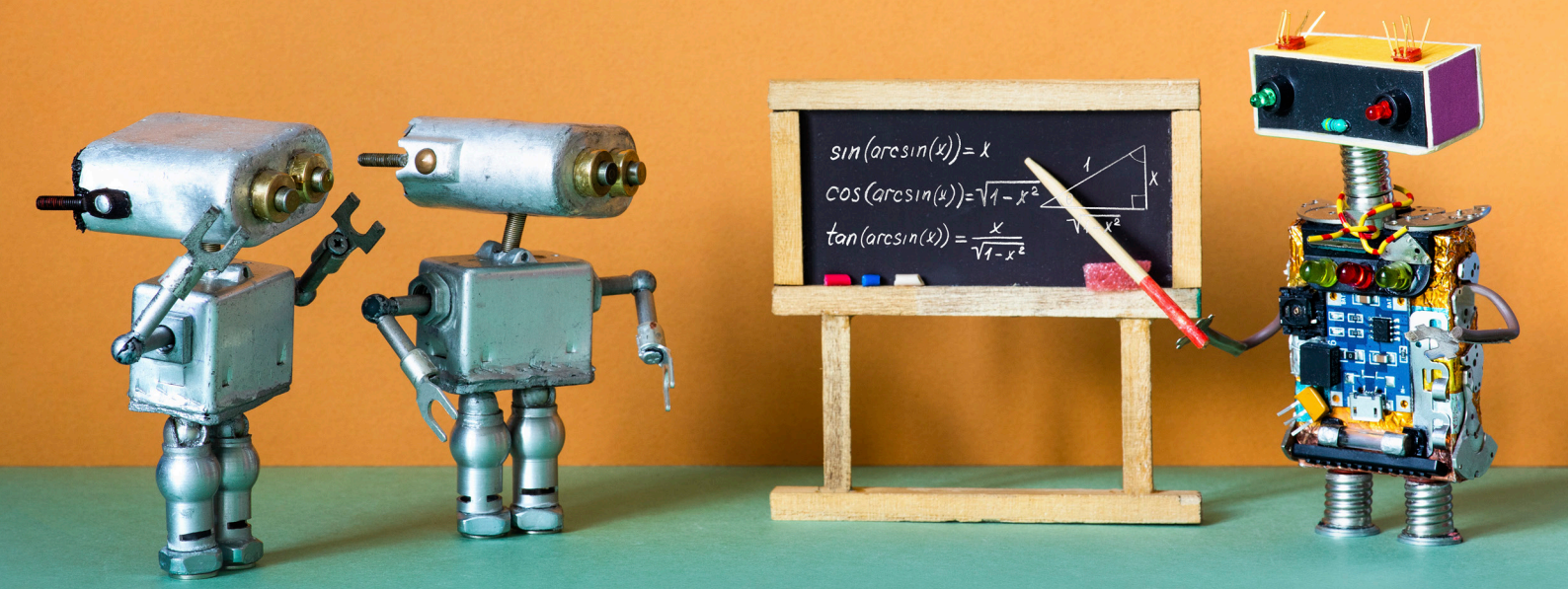
A JOURNEY THROUGH TESTING



Manish Verma and Jay Park, TMEIC, USA, consider the types of testing available for large electric motors and VFD-driven compressors.

You have been tasked to bring a large (>2000 hp) medium voltage electric motor and variable frequency driven compressor (>2.3 kV) or pump into service. The equipment is a critical path for the petrochemical plant. Start-up issues could mean hundreds of thousands of dollars of lost production and delay. The project calls for the equipment to be pre-tested before delivery and site installation, but pre-testing could cause delays. Is it necessary? Where do you start?

Project managers, specifying engineers, discipline experts, and compressor/pump manufacturers in the LNG industry must often manage risk vs costs when designing, specifying, installing, and commissioning a multi-megawatt motor and VFD-driven service. A large LNG refrigeration train for compressing natural gas to 1/600th of its initial volume is a good example. The LNG must be compressed to economically transport the gas, and downtime is costly. One train can cost several million dollars and directly impacts production to the tune of several hundred thousand dollars per day.

