

# Indirect Vector Control of Squirrel-Cage Induction Generator

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### ABSTRACT

**Aims:** This paper presents the control of the output torque of SCIG using indirect vector control (IVC) technique.

**Study design:** IVC is very popular in industrial applications, which doesn't rely on the measurement of the airgap flux because the devices that used to measure the air-gap flux is inaccurate in low speed . The IVC technique has been presented to control the torque of the generator and maintain the flux unchanged .

**Methodology:** The performance of the proposed system is tested using MATLAB/SIMULINK .

**Results & conclusion:** Simulation results are introduced showing improvement control system performance.

**Keywords**—Induction generators; Field orientation; Modeling and simulation ; Torque control.

### 1.INTRODUCTION

Wind energy is one of the most important and promising renewable energy sources in the world, owing to its nonpolluting and economically viable nature. At the same time, related wind energy technology has advanced at a breakneck pace. The control and estimation of wind energy conversion systems is a broad topic that is more complicated than that of dc drives. For variable speed applications in a wide power range, induction generators with cage type rotors have been widely used in wind power generation systems. Wind energy is one of the most important and promising source of renewable energy all over the world, mainly because it is considered to be nonpolluting and economically viable. At the same time there has been a rapid development of related wind energy technology. The control and estimation of wind energy conversion system constitute a vast subject and are more complex than those of dc drives. Induction generators

~~with cage type rotors have been used extensively in wind power generation systems for the variable speed applications in a wide power range.~~ Generally, variable speed wind energy conversion systems with Induction generators require both a wide operating range of speed and a fast torque response, regardless of any disturbances and uncertainties (turbine torque variation, parameters variation and un-modeled dynamics). As a result, more advanced control systems are developed to satisfy the actual requirement. Variable speed wind energy conversion systems have become an affordable choice for wind power applications due to recent breakthroughs in the field of field-oriented control, as well as the rapid development and cost reduction of power electronics devices and microprocessors. When great performance is required, the complexity of a wind energy conversion system increases dramatically. The need for changeable frequency, the complicated dynamics of ac machines, machine parameter fluctuations, and other factors all contribute to this complexity. In recent years, a number of control approaches for cage induction generators have been developed. This leads to more advanced control methods to meet the real demand. The recent advances in the area of field oriented control along with the rapid development and cost reduction of power electronics devices and microprocessors have made variable speed wind energy conversion system an economical alternative for wind power applications. The complexity of wind energy conversion system increases substantially if high performances are demanded. The main reasons for this complexity are the need of variable frequency, the complex dynamics of ac machines, machine parameter variations etc. Various control techniques have been developed in the recent days for the control of cage induction generators.

The control of IM are mainly classified to (V/f Control) , direct or indirect FOC [1-7].

V/F control system is easy to achievement but it is easily prone to instability [8,9].

techniques in which rotor flux is measured by flux measuring coils are generally termed “direct vector control” [10,11]. The use of flux measured may not be acceptable in low speed because the devices that used to measure the air-gap flux is inaccurate in low speed [12]. The indirect field-orientation control systems do without a flux sensor but an accurate measurement of shaft position is required [12,13].

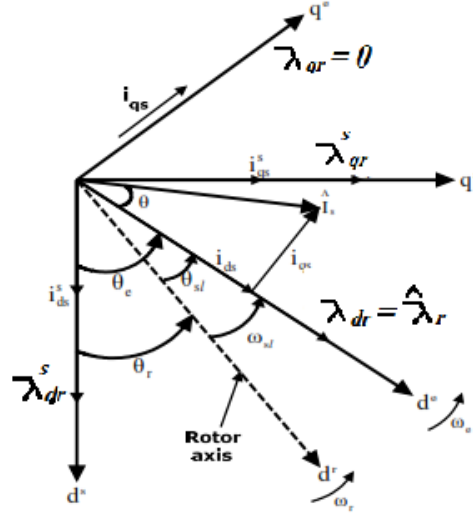
This research introduces the torque control of SCIG using IVC technique. Two models of IVC are presented and simulated . namely, Indirect vector controlled induction generator without torque feedback and Indirect vector controlled induction generator with torque feedback .

