However, flux and torque are also functions of frequency and voltage respectively. In scalar control both the magnitude and the phase alignment of vector variables are controlled. Scalar controlled drives give somewhat inferior performance than the other control schemes but they are the easy to implement. In the following sections scalar control techniques with voltage-fed inverters are discussed.

5.2.1 Open Loop Volts/Hz Control [15]

The open loop Volts/Hz control of an induction motor is far the most popular method of speed control because of its simplicity and these types of motors are widely used in industry. Traditionally, induction motors have been used with open loop 60Hz power supplies for constant speed applications. For adjustable speed applications, frequency control is natural. However, voltage is required to be proportional to frequency so that the stator flux ($\psi = \frac{}{\omega}$) remains constant if the stator resistance is neglected. Figure 5.1 shows the block diagram of the open loop Volts/Hz control method. The power circuit consists of a diode rectifier with a single or three-phase ac supply, filter and PWM voltage-fed inverter. Ideally no feedback signals are required for this control scheme. The frequency ω^* is the primary control variable because it is approximately equal to the rotor speed ω neglecting the slip speed, as it is very small (ideally).

high frequencies is small. The ω^* signal is integrated to generate the angle signal θ^*, and the corresponding sinusoidal phase voltages (*, *, *) signals are generated as

$$^* = \sqrt{2} \quad \cos\theta \tag{5.1}$$

$$^* = \sqrt{2} \quad \cos(\theta - \frac{2\pi}{3}) \tag{5.2}$$

$$^* = \sqrt{2} \quad \cos(\theta + \frac{2\pi}{3}) \tag{5.3}$$

The PWM converter is merged with the inverter block. Some problems encountered in the operation of this open loop drive are the following [15]:

(1) The speed of the motor cannot be controlled precisely, because the rotor speed will be slightly less than the synchronous speed and that in this scheme the stator frequency and hence the synchronous speed is the only control variable.

(2) The slip speed, being the difference between the synchronous speed and the electrical rotor speed, cannot be maintained, as the rotor speed is not measured in this scheme. This can lead to operation in the unstable region of the torque-speed characteristics.

(3) The effect of the above can make the stator currents exceed the rated current by a large amount thus endangering the inverter-converter combination.

These problems are to an extent overcome by having an outer loop in the induction motor drive, in which the actual rotor speed is compared with its commanded value, and the error is processed through a controller usually a PI

The lim

at controlling the magnitude and frequency of the currents or voltages but not their phase angles.

Separately excited dc motor drives are simple in control because they independently control flux, which, when maintained constant, contributes to an independent control of torque. This is made

The components and are only dc components in steady state, because the relative speed with respect to that of the rotor field is zero. Orientation of λ amounts to considering the synchronous reference frame and hence the flux and the torque-producing components of currents are dc quantities, and this makes them to be used as control variables. Till now it was assumed that the rotor flux position is actually available, but it has to be obtained at every instant. This field angle can be written as,

$$\theta = \theta + \theta \tag{5.9}$$

where θ is the rotor position and θ is the slip angle. In terms of the speeds and time, the field angle can be written as

$$\theta = \int (\omega + \omega) = \int \omega \tag{5.10}$$

Vector control schemes thus depend upon how the instantaneous rotor flux position is obtained and are classified as direct and the indirect vector control schemes.

In the direct vector control the field angle is calculated by using terminal voltages and currents or Hall sensors or flux sensing windings. The rotor flux position can also be obtained by using rotor position measurement and partial estimation with only machine parameters but not any other variables, such as voltages and currents. Using this field angle is called the indirect vector control.

In this thesis the indirect vector control for the induction motor is employed so further discussions on the vector control scheme will be emphasized on indirect vector control.

5.3.2 Derivation Of Indirect Vector Control For Induction Motor

In the derivation for the indirect vector control scheme a current source inverter is assumed, in which case the stator phase currents serve as inputs, hence the stator dynamics can be neglected. The dynamic equations of the induction motor in the synchronous reference frame for the rotor taking flux as state variable is given as,

$$+ \ \lambda \ + \omega \ \lambda \ = 0 \qquad (5.11)$$

$$+ \ \lambda \ - \omega \ \lambda \ = 0 \qquad (5.12)$$

where

$$\omega \ = \omega - \omega \qquad (5.13)$$

$$\lambda \ = \qquad + \qquad (5.14)$$

$$\lambda \ = \qquad + \qquad . \qquad (5.15)$$

The definition for the different symbols was given in chapter 3 and so is not repeated here. The resultant rotor flux linkage, λ also known as the rotor flux linkages phasor is assumed to be on the direct axis to achieve field orientation. This alignment reduces the number of variables to deal.

