

# Introduction to AC Drives: The Dynamics and Control of AC Machines

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This 4 hour tutorial will offer the attendees an introduction to the basic concepts used in ac drives for the control of ac machines. The tutorial will present a review of the basic principles of ac machines, followed by the dynamic modeling of these motors. Finally, an easy-to-understand explanation of torque and speed control in ac drives will be presented.

- I. Intro. to Electromechanical Systems
  - A. AC System Block Diagram and Description
  - B. Machine Load Characteristics
  - C. Drive System Elements
  - D. Required Drive Characteristics
- II. Induction Motor Drives
  - A. Physical Construction and Layout
  - B. Steady-State Characteristics
  - C. Speed Control: Variable Rotor Resistance, Variable Voltage, Variable Frequency.
  - D. Constant V/Hz Control, Field Weakening, Capability
- III. Synchronous Motor Drives
  - A. Physical Construction and Layout
  - B. Review of Steady-State Characteristics
  - C. Control of Synchronous Motors
  - D. Load Commutated Drives
- IV. Induction Motor Dynamics
  - A. DQ (Coupled Circuit) Modeling of an Induction Motor
    1. Inductance modeling
    2. Complex notation
    3. Trapped flux model
    4. Induction machine simulation
  - B. Introduction to Small Signal Modeling
- V. Torque (Vector) Controlled Drives
  - A. Torque Control in Synchronous Motors, Brushless DC Drives
  - B. Induction Motor Field Orientation (Steady State), Detuned Operation
  - C. Implementation of a Torque Controlled Drive
  - D. Dynamics of Field Orientation
  - E. Direct and Indirect Field Orientation
  - F. Sensorless Control of Induction Machines

## **Biography**

Prof. Habetler is a native of Racine, Wisconsin. He received the B.S.E.E. degree in 1981 and the M.S. degree in 1984, both in electrical engineering, from Marquette University, Milwaukee, Wisconsin, and the Ph.D. degree from the University of Wisconsin-Madison, in 1989.

From 1983-1985, he was employed by the Electro-Motive Division of General Motors as a Project Engineer. While there, he was involved in the design of switching power supplies and voltage regulators for locomotive applications. In 1985 he was awarded the General Motors Fellowship to attend the University of Wisconsin-Madison.

Dr. Habetler is most well known for his work in sensorless (current- and voltage-based) condition monitoring of electric machines. This includes sensorless bearing fault detection, turn-to-turn insulation fault detection and rotating mechanical fault/unbalance detection. Practical, low cost on-line motor monitoring has been achieved in his work through the use of neural network-based systems that eliminate the need for maintenance experts to interpret the data. This has led to a significant amount of research in neural network applications in power electronics. Other research areas include speed-sensorless direct torque control of ac machines, sensorless speed estimation, sensorless temperature estimation, and controlled rectifiers.

He currently serves as President of the IEEE Power Electronics Society, and as Chair of the Industrial Power Converter Committee of the IEEE Industry Applications Society. He has published over 75 technical papers in power electronics and electric machines, and has worked closely with industry while at Georgia Tech.

# Modern Control Development Tools for Mechatronic Systems

Rik de Doncker  
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Institute for Power Electronics and Electrical Drives  
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## **Abstract:**

Mechatronic systems, power electronic converter and drives are complex systems requiring sophisticated high-speed control functions. At present, to develop the controller and its algorithms off-line simulation tools are used. However, in these simulation environments (MatLab/Simulink, PSpice, etc.), control code is usually not developed keeping real-time execution in mind. As power electronic systems are reaching high switching frequencies (1 to 10 kHz at several kW up to several MW), the controller execution time ultimately needs to match this performance (10 to 50  $\mu$ s). Consequently, the control algorithms need to be coded in an efficient manner and need to be partitioned in code for logic devices and code for microcontrollers or DSPs. For example, PWM, protection and gating signals require fast logic devices. Model based torque control algorithms need DSPs. Furthermore, real-time integrators and functions should be embedded in the control algorithm of DSPs.

To avoid programming errors and remain productive, it is proposed to develop code in a rapid control prototyping environment, which emulates the real behavior of the controller (in off-line simulations) or develop the controller directly on a (real-time) control emulation platform (hardware in the loop). Furthermore, modern floating point DSPs are so powerful that real-time simulators for power electronic converters can be built with high precision. In this tutorial these modern simulation tools are discussed. An introduction is given on DSP architectures and control hardware suitable for drives and mechatronic systems. Next, implementation examples, such field oriented control, direct torque control and control of a multi-dimensional spherical actuator are given. Finally, the tutorial describes the rapid control design methodologies and hardware available today for mechatronic systems.

## **Biography of Professor R. W. De Doncker:**

Rik W.A.A. De Doncker received his Ph.D. degree of Doctor in Electrical Engineering (summa cum laude) from the Katholieke Universiteit Leuven, Belgium in 1986.

