BLDC motor controllers for simple and complex systems

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Modern Brushless DC (BLDC) motor controllers housed in compact assemblies are ideal for integration into systems that require precision control and efficiency. This enabling technology fulfils the requirements of both simple and complex motor systems, while offering significant advantages and improving time to market.

Complete enclosed motor controller solution

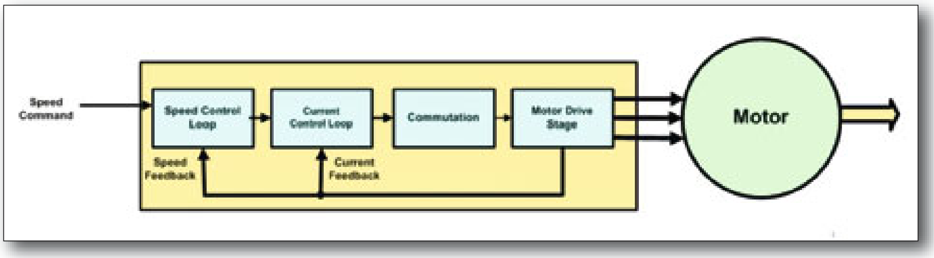
The demand for electric motors is increasing at a rate of 5-6 percent annually, and is projected to rise through 2017 to a total available market of $14.4 billion in the US alone. The growth rate is even higher in China and Asia, as these countries modernize and improve infrastructure. Within these markets, the expansion of mid-range horsepower motors outpaces that of smaller fractional horsepower types. Driving this demand are heating and cooling equipment markets, along with electric vehicles, which will provide the best growth opportunities. All systems, from industrial, avionic, military and space are seeing demand to improve efficiency and reduce weight. Along these lines, European markets have issued a directive to improve motor efficiency. Reductions in size and improvements in operating and ownership cost are also being driven in military and avionic markets worldwide. To achieve these goals, more reliable and efficient motors and control techniques must be considered.

The BLDC motor provides clear advantage over other motor types in terms of optimizing efficiency and size in demanding motor applications. BLDC motors do not have brushes and require less maintenance and system down time. Yet these motors require electronic controllers that range from simple to complex. The motors typically have efficiency of over 80%, and the controllers in the 95% range. Thus the enabling technology is the ever improving evolution of the BLDC motor controller. The most efficient controllers use Pulse Width Modulation (PWM) sampling to drive a motor from DC power. There are other power conditioning requirements that range from rectification of an AC signal to electromagnetic interference (EMI) filtering that is required in most applications. Defining and understanding the motor application is essential to selecting the optimum controller choice. The most common motor control techniques and applications can be broken down as follows:

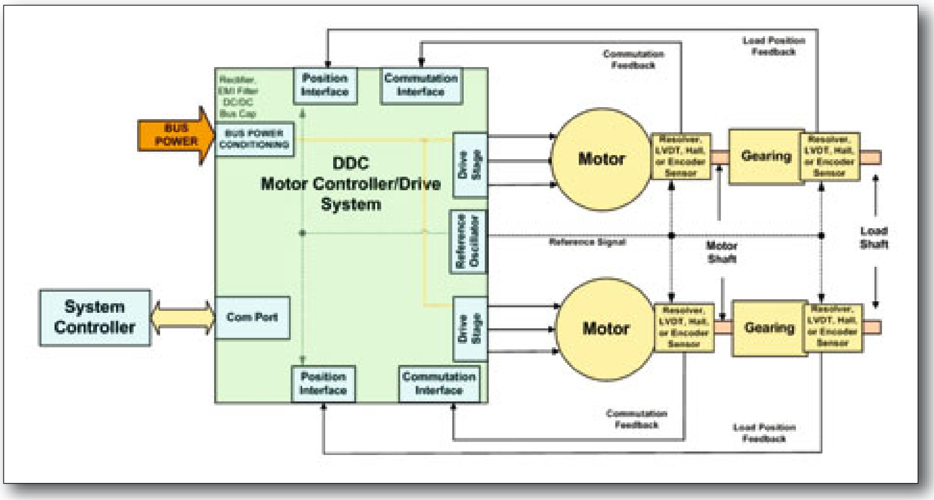
Control	Technique	Applications
Speed	Rotate at constant multiple RPMs	Pumps, Fans and or Compressors
Torque	Maintain force while changing direction	Doors, Wing Slats/Flaps, Fins
Position	Move to precise location	Robotics, Radar, Satellite Communications, Turrets

Each of these systems utilizes specific motor control techniques that require tuning of one or more control loops – torque, speed and/or position. Precision and efficiency is determined on controlling voltage which sets the speed and current that controls the torque. A designer must consider the approaches of analog and digital motor control solutions. Analog motor controllers utilize resistors and capacitors for loop tuning. This typically requires knowledge of control loops and can be supported by data sheets, technical staff and formulas that aid in optimum component selection. Each loops' design characteristics must be chosen carefully.

