Research Article

Parameters Variation to Estimate Performance Characteristics of 3-Phase Asynchronous Motor

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Abstract

The 3-phase asynchronous squirrel cage motors (SCIM) are main competitor machines placed instead of other motors in the commercial and industrial fields. The stator and rotor material selection and construction topology influence the electrical machine design. The results illustrated with the motor of a 15 KW, variable controlled speed, for the constant frequency of 50 Hz or 60 Hz. The motor parameters created inside the simulation model must be matched with the value of a standard parameter for SCIM to achieve a high dynamic response. This work examines the effect of the parameters variation for synchronous motor on the performance characteristics at starting point and at a load change for different time and speed regions. Changing of the rotor power is taken into consideration, this occurs with dynamic change of the hydraulic pump load from the valve.

In the industrial applications, production, and manufacturing, till present there are still struggles to find the most holistic environment of the SCIM to achieve its efficiency at the lowest cost and same time control the motor performance, so we predicted the method of reducing the most effective motor parameters to improve the efficiency.

The offline method used the SCIM parameters to calculate the time-varying current, torque, and rotor speed. The results illustrated that this method was fully consistent with the experiment tests and the standard theoretical values. A MATLAB program is used to simulate this study. The simulation model proved the feasibility of the proposed method with encouraging performance.

Keywords: SimscopeTM, 3-Phase Asynchronous Motor, Parameters Variation, Simulation Model, Torque and Current, Efficiency.

1. Introduction

Three-phase asynchronous motors are the most frequently encountered in the industries. They are simple, rugged, low-price, and easy to maintain (Wildi, 2006). In the stator design of a 3-phase winding, the rotor currents are generated by the relative motion and interaction between the stator and rotor magnetic fields. Induction torque is generated in the rotating part (Moraes et al., 2003).

The SCIM with its advantages is used as the best traditional AC machine application with high efficiency and mechanical stresses, lower cost, and a simple control circuit (Gieras & Saari, 2012; Uzhegov et al., 2016).

During the machine's operation that runs at a high-speed region to achieve the lowest slip, consequentially reached a high value of power factor compared with the other soiled rotating system. For the wound rotor induction motor (WRIM), chopper resistance control can be inserted into the rotor resistance circuits (Ameen & Aula, 2020). The precision design of synchronous machines required optimum estimation for equivalent electromagnetic parameters of SCIM (Ikeda et al., 1990; Zhou & Wang, 2007), such motors without auxiliary electronic devices have an operating problem at high current values in different modes of operation, which implies inadmissible over-heating in their windings, moreover, these motors usually work at very specific speed regimes (Lindsay & Barton, 1973; Tu et al., 2008). The short circuit ring design is the most important item of the motor (Barta et al., 2016). The advanced design of the rotating part can overcome the mechanical and speed limitations of the machine, and different designed methods for short circuit rings compared to the traditional motor. In recent decades, all researchers studied to provide a feasible solution for a high-speed squirrel cage rotor, although no comparison among different solutions was given.

A typical procedure of the asynchronous machine's model is under study broadly separated into two categories: dynamic model and steady-state model. To achieve our purpose, the transient method with dynamic load and time-varying signals is used.

The predicted off-line method for evaluating the motor circuit parameters (Reed et al., 2016), coincides with standard 112 test results of IEEE, using; DC tests applied to the machine's stator winding, rotor short circuit tests, and free rotor test (Tu et al., 2008). In addition to the resistance and inductance of the stator and rotor parameters, there is a mutual inductance affected between them, and all of these values are per unit. Also, the other input values for a 15 KW motor are per-unit such as voltage, current, frequency, power factor …etc.

To analyze the performance of SCIM, the above parameters require a prediction technique using the computer-simulated model for different times and speeds (Ahmadi Jirdehi & Rezaei, 2016; Stephan et al., 1994).

The motor design aims to manufacture motors that have desired characteristics with high efficiency and low-cost values. Structural optimization ideas in mechanical engineering are described in the early 1960s (Wu et al., 2018).

