6 reasons for rapid adoption of HIL testing for Variable Frequency Drives.

- Control software is becoming a key value generator
- Continuous need for new control algorithm development
- System level interoperability requirements
- Modular power converter design requirement
- Grid code compliance
- Control software lifecycle maintenance complexity

Today, nearly 70% of all industrial electricity is consumed by electric motors. However, only small percentage of motor drives are variable frequency drives (15%-20% EU, 12% Germany, 5% worldwide). It is estimated that full penetration of Variable Frequency Drives (VFD) would reduce our total electricity consumption by up to 6%.

Yet the promise of improved efficiency is not the only benefit of VFDs. Advanced variable frequency drives are bringing: new functionality, more sensing and adaptation to industrial processes, improved fault tolerance, new applications, and new business models around drive usage.

Indeed, the 4th Industrial Revolution (or Industry 4.0 or Industrial IoT) is transforming motor drives into intelligent and rapidly evolving edge devices with: formidable and expanding computational power, extensive data analytics capabilit; vast external sensor connectivity; communication gateway capability (enabling ease of connecting drive with the cloud, sensors, neighboring drives etc.) thus unlocking potentially new value generation streams for operators. In addition, industrial IoT opens new opportunities for drives manufacturers to offer new services around data analytics and drives deployment optimization.

Teams developing motor drives are now facing very similar challenges that drove widespread adoption of Hardware in the Loop (HIL) testing in automotive industry. Rising control software complexity and code generation requirements increase both the critical nature and difficulty of extensively testing embedded software. Shrinking time to market requirements, limited development budgets, and shortage of engineering talent make it ever more critical to improve efficiency across the software and system development lifecycle.

Hardware in the Loop testing and model based design and testing practices have been demonstrated to improve project schedule performance by 32%, reduce number of software bugs by 70%, and enable teams to produce 42% more code compared to the ones that didn't use HIL.

Here are six key drivers for rapid adoption of HIL testing for variable frequency drives:

Control software is becoming a key value generator

1

Today motor drives are undergoing similar transformation the cars have undergone over the past decade; they have become literally "supercomputers" on wheels. During that time the complexity of automotive software have increased more than 10 times.

Traditionally, motor drive controllers comprised a fast controller (cascaded type comprising modulator and current/torque/speed/position loops), and a fieldbus communication unit; both implemented on a bare metal DSP processor or similar.

Today, in addition to inner control loops, drives controller consists of: Industrial Ethernet (IE) and wireless communication; drives diagnostic, fault detection and isolation, data analytics, machine learning, and safety subsystems. Furthermore, software is most often distributed between one or more CPUs running a real-time operating system and an FPGA-heterogeneous computational platform.

For manufacturers new software functionality is an opportunity for product differentiation and new value generation without the need for long hardware design cycles-thus maximizing Return on Investment (ROI).

Yet focus on control software requires more disciplined model based design and testing processes. Indeed, model based HIL testing brings much needed capability to: develop and maintain larger code size, shorten time to market, deliver better quality product, survive and thrive with smaller development and testing teams.

Need for new control algorithm developments

2

Although control of motor drives is considered a mature field, there is a constant push for new algorithm developments driven by:

- Support for new types of electric motors
- Deployment of new computationally demanding control algorithms (e.g. Model Predictive Control (MPC) etc.)
- Better fault detection, fault isolation, and runtime adaptation
- New semiconductor switches (e.g. wide-bandgap SiC and GaN devices) w/ faster switching capability
- New or existing topologies that better leverage semiconductor features.

Driven by new applications and fueled by advanced Finite Element Analysis (FEA) software tools, such as JMAG FEA, new and enhanced electric motor designs are constantly developed. These new motor designs require new and improved control algorithms that need to be supported by VFD control software. Indeed, VFD need to support advanced control of all existing motor types and designs and the new ones.

Faster embedded processors enable executing more complex, faster, and more demanding control algorithms including fault detection and isolation algorithms that were not computationally feasible until recently.