The alignment of the d-axis with rotor flux phasor yields

$$\lambda = \lambda \qquad (5.16)$$

$$\lambda \ = 0 \qquad (5.17)$$

$$\lambda \ = 0 \qquad (5.18)$$

Substituting Equations 5.15 to 5.17 in Equations 5.11 and 5.12 causes the new rotor equations to be,

$$+\omega\ \lambda = 0 \tag{5.19}$$

$$+\ \ \lambda = 0 \tag{5.20}$$

Thus from Equations 5.14 and 5.15 the rotor currents are derived as in Equations 5.21 and 5.22.

$$= \frac{-}{\quad} \tag{5.21}$$

$$= \frac{\lambda\ -}{\quad}\ . \tag{5.22}$$

substituting for d and q axes rotor currents from equations 5.21 and 5.22 into Equations 5.19 and 5.20 the following equations are obtained.

$$= \frac{1}{\quad}[1+\qquad]\lambda \tag{5.23}$$

From Equation (5.19),

$$\omega\ = -\frac{\quad}{\lambda} = \frac{\quad}{\quad}\frac{\quad}{\lambda} \tag{5.24}$$

where

$$= \tag{5.25}$$

$$= \tag{5.26}$$

$$= \frac{\quad}{\quad} \tag{5.27}$$

$$= \frac{4}{3}\ . \tag{5.28}$$

Equation 5.23 resembles the field equation in a separately excited dc machine whose time constant is usually in the order of seconds. Substituting the rotor currents, the torque expression can be obtained as

$$= \frac{3}{4}\frac{}{}(\lambda \quad - \lambda \quad) = \frac{3}{4}\frac{}{}(\lambda \quad) = \quad (\lambda \quad) \tag{5.29}$$

From Equation 5.29 it can be observed that torque is proportional to the product of the rotor flux linkages and the stator q-axis current. This resembles the air gap torque expression of the dc motor, which is proportional to the product of the field flux linkages and the armature current. If the rotor flux linkage is maintained constant then the torque is simply proportional to the torque-producing component of the stator current as in the case of the separately excited dc motor. Similar to the dc machine time constant, which is of the order of few milliseconds, the time constant of the torque current is also of the same order.

Equations 5.23 and 5.29 complete the transformation of the induction machine into an equivalent separately excited dc motor from control point of view. The stator current phasor is the sum of the 'd' and the 'q' axes stator currents in any reference frame given as

$$= \sqrt{(\quad)^2 + (\quad)^2} \tag{5.30}$$

and the 'dq' axes to abc phase current relationship is obtained from Equation 5.4.

5.3.3. Implementation Of Indirect Vector Control

The indirect vector controller [16] takes only the speed from the machine while all other parameters are estimated. The implementation of the indirect vector control is as shown in Figure 5.3. The torque command is generated as a function of the speed error signal, generally processed through a PI controller. The flux command for a simple drive strategy is made to be a function of speed, defined by

These current commands are simplified through a power amplifier, which can be any standard converter-inverter arrangement. The rotor position θ is measured with an encoder and converted into necessary digital signal for feedback.

In the above discussion the inverter assumed is a current source to simplify explanation but in this thesis a voltage source inverter is used so the current generated are converted into voltages and are given as the commands for the voltage source inverter.

5.4 Controller Design For Induction Motor

The control objective is to regulate the actual quantity with the reference command. As is discussed above the speed and the flux are controlled to get the reference for the currents, which can be regulated to synthesize the modulation signals for the inverter. Since the speed and flux are dc quantities to regulate these quantities normal PI, PD or PID controller can be used, but usually a PI controller achieves the best performance. Any quantity of the system can be set as the output of the controller provided a relation as to how the controlled quantity effects the variable taken as the output can be given, but this is usually a tough job.

A linearization technique is explained below which helps in the controller design and to decide what should be the output of the controller. After deciding the type of controller, a way to determine the parameters of the controller has to be set forth.

5.4.1. Feedback linearization Control

This control scheme is a type of non-linear control scheme whose design is based on exact linearization. The design technique consists of two steps as described below [21].