In the case of a speed and torque controller, the loops must be tuned correctly. These designs are application-specific and can require additional optimization as the system is tested to the full range of performance. Changes are often required as motors and loads are changed or added. The upside to the analog approach is that these motor controllers come in a compact form. The tuning is accomplished by changing resistors and capacitors to set the proportional and integral loop gains of each loop. The compact size of analog controllers is ideal for use in avionic applications due to the size and the cost of certifying programmable devices. Avionic specifications implemented by the Federal Aviation Administration (FAA) in 2005 to ensure the safety of civilian aircraft electronic systems require rigorous design approach and certification. The specifications that are used for design control are as follows. DO254 sets development and compliance standards for complex electronic hardware such as processors, field programmable gate arrays (FPGAs), digital signal processors (DSP), programmable logic devices (PLD), and application specific integrated circuits (ASICs). The levels for this certification range from A: Flight



Sensorless motor control system



Dual-axis motor control

critical to E: Non Flight critical. DO178B sets development and compliance standards for software used in avionic applications.

Analog controllers are also commonly used in space applications to minimize the cost of radiation-proof components such as processors, ASICs or FPGAs. Radiation test and characterization is still required. Total Dose Testing predicts the life of the electronics and Single Event Testing predicts reaction of events such as solar flares. Manufacturers of these devices such as Data Device Corporation (DDC) design to meet common radiation requirements and perform testing to verify radiation tolerance performance. Additionally, hybrid microcircuits save space and weight.

Digital motor controllers offer several performance and efficiency advantages that make them the controller selection of choice for many applications. The versatility of digital controllers has advanced as the evolution of DSP (digital signal processing) and ASIC (application-specific integrated circuit) based processors now enable designers to create flexible products and improve time to market. The most versatile of these designs are based on DSP architectures which allow integration from simpler sensorless systems to complex multi-axis position control systems. The processing power of the DSP, along with associated graphical user interfaces (GUI), takes the complicated math out of the user design, requiring only basic knowledge and support to meet the expected motor system performance goals. The torque, speed and position loops are often calculated for the designer based upon motor and system parameter entry. Many controllers offer multiple control options.

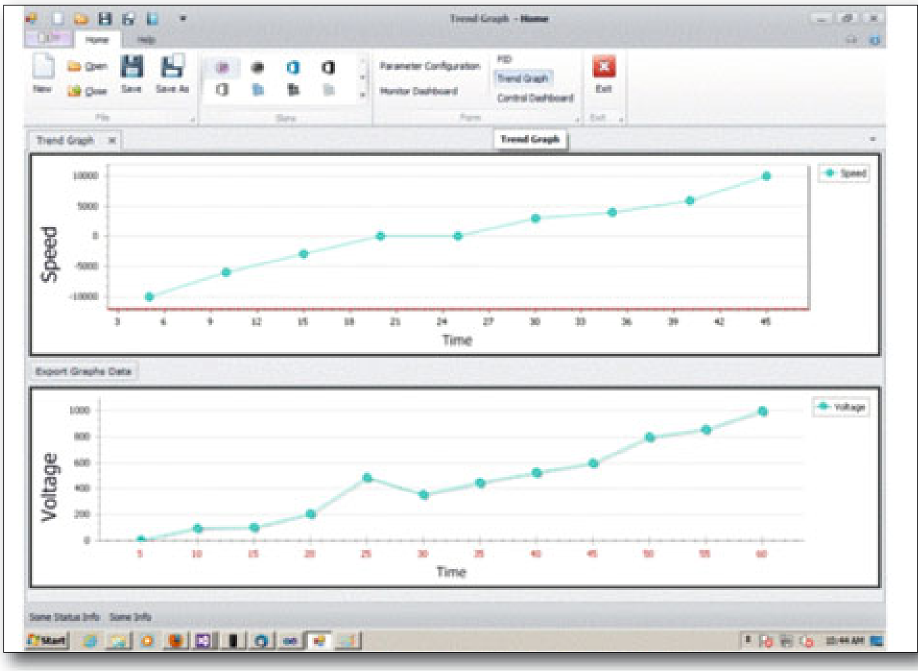
The embedded control and control logic in the DSP can contain complex mathematical calculations and algorithms that are required to gain the efficiencies of the field-oriented (FOC) sinusoidal motor commutation technique. This technique delivers power to the motor by means of a sinusoidal (sine) waveform. The sinusoidal signal provides maximum voltage/speed in relation to the DC bus voltage and reduces noise by over 30% relative to a trapezoidal (trap) drive. The trap drive commutates the motor with a trapezoidal AC signal. The system losses in a sine drive are in the motor, while the trapezoidal drive losses are in the controller. Additionally, a sine wound motor will improve motor efficiencies as well. The torque ripple on a sinusoidal motor can be as low as 1%, while the ripple for a trapezoidal motor is over 13-14%. The sinusoidal system also reduces noise, which is essential to meeting EMI requirements. The trap drive system EMI signature and current ripple are higher due to the sharp edges and flatness of a trapezoidal signal. These signals are modulated by the PWM frequency in the motor controller.

