TESTING LARGE ASDS

Paper No. PCIC-2012-48

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Abstract – Driving compressors and pumps by means of large Adjustable Speed Drive Systems (ASDS) is increasing in oil and gas applications, specifically for gas/oil transportation, gas liquefaction and gas injection/lift. The importance of the ASDS availability for the plant operability calls for extensive factory testing to uncover any possible hidden weakness of components and system design issues before delivery at site. The complete ASDS line-up shall be full load tested before string test with the compressor/pump to prove system electrical performances, protections and control functionalities.

The article focuses on procedures, recommendations and experiences on testing Large Adjustable Speed Drive Systems (ASDS) and it goes through technical challenges to be faced when testing this large equipment. Foundation design, rotor dynamic analysis, but also measurement strategies for distorted load and efficiency calculation are part of the content of this article.

Typical testing requirements in accordance to international standards and oil & gas plant specifications are also discussed in terms of practical solutions to be adopted during tests, feasibility basing on ASDS power rating and need for simulations.

Real cases testing results and method are also treated in order to give handy information

Index Terms — ASDS, IEC 61800-4, IEEE 1566, Drive System Test

I. INTRODUCTION

The paper aims at describing the challenges of testing high power adjustable speed drive systems (ASDS): measurement of power when voltage and current are distorted, efficiency determination and coupling selection. Differences between IEC standards, IEEE standards and major purchaser specifications are analyzed.

An Adjustable Speed Drive System (ASDS) is a system typically made of: input converter transformer, frequency converter, motor, system control and protection and in addition any needed harmonic filters and cooling systems. In oil and gas applications the use of ASDS is continuously increasing and covers all power ranges from few megawatt to tens of megawatt. Two main different ASDS topologies are used in the market: Voltage Source Inverter (VSI) and Load Commutated Inverters (LCI), which may require a different testing approach.

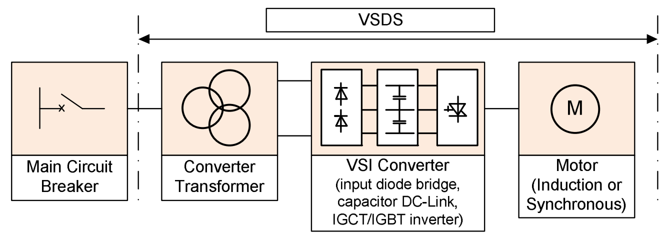

Figure 1: Typical VSI ASDS scheme

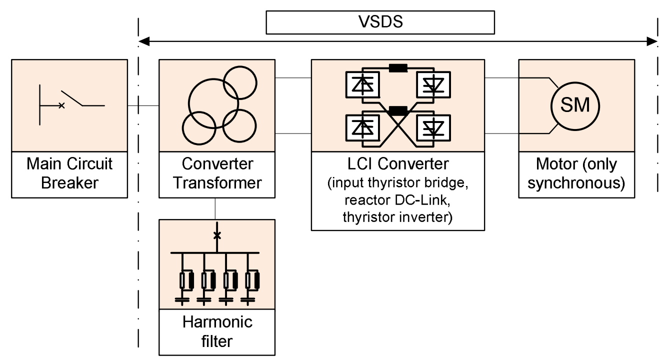

Figure 2: Typical LCI ASDS scheme

Such high power equipment represents a key component for all oil & gas plants since they drive the main loads: pumps and compressors. Because of this, a thorough testing session shall be preferably held before delivery at site in order to:

- Verify that the system design and integration have been properly done;
- Ensure that the required performances are met;
- Check that the protection devices and setting work effectively;
- Test rated ASDS rated power and any overloads the system is design for;
- Run the temperature rise tests with the actual distorted currents;
- Evaluate system efficiency (full load system test is the only way to obtain the real losses of the system, and it is also the only way to measure the real temperature rises before commissioning [1])

II. TYPICAL TEST SET UP AND MAJOR CHALLENGES

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After the successful performance tests at manufacturer premises of individual ASDS components in accordance to the relevant international standards and project specifications, the ASDS shall be lined up for a complete test.

A. Test up

When dealing with power in the megawatt range, even above 15MW, the availability of a suitable load machine is not taken for granted. Depending on the ASDS topology (see Figure 1 and Figure 2), different concepts can be applied to run the equipment at the required load.