Equipment testing provides an opportunity to reduce the risk of start-up issues at the installation site. Since electric motors and

VFDs have made in-roads in the last 20 - 25 years where the incumbent prime mover would have been a gas turbine, a good grasp of the various electric motor and VFD testing terminology and types is necessary.

What is acceptance testing?

Acceptance testing, commonly known as factory acceptance tests (FAT), is a series of tests performed by the equipment supplier at site, and is the last documentation before hand over. FATs demonstrate that the supplier meets all of the contractual agreements, including the latest drawings, data sheets, project specifications, and any deviations that have been approved by the end-user or their representative. It is the equipment supplier's responsibility to perform these tests, record the test data, and issue a final test report to the equipment purchaser. FATs are usually witnessed by the end-user, or their representative at the equipment supplier's facility, or a third-party test stand, and are executed before the final installation at the site. In limited cases, the equipment supplier will perform the tests without a witness. An FAT is not to be confused with site acceptance testing (SAT), which includes all the previous steps but is conducted at the final site installation. The testing requirements must be defined at the purchase order stage of the equipment procurement cycle and not after.

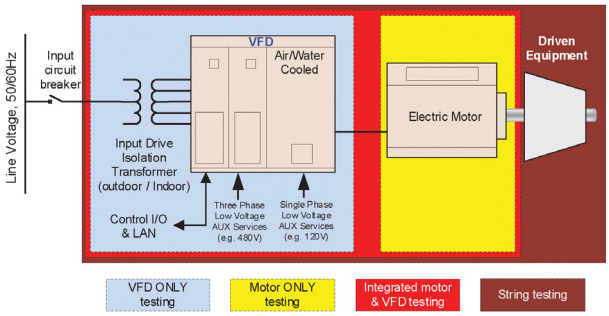


Figure 1. Typical large VFD and motor configuration. © 2017 IEEE. Reprinted with permission.[1]

Table 1. Typical large VFD functional witness test checklist

Physical inspection
Review VFD elementary and outline drawings.
Verify mechanical dimensions.
Identify major VFD components such as converter, inverter, transformer, switchgear (if supplied), blower fans, and others.
Verify VFD nameplate information.
Identify and verify the location of input and output cable terminations.
Verify location of grounding provision.
Verify whether free-issued parts properly located/mounted.
Identify low voltage and control I/O interconnects.
VFD functional testing
Verify operation of incoming switchgear (if applicable).
Verify operation of pilot devices, switches, knobs, and IEDs.
Verify operation of electrical and mechanical interlocks.
Verify operation of blower fans and space heaters (if applicable).
Verify start/stop operation of ASD with unloaded motor.
Verify VFD E-stop sequence.
Verify 4 - 20 mA speed control input.
Verify proper motor rotation.
Verify VFD reset after fault clearing.
Verify of water-cooling pump control (if applicable).
© 2017 IEEE. Reprinted with permission.[1]

Major areas of acceptance testing

Figure 1 shows an electrical illustration of a typical medium voltage motor and VFD-driven compressor. As shown, there are four major types of testing.

VFD-only tests include the main power conversion circuit, associated auxiliary equipment such as a field exciter, and, in specific cases, the drive isolation transformer – where the transformer is integral to the VFD line-up, or the end-user requests the drive isolation transformer to be included as part of the test for certain VFD topologies. VFD-only testing can be further divided into the following set of witnessed and unwitnessed tests, as shown in Figure 2.

Prototype test

Also known as type test, it is undertaken by the VFD manufacturer before a new VFD product line-up is introduced to the market. This is a rigorous test that validates the design, safety, and performance of the drive. Testing to certify the drive to a regulatory body – such as UL, CSA, IEC, etc. – is also carried out at this stage in the presence of appropriate inspectors. Usually, prototype testing, once completed, is not performed again unless the VFD undergoes a major electrical or mechanical design modification. This is an unwitnessed test and is internal to the manufacturer. Application data such as line-side harmonic spectrum; voltage and current THD (line-side and load-side); motor torque ripple; voltage/current waveforms; energisation in-rush current; efficiency; power factor; noise level; and temperature rise are established at this stage.