Wide-bandgap devices can operate at much higher switching frequencies and require different control strategies including faster execution rates. Also, for example multilevel topologies when used with wide-bandgap or silicon devices can deliver improved efficiency, performance, and smaller size and volume.

3 System level interoperability requirements

While typical high-performance motor drive controller today has around 200,000 standard lines of code (SLOC)—which is a little bit more than software size of a typical pacemaker or approximately one half of the Space Shuttle's control software size—most VFD's need to: operate networked with 10's or 100's of drives (from the same or different manufacturers) and sensors; to interface with process level controllers; and to communicate with cloud applications without a glitch. (Today most prevalent communication standards are Industrial Ethernet (IE) protocols that provide determinism and control, such as: EtherCAT, EtherNet/IP, PROFINET, Powerlink, Modbus TCP etc.)

These industrial networks with 100s of drives and sensors and process controllers easily exceeds the total control code size of ~20M SLOC's that becomes comparable to the Boeing 787 control software size.

This control code complexity, especially considering cybersecurity requirements, demands fully automated model based control software testing and verification processes. Hence the use of C-HIL becomes paramount to guarantee product quality and seamless interoperability, while managing cost and complexity.

4 Modular power converter design

Most VFD's are designed in modular fashion in order to cover wider range of power levels and performance requirements. Often, input stage can be configured using either passive front end or active front end modules. Output power levels can be acheived by paralleling a number of modules. DC link capacitor bank can be flexibly configured depending on the application. Similarly, inverter modules can be paralleled to increase the output power level.

VFD controller has to guarantee seamless operation for any given drive configuration and to ensure stability and performance for all electric motor types and all load types under any operating condition.

Testing controller software for all configurations and under all operating conditions (including faults) can only be done efficiently using test automation coupled with C-HIL real-time simulation approach.

5 Grid code compliance

Today's MV and HV drives have to meet more stringent power quality and grid codes: current/voltage distortion, power factor, flicker control, power quality and grid fault performance.

Testing against different grid codes that are constantly evolving can be a daunting and expensive quality assurance task unless testing is automated with model based HIL approach.

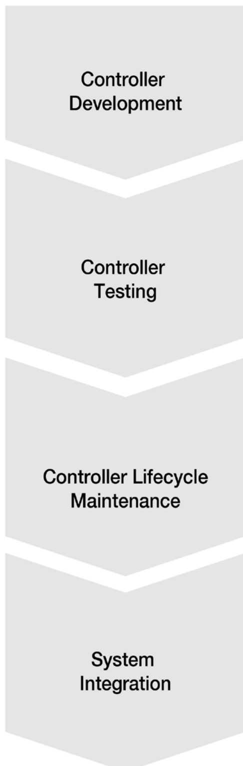

Fig. 1 - V-curve model development process for motor drive

Control software lifecycle maintenance complexity

6

Drives manufacturers today are facing a massive challenge to manage:

- Growing control code complexity.
- Expanding variety of products and product lines.
- Management of all software/ firmware updates and upgrades across the lifecycle.
- Infrastructure for remote deployment of software and firmware updates.
- The need to contantly improve product quality.

At the same time drives manufacturers are being pressured to constantly reduce costs and achieve results with ever shrinking engineering teams and ever shorter.

These orthogonal requirements can only be met adopting disciplined model based design and model based testing development and lifecycle maintenance processes and tools.

From functional and performance testing all the way to fault testing.

Functional testing.	Interoperability testing.	Grid disturbance testing.	Protection testing.	Fault injection testing.	Performance testing.
Operational modes verification Acceleration mode Braking mode Steady state Parking. Static motor parameter identification Dynamic motor parameters identification Fieldbus comms. interoperability	Fieldbus interoperability: Profinet, Ethernet / IP etc.	Phase loss Unbalanced grid Voltage dips Flicker Harmonics Weak grid conditions	Under voltage/over voltage Over current protection Over temperature protection	Motor faulrs Inter winding short Winding open circuit Winding to ground short DC link short circuit	Load profiles Load mechanical inertia Load mechanical faults

Controller Hardware in the Loop (C-HIL) Testing of control software.