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Steady State Modeling and Performance Improvement of Induction Motor Using Different Strategy

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ABSTRACT

Induction motors are the mostly used motors in industrial applications. Improving the efficiency of these motors will lead to significant energy savings, which is the recent trend to face the energy crisis. Based on mathematical analysis, this paper presents the steady state mathematical model of induction motor taking iron loss into account. A comparison analysis between two model that taken iron loss into account with that ignored it. The influence on efficiency, power factor, current and speed under different load conditions has been studied for three cases. The effect of iron loss cannot be ignored, especially on applications related to motor efficiency induction motors. High efficiency occurs due to a favorable balance between copper and iron losses. When induction motors run closed to rated torque and speed, however there are many applications required variable speed and torque. Motor efficiency drops off dramatically when they are subject to partial loading conditions due to unbalance between copper and iron losses.

This paper investigates the optimal operation of a three-phase induction motor through maximizing the efficiency and improving the motor power factor. Performance characteristics at maximum efficiency are presented and compared with a constant V/F method for different load conditions. It is worth saying that the optimal V/F control approach for variable speed operation is the best option for all loading conditions and for any type of load, constant V/F is the best option for constant load torque that is equal to or close to the motor's rated full load.

Nomenclature

R_1	Stator winding resistance.	R_2	Rotor winding resistance.
X_1	Stator winding reactance.	X_2	Rotor winding reactance.
R_m	Iron losses resistance.	S	Motor slip.
X_m	Magnetizing reactance.	w_s	Synchronous angular speed.
X_b	Reactance at rated frequency.	R_{mb}	Iron loss resistance at rated frequency

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1.NTRODUCTION

In the face of the energy crisis, limited resources in nature, and environmental considerations the world has been growing concern about energy consumption. The need for energy conservation is increasing and taking more attention in recent years [1, 2]. As electric motors, in particular, account for 75% of energy consumption in industrial applications, so it is important to improving efficiency and minimized electrical power consumption, saving is to be obtained [3]. There are numerous electric motors utilized in the industry, and induction motors (IMs) make up the bulk of them with a utilization rate of up to 90% [3, 4]. This extensive use of these motors is due to their rugged construction, durability, controllability, and low-cost maintenance [5, 6]. Due to the balance between copper and iron losses, induction motors that are operated near their rated torque and speed have high efficiency. Nevertheless, in conditions of partial loading, its efficiency is significantly reduced [3, 4] Using some control algorithms to implement energy-saving methods for IMs can help to address the issue of the rising power demand. The development of energy-saving technology of electric motors faces two main problems. One of them is the low efficiency motors. The other problem is that the power match between motor and load is not applicable. If the load is adjusted beyond the rated one, this will call for adequate or optimal inputs (voltage and frequency) to the motor. This optimal selection of these inputs will save energy, reduce losses and consequently increase the efficiency of the induction motors. To realize the significant energy saving principle of IM, make sure that the motors operated condition constant before and after saving energy and ensure the output power constant, reducing loss led to reduce the input power [7,8]. The main factor in energy conservation is to determine accurate losses and reduce motor losses to maximize motor efficiency. If the power losses can be reduced by just a few percent, this will have a major impact on the total energy consumption. This paper is structured as in section1, introduction. Section 2 presents in details the model of three phase induction motor; Section 3 discusses the different strategy for saving energy. Section 4 Simulation Results and Discussions. Finally, in section 5 conclusions presented

2. MODEL OF THREE PHASE INDUCTION MOTOR

The equivalent circuit of three phase induction motor can be predicted the performance characteristics of the induction motor. The important performance characteristics in the steady state are the efficiency, power factor, and current. The exact equivalent circuit of three phase induction motor is shown in Fig. 1

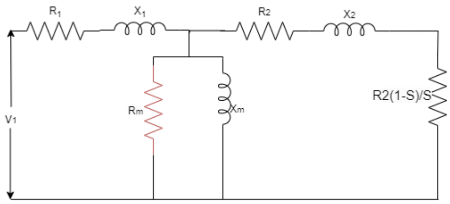


Fig. 1. equivalent circuit of three phase induction motor [9]

