Effect of the Error in the Rotor Reactance of the Induction Motor on its Performance Characteristics with DTC Compared to Scalar Control

Hamdy Mohamed Soliman

Abstract*— Direct *torque control of induction motors has achieved a quick torque response. It is very sensitive to flux estimation (magnitude and orientation). The flux estimation is affected by parameters variation. These parameters are affecting saturation, temperature, and skin effect. The mismatching between the parameters value used in the controller and those in the motor make the actual rotor flux position does not coincide with the position assumed by the controller. Any parameter mismatched in flux estimation will be detrimentally affect the torque response and then on the dynamic performance. So this paper shows the effect of mismatching in rotor reactance between the control model and the machine itself on the performance characteristics of induction motor through applying the direct torque control. The rotor reactance is chosen due to have more effect on the instantaneous slip speed. To show this effect, the mismatching case is compared to matching case and with scalar control. MATLAB program is used to simulate these cases.

Index Terms*— Direct torque control, Induction motor, Rotor reactance error, Scalar control.

I. INTRODUCTION

The principle operation of induction motor has been discovered more than a century ago. With this discovery, the designer is concerned with the development of the material construction, winding insulation, etc. The induction motor becomes favor for users because of its rugged, simplicity of construction, low maintenance and low manufacture cost compared with DC motors. In the past, the induction motor is fed from constant voltage and constant frequency. With development of power electronic, control theory and with invention of the inverters, the induction motor might be used in varied speed application instead of DC motor which didn't realis fast dynamic response i.e. induction motor can be operated under effect of many methods of controls such as scalar control (SC) and direct torque control (DTC). in the SC, the induction motor can be controlled in open loop and in closed loop controls [1-4]. The performance of the induction motor in the drive system depending upon the motor control and current control method or voltage control in power converter. The current control method is preferable this is because it is simple. The quality control of this method depending upon the quality of the waveform which generated. To get good power waveform this depends upon the switching of inverter, modulation index and pulse width modulation (PWM). Some methods of current control such as scalar control is suffer from complicated coupling nonlinear dynamic performance. The open loop control is preferable when high dynamic performance isn't required. In open loop control at constant flux region, the applied voltage on the motor (induction motor) is in portion with frequency (as magnitude only) to keep the flux inside the machine constant to get the rated torque but in the field weakening region, the voltage is kept constant and frequency increases to get speeds behind the rated speed and the load torque is inversely proportional to these speeds. In the field weakening region, voltage reaches rated value so this volt doesn't increase due to not burn the stator winding. With development and inventing the microprocessors and microcontrollers, the induction motor in place of the DC motor in the applications which required high dynamic performance. This occurs with DTC. In DTC, the voltage and frequency can be controlled in the two regions (constant flux region and field weakening region) as in the SC but the voltage is applied as the vector in the space [5-7]. Any mismatching between the control parameters and those parameters in machine itself make the high performance of the drive system is loss. The rotor parameters are more effecting the performance of the drive system. The paper chooses effect of the error study in the rotor reactance due to have more effect on the instantaneous slip speed. To show this effect, the mismatching case between rotor reactance used in the control and for induction motor itself is compared to matching case under effect of DTC and also these cases are compared to SC. This paper is concluded as; I- Introduction, II- Mathematical model of induction motor III Scalar control of induction motor, VI- Direct torque control, V- Simulation result, VI- Conclusion.