When LCI ASDS are used and the scope of supply includes at least two of them, a typical set up is the back to back test. Being the LCI ASDS intrinsically regenerative, the back to back test foresees the line-up of the two systems one against the other with one system operating as motor and the other as generator. As a remark, in case of uni-directional self-ventilated motors, the shaft mounted fans shall be installed in reverse way on the machine operated as generator in order to achieve proper cooling. After testing, the fans shall be mounted in the correct way and rotor balancing shall be rechecked.

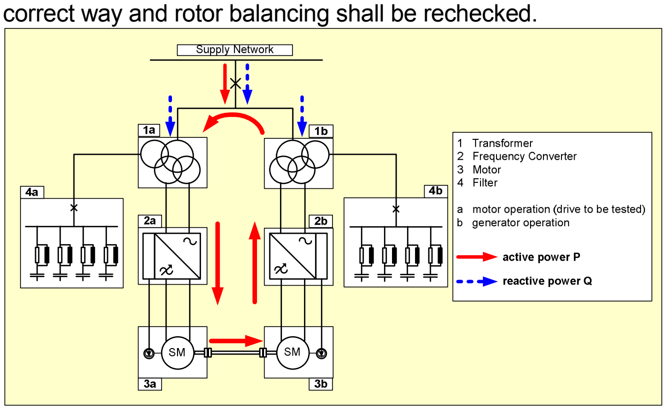


Figure 3: Back to back test typical set-up

However, when VSI ASDS are used, the back to back set up cannot be applied since VSI converters with input diode bridge are not regenerative.

In these conditions and in general in all cases when only one ASDS is part of the supply, a different approach needs to be followed. Due to the large power involved, the best strategy is to adopt a test bed concept based on the energy recirculation: it is necessary to have a regenerative load machine capable of braking the ASDS under test. Typically, the brake system may consist of a regenerative VSI ASDS, i.e a VSI converter having an active rectifier, which is also capable of generating reactive power. In this way, only the losses of the two systems shall be supplied by the test bed feeding network, since the reactive power adsorbed by the load machine can be compensated by the brake machine. This type of test can be referred as full load test.

Conceptually, this set up does not differ from the back to back. However, it shall be noted that in the back to back test the two ASDS shall be identical [1]; while in the full load test this is not a necessary condition.

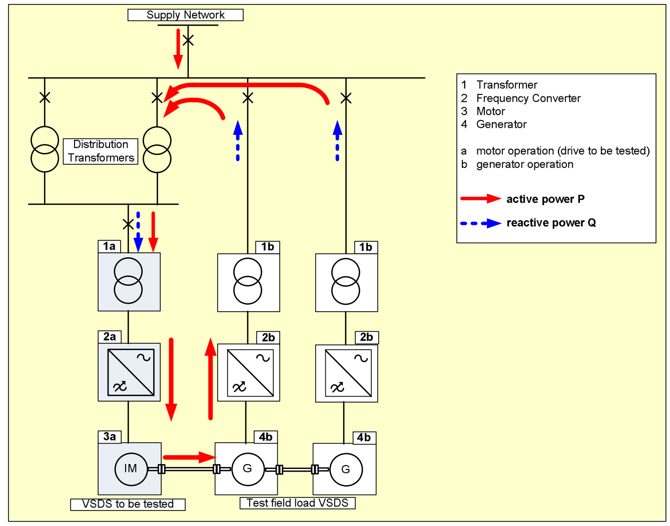


Figure 4: Full Load test set-up

In both configurations, major challenges to be solved are:

1. the availability of power to feed the test bed
2. the frequency matching between test bed network and ASDS input supply frequency design
3. the voltage matching between supplying network and converter transformer input voltage
4. speed matching between load machine and ASDS under test

With the energy recirculation set-up, item 1. can be easily mitigated. However, one important aspect shall still be considered: short circuit power. The short circuit power of the test bed certainly differs from the ASDS design one and installation site one. As such, harmonic distortion measurement shall be properly evaluated.

Item 2. can also be mitigated by properly designing the converter transformer. Transformers designed for 50Hz operation can be used with no adjustments also in 60Hz network for test purposes. However, 60Hz transformers will saturate should they be used on a 50Hz test network. In this case, the testing at 50Hz shall be taken into account during the design phase of the transformer in order to be able to run the test safely. It might be noted that test bed frequency and ASDS design frequency diversity has also an impact on harmonic filters, when part of the supply. In fact, filters designed for 60Hz operation when supplied at 50Hz will show a lower reactive power generation. As such, in order to keep the same reactive power compensation, additional filters may be needed during test. Moreover, the tuning frequency will remain a multiple of 60Hz, while it might be needed (for test bed supply network limitation) to tune them at a multiple of 50Hz. In this case, additional reactor tappings may be foreseen. The other way round will show up in case of 50Hz designed filters operated at 60Hz.