During 1987 he was appointed Visiting Associate Professor at the University of Wisconsin, Madison lecturing and researching field oriented controllers for high performance induction motor drives. In 1988 he was employed as a General Electric Company fellow at the microelectronic center IMEC, Leuven, Belgium. In Dec. 1988 he joined the General Electric Company at the Corporate Research and Development Center, Schenectady, NY where he led research on drives and high power soft-switching converters, ranging from 100 kW to 4 MW, for aerospace, industrial and traction applications. In 1994 he joined Silicon Power Corporation (formerly GE-SPCO) as Vice President Technology. He worked on high power converter systems and MTO devices and was responsible for the development and production of 15 kV medium voltage transfer switches. Since Oct. 1996 he became professor at the RWTH-Aachen, where he leads the Institute for Power Electronics and Electrical Drives (Institute für Stromrichtertechnik und Elektrische Antriebe, ISEA).

Dr. ir. R. W. De Doncker is fellow member of IEEE. He is member of the IEEE-IAS Executive Board, Past Chair of the IAS Industrial Power Conversion Systems Department ('02-'03) and Past Chair of the IEEE IAS Industrial Power Conversion Committee ('99-'00). Currently, he is IEEE Power Electronic Society President ('05-'06). In 2004, he was PESC04-Aachen General Conference Chair. He is the founding chairman of the German IAS-PELS-IES Joint Chapter ('97-'00). He is member of the EPE Association Executive Council (webmaster). He has published over 100 technical papers, won four IEEE-IAS price paper awards and holds 21 patents with several pending.

## Motion Sensors for motion control

M.A. Jarrah

Professor, Director of the Mechatronics Graduate Program,  
American University of Sharjah,  
UAE

Motion distances vary on very wide range from nm to Km. Motion sensors span a wide class of devices: displacement sensors such LVDT, infrared sensors, passive or active, RF proximity sensors as well as microwave and radar, or ultrasonic sensors and emitters. Cameras are also widely used as well as lasers both visible and infrared, magnetic, capacitive, Doppler; interferometers, etc.. The principles behind motion sensors involve wide range. Circular motion can use many types of encoders and tacho solutions.

These sensors are used widely in industry and vehicles uses in addition to the above, vibration sensors, strain gages, piezoelectric and capacitive sensors. In this part of the workshop, sensors used in motion control will be covered.

Motion sensors are powered by many principles, some of them are:

- Acceleration/ Vibration/Force/Pressure/Strain/Stress/Tilt/Inclination
- Encoders/Tacho-Generators/Centrifugal-Centripetal Force/
- Passive Infrared/ Active Infrared (light beam)
- Ultrasonic Beam/Doppler
- Visible Light Beam/ Laser Beam/cameras/ Video

### **Biography:**

Prof. Jarrah received the Diplom Engineer in 1980 in machine design from BeloRussion Polytechnic Institute and the M.S. degree in 1983, in applied mechanics, from Yarmouk University, Jordan and M.S. and PhD degrees in aeronautics and astronautics from Stanford University in 1985 and 1989 respectively.

From 1989-1998, he served as assistant and associate professor of mechanical engineering at Jordan University of Science and Technology. Later, he was selected to develop engineering technology education in Oman in 1998 (omani National Diploma). In 1999, he joined the department of aerospace engineering at King Abdul-Aziz University in Saudi Arabia. In 2000, he joined the American University of Sharjah as associate professor of mechanical engineering where he was promoted to professor rank in 2003. He is the founding director of the mechatronics program at AUS and the founding chair for the International Symposium on Mechatronics AUS-ISM series. Dr. Jarrah is most well known for his work in high angles of attack unsteady aerodynamics and for development of mechatronics education in the region. He also is known of the work on unmanned systems and autonomous systems.

## DC- Motor Control

R. Dhaouadi

Associate Professor, Electrical Engineering  
American University of Sharjah,  
UAE

The aim of this part of the workshop is to use frequency domain and time domain techniques in the analysis and design of DC motor speed control system. Experimental measurements will be made to construct the DC motor complex frequency response. Using these measurements, Bode and Nyquist plots will be used to analyze the performance, stability and robustness of a given Proportional-Integral-Derivative (PID) compensator. Then frequency response methods will be used to make adjustments to the controller parameters in order to improve the control system performance. Speed control using pulse width modulation (PWM), open loop control, closed loop control, unidirectional control with step down converter, and bidirectional control with H-Bridge converter.

### **Biography:**

Dr. Dhaouadi has been on the faculty of the American University of Sharjah since August 2000. He worked before as a visiting researcher at the Hitachi research Laboratory where he was involved in the design and development of high performance speed control systems for rolling mill drives. He was involved also with the research of advanced motor control techniques for induction motors and synchronous motor drive systems. Then he joined the Trondheim Institute of Technology in Norway as a visiting scholar to work on the design and development of power supply and control systems for sub-sea oil-field pumps. The research project was in collaboration with ABB Norway. After joining The University of Tunis in 1994, he established a collaboration program with Rice University to work on an NSF funded project. He was involved with research in the area of modeling, analysis and control of electromechanical systems with harmonic drive gears with particular application to high performance robotic positioning systems.