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Speed Sensorless Control Scheme of Induction Motor against Rotor Resistance Variation

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Abstract: In this paper, a new speed sensor less induction motor scheme which can estimate rotor speed and rotor resistance simultaneously will be described. The rotor flux reference is given as sinusoidal waveform to conduct on-line simultaneous estimation of the rotor speed and the rotor resistance without affecting precise torque control. The estimation can be performed under the condition of not only steady state but also transient state. Hence, the proposed sensor less control scheme is basically robust against rotor resistance variations. Especially, the rotor resistance estimation is performed simply without calculating troublesome trigonometric functions and complicated integral computation. Moreover, the sensor less control scheme has no current minor loop to determine voltage references. It contributes to good control performance at low speed area.

Keywords: Induction Motor, Rotor flux, Rotor Resistance, Rotor Speed.

I. INTRODUCTION

A number of sensor less induction motor drives have been developed in the past [1-5]. However, the performances of this sensor less drives are not sufficient when compared to the sensored ones. A major drawback of these drives is due to the difficulty of control at low stator frequency. Another difficulty is to ensure the robustness of drives against motor parameter variations, especially rotor resistance. Also, it is well known that simultaneous estimation of speed and rotor resistance is hardly obtained in the vector control induction motor drives with constant rotor flux [5]. To solve these problems, we suggested a novel speed sensor less scheme based on a feed forward torque control technique [6, 9]. The control scheme had some different features compared with the classical vector controls. First, the rotor flux was given as a sinusoidal waveform in the d, q reference frame without affecting the torque control performance. It was possible to estimate on-line both speed and rotor resistance using the rotor flux. Second, it did not have any current feedback loops. Thus, we did not need to consider any phase compensations due to the delay between stator voltages and stator currents. Since control voltage could be determined using this feed forward technique, we could exclude complicated process in order to design PI gains in current regulators. Third, the electromagnetic torque was controlled very fast and independent of the rotor flux without inducing any spike currents. Especially, we did not inject any high frequency signal to estimate the rotor resistance, thus we could reduce current ripples and we did not need to design a high band-pass filter to reject them out. Hence, we could reduce the burden of hardware to inject high frequency signals and also software to detect these high frequency signals. However the estimation algorithm of the rotor resistance needed complicated trigonometric calculation.

In this paper, at first, the feed forward type torque control is described. Then, the estimation equations for rotor speed and rotor resistance are derived in d, q reference frame. Also, we show the rotor resistance can be calculated simply. After that, the speed sensor less scheme is described. Finally, through several simulation results using a PWM voltage source inverter and experiments based on a DSP control system, the validity of the proposed method is verified.

II. SIMULTANEOUS ESTIMATION OF SPEED AND ROTOR RESISTANCE

A. The Feed forward Torque Control

Fig. 1 shows the schematic diagram of the feed forward torque control. The most important feature of the method is that the voltage reference does not depend on any feedback stator currents. The voltage command which can get quick torque response is derived from motor circuit equation like

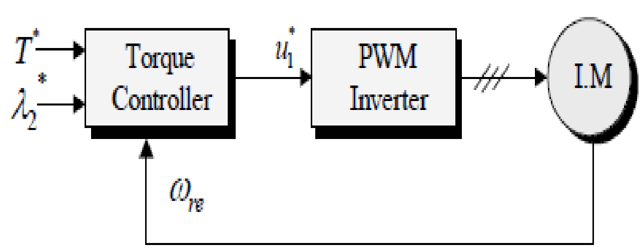


Fig.1. Feed forward torque control scheme

(1). We use torque reference, rotor flux reference, speed information, and motor parameters to determine the voltage reference [6].

