Efficient and Effective Use of Energy: a Case Study of TOFAS

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In this study technical and economical analysis of energy efficiency application to high efficient motors has been done. For this purpose, first of all, the motors with known power and working time which are used by Tofas Turkish Automobile Factory, the largest car manufacturer in Turkey, have been examined. Research of the high efficient motors that will replace the chosen engines has been done and financial statement on their use has been analyzed. In the first step, 158 selected motors have been examined. It has been determined that high efficient motors of a new generation will amortize themselves in 30 months. 14 motors have been eliminated from this replacement procedure because amortization period would be too long to them. Under these circumferences, amortization period will decrease to 16 months for the rest of new motors.

Key words: *Efficiency, high efficient motors, energy efficiency.*

1. Introduction

Today, it is seen that fossil fueled energy resources are being readily exhausted, and still, there is a significant increase in energy use. Although the relationship between usage and reserves causes a dramatic growth in energy costs, it points out to the requirement for the optimal use of available resources.

All over the world among such subjects as climate change caused by global warming, energy and environment security, the efficient and effective use of energy plays an important role.

Without sacrificing the quality of life and production, energy savings can be achieved by means of energy efficiency. The energy to be saved is domestic and clean source of energy whose price is cheap and which should be turned to (Jollands et al. 2009).

We have saving potentials of at least 15% in our industry, at least 35% in our premises and at least 15% in our transportation costs. The energy value when we recover these potentials is higher than the energy we can generate from our renewable energy resources. If we can take steady and successful steps towards energy efficiency, by 2020 we can reduce energy demand by at least 20% (equivalent to 45 million tons of oil). This amount is 2.5 times the electrical energy we can generate from our domestic and clean energy sources and covers the energy requirement of 30 million average households (Senyurt 2009, Eie 2009, Akova 2009, Topal&Umurkan 2009, Eris 2009).

In 2007 in our country, "The Energy Efficiency Act" came into force; "The National Energy Efficiency Action" was initiated by Prime Minister's Circular No 2008 / 2 with participation of public, private and non-governmental organizations and the year 2008 was declared " The Energy Efficiency Year ". Within the scope of the national energy efficiency action, to develop energy culture and efficiency awareness in the society, collaboration environments based on the sense of social responsibility are being developed with ministries, governorates, metropolitan municipalities, lighting, appliances, electric motors and insulation industries, banks, tourist facilities and shopping centers (Satman 2009,Onaygil 2006). Distribution of electrical energy used in Turkey can be seen in Figure 1.

Considering the amount of energy used in various applications in our country, it is clear that the largest share is consumed by industry with approximately 68000 GWh. This figure corresponds

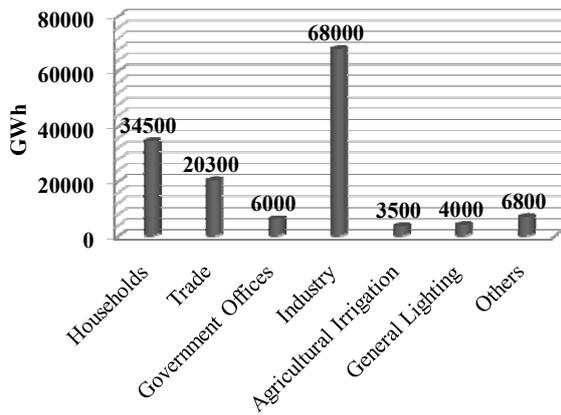to 48% of net electrical energy consumption in Turkey.

Fig. 1. *Distribution of electrical energy used in Turkey. Based on EIE 2008*

Although there are differences from sector to sector, approximately 70% of electricity consumed in industry is used in electric motor systems. Three-phase alternating current asynchronous motors comprise 90% of the electric motors in use. Such intensity in the amount of consumed energy draws attention to this area in the activities of energy-saving and efficient use of energy. The usage areas of energy demanded throughout Turkey can be seen in Figure 2.
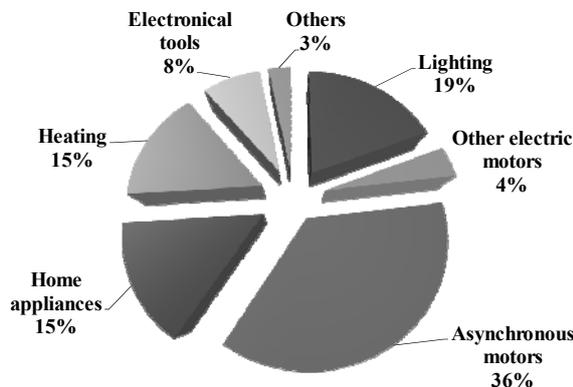

