6 Vector Control Of AC Machines

From the review of synchronous motors and induction motors in previous chapters, it is seen that, generally, in **AC** motors, torque is developed by the interaction between the rotor flux wave and the stator current wave in the airgap of the machine. Both the waves are sinusoidally distributed in space around the airgap at any particular instant of time. They will rotate at the same speed, namely the synchronous speed and are therefore stationary with respect to one another. If these waves are represented by vectors pointing in the direction of the peak of the wave, then the torque can be expressed as the vector product of the rotor flux and the stator current. The *figure* 6.1 represents stator *mmf* and rotor flux by vectors.

In the figure both the stator *mmf* vector $\underline{I}_s$ and the flux vector $\underline{\psi}_r$ are rotating at the synchronous speed ω_1. In other words, *figure* 6.1 represents the location of the two vectors at a particular instant of time as seen by a stationary or stator fixed observer and is a snapshot of the two vectors at a particular instant of time. (Because both the vectors rotate at the same speed, the angle θ which separates them remains constant in the steady state).

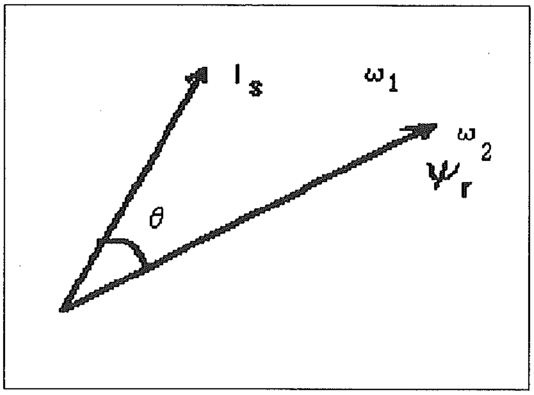

Figure 6.1

The torque developed by the motor is mathematically expressed as

$$M_d = \underline{I}_s \underline{\psi}_r$$

or

$$M_d = |\underline{I}_s||\underline{\psi}_r| \sin \theta$$

where | | represents the modulus or the amplitude of the vector.

Imagine that the stator *mmf* $\underline{i}_s$ is resolved into two spatially orthogonal components, one in the direction of the rotor flux and another perpendicular to the rotor flux. The above expression for torque shows that the parallel component contributes to the rotor flux and the perpendicular component is responsible for production of torque. In **AC** machine theory, the spatial axis along the flux is generally known as the direct axis and the axis perpendicular to the flux is known as the quadrature axis.

At this point, it is appropriate to make a distinction between permanant magnet synchronous motors **PMSM** and Induction motors **IM**.

In the case of **PMSM**, the flux is provided by the rotor magnet. It is not possible to develop additional flux by having a component of the stator *mmf* along the flux axis since the magnet behaves just like an airgap to any external *mmf.*

In order to attain the maximum torque for a given stator current, or to obtain a given torque with a minimum of stator current, it is necessary that the stator *mmf* should be entirely perpendicular to the rotor flux. (*i.e.* the stator *mmf* should only consist of a quadrature axis component, with the direct axis component being zero) The angle θ is therefore always controlled to be 90° (A deviation from this practice occurs when the **PMSM** is operated in the field weakening mode, where θ is controlled to be more than 90°.)

Therefore, the two situations, where the machine is developing torques M_{d1} and $M_{d2} > M_{d1}$ at the same speed ω_1, the relative locations and the magnitude of the two vectors will be as shown in *figure* 6.2a and 6.2b respectively.

figure 6.2. Relative Locations and magnitude of the Vectors for two torques M_{d1} and $M_{d2} > M_{d1}$.

