What is Electric Drive Testing? How does it Work?

Efficiency Testing of Electrical Machines and Electrical Inverters

Author

Mitch Marks, Business Development Manager – Electric Power Testing

HBM Test and Measurement

Introduction

When designing an electric motor drive system, no matter what the application is, there are three elements:

- power source
- power converter
- motor

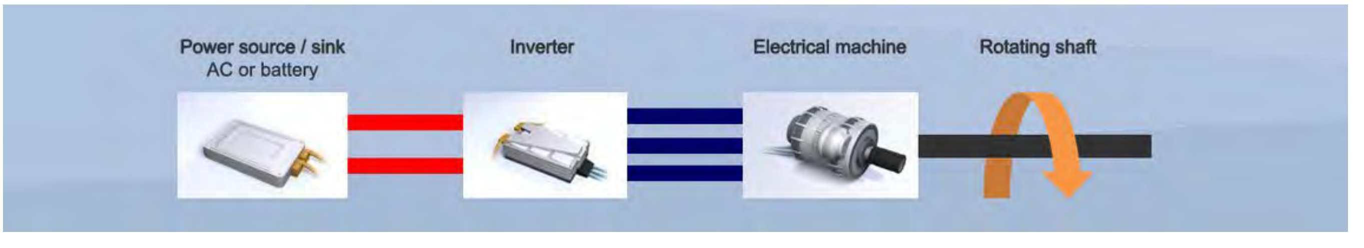
Often, these elements come in the form of a battery acting as a DC Bus – an inverter which changes the DC power to AC power – and a motor which uses the AC power to convert electrical energy into mechanical power. This is sometimes referred to as electro-mechanical power conversion.

What are the engineers trying to achieve?

When designing these systems, engineers are typically trying to maximize efficiency across a drive cycle. They do this by maximizing the torque per amp for as many points as possible. This is sometimes done with clever machine design, and at other times with implementing the appropriate control technique. The inverter, control, and motor need to play nicely together to maximize this goal, but often these things are developed separately. This leads to issues like a very efficient motor but poor efficiency in the inverter. This has led to system level workers and engineers trying to maximize the Power Factor across the system. A slightly less efficient motor can be worthwhile, if it increases the efficiency of the Motor Drive.

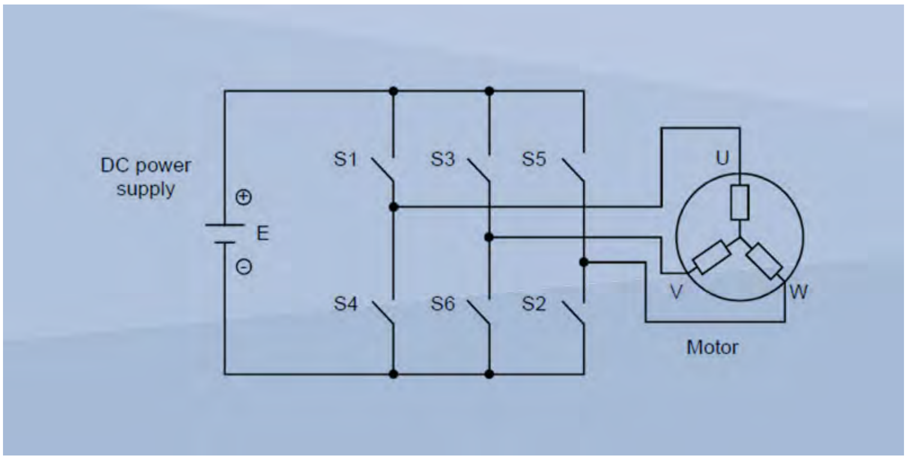
What about power suppliers?

The power supplies for these applications are almost always a battery, but sometimes there could be a rectifier system from a power line to create a DC bus. This DC bus can be raised or lowered using a DC-DC converter which is fed to an inverter. The DC-DC converter may also be included in battery systems to adjust the DC bus to a level that the inverter likes. These batteries are typically of lithium ion construction and in the range of 200-400 volts for automotive applications, but could be as high as 600-800 volts. Not a whole lot of people choose to go any higher than that because life gets a lot more difficult working with that much DC potential.



The role of the inverter

The inverter is a very important part of the system because it is where all the power conversion and control take place. The inverter typically consists of six switches (for a 3-phase operation) which open and close in a specific pattern to create AC power. This pattern is executed at a switching frequency which is often between 9kHz and 25kHz. A frequency below 9kHz becomes very audible; however, for high power applications, a lower switching frequency is necessary to cut down on losses. Higher switching frequencies are limited by both, the physical limitations of the switches as well as increased switching losses. Typically, these switches will be IGBTs or MOSFETs. The level of current will determine the choice of the switch. MOSFETs are typically geared for lower power. IGBTs are meant for higher power. Higher frequencies allow for smaller passive devices and increased control. This has led to a lot of money being invested in wide bandgap devices. These would most commonly be silicon carbide or gallium nitride (GAN) devices. These devices have lower losses and can typically be operated at higher currents and switching frequencies. They are prohibitively expensive and not very robust right now, but they are the future.