The proposed techniques are explained clearly and simulation results are introduced to show its effectiveness.

## **2. MODELLING OF IVC SYSTEM**

Fig. 1 explains the fundamental principle of indirect vector control with the help of phasor diagram. The  $d^s$ - $q^s$  axes are fixed on the stator, but the  $d^r$ - $q^r$  axes, which are fixed on the rotor, are moving at speed  $\omega_r$ . The slip angle between the Synchronously rotating axes  $d^e$  -  $q^e$  and  $d^r$  -  $q^r$  axis is  $\theta_{sl}$  corresponding to slip frequency  $\omega_{sl}$ . Since  $\omega_e = \omega_r + \omega_{sl}$ ,

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl}$$



**Figure .1** Phasor diagram explaining IVC

the derivation of equations of IVC with help of  $d^e$  -  $q^e$  dynamic model of induction machine as following[14,15]:

Stator & Rotor voltage equations:

$$v_{qs} = p\lambda_{qs} + \omega_e \lambda_{ds} + R i_{qs} \quad (1)$$

$$v_{ds} = p\lambda_{ds} - \omega_e \lambda_{qs} + R i_{ds} \quad (2)$$

$$v_{qr} = p\lambda_{qr} + (\omega_e - \omega_r) \lambda_{dr} + R i_{qr} = 0 \quad (3)$$

$$v_{dr} = p\lambda_{dr} - (\omega_e - \omega_r) \lambda_{qr} + R i_{dr} = 0 \quad (4)$$

where:

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr} \quad (5)$$

$$\lambda_{dr} = L_m i_{ds} + L_r i_{dr} \quad (6)$$

and

$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr} \quad (7)$$

$$\lambda_{qr} = L_m i_{qs} + L_r i_{qr} \quad (8)$$

$$L_s = L_{ts} + L_m \quad (9)$$

$$L_r = L_{tr} + L_m \quad (10)$$

$$T_{em} = \frac{3p}{2} (\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}) \quad (11)$$

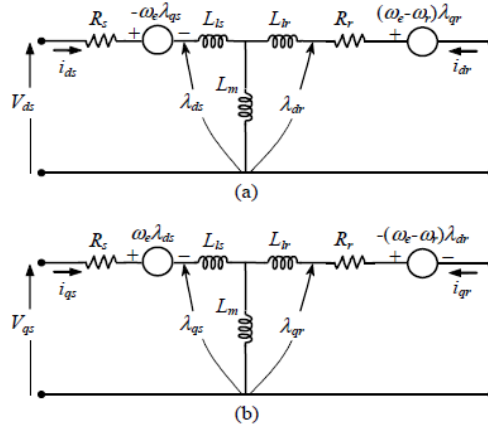


Figure. 2. D-Q model of IM

If the rotor field oriented with d<sup>e</sup> – axis,  $\lambda_{qr}^e$ , would be zero [10 , 11] , that is

$$\lambda_{qr}^e = L_m i_{qs}^e + L_r i_{qr}^e = 0 \quad \text{Wb.turn} \quad (12)$$

$$i_{qr}^e = -\frac{L_m}{L_r} i_{qs}^e \quad \text{A} \quad (13)$$

With  $\lambda_{qr}^e$  is zero , the first equation in Eq. 11 for the developed torque reduces to:

$$T_{em} = -\frac{3p}{2} \frac{L_m}{L_r} \lambda_{dr}^e i_{qr}^e \quad \text{N.m} \quad (14)$$

Substituting for  $i_{qr}^e$  using Eq. 13, Eq. 14 can be written in the desired form of:

$$T_{em} = \frac{3p}{2} \frac{L_m}{L_r} \lambda_{dr}^e i_{qs}^e \quad (15)$$

For  $\lambda_{qr}^e = 0$  , then  $p\lambda_{qr}^e$  must be zero, in which case, the rotor voltages reduces to:

$$\underbrace{v_{qr}^e}_{=0} = r_r i_{qr}^e + \underbrace{p\lambda_{qr}^e}_{=0} + (\omega - \omega_e) \lambda_{dr}^e \quad \text{V} \quad (16)$$

