HIGH-EFFICIENCY ELECTRIC MOTORS: AN ANALYSIS OF A FEASIBLE TARIFF POLICY FOR BRAZIL

Marco Antonio de Paiva Delgado
Ph.D Candidate in the Energy Planning Program-COPPE/UFRJ

Maurício Tiomno Tolmasquim
Professor in the Energy Planning Program-COPPE/UFRJ

ABSTRACT

The main objective is to calculate an average value for an electricity tariff which will facilitate the introduction of high-efficiency electric motors in the production sector. Two computational models will be developed for technical-economic evaluation to assess economic attractiveness by calculating feasible average electricity tariffs in order to create a market for substitution of standard motors by new high-efficiency models (Purchase Decision Model) as well as to determine if retrofitting of standard installed motors by others with high-efficiency characteristics is viable, and, if so, to specify the optimum timing for such substitution (Substitution Decision Model). It should be noted that the Purchase Decision Model takes into account power factor adjustment and the Substitution Decision Model incorporates considerations as to reduction in the electromechanical performance of operating motors. Results indicate that even where average electricity tariffs are low, as in Brazil, high-efficiency motors are economically attractive compared to standard motors. There is an obvious need for complementary instruments to assist massive market penetration.

INTRODUCTION

Despite the economic, environmental and social benefits resulting from more efficient use of energy, energy waste indices in Brazil are still reasonably high, with low tariffs being singled out as the major obstacle to improvement.

The purpose of this paper is to assess the validity of the argument that relatively low electricity tariffs are a major obstacle to improved energy efficiency. In this connection, a technical-economic feasibility analysis of high-efficiency electric motors will be undertaken from the user's perspective, with a comparison to existing conventional models. The decision was based on the following factors: - high participation of standard motors in overall electricity consumption (approximately 55% of total electric power used in industry) and widespread use in the various industrial sectors, - small demand for high-efficiency electric motors in the domestic market (less than 1% of sales of electric induction motors)[1] and the fact that almost all domestic production is exported.[1]

There will be two aspects to the analysis: **Purchase Decision**, a choice between standard electric motors or high-efficiency models within the context of a new installation, and **Substitution Decision**, when a motor, installed and in operation, is retrofitted by an efficient one. Furthermore, in the specific case of Brazil, special attention is given to the practice of rewinding failed electric motors as an alternative to the purchase of new high-efficiency models.* A sensitivity analysis will be performed according to the various types of industrial operation, with respect to the rated life of the equipment and loading of the machines, as well as cost

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*In Brazilian industries in general, when electrical motors are not operational due to burnt windings, they are refurbished, i.e., the insulation is changed and the motor is rewound and put back into operation. Consequently, there is a tendency for the mechanical and electromagnetic losses to increase, increasing operational costs of these machines. The main reason for this is that the cost of refurbishing is roughly 30% to 40% of the cost of an equivalent new standard motor[2].

variations. The main focus of the analysis of the Purchase Decision is the relationship between average electricity tariffs, calculated by means of models, and those actually observed. The results of these comparisons will confirm the advantages or disadvantages of investing in the improvement of energy efficiency. The analysis of the Substitution Decision seeks to determine optimum timing for substitution of standard motors by high-efficiency models, based on average simulated tariffs*. Parameters for economic analysis used in simulations take into account the cost of adjusting the power factor in connection with the different types of motors which compete in the Purchase Decision analysis and reduced performance in relation to the length of use within the context of the Substitution Decision.†

ECONOMIC-FINANCIAL MODEL FOR TARIFF EVALUATION

The first objective of this analysis is to calculate average electricity tariffs which would make energy efficiency feasible with minimum investment, by using techno-economic feasibility simulation models. This approach is based on the Present Value methodology, for a series of constant payments. The second objective is to determine the optimum period for replacing motors in operation by high-efficiency models using the Equivalent Annual Uniform Value method for minimum investment conditions.

Analysis of Purchase Decision Options

Using the Present Value Method (PV), (Equation 1), the purpose of the analysis is to determine the minimum tariff which favours the acquisition of high-efficiency electric motors instead of standard motors, in compliance with minimum established levels for rates of attractiveness and for return on investment by the end of the rated life of the equipment.‡

$$PV = -[Cm_{he} - Cm_{s} - Ca_{PF}] + \sum_{t=0}^{n} Es(1+i)^{-t} \qquad (1)$$

where:

Cm_{he} - cost of high-efficiency motor
Cm_{s} - cost of standard motor
Ca_{PF} - cost for the adjustment of the power factor (defined below)
i - attractiveness rate
n - planning horizon
Es - energy savings due to reduced consumption in relation to the difference in performance.

The above equation considers the energy savings to be constant throughout the time period t, the assumption being that the electromechanical performance of both standard and high-efficiency motors decline according to the same pattern. The energy saving is equal to the difference between the costs of electricity for standard and for high-efficiency motors under the same conditions of operation and maintenance.