Challenge 3. may be very difficult to be compensated when working in the High Voltage Range (i.e. >52kV). However, in the range of voltage up to and including 34.5kV, a typical solution foresees the use of a two-winding distribution transformers having a split secondary winding and a suitable number of off-load tap changers at the primary winding. This way, the split winding can be properly configured (series, delta, star connections) to get the required supplying voltage and the primary tap can be used as fine tuning. For instance, a 23/34.5kV transformer may have the 34.5kV winding split in three parts. When these three parts are connected in series, the output voltage would be 34.5kV; when all single parts will be start connected and then paralleled the output would be 11.5kV while when these would be delta connected and then paralleled the output would be 6.6kV. By having +/-6x2.5% tap changers, the voltage can be then fine tuned. The output power at each voltage level will be limited to the rating current of the windings and the vector group may be expressed as: Y iii iii iii, whereas the “iii” represents an open winding that can be reclosed in the preferred way.

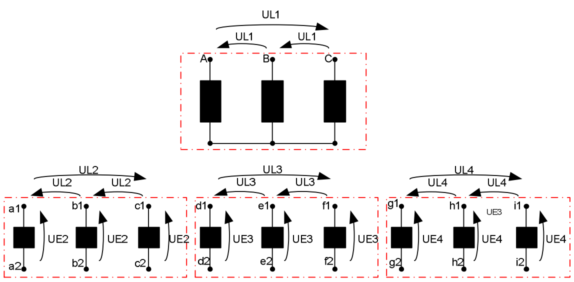


Figure 5: Special distribution transformer configuration

Finally, item 4. poses several challenges especially when operating in the high speed range (i.e above 3000rpm). A well designed load machine shall be capable at operating in constant torque from its rating point down to at least 100rpm and in constant power up to its maximum speed. Since for converter driven machines rated torque means also rated current, in order guarantee proper ventilation in case of operation at very low speeds and rated torque, the load machines shall be preferably servo-ventilated and have dedicated machine driven fans. When dealing with high speed ASDS and the load machine is not suitable to operate at that frequency, the only solution is to use suitable gearboxes. The same issue arises with very low speed motors used for reciprocating compressors where the torque peaks are dramatically high.

B. Measurements

Proper measurement strategy has to be adopted for measuring electrical variables in the case of a distorted load like frequency converter. Especially when Active Power needs to be calculated for efficiency evaluation, particular attention shall be given to the achieved measurements.

Active power is defined as:

$$P = \frac{1}{k \cdot T} \cdot \int_{\tau}^{\tau + k \cdot T} p \cdot dt$$

whereas *p* is the instantaneous power: $p = v \cdot i$

Voltage and currents in distorted environment can be expressed as:

$$v = v_1 + v_h$$

$$i = i_1 + i_h$$

where v_1 and i_1 are the voltage and current fundamental components, with V_1 and I_1 representing the fundamental voltage and current rms value and α_1 and β_1 the angular displacement compared to the reference, and their equation is:

$$v_1 = \sqrt{2} \cdot V_1 \cdot sin(\omega \cdot t - \alpha_1) \quad i_1 = \sqrt{2} \cdot I_1 \cdot sin(\omega \cdot t - \beta_1)$$

while v_h and i_h are the harmonic components, with V_h and I_h representing the harmonic voltage and current rms value; α_h and β_h the angular displacement compared to the reference and V_0 and I_0 the DC components:

$$v_h = V_0 + \sqrt{2} \cdot \sum_{h \neq 1} V_h \cdot sin(h \cdot \omega \cdot t - \alpha_h)$$

$$i_h = I_0 + \sqrt{2} \cdot \sum_{h \neq 1} I_h \cdot sin(h \cdot \omega \cdot t - \beta_h)$$