In other words, the slip speed must satisfy:

$$\omega - \omega_e = -\frac{r_r i_{qr}^e}{\lambda_{dr}^e} \quad \text{elect.rad/s} \quad (17)$$

Also, if  $\lambda_{dr}^e$  is constant then  $p\lambda_{dr}^e = 0$  and from Eq. 4, we will obtain the condition that  $i_{dr}^e$  must be zero, that is:

(18)

And, when  $i_{dr}^e$  is zero,  $\lambda_{dr}^e = L_m i_{ds}^e$ . Substituting this into Eq. 17 & using Eq. 13 , we obtain the following relationship:

$$\omega - \omega_e = \frac{r_r}{4} \frac{i_{qs}^e}{L_r i_{ds}^e}$$

Thus, the FOC gives the same performance a separately excited DC machine; this is done by representing the stator current phasor, in the dq synchronous reference frame, to produce two components: magnetizing current component and torque producing current component. By maintaining the magnetizing current component at a fixed value, the torque is linearly proportional to the torque-producing current component, which is quite similar to the control of a separately excited DC motor .

Figure 3 illustrates the flow chart of IVC.

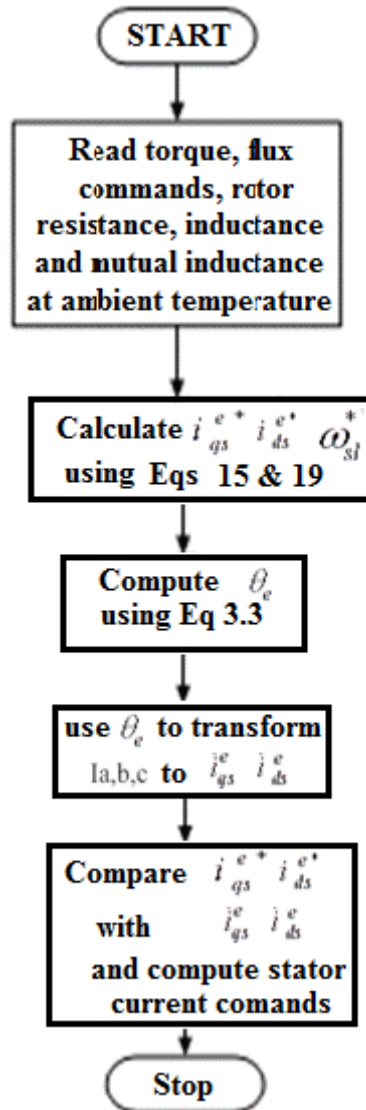


Figure .3 the flow chart of indirect vector control

Fig .4 shows an Indirect FOC system with torque and flux command .