In [10] modeling of induction motor has been carried out by reducing its equivalent circuit to be R-L load and by omitting core losses resistance from circuit and represent iron loss as a function of voltage and speed. In this paper a steady state model is established for induction motor taken core losses resistance into account. The total impedance can be expressed as shown in equation (1).

$$Z_{total} = Z_1 + \frac{Z_m * Z_2}{Z_m + Z_2} \tag{1}$$

This equation can be reduced to R and L elements in term of slip as shown in equation (2) and (3)

$$R_{total} = R_1 + \frac{R_M (X_M X_2)^2 + (\frac{R_2}{S})^2 X_M{}^2 R_M + \frac{R_2}{S}(R_M X_M)^2}{(\frac{R_2}{S} R_M - X_2 X_M)^2 + (\frac{R_2}{S} X_M + R_M X_2 + R_M X_M)^2} \tag{2}$$

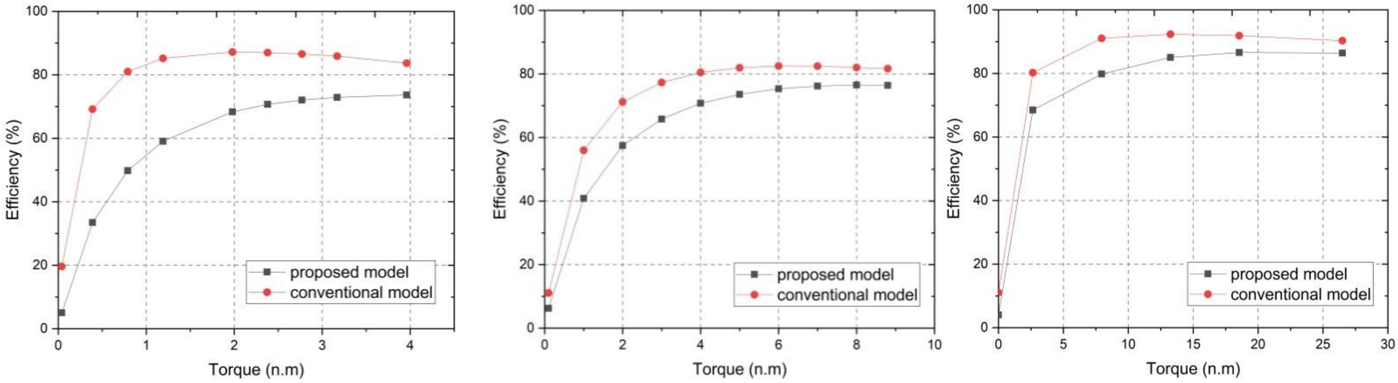
$$X_{total} = X_1 + \frac{(R_M X_M)^2 X_2 + (R_M X_2)^2 X_M + (\frac{R_2}{S})^2 R_M{}^2 X_M}{(\frac{R_2}{S} R_M - X_2 X_M)^2 + (\frac{R_2}{S} X_M + R_M X_2 + R_M X_M)^2} \tag{3}$$

Previous equations represent the mathematical model of three phase induction motor. A simulation program is developed and represented by MATLAB/SIMULINK.

The study was done on three cases:

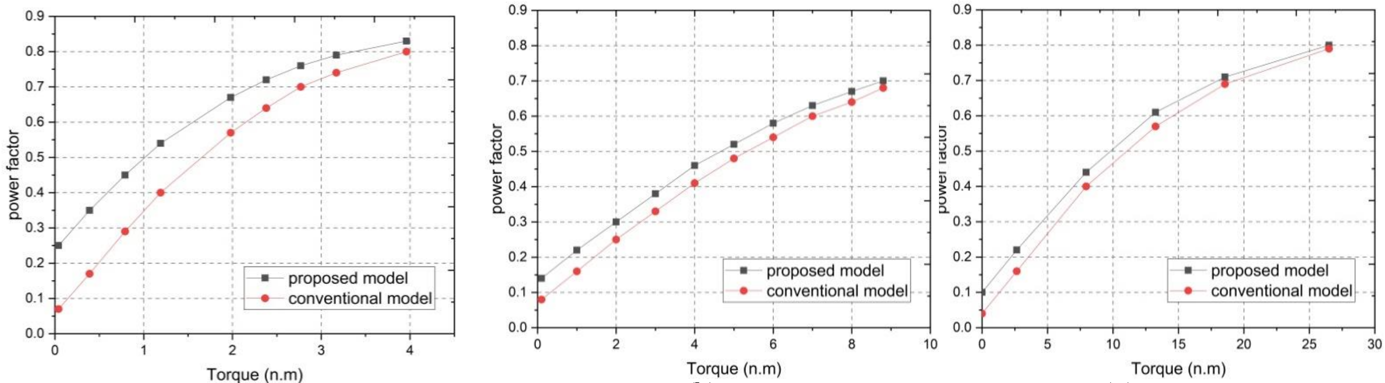
Case study 1: Motor (0.75 HP), Case study 2: Motor (2 HP), Case study3: Motor (5.3 HP).