The instantaneous power is defined as:

$$p = v \cdot i = p_a + p_q$$

The first term

$$p_a = V_0 \cdot I_0 + \sum_{h} V_h \cdot I_h \cdot cos\vartheta_h \cdot [1 - cos(2h\omega t - 2\alpha_h)]$$

is the part of the instantaneous power that is equal to the sum of harmonic active powers. The harmonic active power of order *h* is caused by the harmonic voltage of order *h* and the component of the harmonic current of order *h* in-phase with the harmonic voltage of order *h*. Each instantaneous active power of order *h* has two terms: an active, or real, harmonic power $P_h = V_h \cdot I_h \cdot cos\vartheta_h$ and the intrinsic harmonic power $-P_h \cos(2h\omega t - 2\alpha_h)$, which does not contribute to net transfer of energy or to additional power loss in conductors. The angle $\vartheta_h = \beta_h - \alpha_h$ is the phase angle between the phasors V_h and I_h.

The second term p_q is a term that does not represent a net transfer of energy (i.e., its average value is nil); nevertheless, the current related to these non-active components causes additional power loss in conductors (instantaneous reactive power).

The active power results as the sum of two terms: P_1 and P_H, the fundamental active power and the harmonic active power respectively.

$$p = P_1 + P_h$$

whereas the fundamental active power expressed in [W] is:

$$P_1 = V_1 \cdot I_1 \cdot cos\vartheta_1$$

and the harmonic active power (non fundamental active power always expressed in[W]) is:

$$P_h = V_0 \cdot I_0 + \sum_{h \neq 1} V_h \cdot I_h \cdot cos\vartheta_h$$

For the electrical machine the harmonic active power is not a useful power (does not contribute to the positive sequence torque); consequently, it is meaningful to separate the fundamental active power P_1 from the harmonic active power P_h.

The measurement of P_h itself is not an effective way to evaluate harmonic power flow, because some harmonic orders may generate power while others dissipate power in the observed load, leading to mutual cancellation in the P_h term. Only a complete listing of the harmonic voltage and current phasors (magnitude and phase) can lead to a clear understanding of the contributions made by each harmonic to the electric energy flow.

Traditional power meters operate using simple algorithms which simply operates a product of voltage by current and does not consider their phase shifting at various frequencies. Differences in readings in the 20%÷30% range have been reported for kVA demand meters, solely due to different definitions that the meter manufacturers had implemented in their products [2].

Also the errors introduced by voltage and current transducer shall be considered. Traditional measurement devices such as inductive current transformers (CTs) and potential transformer (PTs) are not well suited for an accurate measurement in the case of distorted load [3].

IEEE 1459 [4] provides criteria for designing and using metering instrumentation when voltages and currents are distorted. All the above phenomena may lead to unreliable power calculations which, as a result, may be responsible for inconsistent efficiency values.

To achieve more accurate measurements linear transducers with wide bandwidth should be preferred. In the Figure 6 and Figure 7, an example of distorted current and voltage waveforms measured with linear transducers are shown. Rogowsky coils and capacitive-resistive dividers are used for current and voltage measurement respectively.

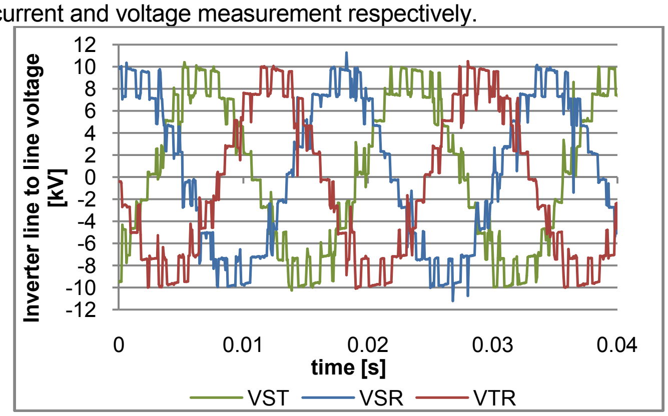


Figure 6: Inverter voltage measurement using capacitive-resistive dividers

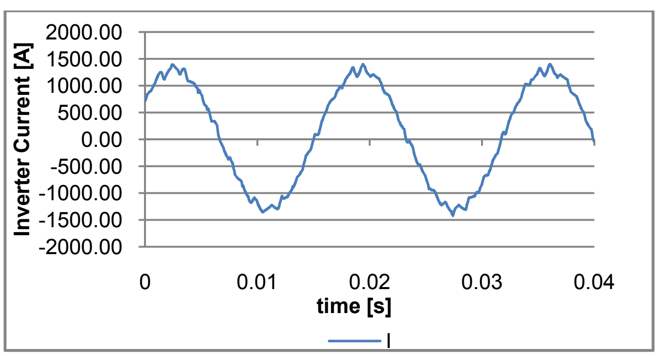


Figure 7: Inverter current waveform measurement using Rogowsky coil

Also, a reliable tool for the discrete Fourier analysis shall be available: the fundamental component of voltage and current and the relative displacement must be known to calculate the power that contributes to the positive sequence torque.