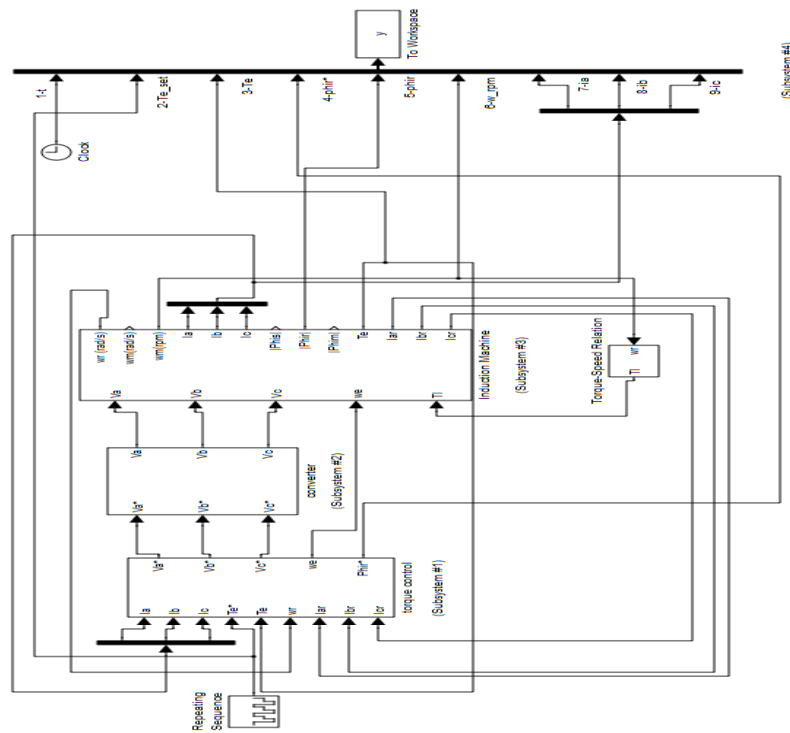


3-phase, 4 pole, 15 hp, 380 v, 60 Hz. The machine parameters are  $R_s = 0.5814 \Omega$  ,  $R_r = 0.4165 \Omega$  ,  $L_{ls} = 3.48 \text{ mH}$  ,  $L_{lr} = 4.15 \text{ mH}$  ,  $L_m = 82.23 \text{ mH}$  and the inertia (J) is  $0.05 \text{ kgm}^2$  .

All of the simulations run with the following sequence for reference torque:

$t = [0 \quad 3 \quad 3.0001 \quad 6 \quad 6.0001 \quad 9 \quad 9.0001 \quad 12] \text{ Sec}$

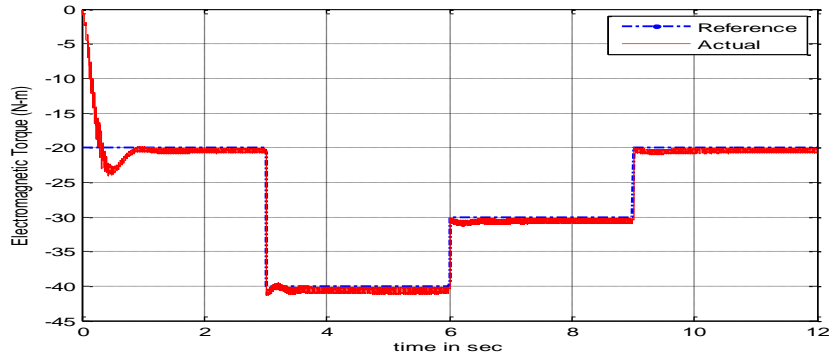
$T_{e(\text{Reference})} = [-20 \quad -20 \quad -40 \quad -40 \quad -30 \quad -30 \quad -20 \quad -20] \text{ N.m}$



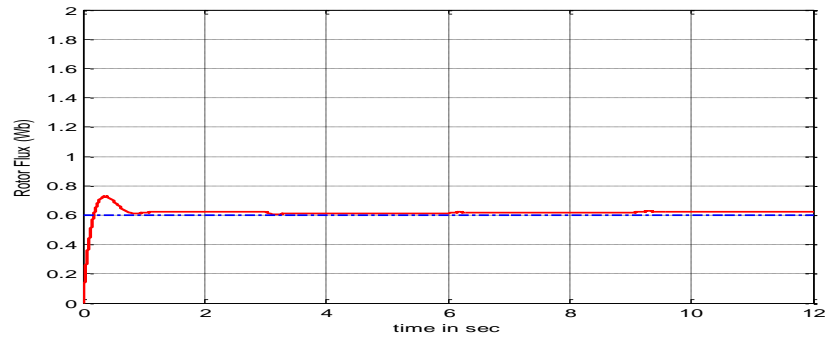
**Figure .5** Shows a typical block diagram of the models

In this section, the two models of the indirect-vector torque-control system, namely, IVC model without torque feedback and IVC model with torque feedback are simulated. The torque and flux responses of the system without torque feedback are shown in Fig. 6a and Fig. 6b respectively. The starting period is considered from time  $t=0-1\text{s}$ . The torque reaches the steady-state after 0.5 s after overcoming the rotor inertia. The torque and flux follow the reference torque and the reference flux respectively with a DC offset. Fig. 6c and Fig. 6d shows the speed response and the stator currents of the machine respectively. The torque increasing causes the speed decreasing and the stator current increasing.