Major VFD component test

Depending on the type of VFD, the major components in the design are the drive isolation transformer; power semiconductor devices (diode, IGBT, SCR, SGCT, IEGT, GTO, etc.); DC link capacitor or reactor; power inverter modules; printed circuit boards; and incoming switchgear (if integral to the VFD). These components are tested individually by their respective manufacturers or the VFD vendor. These tests are also unwitnessed. However, test reports of all individual components that form the basis of the VFD's construction can be provided to the end-user. For VFD topologies with an incoming drive isolation transformer, any heat run test requirements on the transformer should be clearly identified as a requirement in the VFD specification.

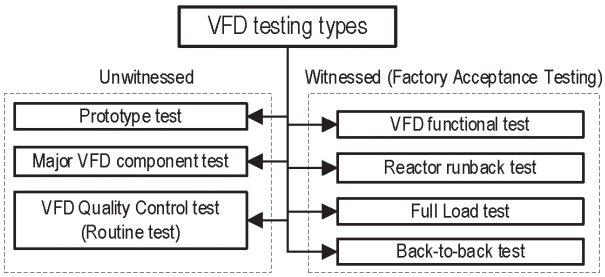


Figure 2. Types of large VFD testing types. © 2017 IEEE. Reprinted with permission.[1]

Table 2. Comparison of routine test items and measurements by NEMA and API standards

NEMA MG-1 Sec 20.16.2	API 541 Sec 6.3.2
No load current	No load current
No load power	Locked rotor current by calculation
No load speed	AC high pot test winding and accessories
High potential test	Insulation resistance
Winding resistance	Winding resistance
None	Vibration
None	Bearing insulation
None	Bearing temperature test
None	Inspection of oil and oil supply
None	Bearing journal clearance and alignment pre-test (optional)
None	Post testing inspection of bearing and journal clearance (optional)
None	Measurement of machine air gap
None	Shaft voltage and current measurements

© 2017 IEEE. Reprinted with permission.[1]

Table 3. Comparison of typical complete test and API complete test

Typical complete test	API 541 Sec: 6.3.5.1
Efficiency	Efficiency
None	Power factor
Locked rotor current	Locked rotor current
Full load current and slip	Full load current and slip
Determine the breakdown torque	Determine the breakdown torque
None	Determine speed torque curve
None	Noise level

© 2017 IEEE. Reprinted with permission.[1]

Under normal cases, it is recommended to request a component test report of the drive isolation transformer.

VFD quality control/Routine test

These tests are undertaken on production VFDs and before they are shipped out. In the event the purchaser plans to come to the factory to witness the test, the routine test is undertaken prior to the customer's arrival. High level items in routine tests include visual inspection; wire continuity; insulation resistance and withstand test; control power; I/O test; adjustment of voltage and current detection; E-stop sequence; transformer ratio test; power supply failure detection; and several items as indicated in Table 1.

VFD functional test

The VFD functional test is usually the test referred to when an end-user requests an FAT. The functional test demonstrates to the client that the VFD is designed as per the mechanical and electrical specifications. Table 1 shows a list of items that are typically performed during a functional witness test. For air-cooled drives, a functional test will last approximately one day and for water-cooled drives, approximately two days. Note that a functional witness test is not to be confused with a full load test.

Reactor runback test

This test is considered as a full load test where the VFD is operated at rated voltage and rated current. The reactor acts as a load to the VFD. It is called a runback test because the power is recirculated through the reactor back into the VFD, hence minimising the power demand from the grid during testing. Figure 3 shows an electrical illustration of a reactor runback test.

Full load test/Back-to-back test

As the name suggests, a full load test is carried out with the project VFD and motor running at near rated conditions. A back-to-back test is like a full load test; however, this testing terminology is usually applied when two active front end drives are tested together that can recirculate current among themselves. Regenerative drives such as LCIs or active front end voltage source inverter (VSI) drives can be tested in a back-to-back arrangement. VSI drives with a diode front end converter are tested using a runback reactor or a representative or project motor connected to a generator.

Motor only test

An FAT for the motor is the minimum requirement, and all motors must pass full tests before delivery to the customer. The term FAT is used by the manufacturer rather than the end-user or purchaser. Electric motor tests can be witnessed, unwitnessed, or observed depending on if the purchaser's preference includes 'in-process' test items.