1. A nonlinear compensation, which cancels the nonlinearities included in the system, is implemented as an inner feedback loop.
2. A controller, which ensures stability and some predefined performance, is designed based on the conventional theory; this linear controller is implemented as an outer feedback loop. Consider the third order system

$$ {}_1 = \sin {}_2 + ({}_2 + 1) {}_3 \quad (5.32) $$

where ‘p’ is the differential operator $= \text{—}$.

$$ {}_2 = {}_1^5 + {}_3 \quad (5.33) $$

$$ {}_3 = {}_1^2 + \quad (5.34) $$

$$ = {}_1 \quad (5.35) $$

To generate a direct relationship between the output y and the input u, let us differentiate the output ‘y’

$$ = {}_1 = \sin {}_2 + ({}_2 + 1) {}_3 \quad (5.36) $$

since is still not directly related to the input u, the differentiation is carried out once again to obtain,

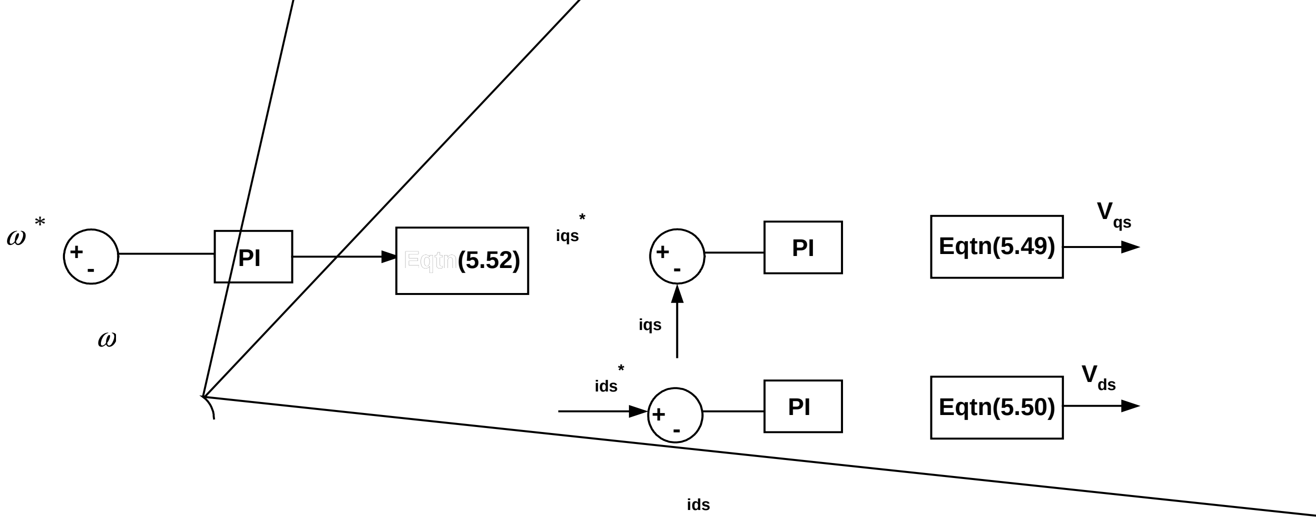
$$^{2} = ({}_{2} + 1) + {}_{1}({}_{1}, {}_{2}, {}_{3}) \qquad (5.37)$$

where ${}_{1}({}_{1}, {}_{2}, {}_{3}) = ({}_{1}^{5} + {}_{3})(\cos {}_{2} + {}_{3}) + ({}_{2} + 1) {}_{1}^{2}$.

Now an explicit relation exists between y and u. If the control input is chosen to be in the form

$$\frac{1}{{}_{2} \quad 1}(- {}_{1})$$ (5018)598 Tm( )TjETEMC/P

If initially e (0)=



ω *
+
-
ω
PI
Eqtn(5.52)
iqs *
+
-
iqs
PI
Eqtn(5.49)
Vqs
ids *
+
-
PI
Eqtn(5.50)
Vds
ids

Similarly,

$$\frac{}{^{*}} = \frac{_{2} + \quad _{2}}{^{2} + \quad _{2} + \quad _{2}} \tag{5.56}$$

$$\frac{\omega}{\omega^{*}} = \frac{_{3} + \quad _{3}}{^{2} + \quad _{3} + \quad _{3}} \tag{5.57}$$

$$\frac{\lambda}{\lambda^{*}} = \frac{_{4} + \quad _{4}}{^{2} + \quad _{4} + \quad _{4}} \quad . \tag{5.58}$$

where $_{1}$, $_{2}$, $_{3}$, $_{4}$ are the proportional parts and $_{1}$, $_{2}$, $_{3}$, $_{4}$ are the integral parts of the PI controllers used.

After obtaining the controller transfer functions, the parameters for the PI controller are to be determined. In designing the parameters of the controller, the denominator of the transfer function is compared with Butterworth Polynomial [22]. The Butter-worth method locates the eigen values of the transfer function uniformlyw j12.004 0 0 12.0

Thus for the other controllers conditions similar to the one given above, for the PI parameters are obtained.

In this chapter a detailed analysis of the control scheme and the controller structure for the induction machine are give, with appropriate2e5 Tm(ve, with appropriav09f1B1