# 1 Applications: Speed and Torque Control

There are many electromechanical systems where it is important to precisely control their torque, speed, and position. Many of these, such as elevators in high-rise buildings, we use on daily basis. Many others operate behind the scene, such as mechanical robots in automated factories, which are crucial for industrial competitiveness. Even in general-purpose applications of adjustable-speed drives, such as pumps and compressors systems, it is possible to control adjustable-speed drives in a way to increase their energy efficiency. Advanced electric drives are also needed in wind-electric systems to generate electricity at variable speed, as described in Appendix 1-A in the accompanying website. Hybrid-electric and electric vehicles represent an important application of advanced electric drives in the immediate future. In most of these applications, increasing efficiency requires producing maximum torque per ampere, as will be explained in this book. It also requires controlling the electromagnetic toque, as quickly and as precisely as possible, illustrated in Fig. 1-1, where the load torque $T_{\text{Load}}$ may take a step-jump in time, in response to which the electromagnetic torque produced by the machine $T_{em}$ must also take a step-jump if the speed $\omega_m$ of the load is to remain constant.



## 1-1 HISTORY

In the past, many applications requiring precise motion control utilized dc motor drives. With the availability of fast signal processing capability, the role of dc motor drives is being replaced by ac motor drives. The

*Advanced Electric Drives: Analysis, Control, and Modeling Using MATLAB/Simulink®*, First Edition. Ned Mohan.

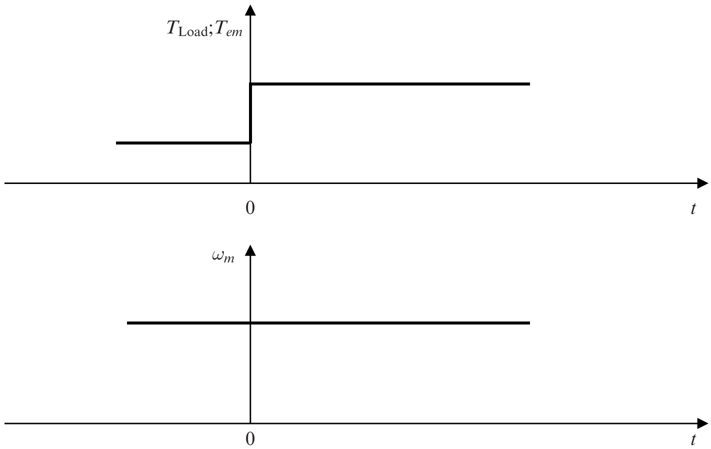


**Fig. 1-1** Need for controlling the electromagnetic torque $T_{em}$.

use of dc motor drives in precise motion control has already been discussed in the introductory course using the textbook [1] especially designed for this purpose. Hence, our emphasis in this book for an advanced course (designed at a graduate level but that can be easily followed by undergraduates) will be entirely on ac motor drives.

## 1-2 BACKGROUND

In the introductory course [1], we discussed electric drives in an integrative manner where the theory of electric machines was discussed using space vectors to represent sinusoidal field distribution in the air gap. This discussion included a brief introduction to power-processing units (PPUs) and feedback control systems. In this course, we build upon that discussion and discover that it is possible to understand advanced control of electric drives on a "physical" basis, which allows us to visualize the control process rather than leaving it shrouded in mathematical mystery.

## 1-3 TYPES OF AC DRIVES DISCUSSED AND THE SIMULATION SOFTWARE

In this textbook, we will discuss all types of ac drives and their control in common use today. These include induction-motor drives, permanent-magnet ac drives and switched-reluctance drives. We will also discuss encoder-less operation of induction-motor drives.

A simulation-based study is essential for discussing advanced electric drive systems. After a careful review of the available software, the author considers MATLAB/Simulink® to be ideal for this purpose—a student version that is more than sufficient for our purposes is available [2] at a very reasonable price, and it takes extremely short time to become proficient in its use. Moreover, the same software simplifies the development of a real-time controller of drives in the hardware laboratory for student experimentation—such a laboratory, using 42-V machines is being developed at the University of Minnesota using digital control.

## 1-4 STRUCTURE OF THIS TEXTBOOK

Chapter 1 has introduced advanced electric drives. Chapter 2, Chapter 3, Chapter 4, Chapter 5, Chapter 6, Chapter 7 and Chapter 9 deal with induction-motor drives.

Chapter 8 deals with the synthesis of stator voltage vector, supplied by the inverter of the PPU, using a digital signal processor.

The permanent-magnet ac drives (ac servo drives) are discussed in Chapter 10 and the switched-reluctance motor drives are discussed in Chapter 11.

A "test" motor is selected for discussing the design of controllers and for obtaining the performance by means of simulation examples for which the specifications are provided in the next section. In all chapters dealing with induction motor drives, the "test" induction motor used is described in the following section. The "test" motor for a permanent-magnet ac drive is described in Chapter 10.

## 1-5 "TEST" INDUCTION MOTOR

For analyzing the performance of various control procedures, we will select a 1.5-MW induction machine as a "test" machine, for which the specifications are as follows:

| | |
|---|---|
| Power: | 1.5 MW |
| Voltage: | 690 V (L-L, rms) |

Frequency: 60 Hz
Phases: 3
Number of Poles: 6
Full-Load Slip 1%
Moment of Inertia 70 kg·m$^2$
Per-Phase Circuit Parameters:

$R_s = 0.002\,\Omega$

$R_r = 0.0015\,\Omega$

$X_{\ell s} = 0.05\,\Omega$

$X_{\ell r} = 0.047\,\Omega$

$X_m = 0.86\,\Omega$.

## 1-6 SUMMARY

This chapter describes the application of advanced ac motor drives and the background needed to undertake this study. The structure of this textbook is described in terms of chapters that cover all types of ac motor drives in common use. An absolute need for using a computer simulation program in a course like this is pointed out, and a case is made for using a general-purpose software, MATLAB/Simulink®. Finally, the parameters for a "test" induction machine are described—this machine is used in induction machine related chapters for analysis and simulation purposes.

## REFERENCES

1. N. Mohan, *Electric Machines and Drives: A First Course*, Wiley, Hoboken, NJ, 2011. http://www.wiley.com/college/mohan.
2. http://www.mathworks.com.

## PROBLEMS

**1-1** Read the report "Adaptive Torque Control of Variable Speed Wind Turbines" by Kathryn E. Johnson, National Renewable

Energy Laboratory (http://www.nrel.gov). Upon reading section 2.1, describe the Standard Region 2 Control and describe how it works in your own words.

**1-2** Read the report "Final Report on Assessment of Motor Technologies for Traction Drives of Hybrid and Electric Vehicles" (http://info.ornl.gov/sites/publications/files/pub28840.pdf) and answer the following questions for HEV/EV applications:

**(a)** What are the types of machines considered?
**(b)** What type of motor is the most popular choice?
**(c)** What are the alternatives if NdFeB magnets are not available?
**(d)** What are the advantages and disadvantages of SR motors?

**1-3** Read the report "Evaluation of the 2010 Toyota Prius Hybrid Synergy Drive System" (http://info.ornl.gov/sites/publications/files/Pub26762.pdf) and answer the following questions:

**(a)** What are ECVT, PCU, and ICE?
**(b)** What type of motor is used in this application?