From the analysis, the variation of efficiency, power factor, current, speed are all considered with the variation of load torque under the condition of rated voltage, rated frequency are shown respectively in Fig. 2 to Fig. 5



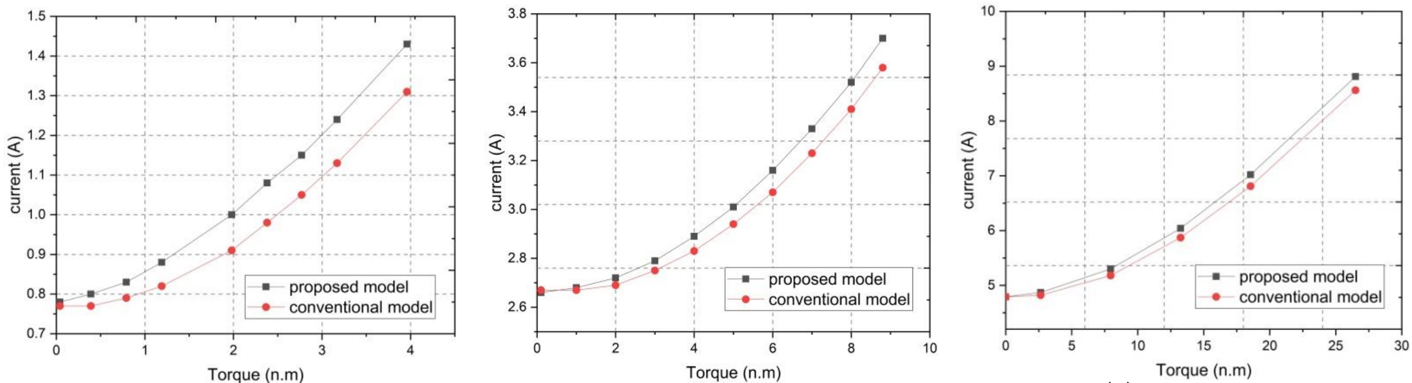
(a) (b) (c)

Fig. 2. The variation of efficiency (a) case study1, (b) case study2, (c) case study3 with torque



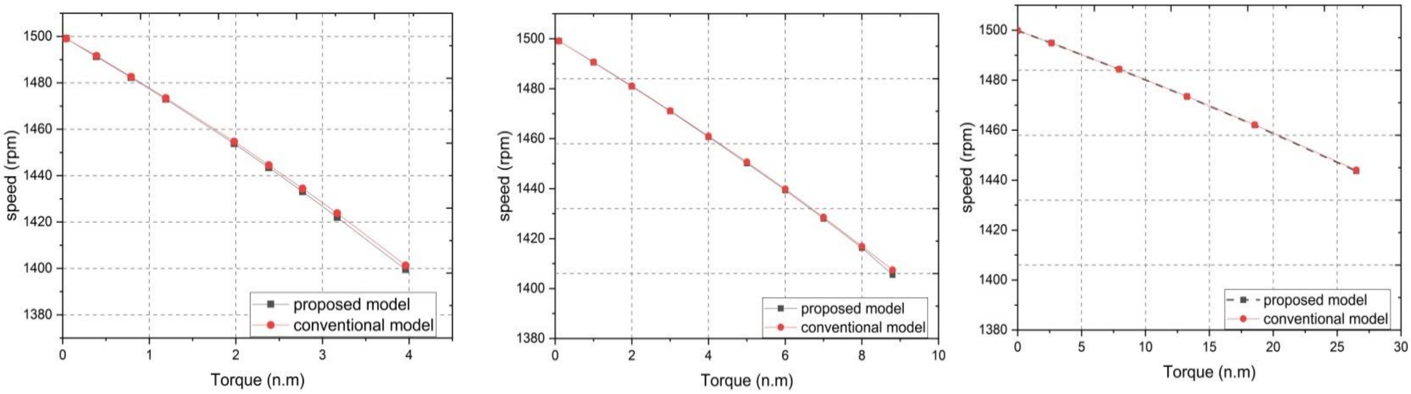
(a) (b) (c)