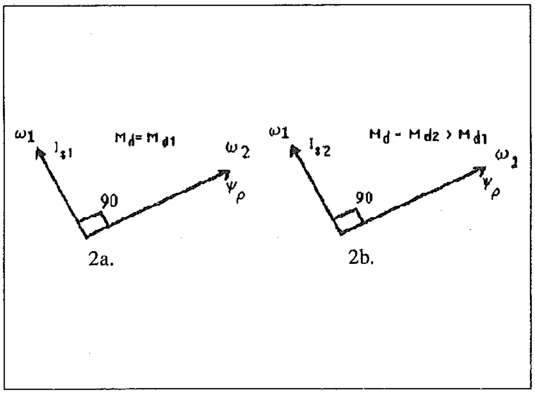

Figure 6.2

It is easy to see the analogy with **DC** motors. The rotor flux is analogous to the field flux and the stator *mmf* to the armature *mmf.* However, in a **DC** motor, the field is usually stationary in space.

The armature is on the rotor and the current in the armature conductors is actually **AC**. But, the commutator produces an armature *mmf* that is stationary in space and always perpendicular to *i.e.,* in quadrature with the field. Thus to control the torque in a DC motor, it is sufficient to control the armature current. To achieve equivalent control in a **PMSM** machine, which does not have a commutator, it is neccessary to sense the instantaneous position of the rotor by means of a resolver or position encoder, and control the position of the stator *mmf* to be at right angles to the rotor flux. As the rotor flux vector rotates in space, the stator *mmf* vector also has to be rotated in synchronization so that the relative position in space is maintained, not only in steady state, but also during transients to obtain the best dynamic response.

This type of control is known as *Vector Control.* In terms of **AC** currents in the individual phases of the stator, it implies that not only the amplitude but the phase of the currents be controlled at all instants of time.

In case of induction motors, the situation is even more interesting. (and complicated !!) The induction motor has no magnet or field winding on the rotor. The *mmf* required to produce the rotor flux by induction has to come from the stator. Therefore, the stator *mmf* has to have a direct axis component to produce flux and a quadrature axis component to produce torque. The rate of change of the direct axis component of the stator *mmf* is limited by the large magnetizing inductance plus the rotor leakage. The principle of Vector Control therefore implies that to obtain fast and well damped control of torque in the induction motor, the quadrature axis component of the stator *mmf* vector should be controlled, keeping the direct axis component undisturbed. In comparison with *figure* 6.2, *figure* 6.3 represents the situation where an induction motor develops torque M_{d1} and $M_{d2} > M_{d1}$ at the same speed. *figure* 6.3 also shows relative locations and magnitude of stator *mmf* vector and the rotor flux vector for the two torques M_{d1} and $M_{d2} > M_{d1}$ in an induction motor.

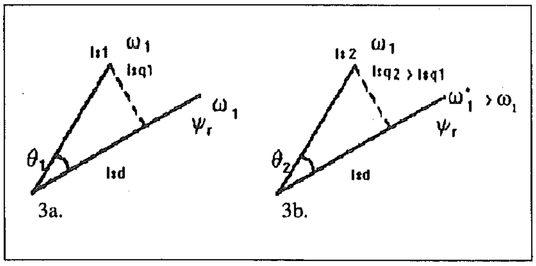

Figure 6.3

The actual running speed of the motor is different from the synchronous speed ω_1 due to slip of the induction motor. To develop an increased torque M_{d2} at the same motor speed, the quadrature component of the stator *mmf* vector has to be increased by increasing the slip frequency. Therefore the speed of rotation of the vectors in *figure* 6.3b is $\omega_1' > \omega_1$.

The complication in Vector Control of induction motors arises from the fact that the position of the rotor flux vector cannot be directly measured as in the case of the PMSM motor by means of a rotor position sensor. This is because the rotor flux rotates at synchronous speed with respect to the stationary observer and at slip frequency with respect to the rotor.

The determination of the instantaneous position of the rotor flux in an induction motor requires signal processing.

6.1. Summary

In order to obtain dynamic performance comparable to that of a **DC** motor from an **AC** motor, the principle of Vector Control has to be applied, wherein the amplitude of the stator *mmf* vector, as well as its position with respect to the rotor flux vector have to be controlled at all instants of time. In practice, this requires sensing of the actual three phase stator currents, their transformation to a co-ordinate frame rotating along with the rotor flux, their comparisions with the set points for direct and quadrature axis components, generation of the required current/voltage reference in the rotor flux frame and finally transformation of the current/voltage references to the stationary or stator reference frame to be impressed upon the motor.

NOTES