The major importance of increasing efficiency at the lowest cost value is to improve power factor, as a result, will save a high percentage of power for all drive systems used in the industry fields; therefore, all designers must be interested in reaching a higher efficiency point of operation (Liu et al., 2009), because a few percentage increases in efficiency leads to a large saving in active power and decrease losses (Auinger, 2001).

All SCIM used in AC electrical drive system must run with a load roughly less than its power rating to increase the whole efficiency, consequently, at light load condition the machine run at poor efficiency, therefore, all input parameters simulated in MATLAB are matching the power rating of 15 KW of the asynchronous motor.

The modeling and simulation in this work were done using Matlab-2017. The computer core-i5 is used 8 GB of RAM to implement all functions that represent a 3-phase signal (voltage, current, and frequency) of power source design measuring a whole components instrument of scopes and two-dimensional diagrams, moreover generating a script MATLAB code that shows the response of asynchronous motor over variable time-load affected directly. The output measured values of voltages, currents, torque, powers, speed, slip, and power factor are computed according to the standard of simulation system required for the machine response over the measuring the parameters variation using different types of sensors based on real time in task offloading (Kishor & Chakarbarty, 2021), then to complete the requirements of enhancement the evaluation based on information technology diagram, the efficiency depends on the ratio of the output to input powers.

2. Related Work

There are different methods to control and obtain high performance for a squirrel cage induction motor (SCIM).
The optimum motor design such as rotor, stator, geometric dimensions, and slot types for the two motor parts are calculated to reach structural optimization, also using software simulation for the equivalent circuit parameters that has been explained by Yetgin et al. (2005).

Mohamed et al. (2016) used a mathematical model to study the effect of parameter variation based on the changing voltage and flux equation in the equivalent circuit, these quantities are affected by frequency, saturation, and temperature degree.

Improvements and study of SCIM concerning the equivalent circuit topology researched by Razali (2012). They used intelligent techniques to study the effect of changing motor parameters, such as flux level on the SCIM output characteristic.

Another related research based on the polynomial regression method by Wu et al. (2018) shows the great importance of the induction machine parameters estimating and used signals with time-varying of current, voltage, and speed, which used an example in the analysis of the equivalent circuit.

The investigation of the spiral sheet rotor for a 3-phase asynchronous motor with high starting torque and steady-state operation companionship with acceptable performance are the objectives work of Mujal-Rosas and Orrit-Prat (2011).

Presentation of parameters for a group of 33 SCIM motors operating as a 3-phase of 380 volts and develop a method for performance characteristics calculation over full-load using a conventional equivalent circuit to industrialize all parts of these motors at Egypt SIEMENS factory was thoughtful by Shanab (2021).

Elkholy et al. (2022) provides a pair of strategies for 3-phase induction motor parameters estimation, named as manufacturer's datasheet method (MDSM) and on-service method (OSM) that address based on actual measurements which does not need to release the motor from the connected load.

A MATLAB simulation predictive model for an induction motor is the proposed method of Sharma (2016) for the motor running at a low and high speed with the selection of optimum switching time for AC electrical drives.

3. Methodology

The asynchronous motor equation can be expressed according to the stator synchronous reference frame (Kundur & Malik, 2022) using the park's transformation (dqo) method which illustrated the stator rotating quantities to a reference stationary axis concerning electrical supply frequency.

Letting (s) represent a stator quantity to be transformed by voltage, current, or flux. The (dqo) transformation is defined by Fitzgerald (2003) and Kundur & Malik (2022).

$$\begin{bmatrix} S_d \\ S_q \\ S_o \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} Cos\,\theta_e & Cos(\theta_e - \frac{2\pi}{3}) & Cos(\theta_e + \frac{2\pi}{3}) \\ -Sin(\theta_e) & -Sin(\theta_e - \frac{2\pi}{3}) & -Sin(\theta_e + \frac{2\pi}{3}) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \tag{1}$$

S- are the quantities to be transformed.
θe- the electrical angle is given as:

$$\theta_e = \int_0^t 2\pi f dt \tag{2}$$

$1/\sqrt{2}$ -- is the zero-sequence coefficients; f-rated electrical frequency.

