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A Practical Primer On Motor Drives (Part 1): What New Design Engineers Need To Know

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Many excellent textbooks have been written on the subject of motor drives. But most of these require pre-requisite knowledge and/or are difficult sources of basic understanding for newcomers. While there is also useful information on the internet, such material is typically aimed at narrow applications or specific products and markets. In addition, many of the public domain materials lack "real-world" examples that are vital to gain a full understanding of the topic. Both textbooks and the internet are more useful reference sources given a broad overview.

This article series aims to provide such an overview by explaining the basics of a motor drive from the input signals (ac line inputs) through motor shaft sensing (mechanical power) and all relevant areas in between. It targets newcomers to these fields desiring a broad overview before seeking deeper technical information from other sources. Among the newcomers this series targets are:

- Engineering students who are just beginning to learn about the field
- Design engineers new to the field or who wish to learn more about this field. This would include software (control) engineers, inverter subsection engineers, systems engineers, power semiconductor device engineers, and motor engineers.
- Plant or field maintenance personnel who may wish to learn more about this topic, but don't wish to read a detailed textbook(s).

Broadly speaking, these articles will address eight main topics:

- AC line voltage and current
- Power semiconductors
- Power conversion systems
- Motors
- Variable-frequency motor drives
- Sensing of motor torque, speed, direction, and rotor-angle sensing
- Power measurements on sinusoidal (ac line) waveforms
- Power measurements on distorted waveforms (e.g., pulse-width modulated outputs from drive systems).

Naturally, within each of these topics, there are many subtopics that need to be addressed in order to provide a solid foundation in motor drives. The following outline lists the specific topics that will be addressed in the subsequent parts of this article series.

- Part 2: Single-Phase AC Line Voltage
- Part 3: Three-Phase AC Line Voltage And Utility Voltage Classes
- Part 4: Single-phase AC Line Current
- Part 5: Three-phase AC Line Current And Winding Configurations

- Part 6: AC Line Power Calculations
  - Power Consumed By Linear, Resistive Loads
  - Power Used (Supplied And Consumed) By Linear, Non-Resistive Loads
  - Power Used (Supplied And Consumed) By Non-Linear, Non-Resistive Loads
  - Single-Phase Wiring Configurations
- Part 7: Power Calculations In Three-Phase Systems
- Part 8: Power Semiconductors
  - Power Semiconductor Device Operation
  - N-Channel And P-Channel Devices
  - Power Semiconductor Device Materials
    - Silicon (Si)
    - Wide Bandgap Materials
  - Power MOSFETs
  - IGBTs
  - IGCTs, GTOs, and SCRs
- Part 9: Power Semiconductors As Implemented In Power Conversion Devices
  - Single Device
  - Series Connection (Half-Bridge)
  - H-Bridge (Full-Bridge) Topology
  - Cascaded H-Bridge Topology
  - Multi-Level Topologies
- Part 10: Motor background
  - Basic Motor Operation
  - Motor Stator Poles And Slots
  - Rotor Pole Pairs
  - Motor Operating Quadrants
- Part 11: AC And DC Motor Types
  - Induction Motors (ACIM)
    - Single-Phase ACIM

        - Three-Phase ACIM
    - AC Permanent-Magnet Synchronous Motors (PMSMs)
    - "Brushless" DC (BLDC) Motors
    - "Brushed" DC Motors
    - Universal Motors
    - AC (Wound-Rotor) Synchronous Motors (ACSM)
    - Switched Reluctance Motors (SRMs)
    - Servomotors
    - Stepper Motors
- Part 12: Variable-Frequency Motor Drives (VFDs)
    - Architecture And Topologies
        - Input-Output Voltage Rating
        - DC Bus (Link) Topologies
        - Power Semiconductor Devices
        - VFD Inverter Subsection Topology
    - Pulse-Width Modulation Techniques
        - Carrier-Based PWM
        - Space Vector (Pulse-Width) Modulation (SVM Or SVPWM)
- Part 13: Motor Drive Control Architecture And Algorithms
    - Control Architecture And Algorithm Overview
    - Scalar V/Hz Controls
    - Six-Step Commutation (Trapezoidal) Control
    - Vector Flux- (Or Field-) Oriented (FOC) Control
    - Vector Direct Torque Control (DTC)
- Part 14: Power Measurements On Distorted Signals
    - Advanced Cyclic Period Detection And Display
        - Choosing A Sync Signal
        - LPF Cutoff Settings
        - Hysteresis Band Settings

        - Sync Signal Display + Zoom
        - Simple Examples For Distorted Waveforms
        - Long Acquisitions With Distorted Signals
- Part 15: Low-Pass And Harmonic Filtering Of Power Measurements
    - Analog Low-Pass Filter
    - Digital Low-Pass Filter
    - Selective Hardware PLL-based Harmonic Filter
    - Selective Software-based FFT Digital Harmonic Filter
    - Selective Software-based DFT Digital Harmonic Filter
    - Examples Using A Selective Software-based DFT Digital Harmonic Filter
    - Line-Reference Drive Output Voltage Probing Combined With Harmonic Filtering
- Part 16: Torque, Speed, Position, And Direction Sensing
    - Torque Sensors (Load Cells, Transducers)
        - 0-x Vdc Output
        - mV/V Output
    - Analog Speed, Direction, Position Sensing
        - Analog Tachometer Signal
        - Resolver
    - Digital Speed, Direction, Position Sensing
        - Pulse (Digital) Tachometer Signal
        - Hall Sensors
        - Quadrature Encoder Interface (QEI)

While this series provides a foundation in the subjects listed above, readers who follow this series are encouraged to seek out sources of more-detailed information to expand their knowledge.

Persons too numerous to mention have assisted the author by enhancing my understanding of these topics. For those who provided time in their labs or during a phone call, thank you for your time and assistance. This article series would not have been possible without your help.

If you have any feedback or questions, find mistakes, or would like to suggest changes or additions, please do not hesitate to contact me. I especially welcome information related to specific and interesting applications of oscilloscopes in the areas described in this document.

About The Author

Kenneth Johnson is a director of marketing and product architect at Teledyne LeCroy. He began his career in the field of high-voltage test and measurement at Hipotronics, with a focus on <69-kV electrical apparatus ac, dc and impulse testing with a particular focus on testing of transformers, induction motors and generators. In 2000, Ken joined Teledyne LeCroy as a product manager and has managed a wide range of oscilloscope, serial data protocol and probe products. He has three patents in the area of simultaneous physical layer and protocol analysis. His current focus is in the fields of power electronics and motor-drive test solutions, and works primarily in a technical marketing role as a product architect for new solution sets in this area. Ken holds a B.S.E.E. from Rensselaer Polytechnic Institute.

For further reading on motor drives, see the How2Power Design Guide, locate the "Power Supply Function" category, and click on the "Motor drives" link.