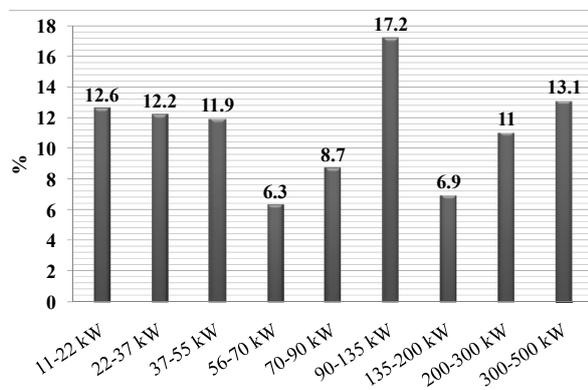Fig.2. *Usage areas of energy demanded throughout Turkey. Based on EIE 2008*

Fig.3. *Power distribution among electric motors used in industry. Based on EIE 2008*

Asynchronous motors are available in various efficiency classes. The European Committee of Manufacturers of Electrical Machines (CEMEP) and declaration of the European Commission, dated on 28 June, 1999 divided the motors according to their efficiency classes. Power distribution among electric motors used in industry can be seen in Figure 3.

There are high efficiency motors (EFF1), motors with improved efficiency (EFF2) and low-efficiency motors (EFF3). By the voluntary agreements concluded by CEMEP with motor manufacturers, it has been decided that the low-efficiency motor (EFF3) production shall be limited. In addition, with growing energy demand in the world, many countries have tried to ensure voluntary or mandatory use of higher efficiency motors.

Efficiency, which is defined as the ratio of output power from the motor to input power consumed by the motor and reflected in the cost, is in fact indicative of the losses occurring in the motor. By the savings to be made in 1% of the amount of energy consumed by asynchronous motors in the entire world, 20 billion kWh per annum of energy can be recovered and this energy is equal to the energy obtained from 36.5 million barrels of petroleum. Table 1 includes the motor efficiency classes according to CEMEP.

Significant cost advantage by a small amount of savings has forced the countries to enact the use of efficient motors and led them to raise awareness of this issue in the society. As a result of this, a rapid increase in the rate of efficiency motor use in Europe, especially in recent years, can be seen (Satman et al. 2009, Onaygil 2006, Colak 2008, Serifoglu 2007).

In the examination carried out by the Electrical Power Resources Survey and Development Administration (EIE) on 2500 motors used by 25 entities on efficiency classes of electric motors used in our industry, the utilization rates of motors belonging to EFF3, EFF2 and EFF1 efficiency classes were found to be 85%, 14% and around 1%, respectively.

While the energy saved by increasing energy efficiency is the most economical resource, resource to be gained by increasing efficiency in electric motor systems is equivalent to twice the energy production of KEBAN Power Plant which has an annual generation capacity of 7950 GWh.

The Ministry of Energy and Natural Resources of the Republic of Turkey has also taken the decision to support to a certain extent the efforts to increase productivity in enterprises in this context and in this regard it started allocating funds for the accepted projects. € 1793721.97 of € 2242152.46 which are the total amount payable allocated to the "Electric Motor Systems".

All of these aspects led to emphasis of replacement of current systems with high efficiency motors to make savings in energy spent on electric motors (Hornfeld 2009, Eldem 2009, Onaygil et al. 2009).

In this study, energy efficiency to be provided to electric motors was enlightened by examining the
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existing motor systems and evaluating the results that emerge if these systems are replaced with high-efficiency motors. By means of this study the possibility to achieve high efficiency and due to

optimization to gain it in new generation motors has been emphasized.

