9 Nonlinear control structures with direct decoupling for three-phase AC drive systems

9.1 Existing problems at linear controlled drive systems

It is clearly recognizable that the 3-phase drive system engineering has reached a relatively mature stage of development (cf. chapters 1-8). The principle of the field orientated control also has largely asserted to be the most used method in commercial systems. The spectrum of solved questions extends from the control and observer structures over the problems of parameter identification (on-line, off-line) and adaptation to the self-tuning and the self-commissioning.

The most implemented structure (chapter 5 or [Quang 1999]) contains a 2-dimensional current controller for decoupling between the magnetization and the generation of torque as well as for undelayed impression of torque. Because of the decoupling the flux and speed control loops could be designed rather liberally. In these structures the current controller and the flux observer are always based on motor models linearized within a sampling period (cf. section 3.2.2).

The linearization is made under the assumption that the sampling time $T$ is small enough for the stator frequency $\omega_s$ to be regarded constant within $T$. Because of this assumption the frequency $\omega_s$ is now a parameter in the system matrix, and the bilinear model becomes a linear time-variant system for which the known design methods of linear systems (cf. chapter 5) can be used.

Although the present concept was very successful, it is recognizable that:

- because of the nonlinear process model (the input quantity $\omega_s$ appears in the system matrix) in high-speed drives with synchronous modulation (cf. section 2.5.2) or in sensorless controlled systems (cf. section 4.3), or
• because of the nonlinear parameters (the main inductance is strongly
dependent on the state variable $i_m$ or $\psi_r$) with respect to the system
stability in systems with parameter identification and adaptation,
some problems often appear, particularly if the system must work at the
voltage limit (i.e. in the nonlinear mode) and therewith the condition $\omega_s = \text{const}$ is no longer fulfilled. If these problems remain unsolved, the drive
quality will be affected considerably. In such cases at least a nonlinear
design would be able to deliver better results.

Within the last approx. 15 years different new ways to design nonlinear
controllers were shown ([Isidori 1995], [Krstić 1995], [Wey 2001]) or
even experimented in motor control ([Ortega 1998], [Bodson 1998],
[Khorrami 2003], [Dawson 2004]), but they were mostly theoretical
works. The practical developments were completely missing. Recently,
some more thorough investigations ([Cuong 2003], [Ha 2003], [Duc 2004],
[Nam 2004]) concerned with practical implementation of the
methods had been forthcoming, particularly on the exact linearization
method discussed in this book.

9.2 Nonlinear control structure for drive systems with IM

In the section 3.6.2 the nonlinear process model of the IM was already
derived as a starting point to the controller design:

$$
\begin{align*}
\dot{x} &= f(x) + h_1 u_1 + h_2 u_2 + h_3 u_3 \\
y &= g(x)
\end{align*}
$$

(9.1)

$$
f(x) = \begin{bmatrix}
-d x_1 + c \psi'_{rd} \\
-d x_2 - c T_r \omega \psi'_{rd} \\
0
\end{bmatrix};
\begin{align*}
h_1 &= \begin{bmatrix} a \\ 0 \\ 0 \end{bmatrix}; \\
h_2 &= \begin{bmatrix} 0 \\ a \\ 0 \end{bmatrix}; \\
h_3 &= \begin{bmatrix} -x_1 \\ 0 \\ 1 \end{bmatrix}
\end{align*}
$$

(9.2)

$y_1 = g_1(x) = x_1; y_2 = g_2(x) = x_2; y_3 = g_3(x) = x_3$

• Parameters: $a = 1/\sigma L_s; b = 1/\sigma T_s; c = (1-\sigma)/\sigma T_r; d = b + c$

• State variables: $x_1 = i_{sd}; x_2 = i_{sq}; x_3 = \psi_s$

• Input variables: $u_1 = u_{sq}; u_2 = u_{sq}; u_3 = \omega_s$

• Output variables: $y_1 = i_{sd}; y_2 = i_{sq}; y_3 = \psi_s$