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Economic evaluation of induction motor based on motor's nameplate data and initial cost

Mohammed Baniyounis[1], Ayman Agha[2], Hudefah Al-kashashneh[2], Abdullah Al-Omoush[2]
[1]Department of Mechatronics Engineering, Faculty of Engineering and Technology, Philadelphia University, Amman, Jordan
[2]Department of Electrical Engineering, Faculty of Engineering and Technology, Philadelphia University, Amman, Jordan

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ABSTRACT

This paper presents a practical approach to calculate the total owning cost (TOC) of a three-phase Induction Motor, which is based on the motor's nameplate data and the purchasing price. The economic evaluation is performed considering both the induction motor electrical energy losses and its amortized annual capital cost. The proposed technique consists of three stages, where the total power losses are determined analytically in the first stage. The load loss factor (LSF) is statistically obtained to determine the total energy losses in the second stage. In the third stage, the economic evaluation was conducted. The obtained results show that the proposed approach is a helpful tool for the decision-maker when comparing the received offers from different vendors and finding the answer to the question of which offer has less TOC. Finally, the proposed method is illustrated through a numerical example and software using MATLAB was performed. Results and conclusions have been summarized and discussed.

Corresponding Author:

Mohammed Baniyounis
Department of Mechatronics Engineering, Faculty of Engineering and Technology, Philadelphia University
Jarash Road, 20 KM out of Amman, Jordan
Email: mbaniyounis@philadelphia.edu.jo

1. INTRODUCTION

Induction motors (IM) have become increasingly popular from the beginning of the industrial age. It is sporadically called the horse of the industry due to their rigidity, simplicity in construction, and less requirement for maintenance. As a result, a proper selection of IM will enhance the overall system efficiency and reduce unjustified investment costs. Different approaches have been proposed to assess the technical and economic IMs' cost and design problems [1]. The amount of energy consumed by all motors to overall electric energy produced varies between 43% and 49% [2], while the IM consumes 96% [3]. Elzbieta and Leszek [4], introduced a statistical technique was used to estimate the motor's collective losses for various motor output powers were computed. The importance of air gap power on power losses was carried out using MATLAB [5]. The prediction of the most prevalent failure affecting the reliability of IM is introduced [6]. A field-oriented control system for enhancing energy efficiency has been developed [7]. In [8], the steps for estimating the efficiency of the IM on the Jobsite are given. However, a rotor frame was developed to enhance the efficiency of IM in terms of cost savings and emission reduction [9]. The finite element technique is used to evaluate the IM design's performance considering the drive control and torque-speed range [10]. The optimal design of the IM considering economic evaluation and efficiency was introduced [11]. The technical, financial, and budgetary cost of replacing the standard efficiency of IM with premium efficiency was investigated [12]. The operational costs, payback period, annual saving in energy, and economic study, in case of single-phase IM is rewound for a three-phase operation are discussed [13]. The economics of IM, planning maintenance, cost-effectiveness, and energy savings by using a cost model as in [14], [15]. The economic efficiency and load condition effects considering the IM life-cycle cost are introduced [16].

Unfortunately, the daily engineering practices while having to select an appropriate offer of IM among many received offers from different suppliers/ vendors has not had enough technical/economic justification and is mainly based on the submitted price and the manufacturers' reputation. The problem becomes very complicated when the price and manufacturer reputation of the received offers are very close. The proposed approach in this paper assists to evaluate the total owning cost (TOC) of the IM based only on the given data of the IM nameplate, as it is sometimes the only available data in the absence of the IM technical datasheet. However, the TOC of IM is obtained based on the amortization of the capital cost of IM, the interest rate, lifetime expectancy, the amount of energy loss, and the existing energy tariff. The adopted technique consists of three stages: the total power losses are determined analytically in the first stage, the mechanical loading of the IM adequate to the LSF is statistically obtained in the second stage, to determine the total energy losses, and in the third stage, the economic evaluation is conducted along with numerical examples, to check the effectiveness of the proposed approach. Also, a particular case is discussed if the IM is used for temporary purposes.

The rest of the paper is organized as follows: section 2 presents the mathematical formulation of the problem. The power and energy losses calculations are introduced in section 3. In section 4, the economic evaluation of the proposed approach is demonstrated. Numerical examples illustrating the effectiveness of the proposed method are presented in section 5. In section 6, a particular case of economic evaluation is discussed. Finally, results, discussion, and conclusions are shown respectively in sections 7 and 8.

