Abstract

Self Commissioning, Parameter Adaptation And Sensorless Operation Of Vector Controlled Induction Motor Drives

Vector controlled induction motor drives combine the ruggedness of the induction motor with the high performance achievable formerly only in dc motor drives. In vector control, high bandwidth torque control is achieved by decoupling the torque dynamics and the flux dynamics. For such a decoupling, it is necessary to detect the magnitude and phase of rotor flux vector instantaneously. There are two approaches for this purpose: direct and indirect vector control.

The direct method of sensing the rotor flux involves either fabricating Hall sensors around the motor or integrating the motor terminal voltages. While fabricating special hardware around the motor will impair the ruggedness of the drive, the integration of the terminal voltages will give poor low speed performance.

On the other hand, the indirect method of rotor flux sensing performs very well at and around zero speed. The indirect method calculates the rotor flux vector magnitude by applying a low pass filter to the stator direct axis current component. The phase angle of the rotor flux vector is obtained by adding a calculated slip angle to the measured rotor angle.

The indirect vector control is more popular because of the superior performance at zero speed. But its performance deteriorates when the motor model parameters are not known accurately. The inaccuracy in the motor model parameters will lead to poor control performance and inefficient operation. Due to this reason, the motor model parameters have to be measured accurately, during commissioning of the drive. Modern drives are sophisticated.
enough to offer *Self Commissioning* algorithms, which measure all the motor parameters, without any external arrangement or operator's intervention.

During operation, the motor parameters may change due to ambient conditions and operating conditions. The vector control algorithm should adapt to these changes. In indirect vector control, rotor time constant is used for calculating both the magnitude and the phase angle of the rotor flux vector. Therefore, this parameter has to be adapted for any changes during operation.

The indirect vector controlled induction motor drive needs a rotor position sensor, which detracts from the ruggedness of the drive. The *sensorless operation* of the vector controlled induction motor drive gains significance in this context.

All the above three problems are addressed in this work. The schemes are applicable to pulse width modulated voltage source inverter (PWM-VSI) fed induction motor drives. Explicit current control loops in rotating frame of reference with PWM-VSI is one of the popular forms of current control in vector controlled drives. This method of current control is adopted in this work. The issues are discussed in subsections.

*Self Commissioning*

Classical methods of parameter measurement may not be easily implemented in a self commissioning drive because they require external arrangements. Therefore, proper methods have to be evolved to measure the parameters of the machine, that are easy to be implemented on a setup with an inverter feeding the induction motor.

In this work, after briefly reviewing the state of art, a simple scheme is suggested for self commissioning, which gives better performance of vector control. The scheme starts with measuring the stator resistance. The VSI is used to apply a dc voltage and in steady state the
dc current is measured, and stator resistance is calculated. The no load test is performed by applying the rated voltage at the rated frequency to the motor. The no load rms current is used to calculate the stator inductances. A new technique is used for measuring the stator leakage time constant, $\sigma T_s$. When a VSI is applying a dc voltage to the motor, if the pulses are blocked, the current in the machine starts falling because the conducting diodes apply a negative voltage across the motor. However, the current cannot become negative because of the diodes in the path. The current decays exponentially with the time constant of $\sigma T_s$. The time taken for the current to fall to zero is used to calculate the $\sigma T_s$. Since $T_s$ is already determined, $\sigma$ is calculated. The induction machine is usually designed to have its maximum power factor at the rated operating conditions. This idea is used to obtain a simple expression for rotor time constant, $T_r$, involving only name plate data and $\sigma$. Because $\sigma$ is already known, $T_r$ is calculated.

The scheme does not require sophisticated algorithms and filters. It does not need any additional hardware arrangements. The test results are also presented.

**Parameter Adaptation**

The rotor time constant is sensitive to both temperature and flux level. The inaccuracy in this parameter will result in a poorly damped second order torque response. It will also result in steady state torque error, which causes additional motor heating and reduced efficiency. A brief review of the literature in this area is presented. This work suggests a simple method for rotor time constant adaptation which does not require any voltage measurement. This adaptation method detects the detuning of the vector control by detecting the error between the calculated and actual phase of the rotor flux vector. The information is used for adapting the rotor time constant.
The information about the error in the phase angle is obtained by comparing the measured direct axis current with a predicted direct axis current. The direct axis current is predicted by applying the stator lag to the direct axis current controller output. The signum of the resulting error quantity, after comparison, is corrected, before it is applied to the adaptation controller. The theory of the scheme is explained in the work. The adaptation controller is of integral type. The method performs well during transients and in the field weakening region.

This method, apart from being one of the simplest adaptation schemes, also performs well even with inaccurate knowledge of the other parameters. Results from experimental drives are presented.

**Sensorless Operation**

The *sensorless operation* of a vector controlled drive refers to the operation of the vector control scheme without speed, position or flux sensors. In this sense, the drives with only current and voltage sensors are also classified under sensorless drives.

There are mainly two types of sensorless drives. The first type employs slip estimation or rotor flux vector estimation methods, without measuring the speed. Many of these schemes require sensing of the terminal voltages. By estimating the slip frequency, the rotor flux angle, or components of the rotor flux in the stationary reference frame, the field orientation is maintained. Most of them are dependent on many motor parameters.

The second type employs the model reference adaptive system (MRAS) approach to estimate the mechanical speed, which is then used for both vector control and speed control. There are many variations in MRAS schemes, which vary in complexity, parameter sensitivity and obtainable lowest speed.
Many sensorless schemes require pure integrators or high gain low pass filters. Most of them are sensitive to parameter variations. It is also difficult to measure accurately the fundamental component of the stator voltage. Some schemes are also sensitive to load conditions. Due to these reasons, sensorless drives are generally regarded as 'low performance drives'.

While most of these sensorless schemes need measurement of voltages, an attempt is made to implement a sensorless drive without voltage measurements in this work. The scheme is very attractive because it avoids the costly voltage sensors. Due importance is given to this idea and proper implementation and design details are given in this work.

The work presents a new basis for analysis and comparison of various vector control schemes, both classical and sensorless. The sensorless scheme with only current sensors is evolved from that analysis.

The proposed sensorless scheme is very similar to the conventional indirect vector control scheme. In this case, the quadrature axis current controller generates frequency command $\omega_1^*$, of the rotor flux vector instead of quadrature axis voltage command. The direct axis current controller generates the direct axis voltage command as in the conventional scheme. But, in the direct axis, besides the feed forward terms, resistance drop is also compensated. This means that, in steady state, the direct axis controller need not generate any voltage command under ideal conditions. Therefore, if the controller generates any command it goes to build up the quadrature axis component of the rotor flux vector, which leads to loss of field orientation. Therefore, the voltage command in the direct axis current controller can be used to check the quadrature axis flux build-up. The quadrature axis voltage command is obtained by simply adding the resistance drop to the feedforward terms. An additional term from the direct axis current controller is also added to the quadrature axis voltage command for
compensation. If the quadrature axis voltage command is generated in the above manner, it can be shown that the $\omega_{i}^{*}$ should be corrected by a term proportional to the derivative of the quadrature axis component of the stator current. Thus, in this work, is implemented using a lead compensator. The implementation details and results are presented for the sensorless operation.