$$u_1^* = \left\{\left(\left(a_{1d}\lambda_2^* + a_{2d}P\lambda_2^* + a_{3d}P^2\lambda_2^* - a_{4d}\omega_{re}\frac{T^*}{\lambda_2^*} - a_{5d}\frac{T^*}{\lambda_2^*}\right) + j\left(a_{1q}\omega_{re}\lambda_2^* + a_{2q}\omega_{re}P\lambda_2^* + a_{3q}\frac{T^*}{\lambda_2^*} + a_{4q}\frac{T^*}{\lambda_2^*}\right)\right)\right\} e^{j\omega_0 t} \quad (1)$$

$$\omega_0 = \omega_{re} + \frac{R_2 T^*}{p\lambda_2^{*2}}$$

$$a_{1d} = \frac{R_1}{M} \quad a_{2d} = \frac{L_1R_2 + L_2R_1}{MR_2} \quad a_{3d} = \frac{\sigma^2}{MR_2}$$

$$a_{4d} = \frac{\sigma^2}{PM} \quad a_{5d} = \frac{\sigma^2 R_2}{P^2 M} \quad a_{1q} = \frac{L_1}{M}$$

$$a_{2q} = \frac{\sigma^2}{MR_2} \quad a_{3q} = \frac{L_1R_2 + L_2R_1}{MP} \quad a_{4d} = \frac{\sigma^2}{PM}$$

$$\sigma^2 = L_1 L_2 - M^2 \quad (2)$$

Also, R_i, L_i (=1, 2: stator and rotor) l_{I}, M, P are the resistances, inductances, leakage inductances, mutual inductance, and pole fair number. Notation '*' means reference value and p indicates differential operator (= d /dt).ω_0 indicates angular frequency of voltage source. The stator current and rotor current can be controlled as (3-a) and (3-b) when we give the voltage command (1) and (2) to motor model as reference [6].

$$\widehat{i_1} = \left\{\left(\frac{\lambda_2^*}{M} + \frac{L_2}{MR_2}P\lambda_2^*\right) + j\frac{L_2T^*}{MP\lambda_2^*}\right\} e^{j\,\omega_0 t} \quad (3\text{-a})$$

$$\widehat{i_2} = \left\{\left(\frac{-p\lambda_2^*}{M} - j\frac{T^*}{P\lambda_2^*}\right\} e^{j\,\omega_0 t} \quad (3\text{-b})$$

Where, notation '∧' means theoretical values from motor reference model to distinguish ideal value from real value detected directly. It is noticed here that the currents have no transient terms about time *t*. Therefore, it is obvious that we can control the instantaneous electrical torque as transient less state with very quick torque response theoretically if we use the proposed voltage command (1).

B. Estimation of the Rotor Speed

Fig. 2 shows speed estimation mechanism using MRAC (Model Reference Adaptive Control). The theoretical q-axis current (4), output of the reference motor model in Fig. 2, can be obtained from (3-a). Using this ideal current $\hat{i}_{1q}$ and detected current i_{1q} from real motor, the rotor speed which we want to estimate can be formulated as (5).

$$\widehat{i_{1q}} = \frac{L_2 T^*}{PM\lambda_2^*} \quad (4)$$

$$\widehat{\omega_{re}} = K_{pt}\lambda_2^*\left(\widehat{i_{1q}} - i_{1q}\right) + K_{it}\int \lambda_2^*\left(\widehat{i_{1q}} - i_{1q}\right)dt \quad (5)$$

Where, K_{pT} and K_{iT} represent proportional gain and integral gain respectively. The controller in Fig. 2 gives voltage reference based on the feed forward torque control as control input to the actual motor.

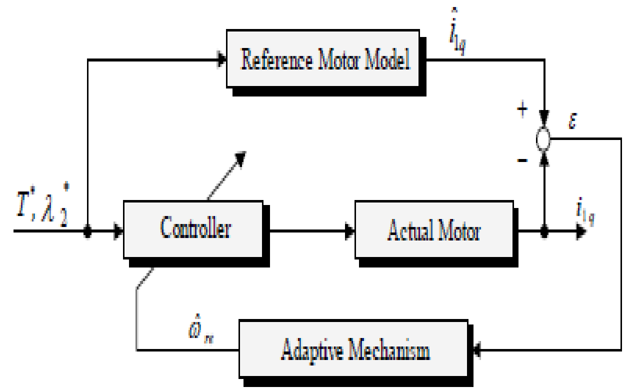


Fig.2. Speed estimation mechanism using MRAC

C. The Variable Rotor Flux with Sinusoidal Waveform

Fig. 3 shows an equivalent circuit of induction motors when the part of q-axis of rotor flux is supposed to zero. Where, u_{1d} and u_{1q} represent component of d- and q-axis of