It is also assumed that both types of electric motors (standard and high-efficiency models) are competitive alternatives for the same purpose, their respective mechanical power, load and hours of operation being

*Average tariffs for September 1995 will be used for subgroups A1 and A4, since the price of the electrical motors analyzed were surveyed at about that time.

†According to HERSZTERG (1996)[3], in several cases of substitution of standard electrical motors by energy-efficient models, there is a need for adjustments to transmission and driven load to prevent loss of improvement level due to surplus dimensioning. The cost for adjusting the load varies from 10% to 20% of the cost of the high-performance motor. Thus, 15% will be added in the simulations to the value of high-performance motors for replacement purposes.

‡10 years of operation will be considered.

presumed equal[*]. The difference between the energy cost and consequent electricity saving is thus provided by the difference in electrical performance between the two types of motors (Equation 2)

$$Es = \left(\frac{\eta_{he} - \eta_s}{\eta_{he} \times \eta_s}\right) \times \left(P \times l \times h \times At\right) \tag{2}$$

where:

P - nominal electric power (kW)
l - motor load (0,1)
h - total working hours within the period considered[†]
At - average tariff[‡]
η_{he} - electromechanical conversion efficiency of high-efficiency motors
η_s - electromechanical conversion efficiency of standard motors

With respect to the parameters and technical characteristics of relevant electric motors for economic evaluation, in addition to their electromechanical performance, the Power Factor (PF) differs for standard and high-efficiency motors. In this simulation, the economic impact of this difference will be incorporated into the initial cost, in the form of investment required to maintain the parity of the power factors for the two competitive types of motor. The high-efficiency motor is presumed to have a PF X and the standard motor PF Y, such that $X > Y$. Thus, the cost of adjusting the PF for standard motors in order to achieve parity with the high-efficiency models will be incorporated into the initial investment in both cases - purchase and substitution. It should be noted that in some cases the PF of standard motors is higher than that of the high-efficiency varieties, thus increasing the cost difference between the two technologies.[§] It is also important to note that almost all standard and high efficiency model electric motors have a power factor lower than 0.92 (minimum according to Brazilian legislation) to 75% load, which causes them to be penalised due to low power factor. This simulation is not concerned with eliminating the low power factor penalty, but with adjusting economic terms in relation to the difference between the respective power factors of the motors under analysis (high-efficiency, standard and rewound[**]); i.e. to find the cost adjustment necessary to equalise the reactive power required by the motors; this cost to be incorporated into the initial investment of the Purchase Decision model.

Calculation of the cost adjustment for the power factor is determined by Equation 3:

$$Ca_{PF} = \left(Q_s - Q_{he}\right) \times Cc_{PF} \tag{3}$$

where:
Ca_{PF} - Cost for adjustment of the power factor (US$)
Q_{he} - Reactive inductive power of high-performance motors (kVAr)
Q_s - Reactive inductive power of standard motors (kVAr)
Cc_{PF} - Cost of adjusting the power factor per kVAr (US$/kVAr)[††]

Reactive power can be calculated with the help of the formula based on the trigonometric relations within the power factor triangle. When applied to Equation 3, we have Equation 4:

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[*] Furthermore, ideal operating conditions are presumed, comprising correct dimensioning and proper maintenance.

[†] The price of electricity refers to a specific period, defined by the total operating hours per month or year.

[‡] In this simulation, average tariff values will be determined, i.e. instead of working with a binomial tariff (composed of the electrical power demand tariff, measured in kW and the average tariff for energy consumption, measured in kWh). In other words, total cost of electric power in monetary value divided by consumption.

[§] In Brazil, the public utilities charge for active energy includes the excess reactive power resulting from a consumer installation power factor below 0.92 (until 1992, the minimum value was 0.85 and only for inductive reactive power).

[**] Considered a variation of the standard motor, with a lower performance and power factor.

[††] US$ 40.00 per kVAr is taken as the average cost for Power Factor correction, considering project, equipment and assembly costs.

$$Ca_{PF} = \left[P \times l \times \left(\frac{tg(arccos(PF_s)}{\eta_s} - \frac{tg(arccos(PF_{he})}{\eta_{he}} \right) \right] \times Cc_{PF} \tag{4}$$

Thus, the cost of adjusting the power factor is included in the models by subtracting the cost relative to the different technologies, such that if $Qs > Qhe$, from the initial investment, and standard motors will have an additional cost for a lower power factor than high-efficiency motors, while the opposite will occur when $Qs < Qhe$.

