Dynamic Model Identification of Induction Motors using Intelligent Search Techniques with taking Core Loss into Account

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Abstract: - Traditionally, dynamic parameters of induction motors can be roughly estimated through conventional tests (no load test, block rotor test and retardation test) and core loss is neglected in the dynamic behaviours analysis. Due to the complication of dynamic behaviours of induction motors, inaccuracy of transient characteristics may obtain when using these dynamic parameters. In order to improving accuracy of dynamic behaviour analysis, however, the inclusion of core loss in the machine model needs to be re-addressed and an intelligent approach to estimated dynamic parameters needs to be adopted. In this paper, three of intelligent search techniques, which are i) Tabu Search (TS), ii) Adaptive Tabu Search (ATS) and iii) Genetic Algorithm (GA), are employed to demonstrate the effectiveness of intelligent identification compared with the conventional model with and without core loss parameter(R_C). The simulation results from dynamic parameters including R_C obtained by the GA in comparison with the experimental results are convinced the effectiveness for this aim.

Key-Words: - Induction Motor, Dynamic Model, Intelligent Search, Core Loss, Tabu Search, Adaptive Tabu Search, Genetic Algorithm.

1 Introduction

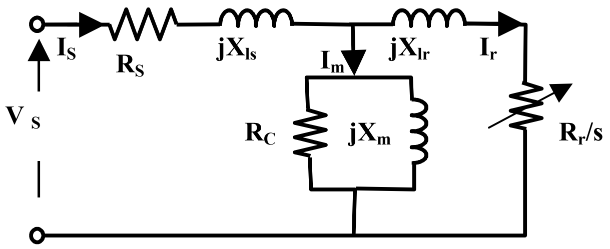
Induction motors are very commonly used in industrial applications over half a century because there are cheap, robust efficient and reliable [1]. Traditionally, the conventional steady state per-phase equivalent circuit has been used to describing steady-state behaviours of three-phase induction motors [1–5]. Furthermore, in simple control, where the accuracy and the precision are not that much significant, such a steady-state model seems to be moderate for describing and represent the dynamic behaviour of induction motors. It is well known that only the standard steady-state per-phase equivalent circuit for three-phase induction motors has included core loss parameter in a simple and effective manner. But the generalized theory of machines neglects core loss parameter in the transient analysis of induction motors.

Presently, however, with the development to complication and high accuracy controlled drive systems of induction motors, dynamic model from traditional steady-state parameters is not enough to represent the exactly dynamic behaviors of induction motor in high accuracy vector controlled drives systems. Thus, the accurate parameter identification of induction motors is challenged for those controlled drives system. Many identification techniques have been studied and have been proposed for dynamic parameter identification of induction motors [6–11]. But there is still lack to include the effect of core loss in dynamic model. However, there has been increasing studied in the detuning effect of that the core loss produces [12–20]. Hence, the effect of core loss should be taken into account and core loss parameter should be re-addressed in dynamic model of induction motors.

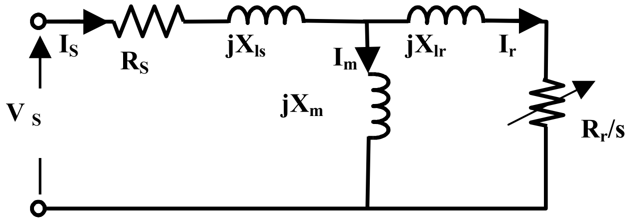
In this paper, the authors have proposed two kinds of dynamic model of induction motor. One is the dynamic model without core loss taking in to account. The other one is with core loss taking into account. And this paper also presents the effectiveness of intelligent search techniques, Tabu Search (TS), Adaptive Tabu Search (ATS) and Genetic Algorithm (GA) techniques, for identifying dynamic parameter of induction motors compared with the conventional techniques (no-load, locked-rotor and retardation tests). The validity of the authors aim is verified by stator current response and speed response from the simulation and the experimental results.