II. MATHEMATICAL MODEL FOR INDUCTION MOTOR

mathematical model of induction motor in synchronous reference frame with taken into account the effect of core loss can be written as the follows

$$v_{qse} = r_s i_{qse} + \frac{d\psi_{qse}}{dt} + \omega_e \psi_{dse} \quad (1)$$

$$v_{dse} = r_s I_{dse} + \frac{d\psi_{dse}}{dt} - \omega_e \psi_{qse} \quad (2)$$

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$$0 = r_r I_{qre} + \frac{d\psi_{qre}}{dt} + (\omega_e - \omega_r)\psi_{dre} \tag{3}$$

$$0 = r_r I_{dre} + \frac{d\psi_{dre}}{dt} - (\omega_e - \omega_r)\psi_{qre} \tag{4}$$

$$\psi_{qse} = L_s I_{qse} + L_m I_{qre} \tag{5}$$

$$\psi_{dse} = L_s I_{dse} + L_m I_{dre} \tag{6}$$

$$\psi_{qre} = L_r I_{qre} + L_m I_{qse} \tag{7}$$

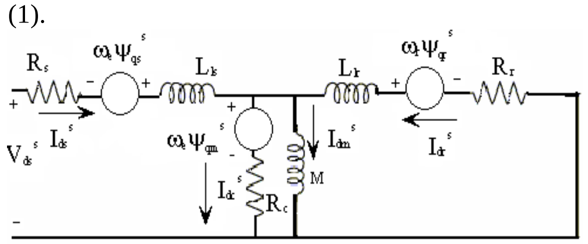
$$\psi_{dre} = L_r I_{dre} + L_m I_{dse} \tag{8}$$

$$T_e = 3\frac{P}{4}\frac{L_m}{L_r}(\psi_{dre} I_{qse} - \psi_{qre} I_{dse}) \tag{9}$$

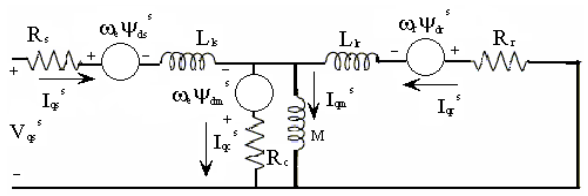
$$J\frac{d\omega_r}{dt} = T_e - T_L - B\omega_r \tag{10}$$

Where v_{qse} and v_{dse} are the q and d axis stator voltage, I_{qse} and I_{dse} are the q and d axis stator current, I_{qre} and I_{dre} are the q and d axis rotor current, ψ_{qse} and ψ_{dse} are the q and d axis stator flux, ψ_{qre} and ψ_{dre} are the q and d axis rotor flux, r_s and r_r are the stator and rotor resistance, L_s, L_r and L_m are the stator, rotor and magnetizing inductances, P is the number of poles, T_e,T_L are the electromagnetic torque and load torque, $\frac{d}{dt}$ is a derivative, ω_r is a rotor speed, B is a friction viscous and J is a moment of inertia.

Based on the d-q voltages equations on synchronous reference frame, the d-q equivalent circuit can be drawn as shown in Fig. (1).



D- axis circuit



Q-axis circuit

Fig. 1 The equivalent circuits of induction motor in synchronous

III. SCALAR CONTROL OF INDUCTION MOTOR

The operating of the induction motor with SC can be represented as Fig.2. the operating regions of induction motor can be classified into:

1- Constant flux region
2- Constant power region

In the constant flux region, the voltage is applied on the motor is in portion with frequency to make the motor flux is constant as the same value of rated flux to keep the motor torque at rated. The most common problem in this region is at low frequency where the voltage drop at the stator resistance cannot be neglected because the motor becomes under excited i.e. the motor flux is reduced about the rated value. To solve this problem, the voltage drops across the stator resistance must compensated.

In constant power region, the voltage is kept constant at rated value and frequency increases to get higher speed for operating region. In this region, the motor voltage doesn't increase because this is harmful for the stator windings i.e. they are designed so as not to exceed the rated value of the voltage. also when they are operated in this region by same criteria of the above region, the motor becomes saturated. Also in this region, due to the voltage doesn't increase and frequency increases, the motor torque is inversely proportional to motor speed.