By applying Equation 2 and 4 to Equation 1 and making PV equal to zero, it is possible to determine an average minimum value tariff conducive to the purchase high-efficiency motors (Equation 5) :

$$At = \frac{\left[Cm_{he} - Cm_s - Ca_{PF} \right]}{\left[(P \times l \times h) \times \left(\frac{\eta_{he} - \eta_s}{\eta_{he} \times \eta_s} \right) \times \left(\sum_{t=1}^{n} (1+i)^{-t} \right) \right]} \tag{5}$$

Analysis of Substitution Decision for Operating Equipment within its Rated Life-span

Hitherto, the analysis has focused on considerations for deciding in favour of purchasing high-efficiency motors as new equipment, the indicator being the relationship between the calculated tariff and average market tariffs. From this point forward, the analysis will be complemented by determining the economic life-span of the motors and by estimating the optimum date for substitution of standard electric motors in operation by alternative high-efficiency models. Following HESS *et.al.* (1992)[4], "The problem is to determine if the benefits of the substitution offset the requisite investment costs. The objective is to compare cash flows with and without the proposed substitution, for purposes of making the best decision." Substitution is prompted by technological development (high-efficiency replacing standard motors) and by the natural wear and tear of the equipment, responsible for a gradual reduction in efficiency and concurrent increase in operating and maintenance costs*. Thus, two decisions are possible. One relative to the feasibility of substitution, i.e. whether the equipment will be replaced or not. The second, when the first decision is positive, will focus on the timing of the substitution (where the useful economic life-span of the equipment is determined).

In order to determine economic life-span, it is first necessary to compute the operating cost of the equipment for different periods (normally up to the end of its rated life). Having determined these costs, the period yielding the lowest annual cost will be considered the economic life-span of the equipment (electric motors in this case). The cost of keeping a given equipment in operation in year k is normally (Ca_k) separated into capital costs in year k (Cc_k) and operating and maintenance costs in year k† (Co_k).

$$Cc_k = (Cm - Rv) \times CRF(i,k) + Rv \times i \tag{6}$$

$$Co_k = d_1 + G \times GF(i,k) \tag{7}$$

where:

Cm	- cost of motor in operation
k	- year analysed (simulating each year [1, 10])

*In this simulation model, it is important to note that: - the cost for adjusting the power factor was not taken into consideration since there is no increase in the electricity load in the existing installation and it is assumed that the user is not penalized for a low power factor; - the residual equipment value (*Rv*), determined by the current market value of the motor when sold as scrap (10% of the value of new motors), is taken to be constant for the whole period under analysis. This consideration was imposed in order to avoid the re-utilization of inefficient equipment;

†Maintenance costs are not considered here, due to lack of data. The estimate is conservative.

d_n	- electricity expenses* for operating the motor in year n
$CRF(i,k)$	- capital recovery factor
G	- constant increase in the operating costs of motor in relation to the reduction in electromechanical performance†
$GF(i,k)$	- gradient factor

Thus the minimum Ca_k between Ca_1 and Ca_{10} will indicate the economic life-span of the motor, i.e. the year k for the optimum substitution of the motor in operation by an identical new one.

In order to analyse the substitution of standard motors by high-efficiency models, it is first necessary to compare the minimum annual cost of the two motors. Substitution will be favoured only when the minimum annual cost of high-efficiency motors is lower than the minimum annual cost for standard models. However, it must be noted that, even if replacement of a standard motor by a high-efficiency model is deemed favourable, this does not mean that immediate action is required. According to HESS et. al. (1992)[4]. "The problem involves a long term decision (replacement) and a short term one (when)." The first can be based on a comparison between minimum annual costs of both types of motors, while the second requires a comparison between minimum annual costs for the high-efficiency motors and costs of maintaining installed motors in operation for a longer period. To replace present motors entails: incurring costs equivalent to the minimum annual cost for high-efficiency motors in the years following the substitution. To maintain the installed motor (considering year j) for another year ($j+1$) implies: - to invest the residual value of the motor that could be obtained through its sale in year j; - to spend d_j in operating expenses; and to appropriate the residual value of the motor in year ($j+1$). Thus, maintaining the present motors involves a cost expressed by Equation 9:

$$C_k = \left[Rv_k \times (1+i)\right] + \left[Co_k\right] - \left[Rv_{(k+1)}\right] \tag{8}$$

Since Rv is constant throughout the considered interval:

$$C_k = \left(Rv \times i\right) + \left(Co_k\right) \tag{9}$$

Finally, year k, when C_k of the installed motor is greater than the minimum annual cost for the high-efficiency model, will be the optimum date for substitution.

SIMULATED SCENARIOS FOR PURCHASE AND SUBSTITUTION MODELS FOR ELECTRIC INDUCTION MOTORS

Relevant Parameters for Evaluating and Selecting Motors

In view of the large number of electric induction motors on the market, only the most popular models have been selected for simulation purposes, particularly those responsible for the greater share of energy consumption. Also, for simulation purposes, only models of electric motors for general use will be taken into consideration. Table 1 provides data related to domestic market sales and their share in total installed capacity of three-phase motors, according to power range. It should be noted that induction motors represent approximately 78% of all three-phase motors installed in Brazil.[10]

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* Defined as electricity cost ($dk = (Pi/(\eta) \cdot i \cdot h \cdot At$).

