



AEROSPACE RECOMMENDED PRACTICE

ARP7490™

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Recommended Guidelines for the Specifications of Motor Control Electronics for Electrically Powered Actuators

RATIONALE

With the increasing use of Electromechanical Actuators (EMAs), Electrohydrostatic Actuators (EHAs), and Electric Back-up Hydraulic Actuators (EBHAs) in aerospace actuation applications, there is a need for guidelines for the creation of specifications for the motor control electronics that are used for operating these actuators. This document has been written to meet this need.

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1. SCOPE

This SAE Aerospace Recommended Practice (ARP) provides guidelines for the creation of specifications for the Motor Control Electronics (MCE) that are used for operating electrically powered actuators including:

- Electromechanical Actuators (EMAs)
- Electrohydrostatic Actuators (EHAs)
- Electric Back-Up Hydraulic Actuators (EBHAs)

1.1 Purpose

This document and the requirements stated herein are intended to be used as a guide by the Electric Flight Control Actuation manufacturer in preparing a detail specification for the MCE required to drive this electric actuation (EHA, EBHA, and EMA). This document may be used in conjunction with applicable industry and OEM specifications to guide the development of a comprehensive MCE specification

These guidelines may be used in whole or in part to form the desired MCE specification. This document will provide guidance on specifying Motor Control Electronics as follows:

- a. Architecture
- b. Input and Output Requirements
- c. Basic Functions
- d. Software/Firmware
- e. Manufacturing/Producibility
- f. Testing

1.2 Field of Application

Due to the similarity between Electrohydrostatic Actuators (EHA), Electric Back-Up Hydraulic Actuators (EBHA), and Electromechanical Actuators (EMA) flight control and utility aerospace actuators and their related MCE requirements, this document may be used as a guide for developing the control electronic specifications for any of these actuator types with a reasonable tailoring to the application.

NOTES:

1. The guideline information is directed towards electric actuation for use in aircraft flight control systems. However, it should be recognized that it might also apply to many other electric actuation or electric motor driven aerospace systems.
2. Unless otherwise indicated in the rest of this document, the MCE term is used to describe the Motor Control Electronics used to drive actuation servomotors.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications should apply. The applicable issue of other publications should be the issue in effect on the date of the purchase order. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR6219	Development of Atmospheric Neutron Single Event Effects Analysis for Use in Safety Assessments
ARP490	Electrohydraulic Servovalves
ARP4386	Terminology and Definitions for Aerospace Fluid Power, Actuation and Control Technologies
ARP4754	Guidelines for Development of Civil Aircraft and Systems
ARP4761	Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment
ARP6025	Duty Cycle Considerations for Electrohydrostatic Actuators
AS478	Identification Marking Methods
AS5643	Interfaces requirements for Military and Aerospace Vehicle Applications

2.1.2 ARINC Publications

Available from ARINC, 2551 Riva Road, Annapolis, MD 21401-7435, Tel: 410-266-4000, www.arinc.com.

ARINC 422	Electrical Characteristics of Balanced Voltage Differential Interface Circuits
ARINC 429	Mark33 Digital Information Transfer System (DITS)
ARINC 485	Electrical Characteristics of Generators and Receivers for Use in Balanced Multipoint Systems
ARINC 629	Multi-Transmitter Data Bus
ARINC 664	Aircraft Data Network

2.1.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D149	Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies
ASTM D1868	Standard Test Method for Detection and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems

2.1.4 European Union Publications

Available from European Aviation Safety Agency, Postfach 10 12 53, D-50452 Cologne, Germany, Tel: +49-221-8999-000, www.easa.eu.int.

RoHS	DIRECTIVE 2011/65/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment
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2.1.5 ISO Publications

Copies of these documents are available online at <http://webstore.ansi.org/>.

ISO2669 Steady-State Acceleration

ISO2678 Insulation Resistance and High Voltage Tests for Electrical Equipment

2.1.6 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

RTCA/DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

RTCA/DO-178 Software Considerations in Airborne Systems and Equipment Certification

RTCA/DO-254 Design Assurance Guidance for Airborne Electronic Hardware Considerations in Airborne Systems and Equipment Certification

2.1.7 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-A-8870 Airplane Strength and Rigidity Vibration, Flutter, and Divergence

MIL-DTL-38999 Detail Specification: Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, And Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification For

MIL-STD-130 Identification Marking of U.S. Military Property

MIL-STD-202 Test Methods, Standard Electronic and Electrical Component Parts

MIL-STD-461 Requirements for The Control of Electromagnetic Interference Characteristics of Subsystems and Equipment

MIL-STD-704 Aircraft Electric Power Characteristics

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests

MIL-STD-1553 Digital Time Division Command/Response Multiplex Data Bus

2.2 Definitions

Terms used in this document are defined in ARP4386. Where new terms are used, the definitions are presented below.