2 Equivalent Circuit and Modelling of Three Phase Induction Motors

Traditionally, the steady state model of a three phase induction motor is represeted by the per phase equivalent circuit, including R_C, where R_C represents the equivalent resistance for core loss [2,3]. The steady state per phase equivalent circuit referred to the stator side of a three phase induction motor, neglecting and including R_C, is given in Fig. 1.



a) With R_C included



b) With R_C neglected

Fig. 1 Per Phase Equivalent Circuit of Three Phase Induction Motors.

As shown in Fig. 1, Vs is the stator phase voltage; R_s and R_r are the stator and rotor winding resistances; X_{ls} and X_{lr} are the stator and rotor leakage reactance. X_m is the magnetizing reactance; and R_c is the equivalent resistance for core loss.

From Fig. 1a, with power being supplied only on the stator side, the voltages and currents can be related as:

$$\begin{bmatrix} v_s \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + Xp & Kp \\ Kp - j\omega_r K & R_r + Yp - j\omega_r Y \end{bmatrix} \cdot \begin{bmatrix} i_s \\ i_r \end{bmatrix} \quad (1)$$

Where $p = d/dt$, $K = \dfrac{R_C L_m}{R_C + L_m p}$, $X = L_{1s} + K$ and $Y = L_{1r} + K$.

From Fig. 1b, the relation between the input stator voltage and the stator and rotor currents can be derived as:

$$\begin{bmatrix} v_s \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + L_s p & L_m p \\ L_m p - j\omega_r L_m & R_r + L_r p - j\omega_r L_r \end{bmatrix} \cdot \begin{bmatrix} i_s \\ i_r \end{bmatrix} \quad (2)$$

Where $L_s = L_{ls} + L_m$, $L_r = L_{lr} + L_m$ and in the steady state $p = j\omega_s$.

The direct and quadrature axis model(d-q model) based on the space phasor theory is widely used for simulation the dynamic behaviour of three-phase induction motors as shown in Fig. 2.

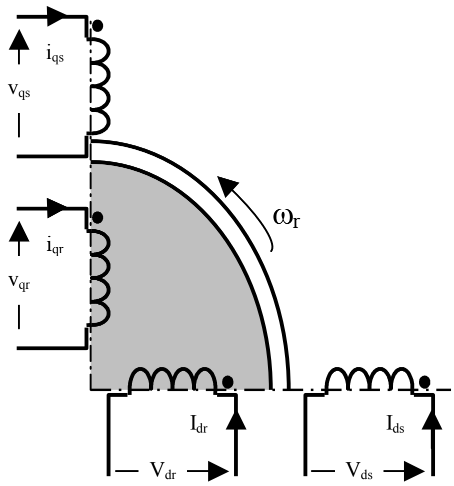


Fig. 2 d-q Axis Representation of Induction Motor.

The generalized theory of machine neglects core loss in the transient analysis of induction motors. From Equation (2) and from Fig. 2, neglecting R_C and with $v_{dr} = v_{qr} = 0$, the following equations can be obtained.

$$\begin{bmatrix} v_{qs} \\ v_{ds} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + L_s p & 0 & L_m p & 0 \\ 0 & R_s + L_s p & 0 & L_m p \\ L_m p & -\omega_r L_m & R_r + L_r p & -\omega_r L_r \\ \omega_r L_m & L_m p & \omega_r L_r & R_r + L_r p \end{bmatrix} \cdot \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \quad (3)$$

Where ω_r is the rotor speed in electrical radians/sec. To represent R_C in the d-q model, Equation (3) should be modified and be written to include R_C in the d-q model as:

$$\begin{bmatrix} v_{qs} \\ v_{ds} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + Xp & 0 & Kp & 0 \\ 0 & R_s + Xp & 0 & Kp \\ Kp & -\omega_r K & R_r + Yp & -\omega_r Y \\ \omega_r K & Kp & \omega_r Y & R_r + Yp \end{bmatrix} \cdot \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \quad (4)$$

The voltage equations are valid under both transient and steady state condition. In order to prove the authors aim, the state equations in the stationary reference frame are chosen. Under transient conditions, the equation of motion as functions of stator currents, rotor currents and rotor speed as shown in equation (5) is used to simulate the speed response compared with the experimental results.

$$J_m \frac{d\omega_r}{dt} = (T_{em} - T_L) + B_m \omega_r \qquad (5)$$

Where $T_{em} = -\frac{3}{2} P L_m (i_{ds} i_{qr} - i_{qs} i_{dr})$,

J_m = Moment of inertia

B_m = Friction coefficient

T_L = Load torque

In this paper, transient condition is starting process of induction motor from standstill to full speed at no load ($T_L = 0$).