The inverse stator voltage transformation defined the (V_a, V_b, V_c) rotating voltages across post ~ 1 and ~ 2:

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} Cos\,\theta_e & -Sin\,\theta_e & 1/\sqrt{2} \\ Cos(\theta_e - 120^o) & -Sin(\theta_e - 120^o) & 1/\sqrt{2} \\ Cos(\theta_e + 120^o) & -Sin(\theta_e + 120^o) & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} \tag{3}$$

Also, the phase voltage (V_a) is defined as

$$V_a = V_{Line} \frac{\sqrt{2}}{\sqrt{3}} Sin(2\pi f + \theta)\,, \tag{4}$$

Where θ, is the electrical phase shift angle between the rotating phases 'a' and the reference frame.

The Pu stator voltage equations are defined by (Kundur & Malik, 2022; Wu et al., 2018):

$$\left.\begin{aligned} V_d &= R_s i_d + \frac{1}{\omega_b} P\psi_d - \omega_s \psi_q \\ V_q &= R_s i_q + \frac{1}{\omega_b} P\psi_q - \omega_s \psi_d \\ \text{And,} \qquad V_o &= R_s i_o + \frac{1}{\omega_o} P\psi_o \end{aligned}\right\} \tag{5}$$

ω_b ; Per-unit base electrical speed.
P; is (d/dt) differentiation factor.
(ψ_d, ψ_q, ψ_o); d-axis, q-axis, and zero-axis sequence stator flux linkages.
R_s ; Stator resistance.
(i_d, i_q, i_o); d-axis, q-axis, and zero sequence component currents.

The rotor voltage equations are defined by Say (1976) and Uzhegov et al. (2016) as follows:

$$\left.\begin{aligned} V_{dr} &= 0 = R_r i_{dr} + \frac{1}{\omega_b} P\psi_{dr} - \theta_r \psi_{qr} \\ V_{qr} &= 0 = R_r i_{qr} + \frac{1}{\omega_b} P\psi_{qr} - \theta_r \psi_{dr} \end{aligned}\right\} \tag{6}$$

V_{dr} and V_{qr} d-axis and q-axis rotor voltages.
ψ_{dr} and ψ_{qr} d-axis and q-axis rotor flux linkages.
$\theta_r = \omega_s - \omega_r$; The angle between the d-axis and a-phase of the rotor.
ω_s ; Per-unit synchronous speed, as a reference, equal to $1\ \mathrm{P.u}$
ω_r ; Per-unit rotational speed.
R_r ; Rotor resistance.

From Equation (2) and Equation (3), the stator and rotor flux linkages can be expressed in terms of (d - q) axes, (Umans et al., 2014) as follows:

Stator flux linkages:

$$\left.\begin{aligned} \psi_d &= L_{ss} i_{ds} + L_m i_{dr} \\ \psi_q &= L_{ss} i_{qs} + L_m i_{qr} \\ \psi_{os} &= L_{ss} i_o \end{aligned}\right\} \tag{7}$$

Rotor flux linkage:

$$\left.\begin{aligned} \psi_{dr} &= L_{rr} i_{dr} + L_m i_{ds} \\ \psi_q &= L_{ss} i_{qr} + L_m i_{qs} \end{aligned}\right\} \tag{8}$$

where:
L_{rr}; rotor self-inductance referred to the stator.
L_{ss}: stator self-inductance, L_{ls} stator leakage inductance, and L_m magnetizing inductance are related by:

$$L_{ss} = L_{ls} + L_m \tag{9}$$

L_{rr} rotor self-inductance, L_{lr} rotor leakage inductance, and L_m magnetizing inductance are related as:

$$L_{rr} = L_{lr} + L_m \tag{10}$$

Power, torque, and efficiency

The instantaneous output power of the stator is:

$$P_r = e_e i_a + e_b i_b + e_c i_c \tag{11}$$

The above expression in per-unit gives the rotor power, and explains the d-q components:

$$P_r = V_d i_d + V_q i_q + 2e_o i_o \tag{12}$$

Similarly; the instantaneous power input to the rotor is:

$$P_r = \frac{2}{3}(V_{dr} i_{dr} + V_{qr} i_{qr}) \tag{13}$$

The per-unit rotor torque is defined as (Fitzgerald et al., 2003):

$$T = \psi_d i_q - \psi_q i_d \tag{14}$$

Neglecting the air-gap losses result in motor efficiency:

$$\text{efficiency} = \frac{\text{rotor power}}{\text{primary losses} + \text{rotor power}} \tag{15}$$