Fig. 3. The variation of power factor (a) case study1, (b) case study2, (c) case study3 with torque



a) (b) (c)

Fig. 4. The variation of current (a) case study1, (b) case study2, (c) case study3 with torque



(a) (b) (c)

Fig. 5. The variation of speed (a) case study1, (b) case study2, (c) case study3 with torque

From the graphs, it is seen that the influence of motor iron loss on efficiency and power factor and it is important especially in saving energy and reduction in power demand. Although the efficiency and power factor of motor is not satisfactorily represented in reduced model, the currents, speed are adequately represented. By comparing three cases study for various motor load factors, it is noticed that the effect of ignoring iron loss resistance on motor efficiency and power factor is greater on motor case study 1(0.75 HP).

3. Different Strategy for Energy Saving

3.1 Optimal V/f:

There is a certain speed (optimum slip) at which maximum efficiency occurs depending only on the motor parameters as shown in (4). Whatever the applied load, the speed is constant for the same motor. So, at a specific torque and speed operating point, there exist only one set of voltage amplitude that operates at maximum efficiency

$$S_\eta = \frac{-B+\sqrt{B(A+B)}}{A} \qquad (4)$$

Where

$$B = [\frac{R_2}{X_M}]^2 * R_1 + \frac{{R_2}^2}{(R_M)} \; ; \; A = [\frac{X_2+X_M}{X_M}]^2 * R_1 + \frac{[X_2]^2}{(R_M)} + R_2$$

For variable speed application, at any operating point for any load, it can be achieved by large number of frequency and voltage, so the purpose is to determine the optimal frequency and voltage that will operate motor at maximum efficiency. At any desired speeds determined the frequency for max efficiency, it is crucial to ascertain the frequency that would yield optimal efficiency for each speed, taking into account the efficiency-speed relation of IM curve fitting may be employed to establish the correlation between frequency and required speed, which may be summarized For variable speed application, at any operating point for any load, it can be achieved by large number of frequency and voltage, so the purpose is to determine the optimal frequency and voltage that will operate motor at maximum efficiency. At any desired speeds determined the frequency for max efficiency, it is crucial to ascertain the frequency that would yield optimal efficiency for each speed, taking into account the efficiency-speed relation of IM curve fitting may be employed to establish the correlation between frequency and required speed, which may be summarized

$$F = 0.0358 * n\,req + 0.1769 \qquad (5)$$

The optimum voltage at maximum efficiency can be determined as shown in equation (6):

$$v = \sqrt{\left(\frac{S_\eta w_s}{3*R_2}\right) * K_l} * \frac{\sqrt{(R_2/S_\eta)^2+(X_2)^2}}{Z} * Z_t \qquad (6)$$

3.2 Constant V/f

V/f control method is the most popular and has found widespread use in industrial and domestic applications [11]. With the introduction of solid-state inverters, constant V/f scalar control is one of the best methods for application required variable speed and torque [12]. Therefore, the scalar V/f control method that consists of open and closed-loop control is used and discussed in many papers research for the purpose of efficiency improvement. The strategy allows upholding a consistent voltage-to-frequency (V/F) ratio. Also, the proposed methodology ensures that the magnetizing flux is maintained at a constant magnitude, thus enabling the torque to continuously remain at its maximum value without any variations. when the motors operate at higher frequency, this will lead to weakening of the magnetic field in order to avoid this issue, the V/F ratio is restricted once the rated frequency has been attained, as depicted in Fig. 6

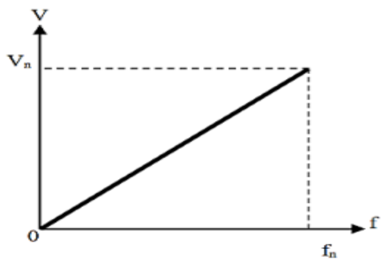


Fig. 6: Linear V/f curve voltage with frequency [13]

At any desired speed, the frequency calculated according to (5) Then, the required voltage was attained following:

$$V_{new} = F_{new} * \left(\frac{V_{rated}}{F_{rated}}\right) \quad (7)$$

3.3 Sensitivity of parameters to frequency variation

The effect of changing frequency takes place on reactance. All reactance's in the equivalent circuit of induction motor are directly proportional to the frequency

$$X = X_b * \left(\frac{F_{new}}{F_{rated}}\right) \quad (8)$$

The relation between iron loss component (R_m) and frequency is nonlinear especially at very low frequency.