† We have considered an annual decrease in electromagnetic performance of 0.4 points for the high-performance motor and of 0.5 points for the standard motor (According to a verbal report, kindly provided by Prof. Shiesko, from the Mechanical Engineering Course in UFRJ, Rio de Janeiro, and to [5, 6, 7, 8] and [9]).

Table 1 - Sales and Share of Total Installed Capacity of Electric Three-phase Induction Motors by Power Range -1995 [10],[11]

Power (hp)	Sales[a]	Capacity (%)
0 - 1	328.353	2
1 - 10	537.678	38
10 - 40	77.947	26
40 - 100	14.544	14
100 - 300	4.951	12
TOTAL	963.473	92

Source: our own work using data from ABINEE, 1995 and GELLER, 1994

a - 1994 domestic sales

The three-phase electric motors covered by the 1996 Energy Efficiency Seal Program* have been taken as reference for the selection: 1 HP, 2 HP, 5 HP, 7.5 HP and 10 HP, in addition to the average power models according to the ranges: 25 HP, 75 HP e 200 HP.

The two tariff simulation models require input data for the technical, economic-financial and operation-related parameters, determined as follows:

- **Technical**: motor power (HP), speed (RPM), useful life-span (months), power factor and efficiency level of high-efficiency and standard motors (for the rewound motors, an automatic percentage drop of 4% in both efficiency and power factor relative to new standard motors is adopted.) [5],[12]
- Economic-financial: the cost of high-efficiency†, standard and rewound motors‡ (US$) and the minimum attractiveness rate for investment. The useful life-span of the equipment was adopted as the planning horizon (120 months). The average market tariff has only been used for the Substitution Decision.
- Operation-related: motor load, daily operating hours and monthly operating days parameters are used for all months of the year.

Sensitivity Analysis

In order to make the average tariffs of the simulation more realistic, we chose to work with four simulation scenarios, using the minimum attractiveness rate and load factor§ of operating motors as controls. Simulations were performed for the following scenarios:

1 - Attractiveness rate of 20% per year and a load factor of 0.244
2 - Attractiveness rate of 40% per year and a load factor of 0.244
3 - Attractiveness rate of 20% per year and a load factor of 0.578
4 - Attractiveness rate of 40% per year and a load factor of 0.578
5 - Attractiveness rate of 20% per year and a load factor of 0.833
6 - Attractiveness rate of 40% per year and a load factor of 0.833

* An award given by the National Program for Electricity Conservation for the most energy-efficient equipment in specific categories.

†6 Electric motor prices are manufacturers' retail prices. It should be noted that rebates of approximately 30% on the list price can be obtained if purchased directly from the manufacturer and, in certain cases, distributors will authorize rebates of 15%. Consequently, simulation results will tend to make investment in substitution more attractive. Simulations for the Substitution Decision will be conservative for users who benefit from these rebates.

‡The average cost of rewinding is within 30 to 40% of the price of a new standard electric motor.

§The utilization factor could also be employed. In this case, LF indicates the degree of utilization of the equipment, varying from 0 to 1. The load factor is defined as the ratio between actual energy consumption for a given period and the product of the power demanded by the duration of the entire period under analysis. The 0.244 load factor represents users which operate in only one shift; 0.578 for 2 shifts and 0.833 for three shifts.

It should be noted that where the user is much above the power factor limit value of 0.92, the cost for adjusting this factor will not be of interest from a financial standpoint. We therefore decided on two environments for each scenario described. The first environment designated as _a_, will not take into account the cost of adjusting the power factor, while environment _b_ will take it into consideration. There are therefore twelve final scenarios (a_1, a_2, a_3, a_4, a_5, a_6, b_1, b_2, b_3, b_4, b_5 e b_6) to simulate the Purchase Decision.

For the Substitution Decision, simulations will be made using average tariffs for tariff subgroups A4 and A1*. Finally, since efficiency, power factor and cost vary according to the rotational speed of the motor, simulations will be performed for 3600 RPM and 1800 RPM† motors, for each power level.