Primary (stator) resistance losses due to the stator current flow in the stationary winding that causes a large amount of dissipation heating power (Razali et al., 2012):

$$P_{st} = I_{st}^2 R_s \tag{16}$$

The stator of SCIM resistance (Rs) with a total number of turns (N), electrical conductivity (σ), active conductor length (Lw), and cross-sectional area (Aw) in the slot:

$$P_{st} = (I_{st})^2 * \frac{NL_w}{\sigma \frac{A_w}{N}} = (I_{st})^2 * \frac{N^2 L_w}{\sigma A_w} \tag{17}$$

I_{st} - is the r.m.s stator current given as:

$$I_{st} = I_d + jI_q \quad (18).$$

4. Simulation Model

The proposed control model as shown in **Error! Reference source not found.** is varied in MATLAB-Simulink at d ifferent time and speed regions to justify the performance control scheme.

The method of simulating-model has been recognized as a researched tool since the beginning of the twentieth century with the development of computers, and it becomes a powerful tool supporting the design, planning, and analysis of different scientific research. Actually, in an electrical machine simulation which acts as a very important technique needed more other fields. The schematic block of a complete SCIM dynamic model indicates all programmable inputs voltage source of 3-phase ideal power supply to the machine with a cylinder rotor type results in no reluctance torque between rotor and stator field (Saied & Mohammed, 2016) with specific parameters and output of Hydro-Mechanical pump as a dynamic load controlled by mechanical valve based on suitable step functions. MATLAB simulation codes transfer deferential functions into a mathematical system to produce efficient items and static calculations using sensors based on a real-time variation of speed, efficiency, torque, and machine active power in per-unit multi-degree dimensions.

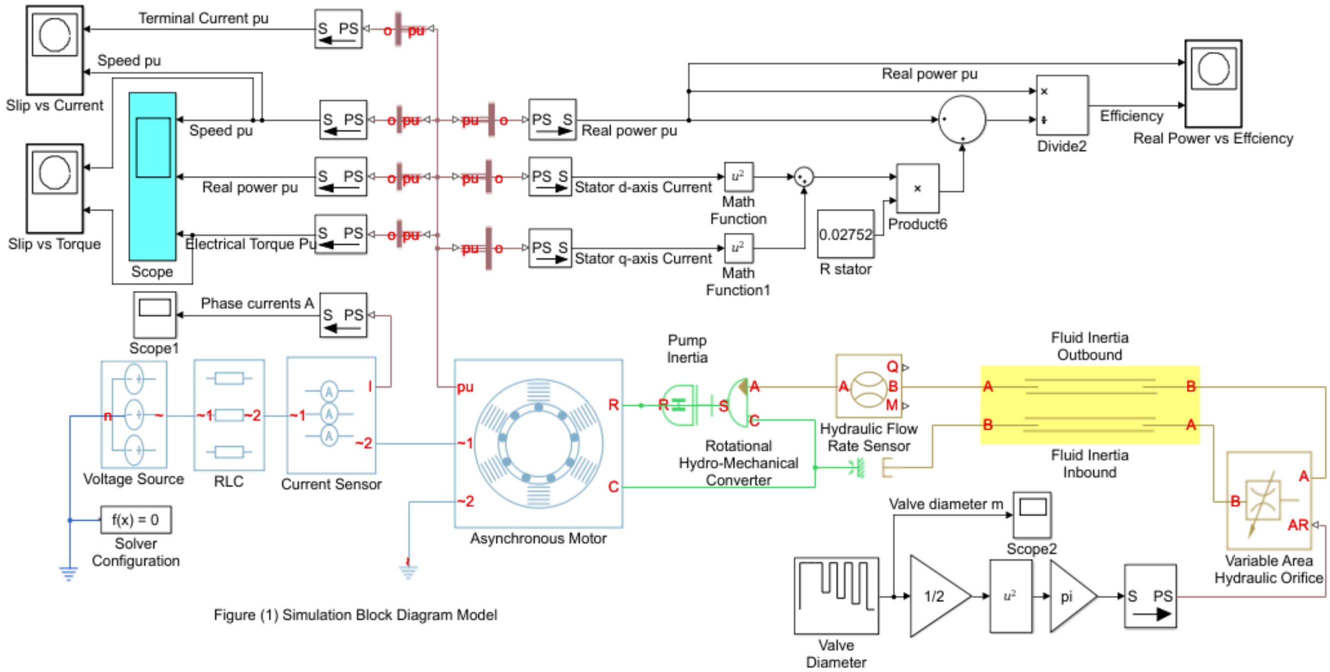
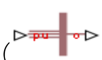
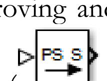