3 Experimental Results

A squirrel-cage induction motor, 0.5-kW, 220/380-V, 50-Hz, 3-phase, is used for the conventional tests as shown in Fig. 4.

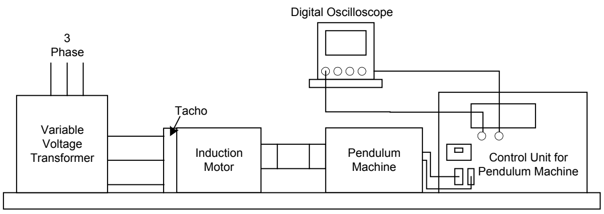


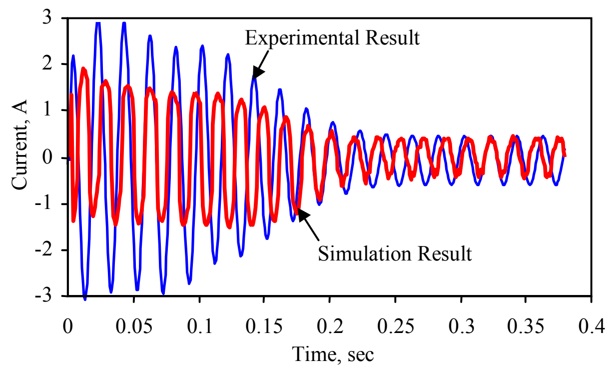
Fig. 3 Block Diagram Representing the Experimental Set.

With the conventional no-load, locked-rotor and retardation tests, the parameters of the induction motor can be obtained. They are put in Table 1. These parameters are used to simulate the stator current and the speed responses compared with the results from experimental test. The comparison results are shown in Fig. 5.

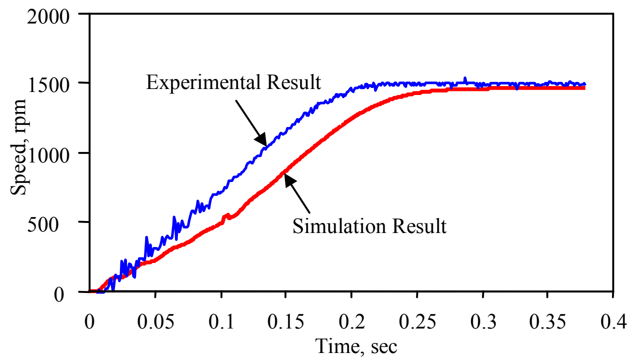
As shown in Fig. 5, inaccuracy of dynamic responses was obtained when using dynamic parameters from conventional tests. Smaller stator current was obtained in the simulation results compared with the experimental results.

Table 1 Induction Motor Parameters from the Conventional Tests.

Induction Motor Parameters	
R_{ls} (Ω)	74.02
R_{lr} (Ω)	62.01
R_c (Ω)	0.6482
L_{ls} (H)	0.2087
L_{lr} (H)	0.2087
L_{ms} H)	3.4377
B_m(N.m.s/rad)	0.0000
J_m(N.m.s^2/rad)	0.0025



a) Stator Current Responses



b) Speed Responses

Fig. 5 Comparison the Dynamic Response between the Experimental Results and the Simulation from Parameters obtained by the Conventional Test Method.

4 Parameters Identification using Intelligent Search Techniques

As illustrated in Section 3, the conventional steady state model can not used to estimate accurately and precisely dynamic parameters. By this reason, many different approaches to identify dynamic parameters of induction motors have been proposed. In this paper, the authors would like to demonstrate the effectiveness of some intelligent search techniques, TS, ATS and GA techniques, to identify dynamic parameters and also would like to demonstrate the effect of core loss in dynamic model for the dynamic response simulation of induction motors. Due to there exist many of works employing intelligent search techniques. So, the details of such techniques are not illustrated in this paper. However, more detail in [21] and [22] may be useful.