C. Efficiency determination

The system full load test allows the determination of the true losses of the system

Two categories of methods are applicable to follow this approach:

a) The determination of losses by direct measurement of the input and the output power. This method requires highly accurate measurements of the power in the input and the output sections of the system (or of each of its components, if required).

b) The direct measurement of losses. This measurement can be accomplished essentially by means of the calorimetric method.

By directly measuring the losses, method b) gives more accurate results, and is preferable in the case of systems characterized by high efficiency values.

The power adsorbed by the auxiliaries shall be or shall not be taken into account for the efficiency determination. If the auxiliary power is to be included in efficiency calculation, as indicated in [1], this shall be considered as system losses.

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{in} - \sum p}{P_{in}} = 1 - \frac{\sum p}{P_{in}}$$

where:

$$P_{in} = P + p_{aux}$$

$$\Sigma p = p_{trafo} + p_{filter} + p_{conv} + p_{mot} + p_{aux}$$

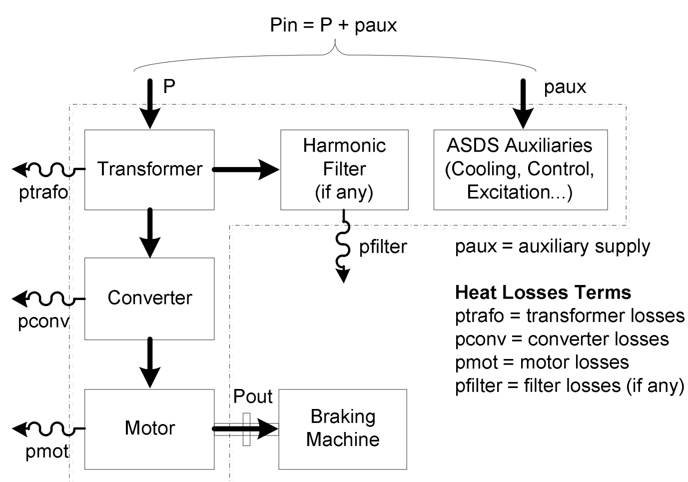


Figure 8: ASDS losses overview

Calculation method		method 1	method 2
p_{aux} included		*YES*	*NO*
P	[kW]	10 000	10 000
p_{aux}	[kW]	100	
P_{in}	[kW]	10 100	10 000
p_{trafo}	[kW]	50	50
p_{conv}	[kW]	100	100
p_{mot}	[kW]	300	300

p_{aux}	[kW]	100	
□p	[kW]	550	450
P_{out}	[kW]	9550	9550
efficiency	[%]	94.55	95.50

Table 1: Efficiency comparison with and without auxiliaries

D. Motor shaft power

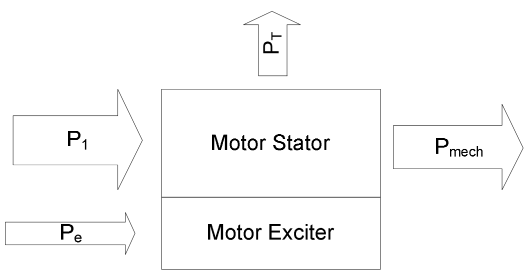
One of the most discussed issues is the determination of the motor shaft power of the machine under test: how to give the confidence that the machine is running at the rated shaft power?

When dealing with large machines, sometimes the direct measure of torque should not be available in the test field. In this case the calorimetric method or calibrated machine method should be used [5].

In the following example the calorimetric method for a 20MW shaft power water cooled synchronous machine is shown. The machine was fed by a 5 level VSI.