The processing power of DSPs also enables flexible motor control that can be utilized in a wide range of applications, from a sensorless motor system, such as a fan or pump, to a complex multi-axis design, such as those that are used in turrets and robotics. The speed controller uses internal sensing and algorithms that are required for speed regulation and also sets the control loop parameters for torque. Torque is proportional to current and speed is proportional to voltage. The bandwidth for the current/torque loop is generally greater than that of the speed loop.

Torque controllers are used in applications that require holding torque and changes in direction, since these controllers maintain smooth transitions in torque through zero speed. This is known as a four quadrant controller. Controlling current/ torque to the motor will allow for precision speed control. Torque controllers utilize a position sensor on the motor to determine the position of the shaft, in order to energize the appropriate winding for precision control. This is most commonly a Hall Effect device, but can alternatively be resolvers, encoders etc. A position controller utilizes an interface with position sensors on the motor and at the load. The position loop is the outer control loop in this system. The speed and torque loops must be tuned as well. All three control loops must be tuned based on the motor and system parameters.

Programmable motor control devices include a GUI that will aid and perform these calculations based upon the motor used and system requirements. As a system is implemented in the lab or fielded, system parameters often change and may require tuning to attain the desired performance. The GUI is the perfect tool to minimize the time impact of additional tuning. Another benefit of tunable controllers is that a motor can be swapped out and its replacement made operational with the simple change of parameters in a short time. Multiple motors can be used with the same controller. This will reduce the cost of ownership which is a key consideration for motor control systems.

DSP-based solutions also allow for interfacing with host processor controlled systems that communicate on serial networks such as CAN, RS-485, RS-422 etc. Alternatively, speed and/or torque can be set by means of an analog voltage input when advanced features are not required. Also, on-board or system processors can coordinate 2-axis movement as required in satellite base stations, radars, turrets or robotic systems. Motor control suppliers such as Data Device Corporation offer products that incorporate all control algorithms and sensor interfaces, as well as provide advanced protection, such as overtemperature, overcurrent,



Screen shot of a data logger

etc. This is true for both analog/trapezoidal drives and digital/sine drives. These devices have protection built in the hardware. The DSP-based solution also can have soft limits set that interface with the motor control system with parameters set by the GUI. The control and power stages for these motor controllers are available in compact form, such as a hybrid or module, which can be integrated into larger systems.

The controllers and supporting electronics typically are mounted on or near the motor. The motor system will also include a DC bus capacitor to reduce ripple and possibly EMI filters to reduce noise on the system bus. Consideration must also be given to dissipate motor energy Back Electro Motive Force (BEMF) that is generated when the motor shuts down. A large amount of mechanical energy is converted back into electrical energy, and this must be considered in the overall system design with implementation of a braking resistor or other method to store or dissipate this energy such as capacitor networks or batteries. For higher voltage systems, the bus capacitor should be of good quality and low equivalent series resistance (ESR) to reduce bus ripple. This capacitor should be located close to the controller to reduce resistance.

Most electronic systems must meet electro magnetic interference (EMI) standards for system compatibility. This ensures that the electronics will not interfere with or be interfered by other devices. Standards govern the devices radiated radio frequency (RF) emissions as well as susceptibility. There are commercial and military standards such as MIL-STD-461 that is typically used for US military and avionic systems and less rigorous FCC standards in the US. Europe issued an EMC Directive (89/336/EC) in the 1980s and other countries have similar standards. A good motor and controller system will be designed to these standards and have an EMI filter integrated into the system. This can be found located in a box level motor control solution at or near the motor. In a larger system, an overall solution is used. The object is to reduce the cost of qualifying the system as well as meeting control system size and weight constraints.

The DSP-based devices feature graphical user interfaces (GUI) that can operate the motor and be used to optimize performance. Complex calculations are carried out for the control loops. The processor memory also enables users to save motor data, such as voltage and current, which may then be viewed through a data logger for analysis. One can analyze start up issues by reviewing motor current, voltage, as well as optimize the bandwidth to reduce torque ripple to optimize motor performance. These types of tools have become the industry standard, and are included with the purchase of the motor controller.

Modern motor control products will continue to meet the growing demand for automation and motor control, as complex systems can now be supported with compact solutions. These designs provide all the processing power required for precise and efficient motor control, and can easily be integrated into box and system level solutions. ■