In order to elucidate the effectiveness of intelligent search techniques, firstly, dynamic response of stator current and rotor speed of a tested induction motor are measured. Secondly, TS, ATS and GA techniques are selected to develop an algorithm to identify dynamic parameters of such induction motor based on space phasor model. The procedure of searching process shows in Fig. 6. For the best searching results in each search technique, the parameters are adjusted to give response best fitting experimental data. An objective function (the sum of squared errors) in equation (6) is the key to perform the properly searching results.

$$f_{obj} = \sum_{i=1}^{N} \left(y_{measured} - y_{simulated} \right)^2 \qquad (6)$$

where $y_{measured}$ is the measured signal
$y_{simulated}$ is the simulated signal
f_{obj} is the objective function

Each searching techniques was used for identify dynamic parameter of induction motor until obtain 5 sets of the best searching results. The average of the best searching results for each technique compared with the conventional test results are shown in Table 2. Although variation of searching results were obtained from each searching techniques but the same tendency and around ½ of the conventional test results of the results were obtained. From the average of parameters of searching techniques given in Table 2, the rotor speed and the stator current responses were simulated using the space phasor model as described in Section 2. The simulation results were compared with the experimental results. The effectiveness and the accuracy of each technique are shown in Fig. 7, Fig. 8 and Fig. 9, respectively.

In case of parameters obtained by TS technique as shown in Fig. 7, without taking R_C in to account, larger magnitude of stator current before the steady state condition were obtained from the simulation results compared with the experimental results.

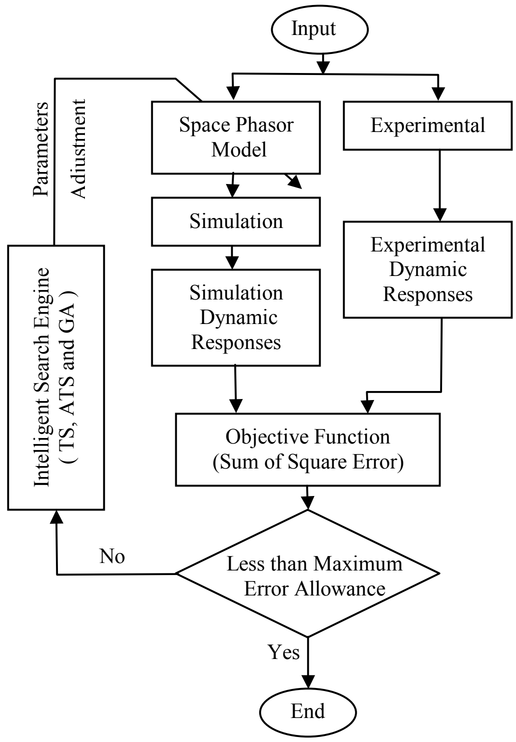


Fig. 6 Intelligent Dynamic Parameter Identification Procedure.

Table 2 Comparison among Obtained Parameters.

	CT	Tabu	ATS	GA
L_{ls} (H)	0.2087	0.07046	0.0713	0.07142
L_{lr} (H)	0.2087	0.0979	0.1081	0.09858
L_{ms} (H)	3.4377	1.00368	0.9463	1.51958
R_{ls} (Ω)	74.02	38.41318	37.6793	38.6659
R_{lr} (Ω)	62.01	37.32834	37.2042	28.9187
J_m	0.0000	0.00378	0.0037	0.00382
B_m	0.0025	0.00098	0.0008	0.0016

And, also, slight deviation of the speed response was obtained. While with taking R_C into account, near the same magnitude of stator current was obtained from the simulation result compare with the experimental result. And the speed response from the simulation results is best fitting with the experimental results.