2. PROBLEM FORMULATION

The economic selection of IM is based on the capital cost and energy losses costs during the analyzed period, where one year is generally considered suitable for economic evaluation purposes. The objective function is to find the minimum total owning cost of IM; this can be mathematically formulated as in (1).

$$Min.\ \{C_{IM.i}\} \tag{1}$$

The corresponding state equations are in (2) and (3).

$$P_n \geq \ P_{IML} \tag{2}$$

$$C_{IM.i} = C_{c.IM.} + C_{losses} + C_{mintenance} \tag{3}$$

Where $C_{IM.i}$ is the annual owning cost of the *i-th* number of IM [$/year], $C_{c.IM}$ is the capital cost of the IM using the present value of an annuity [$/year], C_{losses} is the active energy losses cost of the IM [$/year], $C_{maintenance}$ is the maintenance cost of IM [$/year], P_n is the nominal (nameplate) power for IM in [hp or kW], and P_{IML} is the mechanical load of IM in [hp or kW].

Algebraic equation expressed the active energy losses in [kWh], that is; the total energy losses ΔE and respectively the no-load ΔE_{NLL} and the on-load energy losses ΔE_{LL} is as in (4).

$$\Delta E = \Delta E_{NLL} + \Delta E_{LL} \tag{4}$$

3. POWER AND ENERGY LOSSES CALCULATION

The flow of current in IM causes a loss in power and reduces efficiency. The main types of losses that can occur in IM are:

3.1. Active power losses

3.1.1. Iron losses

The main flux generates these losses in the core, known as no-load losses, namely eddy current and hysteresis losses. These losses depend on the square of the input voltage and core reluctance [17]. The value of these losses varies between 20% and 25% of the total IM losses [18].

3.1.2. Rotor and stator copper losses

These losses are caused by the flow of the load current in the IM windings. These losses are also known as on-load losses, depending on the square of input current and resistance of IM windings [19]. Their sharing amount varies between 55% and 60% of the IM total losses [18].

3.1.3. Friction and windage losses

These are mechanical losses, where the first friction is due to the friction at the bearings while the IM is rotating, whereas changes in the shaft's speed cause the second windage. The value of these losses varies between 8% and 12% of total IM losses and can usually be estimated using empirical equations [20].

3.1.4. Stray losses

These losses are caused by leakage flux induced in the laminations and proportional to the rotor current square. Their sharing amount varies between 4% and 5% of IM total losses [21]. In general, the total active power losses in the IM are as illustrated in Figure 1. In [21], [22], and mathematically expressed as in (5).

$$\Delta P = \Delta P_{NL} + \Delta P_{LL} + \Delta P_{F\&W} + \Delta P_{stray} \tag{5}$$

Where ΔP represents the total active power losses of IM [kW], which is the sum of all type losses that could have a place in IM, that is; respectively, the no-load ΔP_{NL} and on-load ΔP_{LL} power losses, the friction and windage $\Delta P_{F\&W}$, and lastly the stray power losses ΔP_{stray}.

Due to the small amount of $\Delta P_{F\&W}$ and ΔP_{stray}, losses and the difficulty to calculate these losses on job sites or industrial plants. So, henceforth, these two types of losses will not appear in the equations, and their values will be distributed proportionally on the on-load and no-load losses, and thus, in (5) will be reduced to become as in (6) and as follows:

$$\Delta P = \Delta P_{NL} + \Delta P_{LL} \tag{6}$$

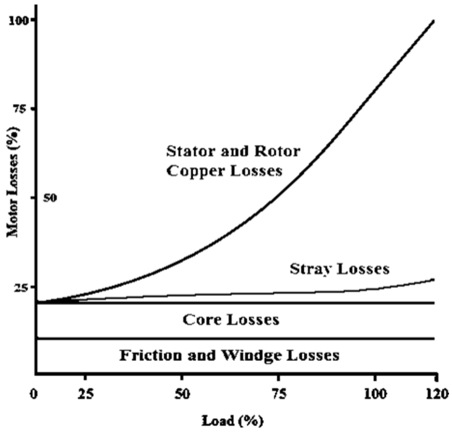

Figure 1. Percent losses types of IM

3.2. Determination of the power losses of IM

The power losses are determined under the following presumptions: the network's voltage magnitude, voltage unbalance, frequency, and the total harmonic distortion (THD) are within the permissible value of the designed parameter of the IM. The total active power losses in (6) is simplified as:

$$\Delta P_{LL} = \Delta P - \Delta P_{NL} \tag{7}$$

The total power losses $\Delta P_{(t)}$ of IM at any time, corresponding to any mechanical loading P_{IML} considering (2), (6), and (7), and after some mathematical arrangement, taking into account the on-load, no-load power losses, and the maximum mechanical loading to the rated capacity of the IM. Then the total power losses can be obtained as in (8), [23].