The flux density is proportional to applied voltage of the machine which in turn proportional to the base frequency.so iron losses can be considered to be proportional to the frequency of power equals (1.1) Iron loss component (R_m) is a function of frequency

Therefore, the iron losses equivalent resistance has been taken to vary with frequency by that ratio.

$$R_m = R_{mb} \left(\frac{F_{rated}}{F_{new}}\right)^{1.1} \quad (9)$$

4. SIMULATION RESULTS AND DISCUSSIONS

A comparative analysis between constant v/f and optimal v/f method will be shown by examining different loading conditions

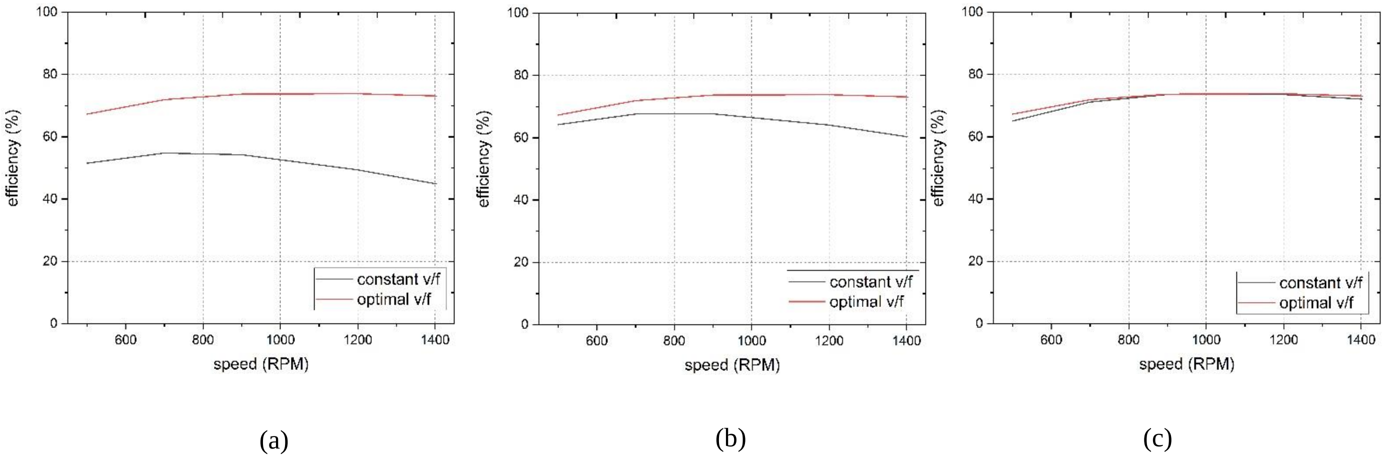
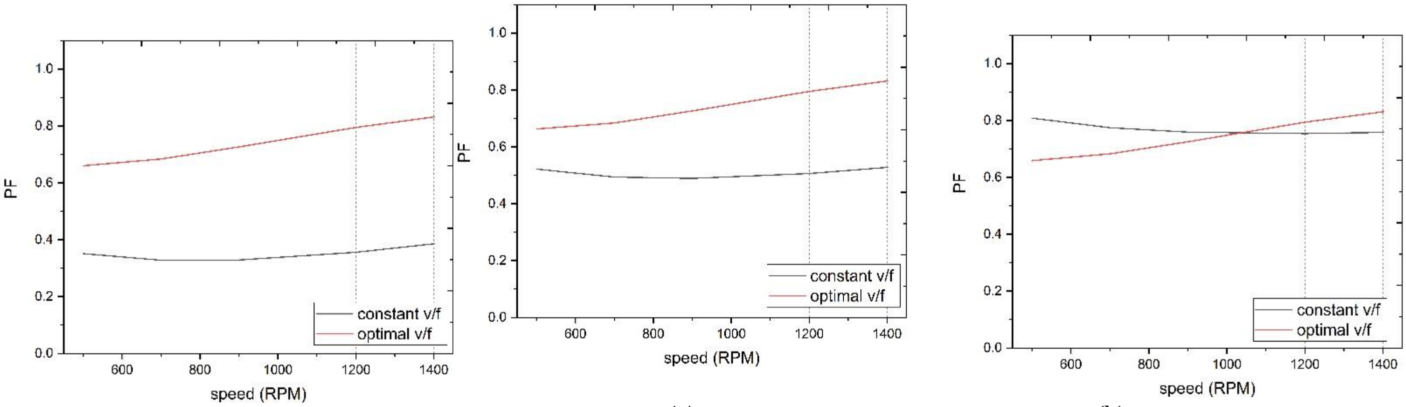
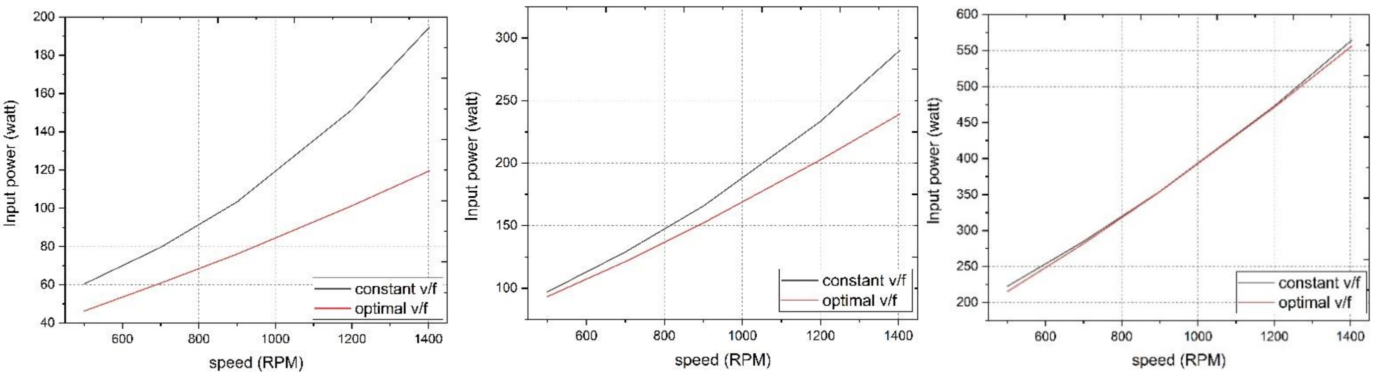