Motor Control Electronics (MCE): The electronics required to power and control electric servo motors.

NOTE: Other terms used to describe Motor Control electronics include:

- Power Control Electronics (PCE)
- Power Drive Electronics (PDE)
- Power Drive Unit (PDU)
- Motor Control Unit (MCU)
- Electronic Unit (EU)

- Motor Power Drive (MPD)
- Electronic Actuator Control Unit (EACU)

For the purpose of this document, these terms may be considered equivalent.

2.3 Symbols and Abbreviations

The symbols and abbreviations used in this document are listed below:

AC	Alternating Current
A/C	Aircraft
ADC	Ampere Direct Current
AFDX	Avionics Full-Duplex
ARINC	Aeronautical Radio, Incorporated
A _{RMS}	Ampere Root Mean Square
AT	Acceptance Test
ATP	Acceptance Test Procedure
ATRU	Auto-Transformer Rectifier Unit
BIT	Built-in Test
CAN	Controller Area Network
CDR	Critical Design Review
CE	Control Electronics
CLAW	Control Law
COM	Command
COTS	Commercial Off-The-Shelf
CS	Conductive Susceptibility
CTE	Coefficient of Thermal Expansion
DC	Direct Current
DWV	Dielectric Withstanding Voltage
EBHA	Electrical Back-up Hydraulic Actuator
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
ESS	Environmental Stress Screening

FCS	Flight Control System
FH	Flight Hours
FHA	Functional Hazard Assessment
FMEA	Failure Modes and Effects Analysis
FW	Firmware
GIDEP	Government-Industry Data Exchange Program
h	Hour
HALT	Highly Accelerated Life Test
HASS	Highly Accelerated Stress Screening
HIRF	High-intensity Radio Frequency
Hrs.	Hours
Hz	Hertz
ICD	Interface Control Document
IGBT	Insulated-Gate Bipolar Transistor
I/O	Inputs/Outputs
Ke	Motor Speed Constant
Kt	Motor Torque Constant
LRU	Line Replaceable Unit
LVDT	Linear Variable Differential Transformer
M	Mega (prefix)
mA	Milli-Ampere
MBU	Multiple Bit Upset
MCE	Motor Control Electronics
MeV	Mega electron Volt
MON	Monitor
MTBF	Mean Time Between Failures
MTBUR	Mean Time Between Unscheduled Removals
n	Neutron
NVM	Non-Volatile Memory
PCB	Printed Circuit Board

PD	Partial Discharge
PDE	Power Drive Electronics
PDR	Preliminary Design Review
PF	Power Factor
PFC	Power Factor Controller or Power Factor Correction
PMSM	Permanent-Magnet Synchronous Motor
PWM	Pulse Width Modulation
RE	Radiated Emission
RF	Radio Frequency
RoHS	Restriction of Hazardous Substances
rpm	Revolution per minute
RS	Radiated Susceptibility
RTD	Resistive Temperature Device
RVDT	Rotary Variable Differential Transformer
SEU	Single Event Upset
SOI	Stages of Involvement
SW	Software
TBO	Time Between Overhaul
THD	Total Harmonic Distortion
TTP	Time-Triggered Protocol
USL	Upper System Level
V	Volt
VA	Volt Amperes
VAC	Volt Alternate Current
VDC	Volt Direct Current
VF	Variable Frequency
V _{RMS}	Volt Root Mean Square
μ	Micro (prefix)
Ω	Ohm

3. MCE PROCUREMENT SPECIFICATIONS

This section and the requirements stated herein are intended to be a guide for the preparation of a MCE specification. The guidelines below may be used to generate a procurement specification based on very high-level requirements where the procurement organization will rely on

- The expertise of the MCE suppliers to provide all of the details of the design, or
- A very detailed specification where the procurement agency has a high-level of expertise and desires to specify highly detailed requirements.

These guidelines may also be used for any level of detail between the two extremes identified above.