$$\Delta P_{(t)} = \Delta P_{NL} + (\Delta P - \Delta P_{NL}) \cdot \left(\frac{P_{IML}}{P_n}\right)^2 \tag{8}$$

According to [18], the no-load losses ΔP_{NL} vary between (20-25) % of the total power losses ΔP, and on-load power losses ΔP_{LL} vary between (55-60) percent of the total power losses. This work and forthcoming calculations will consider the average value of ΔP_{NL} and ΔP_{LL} to be 22.5% and 57.5% of the ΔP. The elimination of $\Delta P_{F\&W}$ and ΔP_{stray} in (6) distributed their values proportionally between ΔP_{NL} and ΔP_{LL}, applying linearization yields that the percentage of the ΔP_{NL} and $\Delta P_{LL\ \text{proportional}}$ to the ΔP are approximately 28% 72%, respectively. Then, the percentage value of ΔP_{NL} and ΔP_{LL} to the ΔP becomes respectively as in (9) and (10).

$$\Delta P_{NL} \approx 0.28 \cdot \Delta P \quad (9)$$

$$\Delta P_{LL} \approx 0.72 \cdot \Delta P \quad (10)$$

Hence, (8) will become as follows:

$$\Delta P_{(t)} = 0.28\,\Delta P + (\Delta P - 0.28\,\Delta P).\,(\frac{P_{IML}}{P_n})^2 \quad (11)$$

simplifying (11) considering (6) yields as in (12):

$$\Delta P_{(t)} = 0.28\,\Delta P + 0.72\,\Delta P \cdot (\frac{P_{IML}}{P_n})^2 \quad (12)$$

3.3. Determination of the energy losses of IM

The energy losses ΔE is calculated as the product of the power losses $\Delta P_{(t)}$ integration over time T. If the time-varying power losses are arranged in descending order from $\Delta P_{(max.)}$ to $\Delta P_{(min.)}$ in equal integrated areas, then the active energy losses can be stated as in (13).

$$\Delta E = \int_0^T \Delta P_{(t)} \cdot dt = \Delta P_{(t)} \cdot T = \Delta P_{(max.)} \cdot \tau \quad (13)$$

Where the sum of the year's hours T = 8760 [h], and τ represents equivalent load losses hours [h/year].

The active energy losses is driven by substituting (12) in (13) as:

$$\Delta E = \Delta P_{NL} \cdot T + \Delta P_{LL} \cdot \tau \quad (14)$$

$$\Delta E = 0.28\,\Delta P \cdot T + 0.72\,\Delta P\,(\frac{P_{IML}}{P_n})^2 \cdot \tau \quad (15)$$

From (15), the value of ΔP is still unknown, considering (2). The total power losses can be calculated using the following formula:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out}+\Delta P} = \frac{P_n}{P_n+\Delta P} \quad (16)$$

where η is the efficiency of IM, and P_{in} is the input power of *i-th* IM in [hp or kW]. The P_{out} is the output power and is also called nominal power P_n, the shaft power P_{shaft}, or the rated power P_{rated}. The nameplate data of the IM is used to obtain the nominal power P_n and the efficiency η. In this case, after modifying (16), the total power losses as a function of efficiency and nominal power are obtained as in (17).

$$\Delta P = P_n\,(\frac{1}{\eta} - 1) \quad (17)$$

3.4. Determination of the equivalent working hours

When the load power of IM P_{IML} varies in time, the load is distributed in equal integrated areas in descending order, from maximum loading power $P_{(max.)}$ to a certain minimum power $P_{(min)}$. In this case, the active energy E consumed during a time T_{eq} will be given by (18).

$$E = \int_0^T P_{IML}\,dt = P_{IML} \cdot T = P_{(max.)} \cdot T_{eq} \quad (18)$$

Where T_{eq} is the equivalent working hours over a year [h].