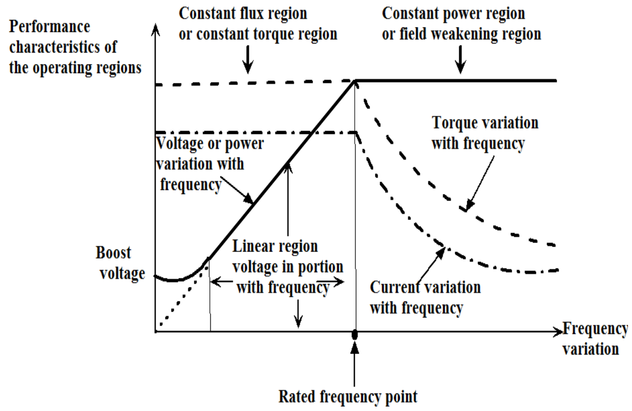


Fig 2. Profile of the scalar control

IV. DIRECT TORQUE CONTROL

The direct torque control introduced for the first time at the hands of Takahashi and Noguchi in 1986. The direct torque control (DTC) is said to be one of the future ways of controlling the AC machine in four quadrants. In DTC it is possible to control directly the stator flux and the torque by selecting the appropriate inverter state. DTC main features are direct control of flux and torque, indirect control of stator currents and voltages, approximately sinusoidal stator fluxes and stator currents, and High dynamic performance even at stand still [8-12]. DTC have several advantages if it is compared to FOC as, Decoupled control of torque and flux, Absence of co-ordinate transforms, Absence of voltage modular block, Absence of mechanical transducers, Current regulator, PWM pulse generation, PI control of flux and torque and co-ordinate transformation is not required, Very simple control scheme and low computational time, and Reduced parameter sensitivity and Very good dynamic properties as well as other controllers such as PID for motor flux and torque, and Minimal torque response time even better than the VCs [11-12].

However, some disadvantages are also present such as: Possible problems during starting, Requirement of torque and flux estimators, implying the consequent parameters identification, and Inherent torque and stator flux ripple [9-13]. Although, some disadvantages are: High torque ripples and current distortions, Low switching frequency of transistors with relation to computation time, Constant error between reference and real torque [12-13].

The stigmatic diagram of the DTC is used here can be seen in Figure 3. In this stigmatic diagram; the reference rotor speed is compared to the measure of the motor speed and the error is introduced to PI controller to deduce the torque command. The torque command is compared to the estimated torque and the error is introduced to the three level hysteresis controller. Also the stator flux command is compared to the estimated stator flux and the error is introduced to the two level hysteresis controller.

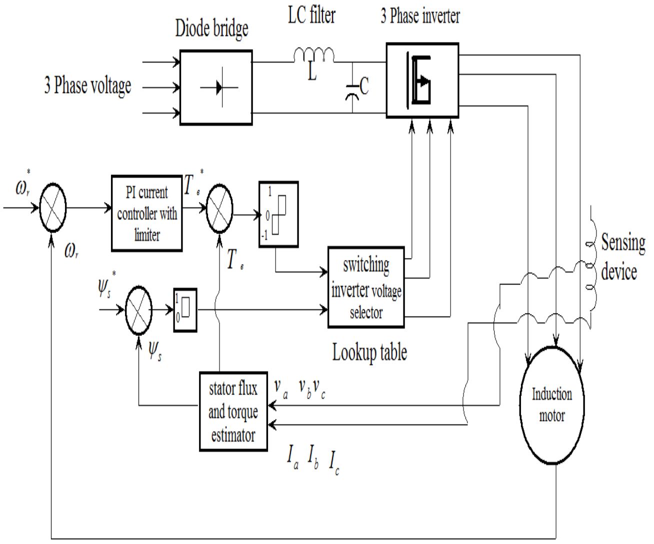


Fig. 3 Stigmatic diagram of the direct torque control of induction motor

V. SIMULATION RESULTS

The effect of the mismatching and matching in the rotor reactance with using DTC on the performance characteristics on the induction motor are simulated. Also these effects are compared to the correct SC. Where the following can be concluded:

Fig. 4 shows the effect of the error when the rotor reactance actual values are higher than the estimating values in the model. If the effect of mismatching in rotor reactance with DTC is compared with both matching parameters and SC the following can be concluded:

1. In SC case the stator current is approximately constant.
2. At DTC with matching parameters the stator current becomes the smallest if compared to both mismatching parameters and scalar control, this is because by matching parameters there is no misalignment in oriented rotor flux position, this means that, the torque and flux current component are perpendicular.
3. In DTC case with mismatching in rotor reactance, the stator current will start increasing gradually depending upon the error, i.e. increasing in stator current is directly proportional to the error between estimating and actual value of rotor reactance.

Fig. 5 indicate the error effect in rotor reactance on the input power. This error results from the mismatching between rotor reactance occurring in both actual machine and its simulated model. The Fig. shows the effect of the error when the rotor reactance actual values are higher than the estimating values in the model this effect is explained as follow,

1. In SC case, the input power is directly proportional to rotor reactance.
2. With DTC of matching parameters, the input power becomes the smallest if compared to both mismatching parameters and SC this is because the stator current here is the smallest value.
3. With mismatching in the rotor reactance, the input power becomes the highest. The increasing in the input power depends upon the error in rotor reactance. With mismatching in the rotor reactance, the motor is converted from decoupled control into coupled control.

As shown in Figs. 6-8, this section obtained effect of DTC with mismatching in rotor reactance on the output power comparing to both matching parameters and with SC this effect is explained as follow,

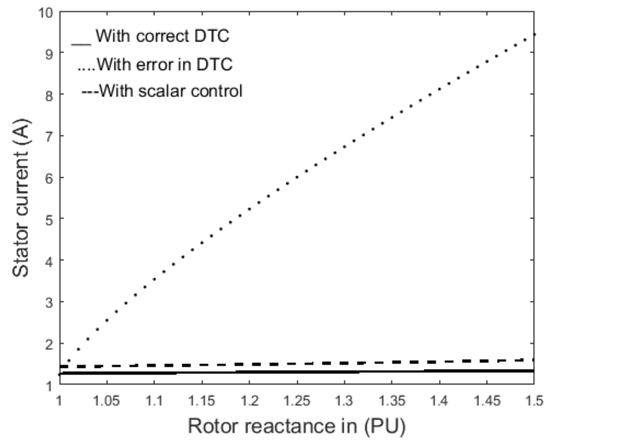


Fig. 4 Variation in stator current with rotor reactance

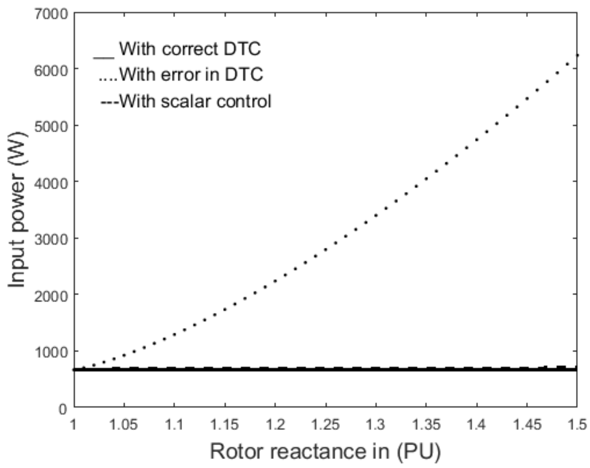


Fig. 5 Variation in input power with rotor reactance

1. In SC case, the output power is decreasing due to decrease in rotor speed at constant load torque.

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2. In both of DTC with matching rotor reactance and without matched rotor reactance due to constant load torque and constant speed (closed loop speed control) the output power is constant.