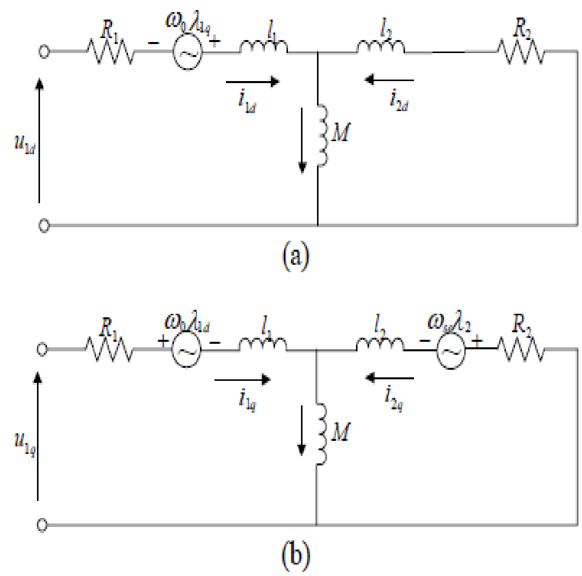


Fig.3. Equivalent circuit in a synchronous reference frame; (a) rotor flux axis, (b) torque axis

source voltage individually. Also, λ_{1d}, λ_{1q}, and λ_2 mean dand q-axis component of stator flux, and rotor flux. ω_{se} indicates slip frequency. The stator currents can be derived as follows in d, q reference frame;

$$i_{1d} = \frac{1}{M}\lambda_2 + \frac{L_2}{M}\frac{1}{R_2}P\lambda_2 \quad (6\text{-a})$$

$$i_{1q} = \frac{L_2}{M}\frac{1}{R_2}\omega_{se}\lambda_2 \quad (6\text{-b})$$

Where,

$$\lambda_{2d} = Mi_{1d} + L_2 i_{2d} = \lambda_2$$
$$\lambda_{2q} = Mi_{1q} + L_2 i_{2q} = 0$$

If we give the rotor flux as a conventional constant value, we know that we cannot get rotor resistance information from (6-a). Furthermore, it is noticed that the rotor resistance and slip frequency cannot be obtained simultaneously from (6-b). However, it is very clear that if we give the rotor flux as sinusoidal waveform properly, we can estimate the rotor speed and rotor resistance simultaneously from these (6-a) and (6-b). If we give rotor flux as sinusoidal waveform (7), then the rotor resistance can be estimated as (8).

$$\lambda_2^* = \lambda_2(1 + A\sin\omega t) \quad (7)$$

$$\widehat{R2} = \left(L^2 * B^2 * \lambda_R\right)/((MPi_{1d} - P\lambda_2^* + (\frac{L_2 B^2}{R_2} * \lambda_2^*)) \quad (8)$$

As shown in (8), the rotor resistance can be obtained simply without calculating troublesome trigonometric functions and complicated integral computation. Also, the estimation of the rotor resistance can be conducted simultaneously with speed estimation (5).

D. Speed Sensor less Control System

Fig. 4 shows speed sensor less control system based on (5) and (8). It is consisted of four major parts such as speed controller, torque controller, rotor resistance estimator, and rotor speed estimator. The speed and rotor flux are given to the speed controller as command. The speed estimator uses rotor flux, torque, detected stator currents, and motor parameters. Also, the rotor resistance estimator uses estimated speed, motor parameters, and detected motor stator currents. The reference model is same as the reference motor model in Fig. 2 and it means (4). It is noticed again here that the voltage reference does not depend on currents.