CONSOLIDATION AND ANALYSIS OF SIMULATION RESULTS

Consolidation of Results of Simulation for Purchase Decision for Electric Induction Motors

As mentioned earlier, simulations relate to the purchase of competitive alternative equipment - high-efficiency versus new standard motors (Case 1) and high-efficiency versus rewound motors (Case 2). Distribution relating to viable acquisition simulations per scenario and based on average tariffs for Group A and Sub-group A4 are presented in Figure 1, Case 1 and in Figure 2, Case 2 in which it can be noted that:

- in industries which operate with three shifts (average load factor of 0.833) all simulations for acquisition of high-efficiency motors were viable, even when high rates of attractiveness are desired (40% per annum);
- in industrial plants which operate with two shifts (average load factor stipulated at 0.578):
    - considering the minimum attractiveness rate of 20% per annum, the acquisition of high-efficiency motors is viable in all cases.
    - considering an attractiveness rate of 40% per annum, all simulations were viable for the acquisition of high-efficiency motors for users in sub-group A4. An average increase of only 23% on the average tariff of group A would be required for the acquisition of all high-efficiency electric motors to be viable;
- in industrial units which operate with only one shift (average load factor stipulated at 0.244) the use of high-efficiency motors is viable, as long as the need to adjust the power factor is taken into account and the company accepts an attractiveness rate of 20% per annum;

The Brazilian practice of rewinding damaged motors does not affect the above conclusions. This can be explained by the fact that a rewound motor, despite a lower initial cost, is less efficient and has a lower power factor than a new motor; the acquisition of high-efficiency 2HP/3600rpm and 10HP/3600rpm motors is viable within all scenarios analysed, while the acquisition of high-efficiency 2HP/3600rpm, 5HP/3600rpm, 7.5HP/3600rpm, 10HP/3600rpm and 25HP/3600rpm are only not viable in the worst scenario, where a company works in only one shift, desires a high rate of return on investment (40% p.a.) and does not take into account the adjustment for power factor. In a localised analysis, the best scenario for the acquisition of high-efficiency motors (b5) has an average viable tariff approximately 4 times lower than the worst scenario (a2) (Table 2).

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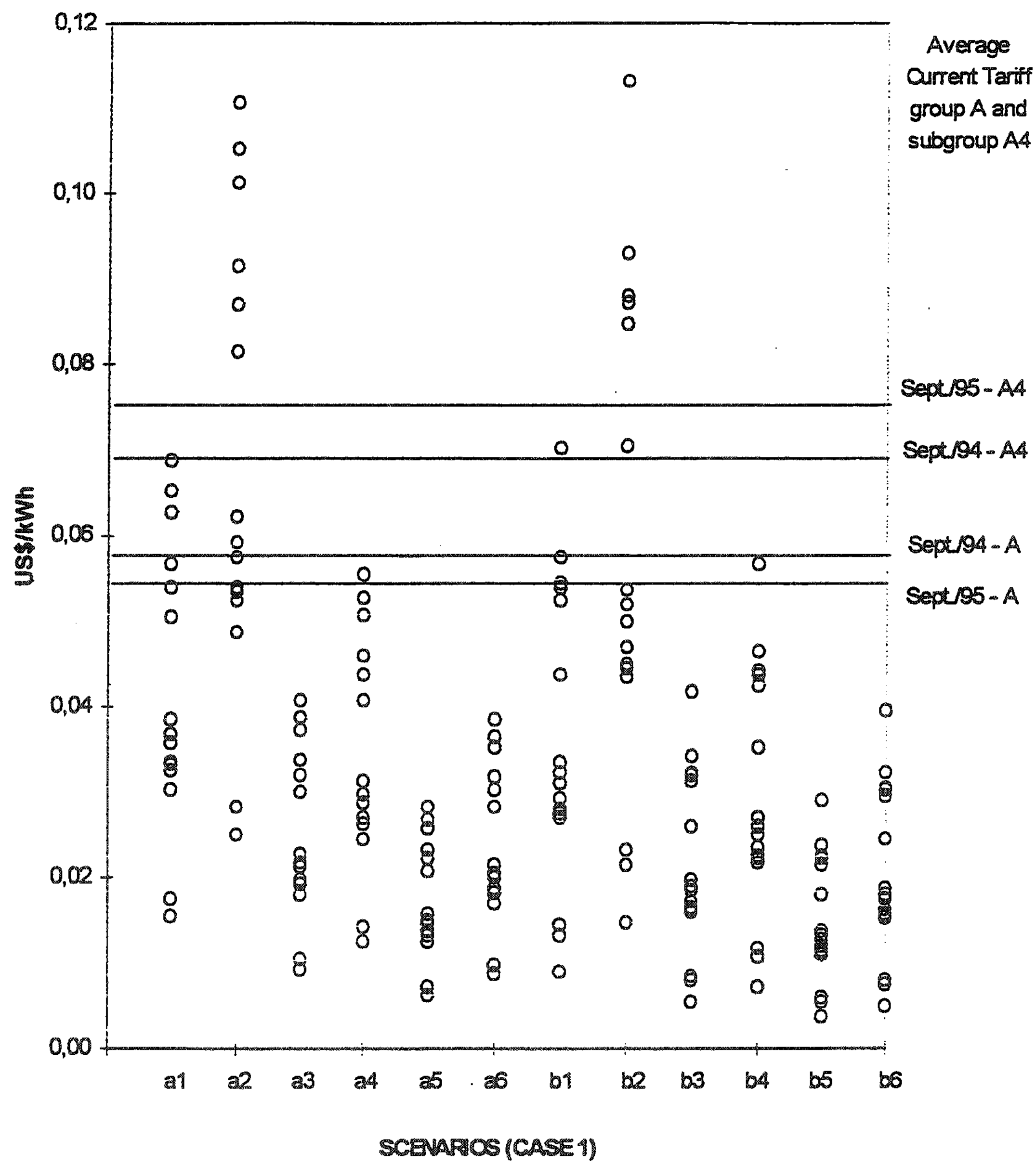
*The power supply for group A is subdivided into: subgroup A4 (voltage between 2.3 kV and 25 kV); subgroup A3 (voltage up to 69 kV), subgroup A2 (voltage up to 138 kV) and subgroup A1 (voltage up to 230 kV). Subgroup A4 (of medium voltage, provided through the distribution network) comprises the majority of small and medium industries and medium and large commercial/service facilities. The other subgroups (high voltage, provided directly by transmission and sub-transmission systems) incorporate large industries and the so-called "large energy consumers." As an operational consequence, the average tariff is obviously greater for subgroup A4 (0.06407 US$/kWh) and diminishes for the other subgroups (A3: 0.04956 US$/kWh; A2: 0.03363 US$/kWh, A1: 0.02678 US$/kWh)[13]

