficiency difference, especially between the motors with high power.

Acknowledgement

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Conflict of Interest Declaration

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study complies with research and publication ethics.

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