The monthly equivalent working hours $T_{(w/m)eq.}$ (also known as maximum load utilization time) is presented in [24]-[27] and can be calculated as in (19). Also, the relation between $T_{(w/m)eq.}$ and T_{eq} can be obtained from (20).

$$T_{(w/m)eq.} = 2 \cdot D_{(w/y)} \cdot \left(\frac{n_s}{3} + \frac{3-n_s}{3} \cdot \frac{A_{p\,(aw)}}{A_{p(w)}}\right) + 2 \cdot (365 - D_{(w/y)}) \cdot \frac{A_{p\,(aw)}}{A_{p(w)}}) \quad (19)$$

$$T_{eq} = N \cdot T_{(w/m)eq} \quad (20)$$

Where $A_{p(w)}$ is the sum of the consumed active energy (day and night) during the time of operation per month in [kWh], $A_{p(aw)}$ the consumed active energy after the time of operation per month in [kWh], $D_{(w/y)}$ is the number of working days over the year (excluding holidays, shutdowns, and weekends), n_s =1-3 is the number of working shifts during the time of operation in one day, and N is the number of months (N=1-12, where N=12 for one year).

3.5. Determination of the maximum loss time

The product of integration power losses $\Delta P_{(t)}$ over a certain period of T is the energy losses ΔE. Now, if the time-varying of power losses values are arranged in descending order from maximum value $\Delta P_{(max.)}$ to minimum value $\Delta P_{(min.)}$, as depicted in Figure 2, [24]. Where the areas under the curve of the dotted and straight lines are equals.

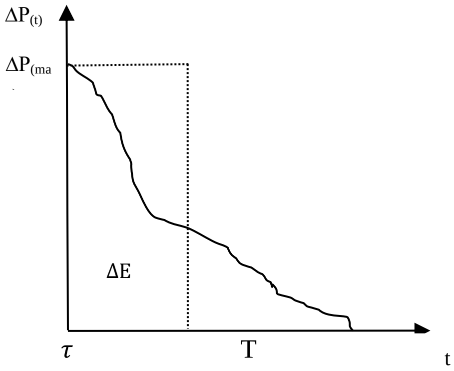

Figure 2. Maximum loss time curve

The relationship between the equivalent load loss time τ and the LSF, [28] is as in (19).

$$\tau = LSF.T \tag{21}$$

LSF represents the load loss factor [/] and (T = 8760h) is the year's hours. The overall average energy loss ΔE in [29], [30] is obtained by multiplying the load loss factor LSF with the power losses and a certain period of time. Substituting (21) into (13) yields (22).

$$\Delta E = \Delta P_{(max.)} \cdot T \cdot LSF \tag{22}$$

The relationship between the load factor LF and Load Loss Factor LSF is presented in [29].

$$LSF = (1-k) \cdot LF^2 + k \cdot LF \tag{23}$$

The value of k varies between zero and one, and it depends on the load curve profile. Also, it is different from one country to another e.g., $k=0.16$ in the USA for a rural power grid and $k=0.3$ for an urban power grid, $k=0.2$ in Great Britain and Australia, and $k=0.33$ in Poland. In this paper, the value of $k=0.33$ will be considered. The value of the load factor LF in (23) can be calculated as the ratio of equivalent working hours over a year T_{eq} to the year's hours T [24], [31] and as in (24).

$$LF = \frac{T_{eq}}{T} \tag{24}$$

4. ECONOMIC EVALUATION

The annual owing cost of IM, $C_{IM.i}$ of *i-th* IM can be expressed as the sum annual capital cost of the IM using the present value of the annuity $C_{c.IM}$, considering the unit cost C_e of active energy [\$/kWh] and the energy losses value in [kWh]. Then the $C_{IM.i}$ can be determined as in (25).

$$C_{IM.i} = C_{c.IM.} + C_e \cdot \Delta E_i \tag{25}$$

The formula in (25) represents the annual owing cost of the *i-th* IM with different capital costs and different energy losses. Considering the rate of discount or interest rate r, the life expectancy *n- year*, the present value PV of the IM [\$]. Then, the annual capital cost $C_{c.IM.}$ of IM [32], [33] can be expressed as in (26).

$$C_{c.IM.} = \frac{r \cdot (PV)}{1-(1+r)^{-n}} \quad (26)$$

Where the life expectancy for IM is assumed n=15 years. Based on the above procedure and equations, an algorithm has been developed. Figure 3 demonstrates the flowchart of the proposed approach.