3.1 General Structure of Procurement Specification

The following general structure for the Procurement specification is recommended:

1. SCOPE

- 1.1 Purpose
- 1.2 Background
- 1.3 Item Description
- 1.4 Priorities
- 1.5 Document Organization

2. REFERENCES

- 2.1 Applicable Documents
 - 2.1.1 SAE Publications
 - 2.1.2 Radio Technical Commission for Aeronautics Documents
 - 2.1.3 U.S. Government
 - 2.1.4 ISO
 - 2.1.5 Industry
 - 2.1.6 Precedence
- 2.2 Definitions
- 2.3 Symbols and Abbreviations

3.0 REQUIREMENTS

- 3.1 Interface
 - 3.1.1 Electrical Interface
 - 3.1.1.1 Input Power
 - 3.1.1.2 Output Power

3.1.1.3 Commutation Sensor Interface

3.1.1.4 Control Interface

3.1.1.5 Data Interface

3.1.1.6 Position Sensor Interface

3.1.1.7 Miscellaneous Sensor Interface

3.1.1.8 Miscellaneous Output Interfaces

3.2 Physical Requirements

3.2.1 Mechanical Interface

3.2.1.1 Envelope

3.2.1.2 Electrical Connectors

3.2.1.3 Thermal Interface

3.2.2 Weight

3.3 Functional and Performance Requirements

3.3.1 Performance

3.3.2 Control

3.3.3 Actuator Monitoring

3.3.4 MCE Internal Monitoring

3.4 Environmental Requirements

3.4.1 General

3.4.2 Actuator Mounting Temperature

3.5 Design and Construction

3.5.1 Electromagnetic Environment Effects

3.5.2 Electrostatic Discharge Protection

3.5.3 Interchangeability

3.5.4 Safety

3.5.5 Hazardous Material

3.5.6 Product Marking

3.5.7 Serialization

3.5.8 Segregation (Channels, Com/Mon)

3.5.9 Sealing vs Vent and Drain

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Verification Methods

4.2 Verification Matrix

4.3 Acceptance Tests

4.3.1 Examination of Product

4.3.2 Functional Test

4.3.3 Environmental Stress Screening

4.4 Qualification Test

4.4.1 Environmental Tests

4.4.2 Electromagnetic Compatibility Tests

5.0 PREPARATION FOR DELIVERY

5.1 Cleaning

5.2 Preservation

5.3 Packaging

5.3.1 Shipping Container

5.3.2 Shipping Container Marking

6. NOTES

6.1 Revision Status

4. DETAILED SPECIFICATION ITEM DESCRIPTIONS

4.1 Scope

The Scope section should include a description of the scope of the specification, if the intent is to provide a high-level requirement from which the supplier is to define the details or if the specification is intended to be a detailed specification of the desired MCE. The scope should state if the MCE provides only power electronics or if control is also to be included.

4.1.1 Purpose

The Purpose section is optional and is used to define the purpose of the specification such as providing high-level requirements, detailed requirements, goals, etc.

4.1.2 Background

The background is optional and will typically provide the reader with any background information related to the application, the MCE usage, limitations, etc.

4.1.3 Item Description

This section provides the top-level description of the MCE including the following:

NOTE: Also intended to define a common purchaser/supplier terminology, may be worth to mention.

- a. The high-level description of the motor/actuator to be driven
- b. The number of control channels and or motors to be driven
- c. The Design Assurance Level
- d. The need for monitor channel
- f. The input power characteristics
- g. The control interface to the higher-level system
- h. The dispatch reliability and level of fault tolerance
- i. Other descriptions as needed.

A system block diagram or high-level schematic diagram, as shown in Figures 1 and 2, may also be provided in this section.

Typical Item Descriptions are as follows:

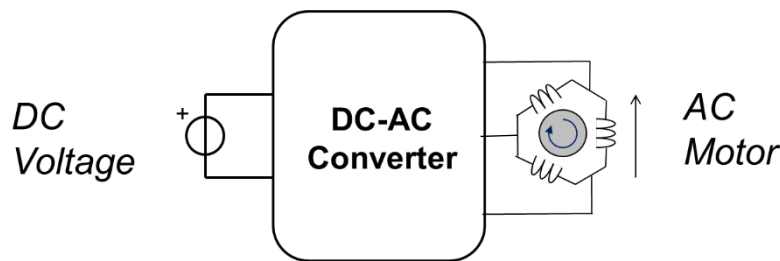


Figure 1 - Typical motor control electronics (MCE)

NOTE: This is shown with DC power supply for example, and it converts DC power supply into Electrical Energy for Brushless Electric Motor.