Taking over control?

Control is something that everyone keeps pretty tight-lipped about how they specifically do it. It's a software, hence it is easy to keep it under wraps. The controller will look at what the torque and speed are, and determine the switching frequency, Pulse Width Modulation (PWM) method, and how to optimize efficiency. These aspects can change quickly throughout a cycle. Most types of control, regardless of the motor type, are a version of field-oriented control (FOC). A growing trend is Deadbeat current control; however, all controls will be closed loop current control.

The control is where the direct-quadrature (dq0) reference frame transformation will take place. This is a mathematical translation to visualize and control the 3 phase PWM, based on what the system needs. It is simply a sine and cosine manipulation with a position reference to make 3 phases look like 2 (not trivial).

The history of the math for controlling and understanding the induction machine took about 50 years for people to solve. It is amazing that we were using the machine 50 years before we could understand it!

Models need to be validated

Everyone uses computer models before they do anything. Models are cheap and can be run very quickly as well as in an optimized manner. Building motors and controllers is not a fast process. Motor and control optimization take place in models and FEA. Everyone does this before they build anything. Models are very good at predicting motor and inverter behavior and are an unbelievably useful tool. Most places have a whole group of engineers working on models. Researchers love model validation because it lets them have more confidence in their models; therefore, they can then use these models to predict the motor and control behavior. This is an area where our products could come into play, validating models.

At the end of the day, most applications have size restrictions and cost restrictions, which determine many of the variables before motor design even begins.
Hence, we have the choice of topology and small details, based on the control scheme that groups want to use. There are also choices that can be made with cooling, and how the motors are wound. The main types of motor are induction, permanent magnet, wound field, and switched reluctance. Induction motors are the easiest to control, we understand them the best, they are a total workhorse of industry; however, their downside is that the field needs to be excited, which results in losses. Permanent magnet (PM) motors are used a lot in applications where efficiency is important and size is a restriction, as they have a higher Power Density because the magnet supplies the rotor field rather than having the losses in the rotor

These PM motors require an inverter and a lot of cooling and care when operating in different modes. They also have the down-side of losing out on Constant Power Speed Ratio CPSR, because the field cannot be weakened as easily. Field weakening is a method of reducing the rotor's magnetic field in order to increase the speed of a machine. We can weaken the field in the Induction Machine or PM machine by injecting q-axis current. The need to have controlled amounts of q axis (used to control torque) or d axis (used to control rotor field) current for FOC is a reason why many groups are interested in monitoring their dq0 plots in real time. With a PM machine more considerations need to be taken because the magnets can become demagnetized during field weakening and back emf may need to be monitored.

Synchronous Reluctance (SR) motors have a very simple rotor which is simply a lamination with a specific pattern. These motors use the property of reluctance torque in order to create rotational motion. These motors are very useful in a variety of applications because of their simple construction but have the downside of creating a large amount of noise and vibration. For this reason, they have only been used in specific scenarios. During testing of these machines, researchers are mainly interested in having a vibration map of what torque and speed vibrations are the strongest.

The cooler the motor, the less the losses; the less the losses, the higher the efficiency.
Additionally, if magnets get too hot, they can demagnetize in certain regions, which can be very bad. Hence, keeping the windings and switches cool is very important. Switches will have higher losses and can also explode if they get too hot. Researchers spend a large amount of design time on exploring cooling strategies to make their machines more efficient. Cooling systems are often water, oil, or glycol pumped and sprayed over the areas that it is desired for heat to be removed.

The stress on cooling machines has made motor temperature monitoring an important part of operation and testing. A test will have thermocouples for monitoring temperatures which are logged or sent to a control system for shutdown. Having these logged values synchronized with the data would be of interest for researchers to know when and where temperature changes happened in response to their controls. This is another area where data can be used for model validation.

Increasing the efficiency

The best way of covering many of the above mentioned topics is efficiency mapping and dyno testing or dynamometer testing. Everybody wants to increase the efficiency of their systems. Having the raw data is important for this, because if something goes wrong you can reference previous tests and also perform in-depth analysis in a post processing program such as MATLAB. Furthermore, this is of the utmost importance for dynamic testing, because when carrying out dynamic loading or testing drive cycles, if you don’t have the raw data, you can get some weird inaccurate efficiencies.

When they start testing, they will have a set DC bus voltage, followed by a set speed.

They will then load the machine with a certain torque. You will do this for all of the desired torques and speeds available in the range of the machine. This will then give you the efficiencies for all desired set points, and you obtain an efficiency map. These points will be taken at a specific temperature range. Sometimes you have to wait for the machine to cool down in order to take a measurement at a set point. This is where HBM’s electric motor and drive testing system can save a lot of time for customers because taking test points in a number of cycles rather than a number of seconds will have the machine spending less time heating up.

Often, people will test the limits of the machine, and basically blow them up; or attempt to. They will push to achieve the maximum speed to know the mechanical limits of their machine. The ability to trigger and have a buffer of data will allow researchers to understand not only where their machine failed but how it failed.