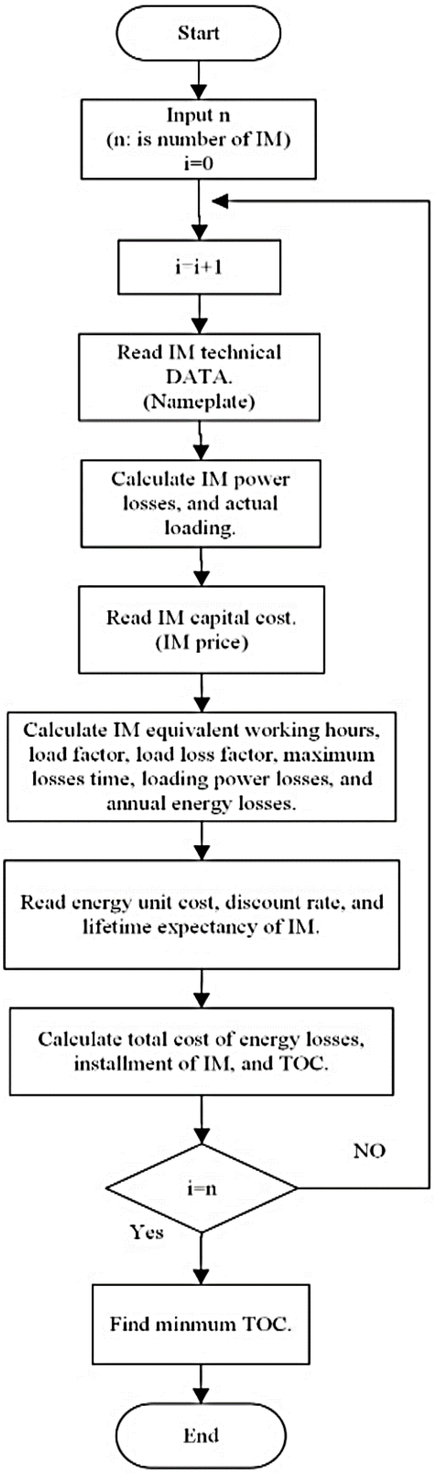

Figure 3. The proposed TOC computing algorithm

5. NUMERICAL EXAMPLE

This section presents a numerical example to demonstrate the proposed method. The input data and the calculations are conducted as follows.

5.1. Induction motor technical data

The input data for *i-th* number of the IM is generally received from different manufacturers/ vendors/suppliers with different specifications and prices. This task is regular daily work for the tender engineer or the plant engineer in the industrial plant. Therefore, this example will perform an economic evaluation for three offers received from different suppliers. However, irrespective of the number of IM, the economic evaluation is the same. Therefore, the input technical and operational data for the received offers, IM-1, IM-2, and IM-3, are presented in Table 1.

Table 1. Induction motor technical data

Item	IM-1	IM-2	IM-3
Electrical parameters			
Power [kW]	22	22	22
Voltage [V]	400	400	400
Current [A]	42.5	39	40.78
Frequency [Hz]	50	50	50
cos ϕ [/]	0.89	0.89	0.85
Number of poles	4	4	4
Winding connection [Y/Δ]	Y	Y	Y
Operational and mechanical parameters			
Insulation class	F	F	F
Duty cycle	S1	S1	S1
IP (ingress protection)	55	55	55
Mechanical dimensions	same	same	same

Note: the name of manufacturers is hidden due to the privacy policy

The received ex-work price of each IM is as indicated in Table 2, where some suppliers offer fuel oil blended (FOB) or casparian strip integrity factor (CIF) prices with different currencies, others include custom, and value-added tax (VAT). However, the procedure is the same, and all offers shall be brought to the same level, as shown in Table 2.

The unit price of electrical energy differs from one county to another; also, in each country, typically, there are several tariffs applied for different types of consumers. Therefore, the applicable tariffs where the IM will be installed shall determine the unit price of energy needed for economic evaluation. In this example, the medium industrial is applied [34]. However, suppose the IM has to work in a continuous mode of operation (three shifts). In that case, the arithmetic average of the day and night tariffs is considered, the energy unit price is as in Table 3.

Table 2. Induction Motor total purchasing cost (IM Price)

Item	IM-1	IM-2	IM-3
CIM. (EX-work Price) [$]	1464.00	632.20	1890.34
Customs (20%)	292.80	126.44	378.07
VAT (16%)	234.24	101.15	302.45
TAX (5%)	73.20	31.61	94.52
Erection (8%)	117.12	50.58	151.23
CIM. (total cost) [$]	2181.36	941.98	2816.60

Table 3. The energy unit cost

Item	$/kWh
Day electricity tarif, $C_{e.D.\ Day\ tariff}$	0.1254
Night electricity tarif, $C_{e.N.\ Night\ tariff}$	0.1056
Average electricity tarif, $C_{e(avg.\ D+N)}$	0.1155

5.2. Induction motor calculation

The numerical calculation is demonstrated for MI-1 only; however, the calculation for IM-2 and IM-3 are in the same way. The result of the calculation for the three motors will be summarized in Table 4.