Fig. 7. Efficiency -Speed Characteristics (a) TL=15%Tfl (b) TL=30%Tfl, (c) TL=70%Tfl



(a) (b)
(c)

Fig. 8.Power Factor- Speed Characteristics (a) TL=15%Tfl (b) TL=30%Tfl, (c) TL=70%Tfl



(a) (b) (c)

Fig. 9. Input Power- Speed Characteristics (a) TL=15%Tfl (b) TL=30%Tfl, (c) TL=70%Tfl

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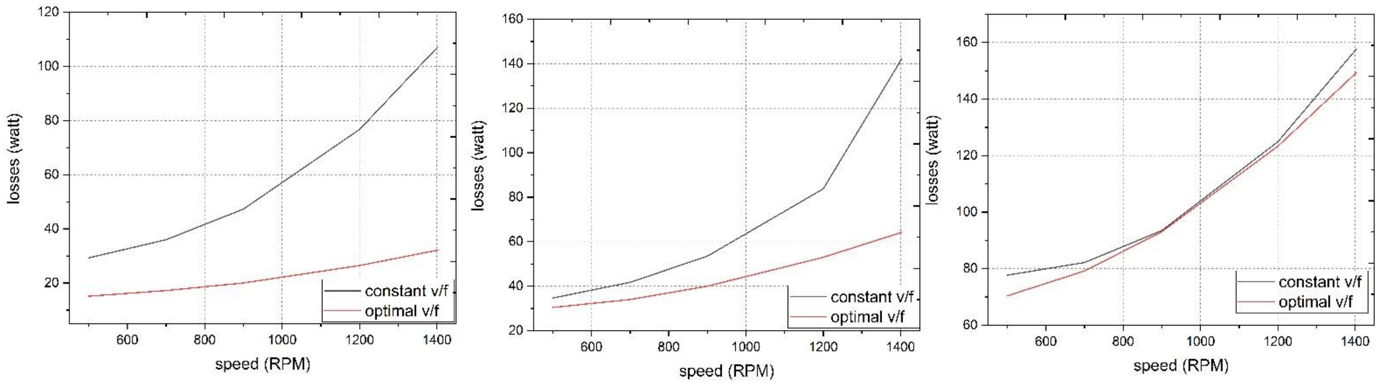