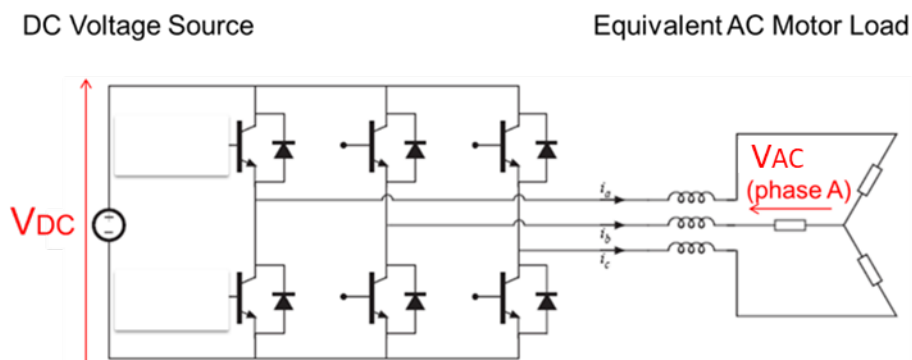


Figure 2 - Typical MCE electrical architecture

NOTES:

1. The configuration that is shown is a 6-Switch Bridge Inverter to convert DC to controlled AC to Drive Motor).
2. The AC motor is represented here in the simplest electrical modeling limited to equivalent inductance and resistance contributors and star connection for windings.
3. The architecture shown here is only the power view, not the control view. The control view is mentioned in the dedicated paragraph.

The MCE should include the following sub-systems and functions:

- An Inverter
- The Motor Control Logic
- A Rectifier Bridge or an Auto-Transformer Rectifier Unit or a Power Factor Controller (AC inputs only)
- The EMI filtering
- The aiding load energy management system (if required)
- The in-rush current control circuit (if required)
- The motor commutation sensor excitation and demodulation
- The motor phase voltage/current control
- The electrical connectors (the number of connectors used should be defined to achieve a good segregation between high and low power signals and between command and monitoring signals)
- The internal electrical connectors between boards or circuits within the MCE
- The actuator position sensor excitation and demodulation (if required)
- The motor temperature sensor or switch information treatment (if required)
- The bridge temperature and motor current information sensors
- The solenoid and other utility drivers (if required)
- An independent electrical heating or cooling device (if required)
- The interface data bus
- The enclosure
- The health monitoring functions
- The actuator loop closure control logic (if required)

The MCE is to perform at least the following functions:

- The conversion of electrical energy from an electric power bus (AC or DC) to commutated current-controlled AC sine or 6-step trapezoidal motor phase currents
- To provide this commutated output current as a function of torque (current), speed, or position command depending on the MCE control strategy
- The electrical interface with upper-level system
- The communication with upper-level systems to receive commands and to report status
- The electric power bus (AC or DC)
- The EMC/lightning protection, signals filtering, etc.

- The electrical energy dissipation (aiding load and deceleration, if specified)
- The power limitation function for power management optimization (if specified)

4.1.3.1 System Block Diagram

A high-level block diagram of the desired MCE is recommended. Figures 3 to 7 show some examples that may be used as a starting point.

If the MCE specification writer is knowledgeable in MCE design, these figures could provide almost any level of detail desired. Others may opt to provide only a high-level diagram or even no diagram as appropriate. In all cases, it is recommended that a detailed MCE Block diagram be provided as part of the subsequent design package and possibly the proposal package.