Table 1.   Motor efficiency Classes according to CEMEP

Output Power (kW)	two-pole motors (%)			four-pole motors (%)		
	EFF1	EFF2	EFF 3	EFF 1	EFF2	EFF 3
1.1	>= 82.8	>= 76.2	< 76.2	>= 83.8	>= 76.2	< 76.2
1.5	>= 84.1	>= 78.5	< 78.5	>= 85.0	>= 78.5	< 78.5
2.2	>= 85.6	>= 81.0	< 81.0	>= 86.4	>= 81.0	< 81.0
3	>= 86.7	>= 82.6	< 82.6	>= 87.4	>= 82.6	< 82.6
4	>= 87.6	>= 84.2	< 84.2	>= 88.3	>= 84.2	< 84.2
5.5	>= 88.6	>= 85.7	< 85.7	>= 89.2	>= 85.7	< 85.7
7.5	>= 89.5	>= 87.0	< 87.0	>= 90.1	>= 87.0	< 87.0
11	>= 90.5	>= 88.4	< 88.4	>= 91.0	>= 88.4	< 88.4
15	>= 91.3	>= 89.4	< 89.4	>= 91.8	>= 89.4	< 89.4
18.5	>= 91.8	>= 90.0	< 90.0	>= 92.2	>= 90.0	< 90.0
22	>= 92.2	>= 90.5	< 90.5	>= 92.6	>= 90.5	< 90.5
30	>= 92.9	>= 91.4	< 91.4	>= 93.2	>= 91.4	< 91.4
37	>= 93.3	>= 92.0	< 92.0	>= 93.6	>= 92.0	< 92.0
45	>= 93.7	>= 92.5	< 92.5	>= 93.9	>= 92.5	< 92.5
55	>= 94.0	>= 93.0	< 93.0	>= 94.2	>= 93.0	< 93.0
75	>= 94.6	>= 93.6	< 93.6	>= 94.7	>= 93.6	< 93.6
90	>= 95.0	>= 93.9	< 93.9	>= 95.0	>= 93.9	< 93.9

2.   Efficiency of asynchronous motors

The methods used in efficiency calculation of asynchronous machines are listed below.

Energy saving = motor power (kW) · load factor · operating hours·[(1/Efficiency$_{old}$–efficiency$_{new}$)]

Cost Savings = Energy Savings · Energy Price

Repayment period = Investment Cost / Energy Cost Savings

2.1. Electrical motor efficiency when shaft output is measured in watts

If power output is measured in watts (W), efficiency can be expressed as:

$$\eta_m = P_{out} / P_{in} \qquad (1)$$

where:

η_m - motor efficiency;
P_{out} - haft power out (watt, W);
P_{in} - electric power in to the motor (watt, W).

2.2. Electrical motor efficiency when shaft output is measured in horsepower

If power output is measured in horsepower (hp), efficiency can be expressed as:

$$\eta_m = P_{out} \, 746 / P_{in} \qquad (2)$$

where:
P_{out} - shaft power out (horsepower, hp);
P_{in} - electric power in to the motor (watt, W).

2.3. Losses

Losses can be classified as follows:
–   Primary and secondary resistance losses: The electrical power lost in both primary rotor and secondary stator winding resistance is also called copper losses. The copper loss varies with the load in proportion to the current squared and can be expressed as

$$P_{cl} = R \, I^2 \qquad (3)$$

where
P_{cl} - stator winding - copper loss (W)
R   - resistance (Ω)
I   - current (Amp)

–   Iron losses: These losses are the result of magnetic energy dissipated when the motor's magnetic field is applied to the stator core.
–   Stray losses: Stray losses are the losses that remain after primary copper and secondary losses, iron losses and mechanical losses. The largest contribution to the stray losses is harmonic energies generated when the motor operates under load. These energies are dissipated as currents in the copper windings,

harmonic flux components in the iron parts, leakage in the laminate core.
- Mechanical losses: Mechanical losses include friction in the motor bearings and the fan for air cooling (Colak 2008).