FAT items can be defined as 'routine' or 'complete' in standards such as NEMA MG-1, IEEE 112, and the IEC 60034. A routine test is the minimum and mandatory tests which are performed by the motor manufacturer on every motor. However, the basic scope of a routine test can be significantly different depending on the motor design standard. Table 2 compares the routine test items between NEMA MG-1 and API 541 5th edition standard.

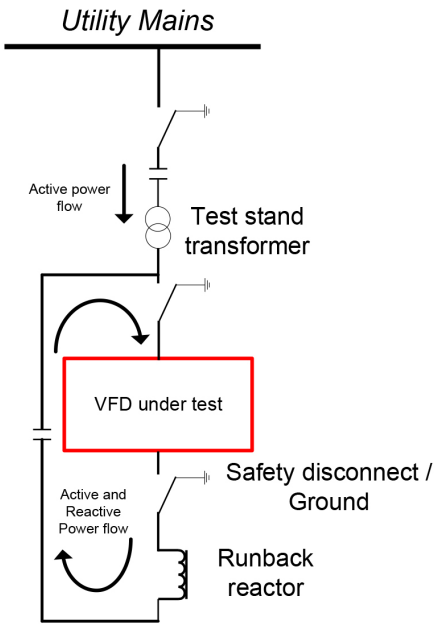


Figure 3. Runback reactor test set-up. © 2017 IEEE. Reprinted with permission.[1]

Table 2 shows that routine test items can be substantially different, depending on which one of the standards is applied to the motor. Therefore, it is crucial that the scope of testing be clearly defined and agreed upon before the PO acceptance.

The complete test is a very common part of FAT to be witnessed. The definition of a complete test is defined in API 541 5th ed., sec 6.3.5.1 as seven additional tests to the routine test list. NEMA MG1 does not have a 'complete' test definition. A routine test will be performed for all motors, but complete tests will be typically performed on one motor per type, thus the complete test is also known as a type test. Table 3 shows the comparison between a typical complete test and API 541 specified complete test.

Also, the API 541 standard specifies 'special tests' when requested by the end-user or purchaser. API 541 or 546 standards are effective guides to understand terminology, acceptance criteria, why the test is carried out, and the impact that a test will have on the life of the motor. Understanding which test may be harmful to the motor should be part of the preparation. A technician may want to rerun a test, which should be carefully considered if the test can reduce the life of the motor.

The IEEE 112 standard is a test procedure that describes motor efficiency testing. The method F is common for very large motors. It also describes most other common poly-phase motor tests. For testing large motors, NEMA MG1 Sec. 20.16.1 specifically indicates that testing is undertaken per IEEE 112.

The IEC 60034 and all of its parts is similar to NEMA MG1. IEC 60034-2 is an efficiency testing standard in which IEEE has published many papers on the comparison of the different methods. For the purpose of this article, the efficiency standard should be defined at the time of the contract, and the witnessing engineer should be familiar with the procedure and acceptance criteria.

Conclusion

Testing a medium voltage electric motor and VFD-driven compressor or pump is a critical step in starting up a petrochemical facility such as an LNG terminal. Often there is confusion, misalignment of expectations, and, in many cases, lack of knowledge of the terminology used in the world for electric equipment testing. While this article provides a basic understanding of the different kinds of tests available for a large (medium voltage) VFD and motor, it is recommended to visit the scholarly papers referenced below to learn more about the subject. LNG

Bibliography

- VERMA, M., GRINBAUM, I., ARNOLD, J., and NANNEY, J., 'Preparing to witness a multimegawatt motor and adjustable speed drive acceptance test – The basics,' *IEEE Transactions on Industry Applications,* Vol. 54, No. 1 (2018), pp. 873-882.
- BOGH, D.L., DUNN, D.G., STRANGES, M.K.W., and STRANGES, N., 'A user's guide to factory testing of large motors: What should your witness expect?,' 2009 Record of Conference Papers - Industry Applications Society 56th Annual Petroleum and Chemical Industry Conference, Anaheim, CA, (2009), pp. 1-8.

Note

Certain sections of this article were published in *IEEE Transactions on Industry Applications,* Vol. 54, No. 1 (Jan-Feb 2018), pp. 873-882,, doi: 10.1109/TIA.2017.2742466. Reprinted with permission.