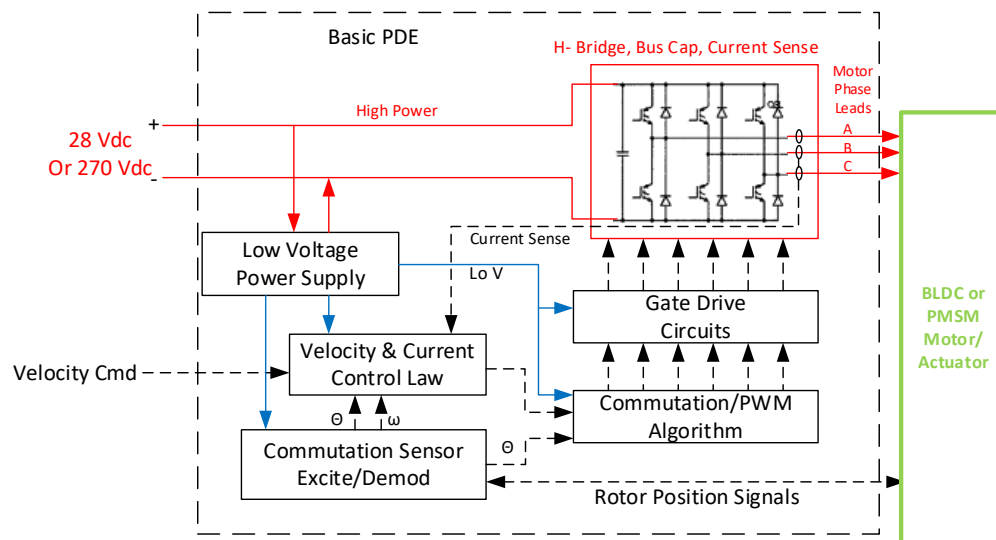


Figure 3 - A basic MCE

NOTE: This provides a simple motor velocity in response to a velocity command and operates from a DC Power Bus).

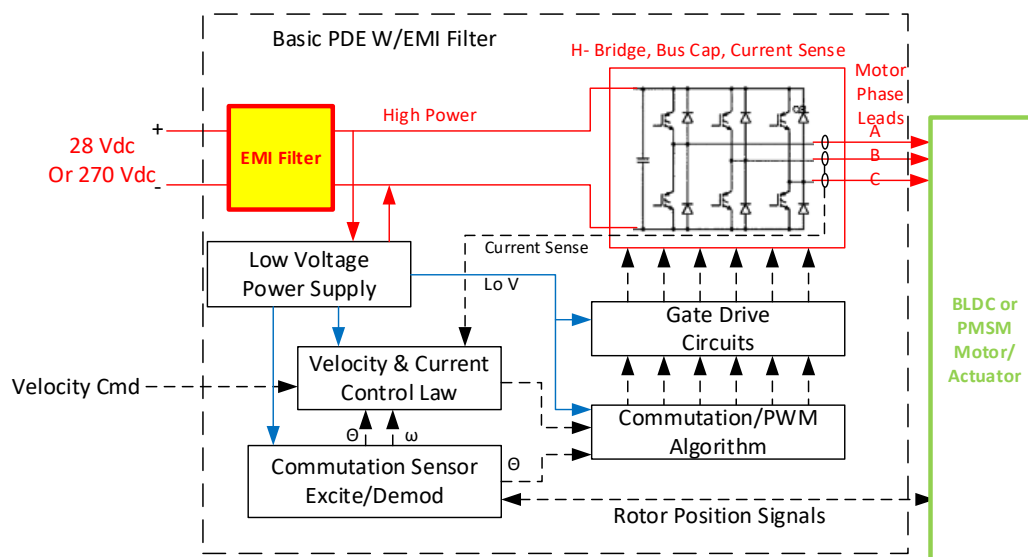


Figure 4 - A basic MCE with an EMI filter

NOTE: This provides a simple motor velocity in response to a velocity command and operates from a filtered DC power bus.