Figure 1. Simulation model.

Transducer measurement block () as output per unit from an asynchronous machine based on selected values. The per-unit calculation measured by using the value of elements as the input signal vector with mathematical expressions directly outputs the element value from the input signal vector.

A Simulink model has been developed using an important block-set software tool for presenting the relation between physical signal and Simulink leading to improving and modifying a characteristic of the desired units for the output signals. For Physical to Simulink conversion () the input physical signal function comes into commensurate with an electrical unit. If we reach a desired output unit, the output gain of the applied block equal to the conversion factor leads to the output of the Simulink signal. Moreover, the Simulink to Physical conversion (), predicted parameter value controls the actual physical signal at the external port of the simulated block; it will be an input signal for the SimscapeTM physical network.

The per-unit parameters used in the simulation are from Kundur and Malik (2022), see Table 1.

Table 1. Simulation parameters for 15 KW for 3-phase SCIM motor.

Description	**Variables**	**P.U. Values**
Supply Voltage	400 V	
Supply Frequency	(50 or 60) Hz	
Reference Speed	ω (rpm)	1
Number of poles	2	
Stator resistance	R_s (Ω)	0.02752
Stator inductance	L_s (H)	0.0992
Rotor resistance referred to stator	R'_r (Ω)	0.015466
Rotor inductance referred to stator	L'_r (H)	0.04522

Mutual Inductance	L_m (H)	1.8730
Mutual Resistance	R_m (Ω)	0.0992

5. Results

This work explained and compared the results of the motor with theoretical values. **Error! Reference source not found.** illustrated a developed representation of SCIM control model results at different speed regions. In the simulation, the motor starts at zero seconds with the reference torque 0.225 P.U. and starting current 72 A from a power supply, where it reaches the rated value at 2.71 seconds, the motor stops after 9 seconds, once the motor attained roughly stop time, the torque becomes at a minimum value near the synchronous rotor speed, also the valve diameter obtain 0.04 m, and measured fluid oil is stopped following from the tank to the hydraulic pump which represents the mechanical load.