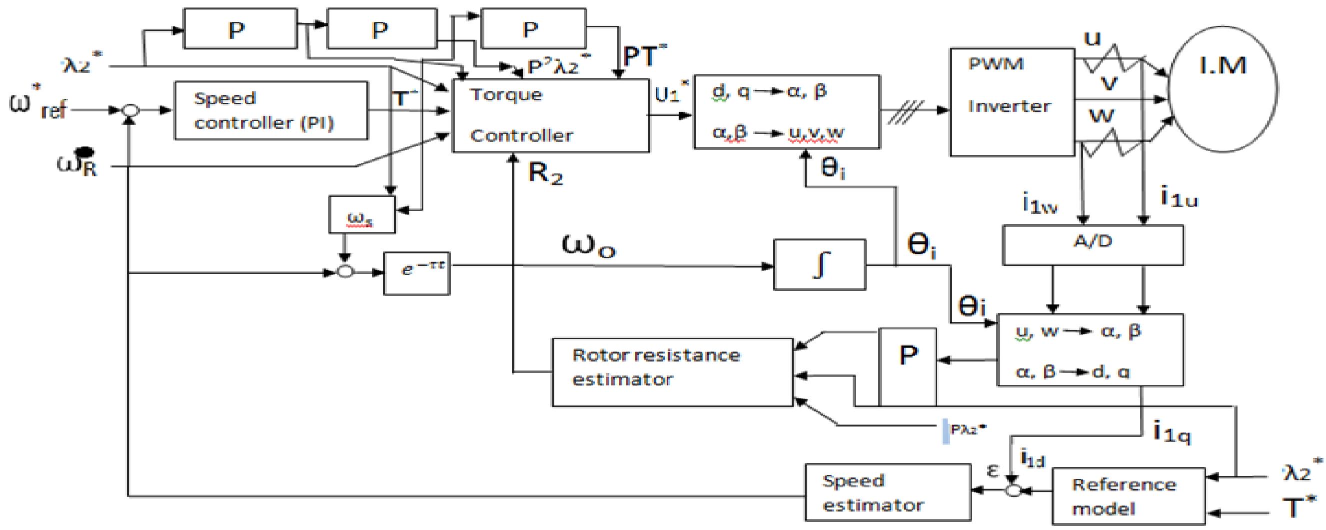
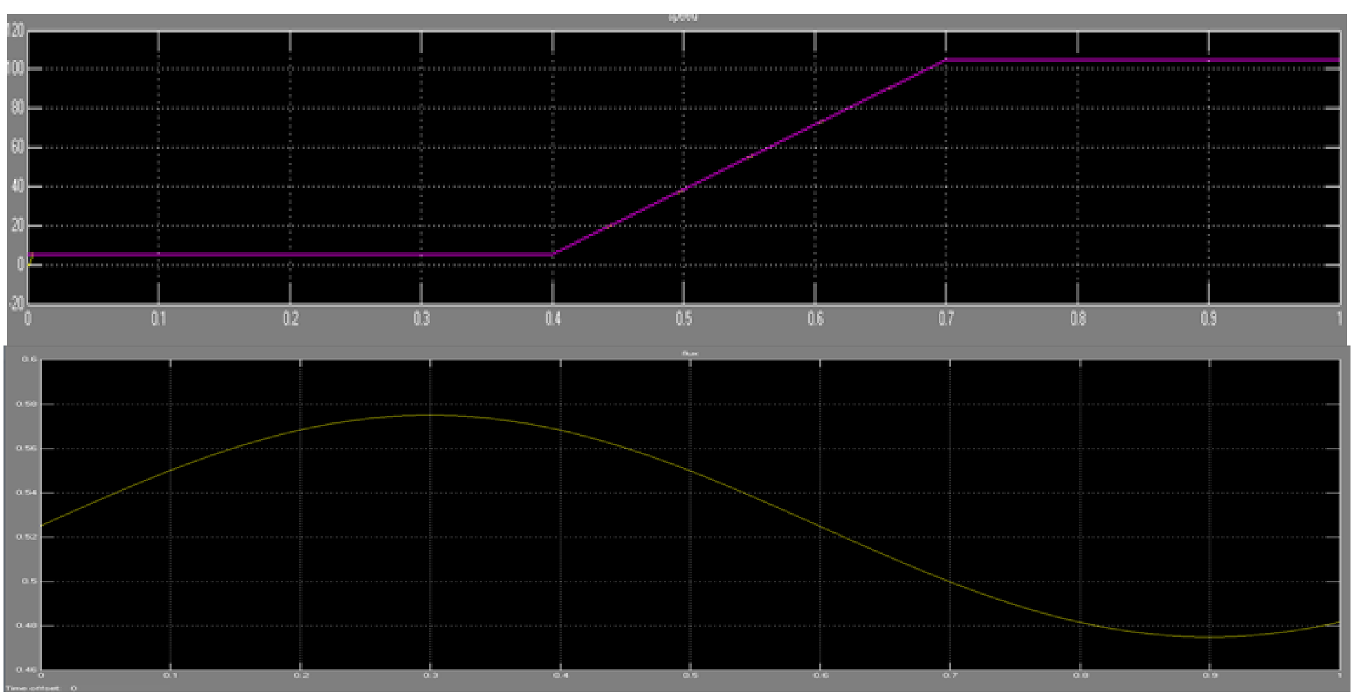