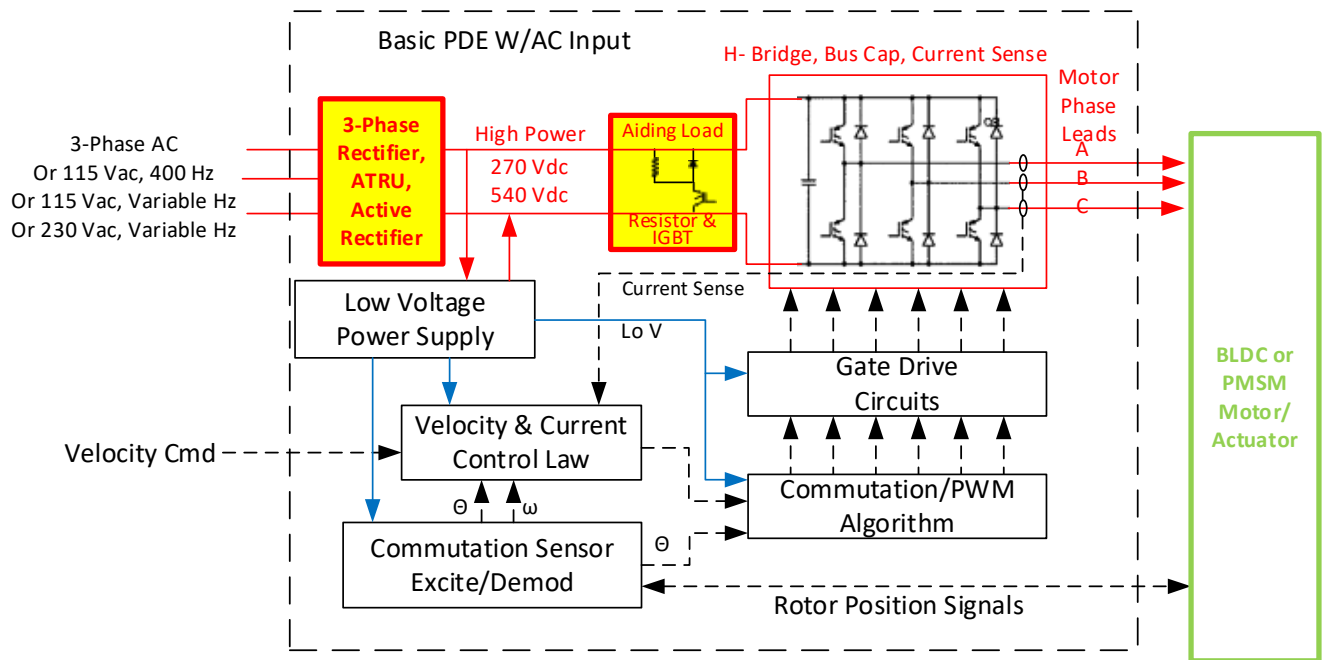


Figure 5 - A basic MCE with AC input and regenerated energy management

NOTE: This provides simple motor velocity in response to a velocity command and operates from an AC Power Bus, regenerated energy management may be required if passive rectification is used.

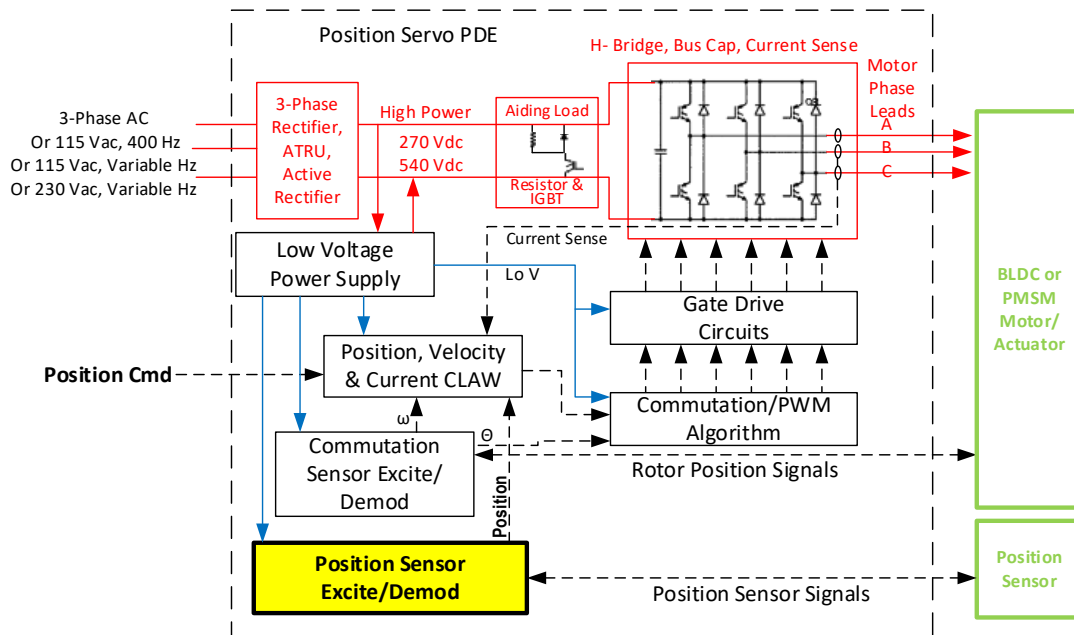


Figure 6 - A position servo MCE with AC input and regenerated energy management

NOTE: This provides the same features as Figure 5 but adds the ability to receive position commands and close the position loop around the actuator's position sensor feedback.