– Input power

Based on the IM-1 shown in Table 1, the input power is calculated as:
$P_{in} = \sqrt{3} \cdot V_n \cdot I_n \cdot cos\ (\theta) = \sqrt{3} \cdot 400 \cdot\ 42.5 \cdot 0.89 = 26205.92\ \ kW.$

- Efficiency

The efficiency of IM-1 can be calculated using (14) as follows:

$$\eta = \frac{P_n}{P_{in}} = \frac{22000}{26174.9} = 0.8395$$

- Total power losses

The total power losses using (17) is calculated as:

$$\Delta P = P_n\ \left(\frac{1}{\eta} - 1\right) = 22000 \left(\frac{1}{0.8395} - 1\right) = 4.205\ kW.$$

- Actual loading

The actual loading (mechanical loading) of the IM-1 is equal:

$$P_{IML}\ \ = k_f\ .P_n = 0.9\ x\ 22000 = 20.02\ kW.$$

where k_f = 0.9 is the ratio of the mechanical load to the nameplate power of the IM.

- Equivalent working hours

The equivalent working hours over a year T_{eq} is calculated for the operational mode of one shift (8) hours a day and five days a week excluding holidays, where the energy consumed for essential load after the working hours is equal $A_{p\ (aw)}/A_{p(w)}$ = *20%*. Using (19) and (20) respectively has been obtained:

$$T_{(w/m)eq.} = 2\ x\ 244 \left(\frac{1}{3} + \frac{3-1}{3} \times \frac{20}{100}\right) + 2(365 - 244)\ x\ \frac{20}{100} = 278.6\ h/m.$$

$$T_{eq} = 278.6\ x\ 12 = 3343.2\ h.$$

- Load factor

Load factor using (24):

$$LF = \frac{3343.2}{8760} = \ 0.3783.$$

- Load loss factor

The (LSF) is obtained from (23), for k=0.33, [28].

$$LSF = (1 - 0.33) \cdot 0.3783^2 + 0.33\ x\ 0.3783 = 0.221.$$

- Maximum loss time

The maximum loss time determination (τ) is obtained by using (21);

$$\tau = 0.221\ x\ 8760 = 1933.8\ h.$$

- Total power Losses

The total power losses $\Delta P_{(t)}$ is obtained by using (12).

$$\Delta P_{(t)} = 0.28\,x\ 4.206 + 0.72\ x\ 4.206 \cdot \left(\frac{20.02}{22.0}\right)^2\ \ = 3.68\,kW.$$

- Energy losses

The annual energy losses, ΔE as in (15);

$$\Delta E\ = 0.28\ x\ 4.205\ \ x\ 8760\ +\ 0.72\ x\ 4.205\ x\ \left(\frac{20.02}{22.0}\right)^2 \cdot 1933 = 8{,}749\ kWh$$

The MI-1, MI-2, and MI-3 calculation results are summarized in Table 4.

5.3. Economic evaluation of annual owing cost

5.3.1. Amortized present value of IM

The capital cost of the IM using the present value of an annuity [$/year], considering a discount rate *r=8%* and the lifetime of IM, *n=15* years, using (26) the following is obtained.

$$C_{c.IM.} = \frac{0.08 \ \cdot (2181.36)}{1-(1+0.08)^{-15}} \ = \ 254.85 \ [\$/year].$$

5.3.2. Energy losses cost

The total cost of energy losses ($C_e \cdot \Delta E_i$) based on (25):

$$0.1254x\,8.749 = 1096.68\,kWh$$

The economic calculations are summarized as shown in Table 5.

Table 4. Induction motor power losses and energy losses

Item	IM-1	IM-2	IM-3
Calculated efficiency, η [%]	0.840	0.915	0.916
Total power losses at full load, ΔP [kW]	4.206	2.047	2.015
Actual power load, P(t). [kW]	20.02	20.02	20.02
Equivalent working hours, Teq.[h]	3313.6	3313.6	3313.6
Load factor , LF [/]	0.3783	0.3783	0.3783
Load loss factor, LSF [/]	0.221	0.221	0.221
Equivalent loss hours, τ [h]	1,933.28	1,933.28	1,933.28
Loading power losses $\Delta P_{(t)}$ [kW]	3.68	1.79	1.77
Energy losses, ΔE [kWh/yr.]	8,749	4,259	4,191

Note: IM-1 is loaded by k_f equal 91% from its nominal capacity (i.e 0.9. 22 kW). (i.e $P_{mech.load}$).