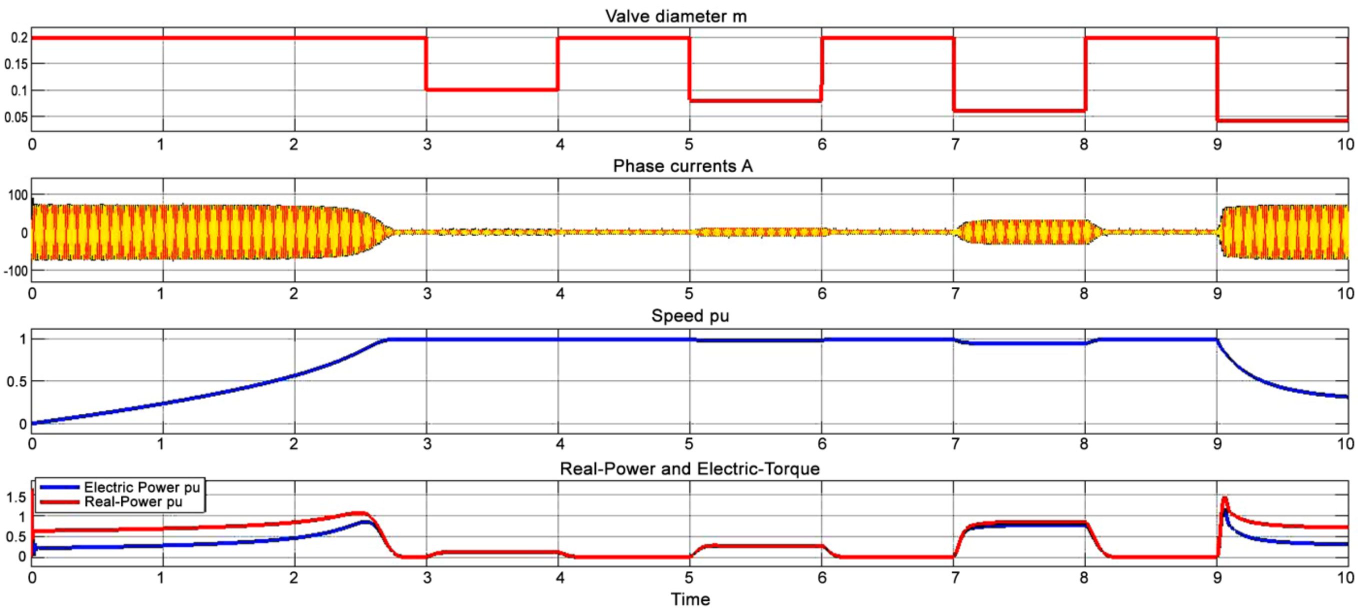


Figure 2 Control model results

Error! Reference source not found. shows the torque and current speed curves of 15 KW, 50 Hz, and 400 V that have parameter values given in Table 1.

With the rising of the rotor resistance by a factor of 1.025 P.U., the new Torque-speed curve indicates that the starting torque is 0.567 P.U., and the motor develops a maximum torque of 0.848 at a slip 0.15 greater than the original slip for the corresponding starting current 3.709 P.U.

If we again change the rotor resistance so that it becomes 1.05 P.U., the torque attains the same breakdown at a high slip value of 0.19, and the locked-motor current is 3.708 P.U.

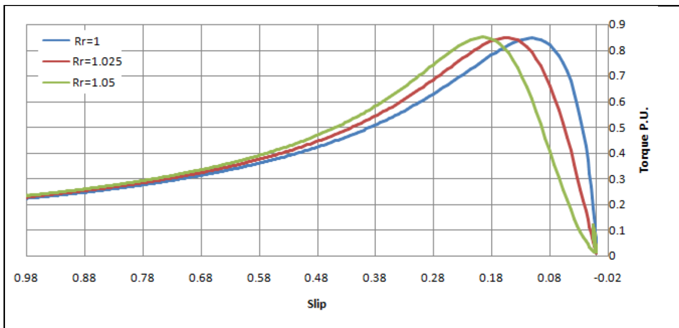


Figure 3 (a)

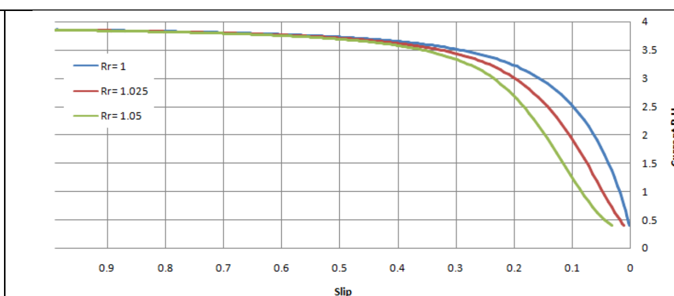


Figure 3 (b)

Figure 3. (a) Torque slips characteristic, (b) Current vs. slip.

In summary, the torque and speed curves are greatly affected by a change of motor parameters, a high parameters value is eligible due to appropriate with a high starting torque (Kundur & Malik, 2022) and withstand a high current for start. **Error! Reference source not found.** illustrates three different electrical motor parameters, which are the key to c ontrolling output power and minimizing the losses (Erdogan et al., 2015) in Equation (16).