Motor shaft power is given by:

$$P_{mech} = P_M + P_E - P_T$$



Where:

P_{mech}	Motor Shaft Power
P_1	Motor Input Power (fundamental)
P_e	Input Excitation Power
P_T	Motor Losses

- The input motor power (P_1) and the excitation power (P_E) adsorbed by the machine is measured by means of voltage and current transducers.
- The motor losses (P_T) are measured by means of calorimetric method ([8], clause 7.3).

$$P_T = P_{irs} + P_{ers}$$

The calorimetric losses of the machine under test consist of:

- losses inside the reference surface P_{irs},
- losses outside the reference surface P_{ers},

The "reference surface" is a surface completely surrounding the machine such that all losses produced inside it (P_{irs}), and not measured calorimetrically, are dissipated through it to the outside.

The loss inside the reference surface P_{irs} is determined as:

$$P_{irs} = P_{irs,1} + P_{irs,2}$$

$P_{irs,1}$ is the loss dissipated into the cooling water:

$$P_{irs,1} = c_{pw} \cdot Q_w \cdot \rho_w \cdot \Delta\theta_w$$

where:

Q_w	is the volume flow rate of the cooling water (m^3/s)
$\Delta\theta_w$	is the temperature rise of the cooling water (K)
c_{pw}	is the specific heat capacity of the cooling water in kJ/(kg·K)
ρ_w	is the density of cooling water in kg/m3 at the temperature at the point of flow measurement

$P_{irs,2}$ is the loss dissipated through the "reference surface" by convection:

$$P_{irs,2} = h \cdot A \cdot \Delta\theta_s$$

where:

$\Delta\theta_t$	is the temperature difference between the average reference surface temperature and the ambient-air temperature (K)
h	is the heat transfer coefficient, clause 7.3.4.3 of [8] refer to 10 ÷ 20 W/(m^2·K)
A	is the area of the reference surface (m^2)

P_{ers} is the losses by friction into the bearings

$$P_{ers} = c_{poil} \cdot Q_{oil} \cdot \rho_{oil} \cdot \Delta\theta_{oil}$$

Where:

Q_{oil}	is the volume flow rate of the lube oil (m^3/s)
$\Delta\theta_{oil}$	is the temperature rise of the lube oil (K)
c_{poil}	is the specific heat capacity of the lube oil (kJ/(kg·K)
ρ_{oil}	is the density of lube oil in kg/m^3 at the temperature at the point of flow measurement

Motor losses calculated according to calorimetric method are listed in Table 2.

Lube-oil flow rate, Q_{oil}	[l/min]	34.30
Lube oil inlet temperature	[°C]	42.50
Lube oil outlet temperature	[°C]	63.00
Specific heat capacity of lube oil, C_{poil}	[kJ/(kg·K]	2.00
Density of Lube Oil, ρ_{oil}	[kg/m3]	855.00
P_{ers}	[kW]	20.04
Cooling water flow rate, Q_w	[m3/h]	61.00
Water inlet temperature	[°C]	20.00
Water oil outlet temperature	[°C]	24.50
Specific heat capacity of water, C_{pw}	[kJ/(kg·K]	4.18
Water Density, ρ_w	[kg/m3]	995.80
$P_{irs,1}$	[kW]	317.23
Motor surface Area, A	[m2]	41.50
Heat transfer coefficient, h	[W/m2 K]	12.00
Ambient Temperature Average	[°C]	18.00
Surface Temperature Average	[°C]	36.00
$P_{irs,2}$	[kW]	8.96
Total Motor Losses	[kW]	346.24
Power adsorbed by the Motor, P_1+P_e	[kW]	20554.39
Motor shaft Power, P_{mech}	[kW]	20208.15
Motor efficiency	[%]	0.98

Table 2: Total Motor Losses

E. Foundation design and Vibration measurement

Special care has been taken to design the foundation for the rotating machines.

The foundation shall be designed in order to ensure a rigid mounting for the rotating machine (IEC 60034-14)

A Finite Element (FE) model of the foundation resting on the Winkler spring bed was set up to compute flexible eigenvalues and eigenvectors (Figure 9 shows the flexible mode 18).