The effect of mismatching in rotor reactance with DTC on the power loss is studied here. Fig. 9 shows the effect of the error when rotor reactance actual values are higher than the estimating values in the model.
when the mismatching effect is compared to both matching parameters with DTC and with SC, the following can be concluded:

1. In SC case the power loss is directly proportional to rotor reactance.

2. In DTC of matching parameters, the power loss becomes the smallest due to decrease in the stator current.

3. With mismatched in rotor reactance, the power loss will start increasing gradually depending upon the error in mismatched parameters, i.e. increasing in power loss is directly proportional to the error between estimated and actual rotor reactance.

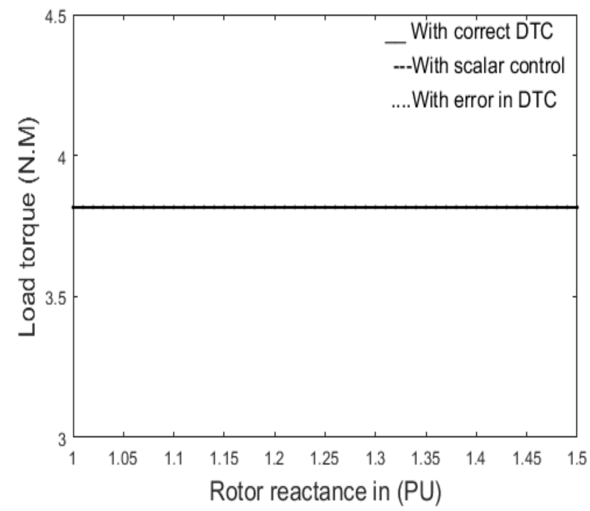

Fig. 6 Variation in load torque with rotor reactance

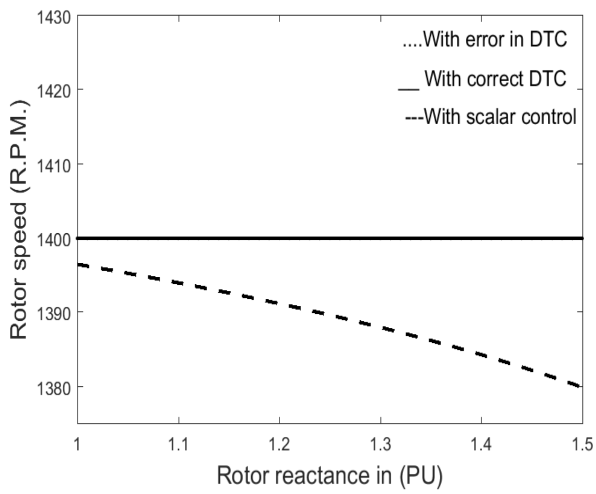

Fig. 7 Variation in rotor speed with rotor reactance

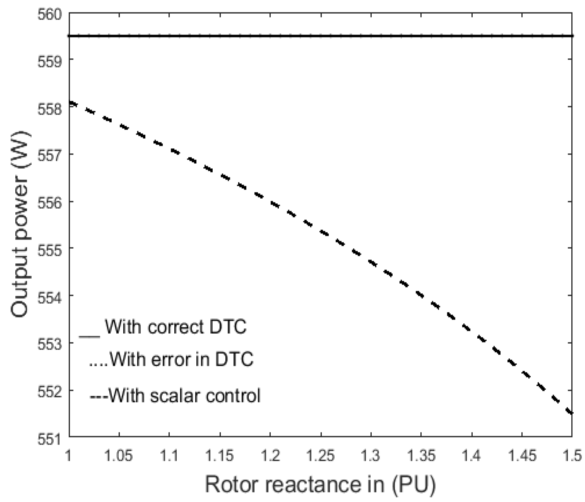

Fig. 8 Variation in output power with rotor reactance

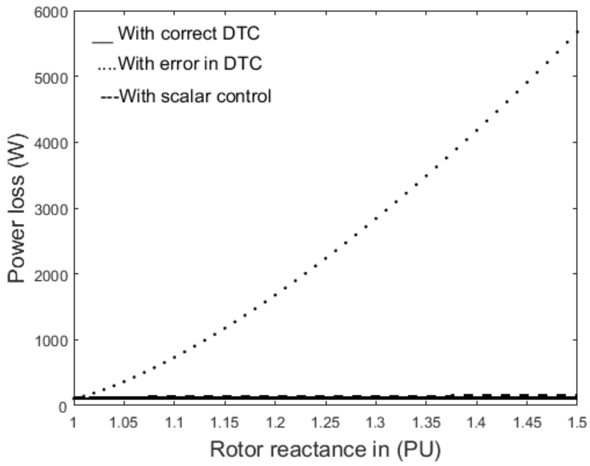

Fig. 9 Variation in power loss with rotor reactance

The misalignment effects the efficiency is discussed. This misalignment comes from the mismatching between rotor reactance occurring in both actual machine and its simulated model. Fig. 10 shows the effect of the error when the rotor reactance actual value is higher than the estimating values in the model. consequently, it has been concluded that:

1. In SC case the efficiency is inversely proportional to rotor reactance.

2. With DTC matching rotor reactance, the efficiency becomes highest if compared by other cases this is due to by matching parameters no misalignment in oriented rotor flux, this means that, the torque and flux current components are perpendicular which means that efficiency is higher.