In case of parameters obtained by ATS technique as shown in Fig. 8, without taking R_C in to account, larger magnitude of stator current before the steady state condition were obtained from the simulation results compared with the experimental results. While with taking R_C into account, near the same magnitude of stator current was obtained. Speed responses from the simulation results with and without taking R_C into account are best fitting with the experimental results.

In case of parameters obtained by GA technique as shown in Fig. 9, without taking R_C in to account, largest magnitude of stator current before the steady state condition were obtained from the simulation results compared with the other techniques and the experimental results. While with taking R_C into account, near the same magnitude of stator current was obtained. Speed responses from the simulation results with taking R_C into account is best fitting with the experimental results than the simulation results with taking R_C into account.

All the simulation results with taking core loss into account show the accuracy of each searching techniques for parameter identification of induction motor.

However, the effectiveness of each searching techniques can be comparing by the calculation time. High accuracy and precisely with shortest time for calculation are the key for indicate the most effective searching technique. As shown in Table 3, calculation time of GA technique is shorter than the other techniques. So, dynamic parameters identification using GA technique may be the most effectiveness searching techniques for induction motor compare with those the two techniques.

Table 3 Comparison of Calculation Times.

	TS	ATS	GA
Calculation Time (sec)	7595.658	902.57	349.963

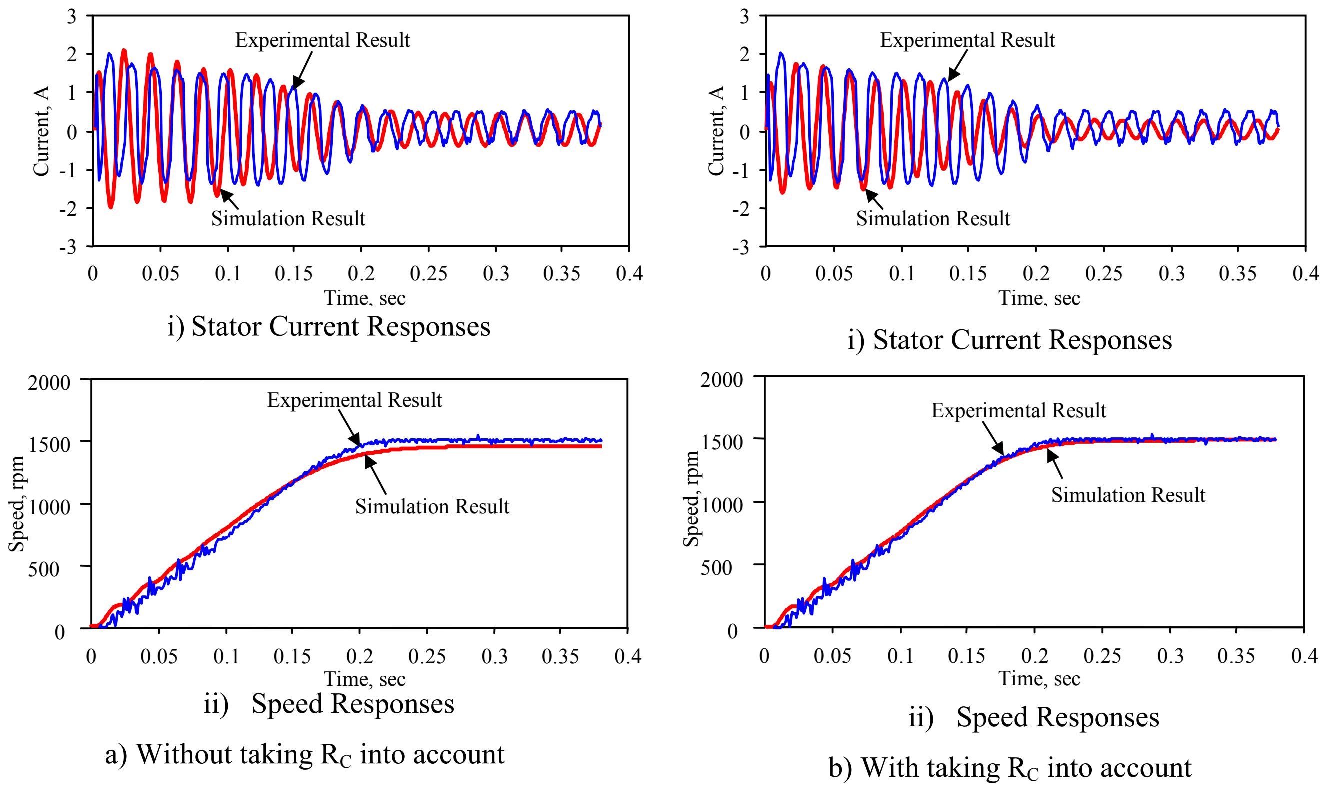
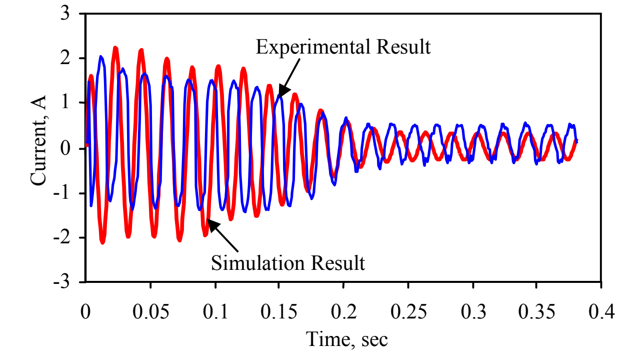
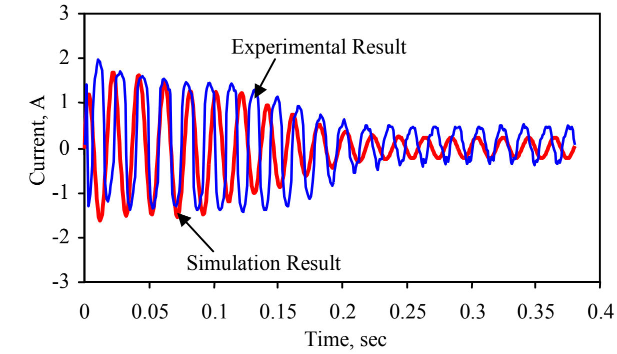