Fig.4. Speed sensor less control system



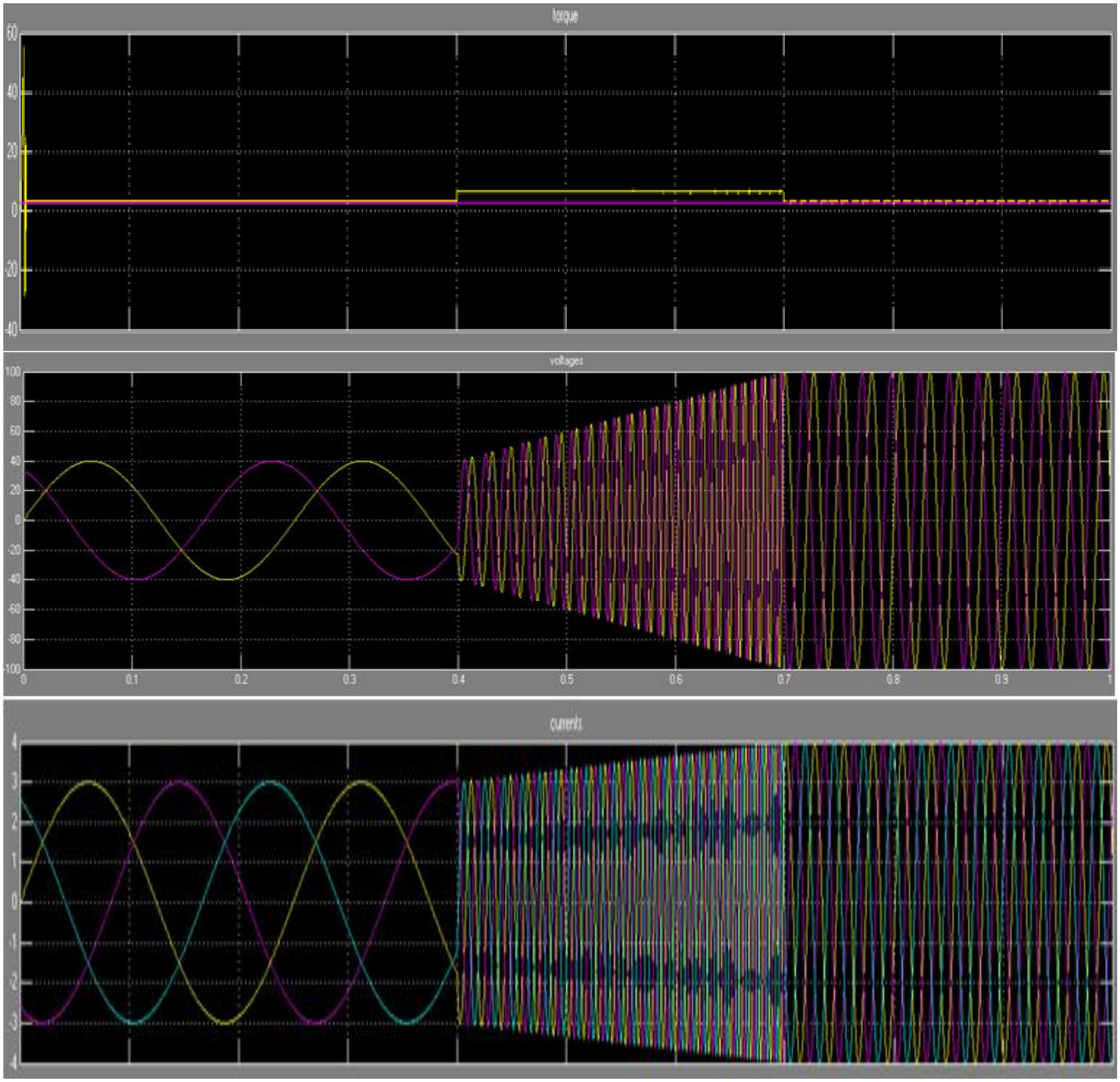


Fig.5. Torque response and rotor flux under stepwise command

To verify the proposed sensor less control scheme, the simulations are performed using the PWM voltage-source inverter and an I.M whose parameters are listed in Table I. The carrier frequency is set at 3 kHz and the sampling times for speed calculation and current integration of I.M model are set at 1 ms, and 1μs respectively. At first, the feed forward torque control performances are investigated based on Fig. 2. As we put the focus on the torque control performance, we excluded the speed controller, rotor resistance estimator, and rotor speed estimator in Fig. 4. The actual rotor speed was calculated by using the information of currents and motor inertia in this simulation. Also, we supposed that the rotor resistance had real value and it was not changed.

III. NUMERICAL SIMULATION

TABLE I: RATED VALUES AND MOTOR PARAMETERS

P_R	2.2 [kW]	P	2
u_R	220/380 [V]	i_R	9.2/5.3 [A]
R_1	2.54 [Ω]	R_2	0.43 [Ω]
L_1	169.11 [mH]	L_2	169.11 [mH]
M	163.25 [mH]	J	0.003 [$Nm \cdot s^2 / rad$]