(a) (b) (c)

Fig. 10. losses -Speed Characteristics (a) TL=15%Tfl (b) TL=30%Tfl, (c) TL=70%Tfl

Fig. 7 display the variation of motor efficiency with different load condition at different speed, it can be noticed that at low load, optimal method achieve improved in efficiency with wide range of speed, however at load near to rated observed that the close result between constant v/f and optimal v/f method. Fig. 8 display the variation of motor power factor with different load condition at different speed, it can be noticed that at low load, power factor improved in optimal method with wide range of speed, however at load near to rated observed that optimal method preferred at high-speed range.

Fig. 9 and Fig. 10 display the variation of input power and losses with different load condition at different speed, it can be noticed that at low load, for optimal method, input power and losses decreased comparing with constant v/f.

Table 1: Simulation readings for optimal v/f control in 0.75Hp induction motor at different speed

speed	Load torque	Input power (watt)	Output power (watt)	Efficiency (%)	% Input power savings compared to constant v/f
500 rpm	15%	46.3	31.16	67.3%	23.4%
	30%	93.22	62.75	67.3%	3.89%
	70%	215.3	144.9	67.29%	3.27%
700 rpm	15%	60.87	43.64	71.92%	23.54%
	30%	121.3	87.28	71.92%	5.96%
	70%	282	202.8	71.92%	1.05%
900 rpm	15%	76.1	56.08	73.7%	26.4%
	30%	152.2	112.2	73.7%	8.147%
	70%	353.9	260.8	73.69%	0.112%
1200 rpm	15%	101.3	74.81	73.83%	33.13%
	30%	202.6	149.6	73.83%	13.15%
	70%	471.1	347.8	73.83%	0.317%
1403 rpm	15%	119.6	87.43	73.13%	38.57%
	30%	239.1	174.9	73.13%	17.52%
	70%	555.7	406.4	73.13%	1.489%

Table 1 shows the simulation results for optimal v/f control according to constant speed at different speed. At light load and different speed, it is noticed that optimal v/f method achieved efficiency greater than in constant v/f, method. when optimal v/f is used, efficiency found to be 67.3 %, However, when constant v/f method used, the efficiency decreases resulting in a saved energy up to of 23.4%, 26.4%33.13% respectively. At load close to rated and different speed, the efficiency of a model that when using optimal v/f is greater than that of a model that used constant v/f. when optimal v/f is used, efficiency found to be 67.3 %, However, when constant v/f method used, the efficiency decreases resulting in a saved energy up to of 3.27%,1.05%,0.317% respectively

5. CONCLUSIONS

In this paper, the steady state model that taken iron loss into account is established and compared with traditional model that ignored it. The model is simulated using MATLAB/Simulink. The study has been developed for three cases at different load condition. It is importance to incorporate core loss in the modeling of machines that operate at a low light load as the load decrease; the core loss eventually takes over. Also, if the machine operates under high load conditions, considering core loss renders more accurate and valid model analysis than ignoring the iron loss. it is observed that the effect of ignoring iron loss resistance on motor efficiency and power factor is greater on motor case study 1(0.75 HP). then this paper discussed optimal method and compared with constant v/f method. Maximum efficiency occurs at optimum slip, which depending on the motor parameter and frequency at different operating speeds, optimal v/f method achieved maximum efficiency and improved power factor at the different condition of loading. It can be noticed that constant v/f method doesn’t prefer at light constant load torque, it gives low efficiency, but it can achieve maximum efficiency near to full load torque

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