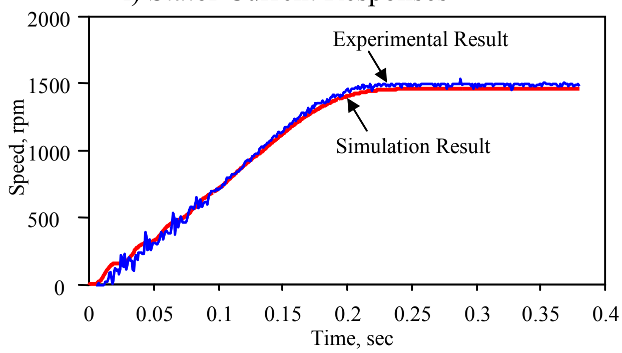
Fig. 7 Comparison the Dynamic Response between the Experimental Results and the Simulation Results from Parameters obtained by the Tabu Search based Method.



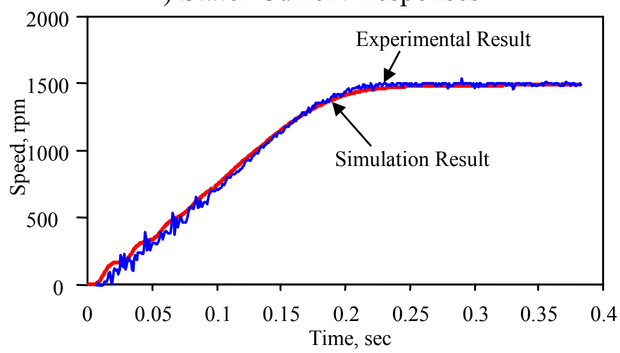
i) Stator Current Responses



i) Stator Current Responses



ii) Speed Responses

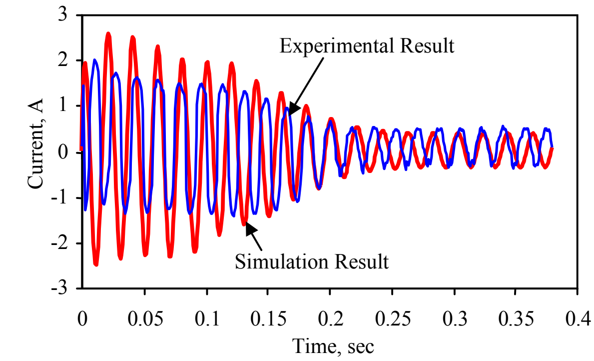


ii) Speed Responses

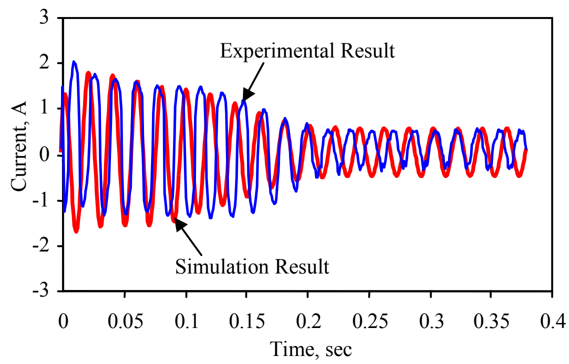
a) Without taking R_C into account

b) With taking R_C into account

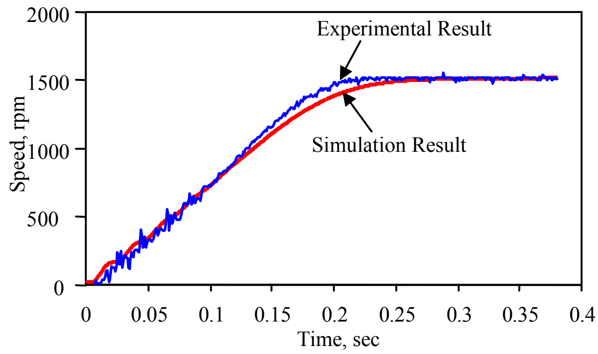
Fig. 8 Comparison the Dynamic Response between the Experimental Results and the Simulation Results from Parameters obtained by the AdaptiveTabu Search based Method.



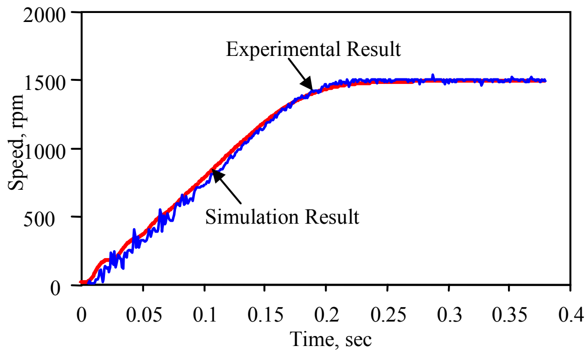
i) Stator Current Responses



i) Stator Current Responses



ii) Speed Responses



ii) Speed Responses

b) With taking R_C into account

b) With taking R_C into account

Fig. 9 Comparison the Dynamic Response between the Experimental Results and the Simulation Results from Parameters obtained by the Genetic Algorithm based Method.

5 Conclusions

The effectiveness of an intelligent approach to estimate dynamic parameters of induction motors with and without taking core loss into account illustrates in this paper. Although, the parameters of induction motor can be roughly estimated through conventional tests (no-load, locked-rotor and retardation tests) due to the complication of space phasor equations describing dynamic behaviours of induction motors, they may cause inaccurate estimation, especially when transient characteristics are seriously required. Tabu Search (TS), Adaptive Tabu Search (ATS) and Genetic Algorithm (GA) techniques are employed to demonstrate this intelligent identification. All the simulation results with taking core loss into account show the effectiveness of each technique for parameter identification of induction motor. However, high accuracy and precisely with shortest time for calculation are the key for indicate the most effective searching technique. Due to shortest calculation time, dynamic parameters identification using GA technique may be the most effectiveness searching techniques for induction motor compare with Tabu Search (TS) and Adaptive Tabu Search (ATS) techniques.

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