Table 5. Induction motor economic input data.

Item	IM-1	IM-2	IM-3
Present value (PV), [$]	2181.36	941.98	2816.60
Interest rate/year, [%]	8.00	8.00	8.00
IM lifetime expectancy, number of years (n),	15.00	15.00	15.00
The capital cost of the annuity, CcIM (PV/yr.), [$]	254.85	110.05	329.00
Cost of energy losses, (Ce · ΔE), [$]	1097.10	534.07	525.58

5.3.3. Total owing cost

The total owing cost of IM-1 is calculated as in (25).

$$C_{IM.i} = 254.85 + (0.1254 \ \times \ 8{,}749) \ = \ 1{,}351.97 \ [\$/year].$$

The economic evaluation results of IM-1, IM-2, and IM-3 are presented in Table 6.

Table 6. Summary of annual owning cost of IM, [$/yr.]

Mode of operation (No. of shifts)	IM-1	IM-2	IM-3
1	1,351.97	644.12	854.58
2	2,052.05	984.94	1,189.97
3	3,118.36	1,504.02	1,700.80

6. SPECIAL CASE OF ECONOMIC EVALUATION

Contracting companies constructing projects in different countries typically use the equipment during the project's construction. After completing the project, they either leave the used equipment to the owner of the project as a part of the spare parts list or sell these types of equipment as second-hand equipment. This section will discuss the return arising from selling the used equipment after the project's completion. In general, the used equipment price is subjected to bargaining bases. They are about (40-60)% of the purchasing price subject to time of use and the equipment's condition. The construction time of the projects varies typically between (18-36) months or even more for the megaproject.

6.1. Total owing cost of the special case

The TOC for this case is:

$$TOC = \ C_{IM}\,.(0.40-0.60) + C_e\,.\Delta E \qquad (27)$$

T_{eq} is calculated for two shifts of an operational mode of (16 hours a day and six days a week excluding holidays), with the expectation that the essential load after the working hours is equal $A_{p\,(aw)}/A_{p(w)} = 10\%$

and the number of working days over the year is equal $D_{(w/y)} = 300\ day$. The calculation summary for this case is obtained, as shown in Table 7.

Table 7. Total owing cost for a particular case [$/yr.]

The selling price of IM (%)	Project duration (month)	IM-1	IM-2	IM-3
40	18	3574.68	1692.20	2420.92
40	24	4475.39	2130.67	2852.42
40	30	5376.11	2569.14	3283.92
40	36	6276.82	3007.61	3715.41
45	18	3683.75	1739.30	2561.73
45	24	4584.46	2177.77	2993.22
45	30	5485.17	2616.24	3424.72
45	36	6385.88	3054.71	3856.22
50	18	3792.81	1786.40	2702.53
50	24	4693.53	2224.87	3134.03
50	30	5594.24	2663.34	3565.53
50	36	6494.95	3101.81	3997.02
55	18	3901.88	1833.49	2843.34
55	24	4802.59	2271.97	3274.83
55	30	5703.31	2710.44	3706.33
55	36	6604.02	3148.91	4137.83
60	18	4010.95	1880.59	2984.14
60	24	4911.66	2319.06	3415.64
60	30	5812.38	2757.53	3847.14
60	36	6713.09	3196.01	4278.63

7. RESULTS AND DISCUSSION

This paper presents a method for calculating the annual owing cost of three-phase IM. The economic evaluation is based on the IM data that appears on the motors' nameplate. Two modes of operation are presented and discussed; in the first mode, the IM is used for permanent purposes of use with one, two, or three shifts daily, the results are as presented in the numerical examples in section 5, wherein in the second mode of operation, the IM is used for temporary or short time purposes with a plan to sell the equipment after finishing the needs of its use, the results are as presented in section 6. The name of the IM manufacturers was hidden due to the privacy policy. In addition, the IM-1 and IM-3 are from well-known brand name manufacturers. On the other hand, IM-2 is not from a well-known manufacturer and still does not have enough reputation in the Middle East market. Hence results of the analysis as shown in Table 5 that, although the initial price of IM-2 is respectively less than IM-1 by approximately 43% and IM-3 by 33%, the TOC of IM-2 is lower than IM-3 by 25% and IM-1 by 48%. Therefore, the initial price of the IM cannot always guarantee the result of the minimum TOC.