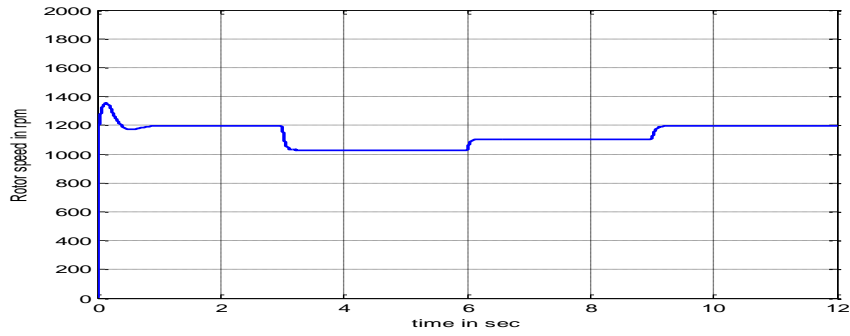
In the feedback model, there is a torque sensor on the shaft and therefore the reference  $I_{qs}$  is based on the difference between the reference torque and the actual torque, commanded through a PI controller. This provides better response on the torque and flux as shown in Fig. 7a and Fig. 7b respectively. Note that in this system, any change in the torque does not alter the rotor flux. Decoupling is attained and the torque follows the torque reference.



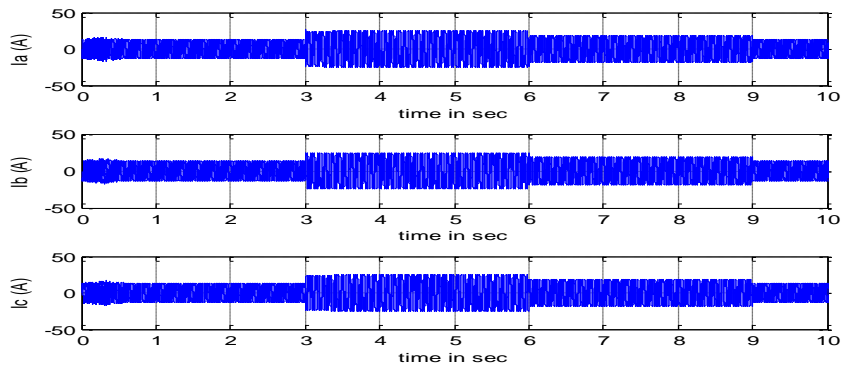
(Figure 6a) electromagnetic torque (N.m)



(Figure 6 b) rotor flux (Wb)

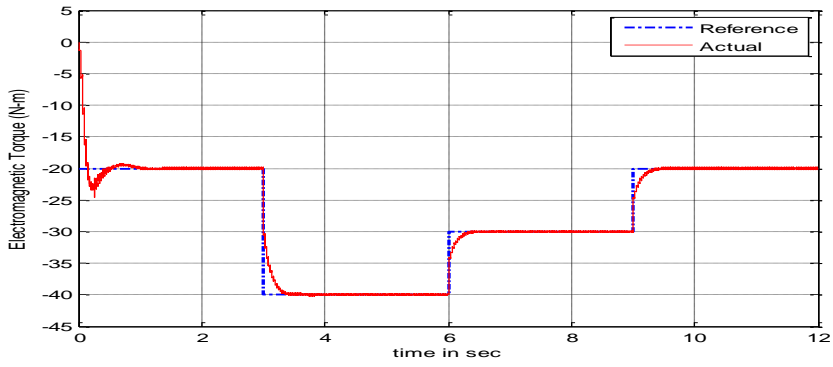


(Figure 6 c) rotor speed (r.p.m)