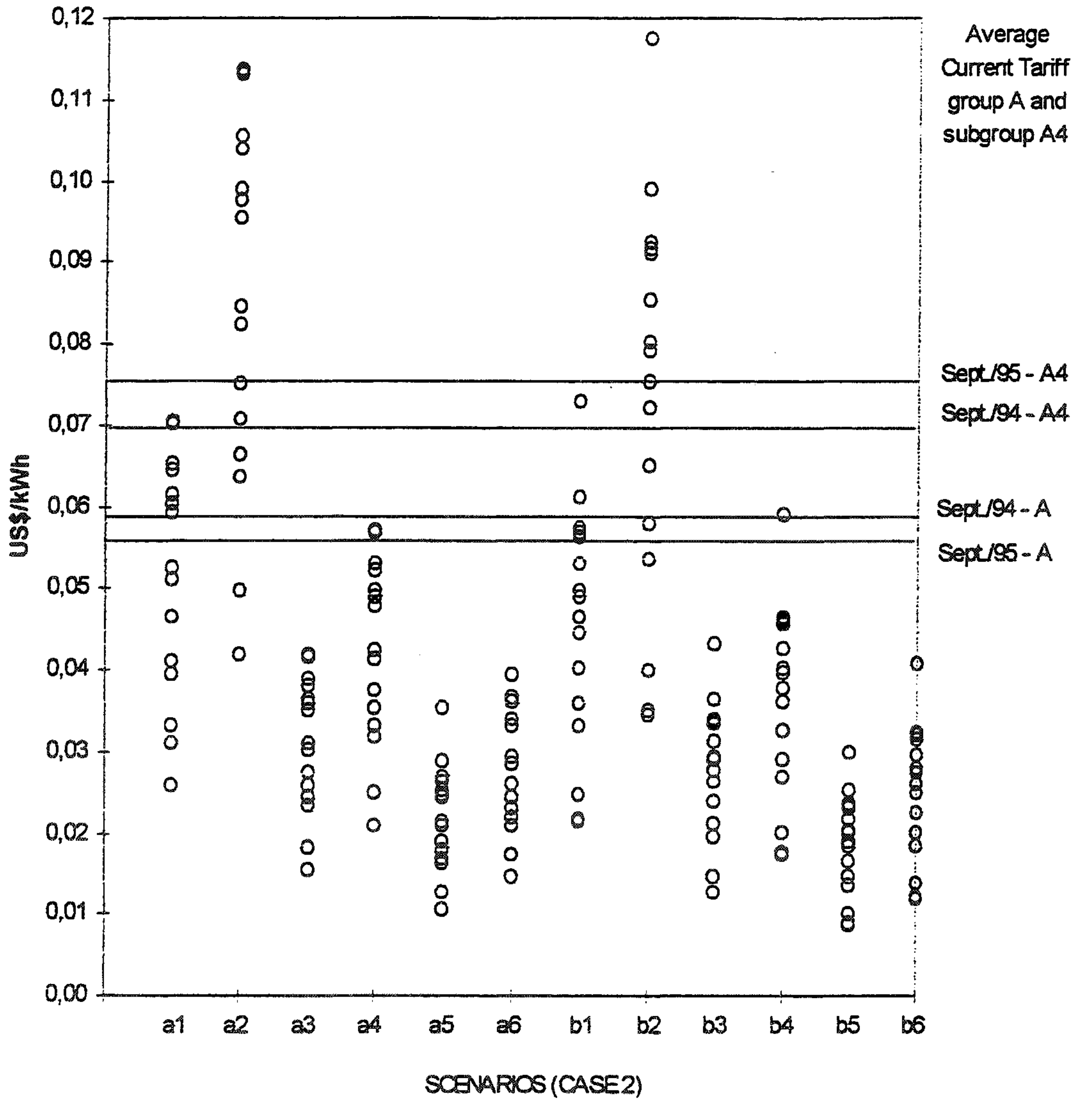
†576 simulations were performed.