3. In DTC case with mismatching in rotor reactance, the efficiency will start decreasing gradually, this decreasing depends upon the error in rotor reactance i.e. decreasing in efficiency is directly proportional to the error between estimating and actual rotor reactance. Also the efficiency in this case is inversely proportional to actual rotor reactance

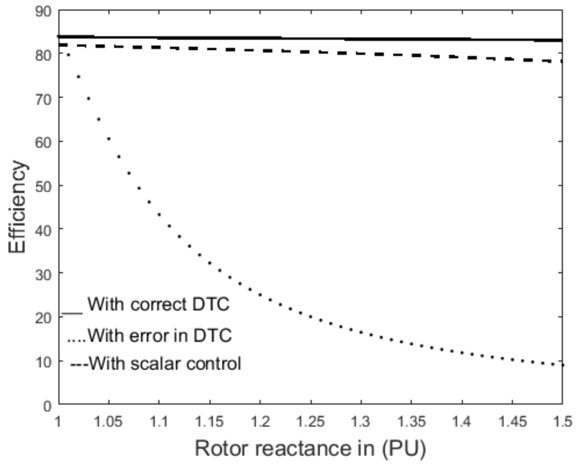

Fig. 10 Variation in efficiency with rotor reactance

VI. CONCLUSION

Due to the error in the rotor reactance, the level of the flux is not properly maintained, and the torque response is not as desired. With this error the stator current may be increased above the rated. This increasing depends on the error in rotor reactance. It leads to the motor over loaded current. The power loss increases and leads to efficiency decreasing with mismatching DTC. Thus the mismatching in the rotor reactance will be degraded the performance of induction motor.

APPENDIX 1

MOTOR DATA

Line to line voltages	380V
Rotor speed (n_r)	1400 R.P.M
Pole pairs	2
Full load torque (T_f)	3.82 N.m
Power factor (pf)	0.8
Stator resistance	13 Ohm
Stator reactance	10.5 Ohm
Magnetizing reactance	231 Ohm
Rotor resistance	2.25S+12.35 Ohm
Rotor reactance	-3.694S+19.2643 Ohm
Output power	0.75 hp
T_s/T_f	2.33
T_{max}/T_f	2.62
I_s/I_f	4.22
Efficiency	0.72

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AUTHORS PROFILE

Dr. Hamdy Mohamed Soliman was born in Cairo-Egypt on 26 December 1970, He received B. Sc. in Electrical Power and Machine Engineering from Helwan University in 1993, master of science in area of electrical machine and drive systems. Master of science is from Benha University and PhD Degree from Cairo University, Giza, Egypt in 2016. The area of PhD is electrical machines and drives. He is a director of development and research of train units in Egyptian company metro. His current research interests include power electronics, motor controls and drive systems.