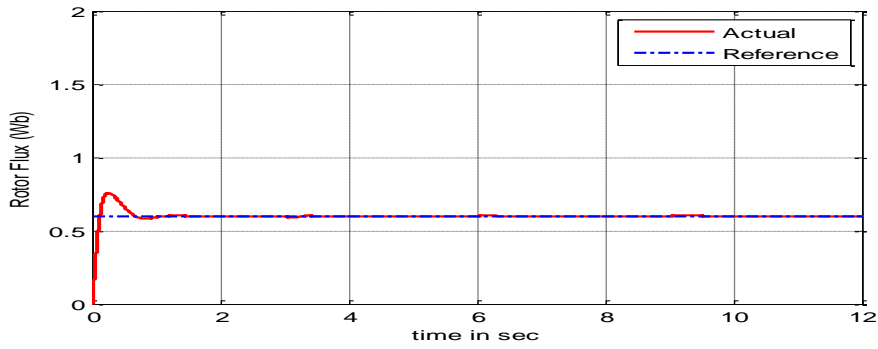


(Figure 6 d ) Stator currents (A)

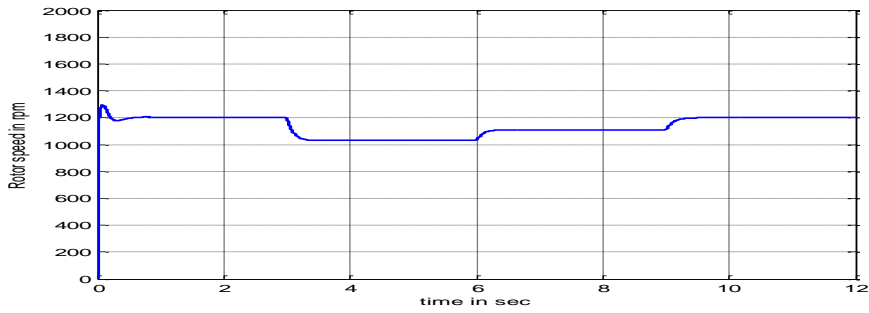
Figure. 6 Response of IVC without torque feedback



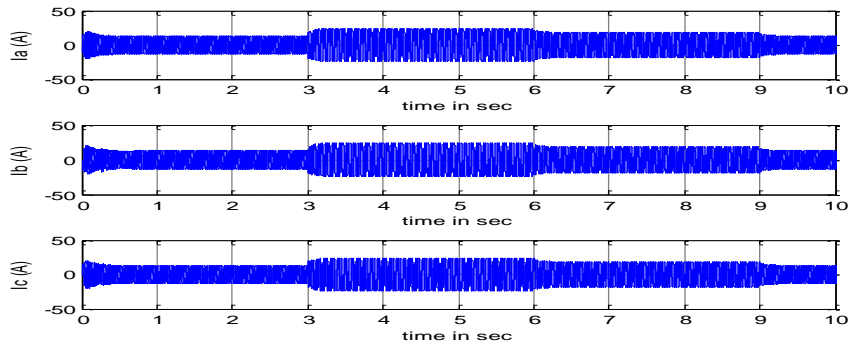
(Figure 7a) electromagnetic torque (N.m)



(Figure 7 b) rotor flux( Wb)



(Figure 7 c) rotor speed (r.p.m)



(Figure 7 d) stator current(A)

Figure 7 Response of tuned IVC system with torque feedback

#### 4. CONCLUSIONS

The goal of FOC system is to maintain an angular relationship between the stator current space vector and one internal field vector, usually rotor flux or stator flux. The FOC makes decoupling between these vectors, and it is used to simplify the torque control of SCIG. The simulation of IVC technique has been achieved and the following notes may be concluded:

- 1- The rotor flux is kept constant even during changes in generated torque. This indicates that decoupling control of flux and torque been obtained.
- 2- The system with torque feedback gives better response in comparison with the model without torque feedback .
- 3- The decoupling in IVC technique is depended on the accuracy of slip determination. The slip calculation depends on the rotor resistanc and inductance which varies continuously with the operational conditions. Also, the IVC technique requires speed or position sensor .

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