Figure 1 - Viable tariffs for acquisition of high-efficiency motors in detriment to standard motors (case 1) compared with average tariffs in group A and sub-group A4 in September 1994 and 1995.



Obs.: The points is each of the scenarios represent the 16 motors, selected according to their power and rpm

Figure 2 - Viable tariffs for acquisition of high-efficiency motors in detriment to rewound motor (case 2) compared with average tariffs in group A and sub-group A4 in September 1994 and 1995.



Obs.: The points is each of the scenarios represent the 16 motors, selected according to their power and rpm

Table 2 -Average tariff for a viable decision to acquire high-efficiency electric motors for selected scenarios (US$/kWh)

Power (HP)	3600 RPM				1800 RPM			
	Worst Scenario (a2)		Best Scenario (b5)		Worst Scenario (a2)		Best Scenario (b5)	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
1	0,05749	0,09554	0,01466	0,02435	0,05245	0,08240	0,01337	0,02100
2	0,02837	0,04992	0,00723	0,01272	0,06214	0,09911	0,01584	0,02526
5	0,05362	0,07063	0,01367	0,01800	0,05924	0,07508	0,01510	0,01914
7,5	0,04868	0,06362	0,01241	0,01622	0,08708	0,11346	0,02220	0,02892
10	0,02494	0,04190	0,00636	0,01068	0,08145	0,10553	0,02076	0,02690
25	0,05366	0,06630	0,01368	0,01690	0,10516	0,09765	0,02681	0,02489
75	0,05399	0,08457	0,01376	0,02156	0,09158	0,10386	0,02334	0,02648
200	0,10134	0,11329	0,02583	0,02888	0,11081	0,11371	0,02824	0,03536

A localised analysis of high load factor (0.578 and 0.833) users, as the largest consumers of electric power, provides the following results:

Table 3 - Consolidated Simulation Results by Tariff Subgroup, Environment, Case and Motor RPM

Tariff Subgroup	Feasible Purchases (%)	Within the Universe of NON-Viable Purchases					
		Environment (%)		Case (%)		RPM (%)	
		a	*b*	*1*	2	*1800*	*3600*
A1	75.4	60.3	39.7	37.3	67.7	73.0	27.0
A2	89.1	55.2	44.8	37.9	62.1	75.9	24.1
A3	100.0	-	-	-	-	-	-
A4	100.0	-	-	-	-	-	-

Thus, Table 3 shows that:

- In both cases, in all scenarios, for all types of motors (power and rpm), the present average tariffs of subgroups A4 and A3 are favourable to the purchase of high-efficiency as compared to standard motors. In subgroups A2 and A1, simulations indicate feasibility by 89.1% and 75.4%, respectively, for the purchase of high-efficiency motors;
- The internalisation of the cost of power factor adjustment (Environment b) improves conditions for acquisition of high-efficiency motors;
- The practice of rewinding standard motors diminishes the attractiveness of purchasing high-efficiency motors (Case 2);
- High rotation motors (3600 rpm) have a better performance in terms of energy gains in comparison with low rotation motors (1800 rpm).

Simulating the Retrofitting of Operating Electric Motors

Contrary to the Purchase Decision, the Substitution Decision seeks to determine if replacement is advantageous and, if so, the optimum timing. Consolidated results for decisions and timing can be analysed in Table 4 (1800 RPM) and Table 5 (3600 RPM).