3. TOFAS

Having been founded in 1968 by late Vehbi Koç, the founder of Koç Group of Companies, currently being equally controlled by Koç Holding and Fiat S.p.A., TOFAS is one of the Fiat Auto 3 strategic production centers worldwide today. TOFAS symbolizes great value and power without an argument within the Turkish Automotive Industry and is a global player who holds the title of being the only establishment of Koç Holding manufacturing passenger cars which are exported from our country to the whole world through its compact sedan model Fiat Linea, in addition to the models such as Doblo and Fiorino that represent the Fiat branded face of Minicargo Project manufactured in Bursa plant.

Within the scope of the vision "to be the most competitive and self-sufficient passenger car and commercial vehicle development center of Fiat until 2010", Tofas owns the biggest R&D center in the Turkish Automotive Sector. TOFAS is one of Fiat's 2 biggest centers in Europe and 3 in the world (Tofas 2011).

4. TOFAS and its high efficiency motors

First of all, updating of the motor range was performed in the factory. As can be found from the issues explained up to this paragraph, it is very important that the motor to be changed is between certain powers and operates under continuous and constant load. Given these considerations, the four sections in TOFAS are found to be ideal. These sections are "Thermal Power Plant", "Treatment Plant", "Repair Workshop" and "R&D".

The total number of 3-phase asynchronous motors in these four-sections is 266. Out of these 266 motors, the motors below 1.1 KW and over 160 KW, together with motors operating below 1000 rpm were excluded from the application. The reason lies in the fact that the motor prices outside this spectrum are not economical under the conditions of our country. After this exclusion 158 motors remained and efficiency enhancement project (EEP) was performed on them.

Since the factory is in the working order of 3 shifts and sometimes this number may fall down to 2 or 1 shift, daily working hours of the motors in these sections were taken 12 hours.

First, efficiency values of the motors found suitable to EEP were determined. Then, high-efficiency motors that could be used instead of these motors were selected according to load and speed of the existing motors and the amount of annual savings

was calculated over the efficiency values of old and new motors. While calculating scrap, current scrap purchase price in the market was taken as the basis.

After all calculations the cost of new motors has been calculated to be € 120851.88. Scrap purchase price of the old motor is € 6986.36. Total investment cost is € 113865.51. For gain calculations, electricity price of 1 kWh has been regarded as € 0.08 and total energy savings per year have been calculated as 577716 kWh. By considering all these values, total financial gain per year has been found € 47246.25 and total financial gain per month - € 3937.1. The repayment period has been calculated 28.92 months.

In this application, 1 Euro has been calculated as 2.201Turkish Lira (TL). As can be seen from the feasibility resulting from the application, the costs of the motors with a power over 55 KW are much higher than those of the motors with a power below 55 KW. Considering the costs and annual profits of these motors, it appears that their annual profit rates are lower than annual profit rates of the motors below 55 KW.

When 14 motors with a power over 55 KW were excluded from feasibility and the feasibility values were re-calculated; the values obtained can be seen in Table 2.

Table 2.   Results of re-calculation

New Motor Cost	€ 52674.24
Scrap purchase price of the old motors	€ 3900.5
Total Investment Cost	€ 48773.74
Total energy savings per year	456227 kWh
Total financial gain per year	€ 34856.88
Total financial gain per month	€ 2904.74
Repayment Period	16.79 months

Reason for mentioning this point is the fact that the amortization period of 30 months can be evaluated as a long period for some companies. Today, an amortization period of 16 months is an ideal period of time for medium sized or bigger sized companies.

5. Conclusions

Energy efficiency is crucial in today's world. Energy efficiency is financially essential and important to our world which suffers due to global warming and the greenhouse effect.

As can be seen from this study, the most effective result may be achieved when efficiency enhancement projects are applied to asynchronous motors. It has been enlightened by examining the existing motor systems and evaluating the results emerging when old motors are replaced with the most suitable high-efficiency ones. It has been clearly indicated that high efficiency and gain can be achieved by means of optimizing new generation motors.

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Efektyvus energijos naudojimas – „Tofas" pavyzdys

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Straipsnyje aprašoma didelio našumo variklių energijos efektyvumo didinimo ekonominė ir techninė analizė. Šiam tikslui nustatyto našumo varikliai buvo tirti Turkijos automobilių gamykloje „Tofas". Atliekant tyrimą, buvo vykdomas finansinis vertinimas, siekiant įvertinti naujų efektyvių įrenginių atsipirkimo trukmę.