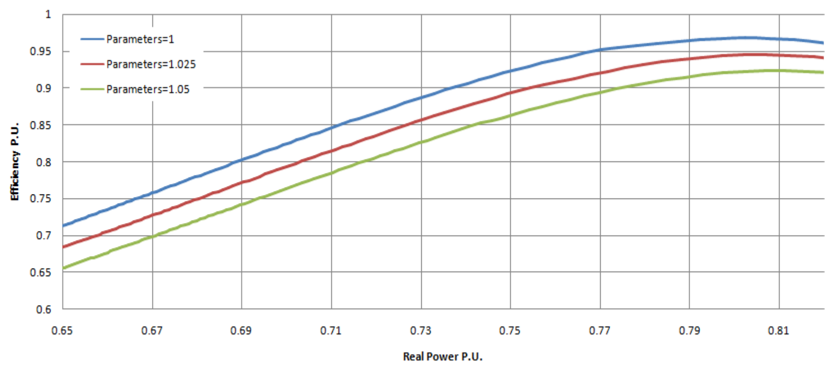


Figure 4. Effect of changing parameters on Efficiency vs. output-power

Error! Reference source not found. describes the speed-efficiency characteristic, that explained the increase of o utput efficiency with the load increases, constant over a narrow power domain, then slowly begins to decay. This visualized typical for all electrical machines efficiency curves (Wildi, 2006). At all times electrical motor manufacturers endeavor to achieve a high-efficiency level at full load.

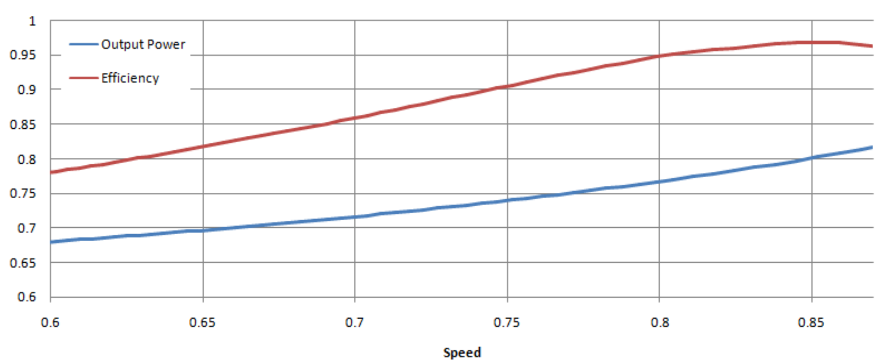


Figure 5. Efficiency and output-power vs. speed curves.

6. Conclusion

Combined with rapid technological progress, the squirrel cage induction motors SCIM drivers have been widely used instead of the other motors at different modes of operation in the industrial application. The parameters and performance with associated losses of the designed machine are not constant and differ according to operation speed regions. The manufacturing design objectives are to obtain a high-performance characteristic, also to control the developing torque at a high rotational speed at the motor's shaft with an acceptable efficiency level. Predesign techniques are used to evaluate motor operation using parameters variation of SCIM model to obtain time-varying of current-signal, power, torque, efficiency, and motor speed to investigate the external performance characteristics with dynamic results of the simplified modeling parameters adjusted and compared, consequently, they validate mathematical values and confirm with a steady-state performance of SCIM operation.

The theoretical dynamic model can mathematically be developed in the form (d - q) axis of the park's transformation equations used in implementation, the selected frequencies related to the actual value of 50 Hz or 60 Hz. The dynamic model is computed for a 15 KW motor under different times and speed regains from rest to synchronous speed.

Our purpose is to obtain a desired output performance characteristic by predicting and simulating equivalent circuit parameters for the SCIM model, and the stator resistance can be controlled to increase the system's efficiency.

All the measured data of the motor have been illustrated in set output graphs. All graphs agree with the predicted analysis value of various model off-line parameters.

MATLAB with required advantages including the ability of measurement and control to obtain all motor performance values used in this research, it is flexible to avoid any undesired procedure in parameter estimation to reach the optimal results.

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