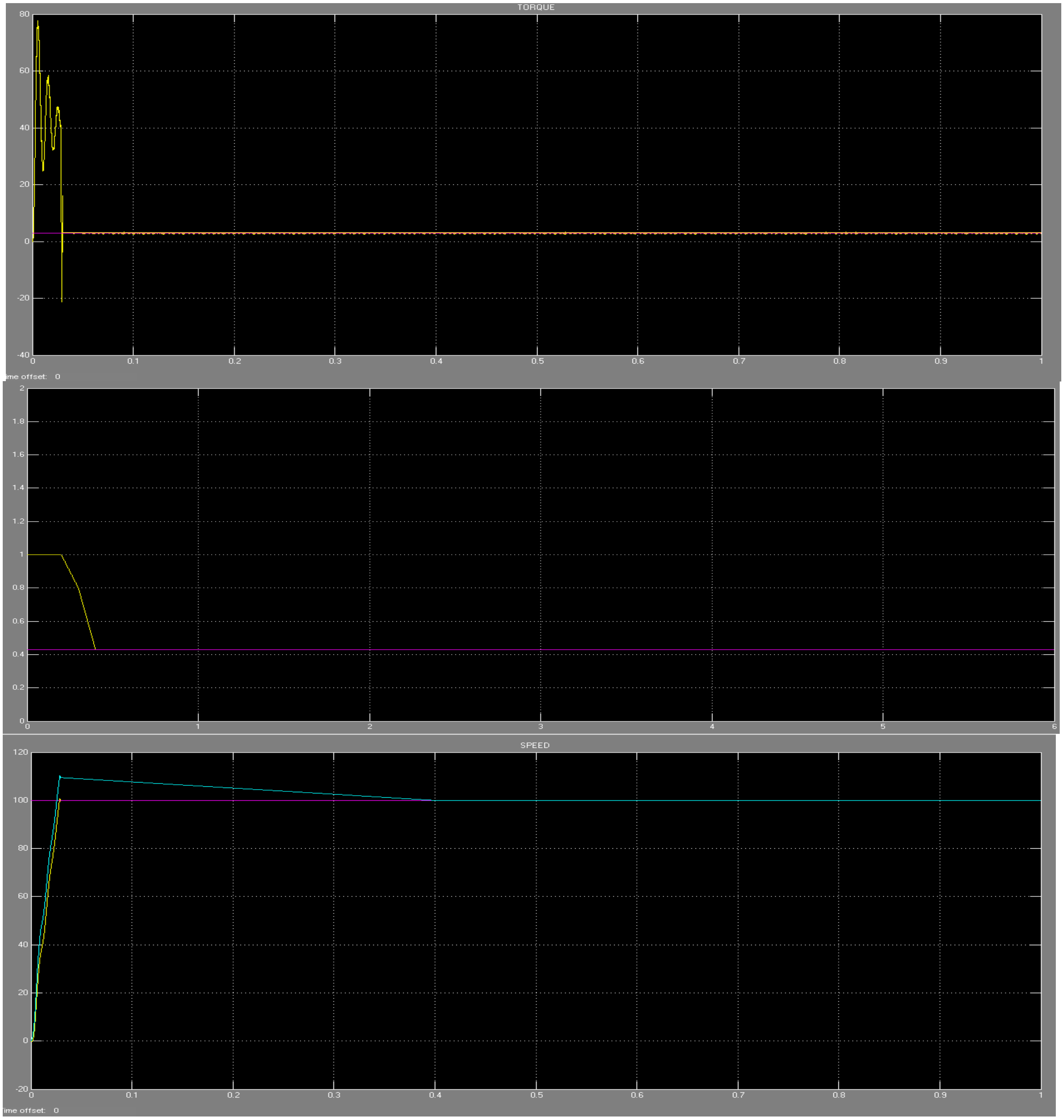


Fig.6. Simulation result of rotor resistance identification under the stepwise speed change.

Fig. 5 shows good agreements between torque reference and its responses even though the variable stepwise torque commands are given to the system. We can see some pulses with very small width at the time when torque command is changed abruptly from phase voltage reference in Fig.5. It can contribute to excellent torque control performance without transient torque. In spite of this voltage command of sinusoidal wave with pulses, we cannot find out any spike currents. Above figure represents the effect of estimation errors of rotor resistance to estimation speed and torque response. Its influence in estimation speed is bigger than the one in torque responses It is well known that the rotor resistance is changeable parameter during motor operation. And also, we know that it is very difficult to estimate the rotor resistance simultaneously with speed. In order to estimate speed influence in estimation speed is bigger than the one in torque responses. Fig. 6 shows a sample of simulation results about rotor resistance identification under the condition of constant speed reference. In this simulation, the initial value of the rotor resistance was 1 Ω and convergence characteristics of the rotor resistance according to time t was investigated. We can see some mismatches between speed reference and estimated speed during a couple of seconds in Fig.7. They are considered the influence of the rotor resistance estimation errors that was given by us on purpose. However, it does not matter because time constant of rotor resistance is big enough for correct estimation errors. Moreover, we estimate it from instant of motor start. Fig. 8 represents a sample of simulation results about rotor resistance identification under the condition of variable speed reference. We can see that the estimation rotor resistance converges to a real value after a few seconds.

V. CONCLUSION

In this paper, a robust control against rotor resistance variation for speed sensor less induction machines based on the feed forward torque control was proposed. Especially, the method aimed at the simultaneous on-line estimation of the rotor speed and the rotor resistance. In the proposed method, the rotor flux was given sinusoidal waveform. Using the variable rotor flux and MRAC, the rotor resistance and the rotor speed could be estimated with fairly good precision. Through simulation results, the validity of the proposed Sensor less control scheme was initially verified.

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