Table 4 - Optimum Date for Replacing Standard 1800 RPM Motors by High-Efficiency 1800 RPM Models, at Present Tariff Level

Tariff	Subgroup A4 (0,06407 US$/kWh)						Subgroup A1 (0,02676 US$/kWh)					
Scenario/Motors	1	2	3	4	5	6	1	2	3	4	5	6
1 HP	LS	-	1 year	LS	1 year	LS	-	-	LS	-	LS	-
2 HP	LS	-	9 years	LS	1 year	LS	-	-	LS	-	LS	-
5 HP	LS	-	1 year	LS	1 year	4 years	-	-	LS	-	LS	LS
7,5 HP	-	-	LS	LS	LS	-	-	-	-	-	LS	-
10 HP	-	-	LS	LS	4 years	LS	-	-	-	-	LS	-
25 HP	-	-	LS	-	8 years	LS	-	-	-	-	LS	-
75 HP	-	-	LS	LS	7 years	LS	-	-	-	-	LS	-
200 HP	-	-	LS	-	LS	LS	-	-	-	-	-	-

Table 5 - Optimum Date for Replacing Standard 3600 RPM Motors by High-Efficiency 3600 RPM Models, at Present Tariff Level

Tariff	Subgroup A4 (0,06407 US$/kWh)						Subgroup A1 (0,02676 US$/kWh)					
Scenario/Motors	1	2	3	4	5	6	1	2	3	4	5	6
1 HP	LS	-	2 years	LS	1 year	LS	-	-	LS	-	LS	LS
2 HP	LS	LS	1 year	5 years	1 year	1 year	-	-	LS	LS	LS	LS
5 HP	LS	-	1 year	LS	1 year	4 years	-	-	LS	-	LS	LS
7,5 HP	LS	-	1 year	LS	1 year	1 year	-	-	LS	-	LS	LS
10 HP	4 years	LS	1 year	1 year	1 year	1 year	LS	-	LS	LS	LS	LS
25 HP	LS	-	1 year	LS	1 year	1 year	-	-	LS	-	LS	LS
75 HP	LS	-	LS	LS	1 year	LS	-	-	LS	-	LS	LS
200 HP	-	-	LS	-	LS	LS	-	-	-	-	LS	-

Key:

X years : starting date at which retrofitting becomes feasible
LS : feasible acquisition after useful life-span of operating motor.
- : acquisition is not feasible

From Tables 4 and 5, it can be observed that:

- Similar to the simulations for the Purchase Decision, high rotation high-efficiency motors (3600 RPM) perform better than the1800 RPM;
- The worst results in the simulation were those for the 200 HP motor, due to the high cost of technological upgrade and to the low gains in performance comparing high-efficiency to standard motors;
- Replacement is not feasible for subgroup A1.
- Looking at the average A4 tariff, 34.3% of simulations favour the substitution of standard by high-efficiency motors in the very first year of operation.
- Looking at the average A4 tariff, 43.7% of simulations favour the substitution of standard by high-efficiency motors, 80.9% of which in the first year of operation.
- Considering the feasibility of acquiring a high-efficiency motor at the end of the life-span of an operating motor, 52.8% are feasible with subgroup A1 tariffs, while 83.3% are feasible with subgroup A4 tariffs.

As can be ascertained, retrofitting motors is most indicated for small and medium scale industries and for medium and large scale commercial/service establishments, which normally come under Subgroup A4 with respect to power supply. Nevertheless, results for the "large consumers" in Subgroup A1 can be improved upon, since these industries generally operate with a high load factor (LF>0,85), with various electric motors operating at a level close to the unitary load factor.

CONCLUSIONS

Despite the environmental, social and economic benefits resulting from improvements in energy efficiency, little practical action is actually taken along these lines. The price of readily available energy is commonly considered the main obstacle to the widespread use of more energy efficient technologies. With reference to electric induction motors, results obtained indicate that the present average tariff level is not an obstacle to the introduction of more efficient technology. Looking only at the tariff aspect, it would make sense to put into operation almost all high-efficiency motors currently available. These results indicate that realistic prices are an important strategic element to stimulate widespread rationalisation of energy uses. However, the price effect is often limited by frequent market imperfections. Barriers to the availability of high-efficiency motors on the market include:

* few are available for immediately delivery.[14] In fact, as the sale of these motors is still insignificant, they are not easily found in stock in the majority of specialised shops and authorised distributors;
* sensitivity to initial cost of equipment. This barrier, a result of the short term culture which exists in Brazil where investments with Pay-back of over 2 years is often considered unfeasible;

* Brazil's recent inflationary environment. The economic instability of the past in many instances transferred investment from the productive to the financial sector. Nevertheless, if the economic stabilisation process continues, this barrier will become less, especially as a result of educational and marketing actions;
* aversion to risk indicated by the highly attractive rates demanded by business for investment in the productive sector.

According to POOLE, HOLLANDA & TOLMASQUIM (1995)[15]: "This (price) is the most important signal to encourage the appropriate use of energy. Used exclusively, however, it has not been sufficient in itself: in countries with realistic energy prices, sub-optimum use has been observed, even when efficient technology is available and demonstrably yields better economic results." Other instruments, such as availability of more efficient equipment, norms, regulations, credit, information, education, marketing, etc., may contribute significantly to promoting energy rationalisation, thus complementing and even strengthening the price signalling process. In this case, the role of the State would be to articulate these instruments so that interaction among the various agents is as encompassing and beneficial as possible for the country as a whole.

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