The manipulation of the developed software shows that any change in energy unit price will affect the TOC of the IM. However, for the illustrated example, the increment of the current tariff of electrical energy even by 40% does not change the sequences TOC of the evaluated IM. On the contrary, if the energy unit cost in Table 3 is decreased by 37% or more, then the lowest TOC will be IM-2, IM-3, and IM-1. Based on that, the IM with a lower TOC does not necessarily have the same if applying another electricity tariff. The summary of the annual owning cost of the three presented IM is as in Table 6. The TOC of the IM used for temporarily or short period of use with different times of use and different selling price after the use as in Table 7, shows that, even if the selling price of the used IM varies between (40-60) percent of the purchasing price, the initial price is still dominated in the result of TOC.

8. CONCLUSION

This paper presents a novel methodology of economic evaluation of IM. The TOC is demonstrated via a flow chart algorithm, performed numerical examples, and devolved MATLAB software. The analyses show that; the initial price of the IM doesn't guarantee the minimum TOC. The unit price of electrical energy and other economic factors like the equipment's interest rate and life expectancy are also having a substantial impact on the final TOC. The initial price of IM used for temporary purposes is the primary factor affecting the economic evaluation of IM. Finally, the presented approach is a very good tool to calculate the TOC of IM. Still, nothing can compensate the good engineering practice for the final decision for which offer we have to go, considering the effect of other factors like service after sell, and availability of the spare part.

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BIOGRAPHIES OF AUTHORS

Mohammed Baniyounis received his BSc. Degree in Electrical Engineering for the University of Jordan. He obtained his MSc. and Ph.D. in 2006 from the University of Kaiserslautern, Kaiserslautern, Germany. He has Strong Knowledge and experience of Re-Engineering and Reverse Engineering delegated through specifications and verification of software/hardware systems using different tools and logic. Besides his expertise in the Distributed and Concurrent Systems approach for software modeling, design and development. He is interested in applying these methods introduced above along with Software Engineering technologies to solve automation and control specific problems. The basic knowledge of electrical machines also assists this Know-how. Currently, he is the acting Dean of Engineering and Technology Faculty at the Philadelphia University in Amman. He can be contacted at email: mbaniyounis@philadelphia.edu.jo.

Ayman Agha received his MSc, BSc (Hon.), and Ph.D. degrees in electrical power engineering, from the University of Science and Technology-AGH, Cracow-Poland in 1989 and 1997 respectively. He joined Jordan Phosphate Mines Co. (JPMC) in 1989 as a maintenance, planner, and preventive maintenance engineer and at the project's department till the 2000 year. From 2000 to 2004 he worked as a Studies and Design Department Manager in Alfanar Co. Riyadh/KSA. In 2004 re-joined his work in JPMC, worked for Megaprojects. Since 2013, he has been a certified Consultant in Electrical Power Engineering and Projects (PQAC-JAE-Jordan). His research interest includes power systems efficiency, nonlinear systems, optimization theory, and reactive power compensation. Currently, he is an assistant professor in the Department of Electrical Engineering, at Philadelphia University, Amman-Jordan. He can be contacted at email: aagha@philadelphia.edu.jo.

Hudefah Al-kashashneh received the M.Sc. degree in Mechatronics Engineering from Philadelphia University, Jordan, in 2019 and a B.Sc. degree in Electrical Power and Control Engineering from the Jordan University of Science and Technology, Jordan, in 2012. He currently works as a Laboratory Supervisor at the Department of Electrical Engineering, Philadelphia University. The following themes describe the researcher's interests: smart grids, renewable energy systems, power system stability, artificial intelligence, electrical machine, and Internet of Things (IoT). He can be contacted at email: hudefah_hb@yahoo.com.

Abdullah Al-Omoush received his MSc in Electronic Systems from Cranfield University, UK in 1992 and his BSc (Hon) from Salford University, UK in 1982 in Electrical and Electronic Engineering. He joined the Royal Jordanian Air force (RJAF) in 1982 -2002 where He worked in the fields of electronic communication systems, Avionic Systems, and Electronic Warfare Systems. Currently, he is a lecturer in the Department of Electrical Engineering at Philadelphia University, Amman-Jordan. He can be contacted at Alomoush@Philadelphia.edu.