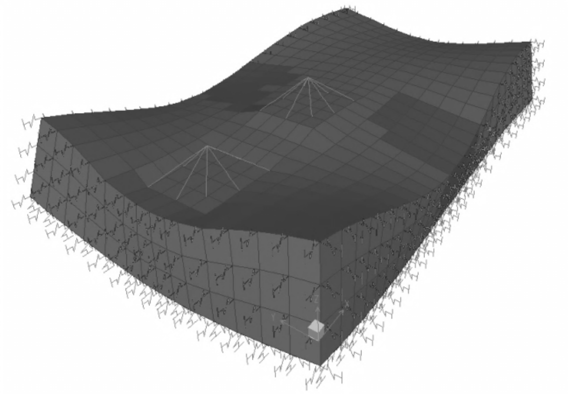


Figure 9 FE Model of Foundation

Since flexible modes can be excited by unbalance force, a dynamic analysis was carried out with the FE model to evaluate the foundation vibration at the motor fixing point.

Tests at sinusoidal supply normally only confirm mechanically induced vibrations. It is possible that electrically induced vibrations will be different. To have complete vibration test results, it is necessary to test the motor together with the converter that will be installed with the motor in-situ [6]. Full load testing represents the best way to have additional information regarding ASDS motor mechanical performance. In fact, other important oil & gas standards such as API546 [7] and 541 [8] require that the vibration limits for motors driven by ASDS are the same as for fixed speed units. The limits shall be met at all supply frequencies in the operating speed range.

F. Rotor dynamic analysis and pulsating torque in the air gap

Care should be considered when designing the coupling of the machine under test and the braking machine (either in the back to back test set up or full load test set up).

The coupling between the motor and brake shall be designed in order to withstand short circuit torques and to avoid possible resonances due to the pulsating torque in the air gap of the rotating machines generated by the converter operation

The shaft line of the back to back test of synchronous machines (18MW shaft power) is shown in Figure 10

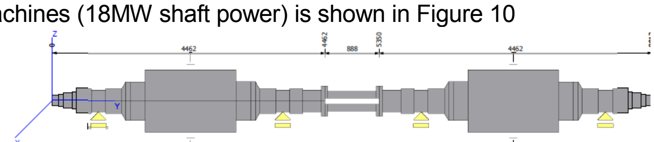


Figure 10 – back to back shafting

The power converter driven machines are subject to pulsating torque in the air gap. For example, in case of LCI ASDS, the spectrum of those torques are shown in Figure 11 (the figures refer to a Load Commutated Inverter 12/12 pulse)

The pulsating torque components are due to the current harmonics which are impressed on the motor by the converters. These pulsating torque components can be classified as follows (f_M = motor frequency; f_N = line frequency):

- integer pulsating torques with the frequencies $n \cdot f_M$, (n = 6, 12, 18, 24)
- non-integer pulsating torques with the frequencies $k \cdot f_N$ (k= 6, 12)
- non-integer pulsating torques depending on both the network frequency and the motor frequency according to: $f = |n \cdot f_M \pm k \cdot f_N|$ (n = 6,16; k = 6, 12).

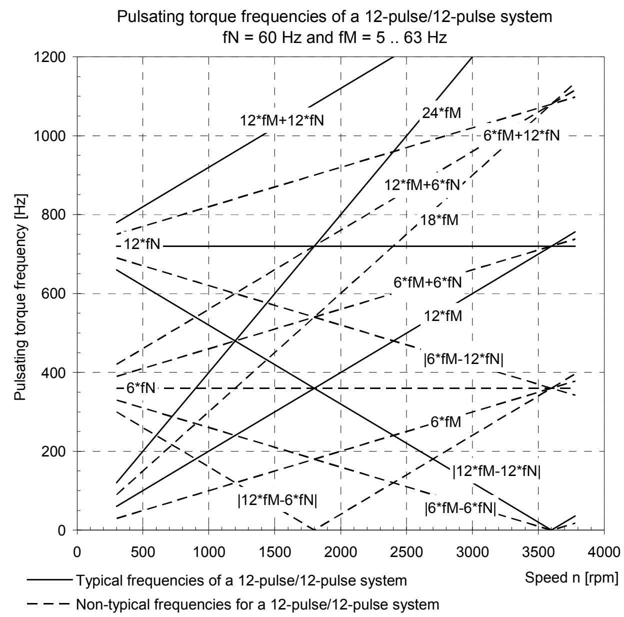


Figure 11 – Pulsating Torque Frequencies

Although the amplitudes of the pulsating torque are small compared to the driving torque, they can excite resonances when their frequencies coincide with a natural frequency (modes) of the shafting.

The coupling shall be designed in order to guarantee a separation margin between the intersections (resonances) of the inclined lines and the modes.

G. Fault test

Fault test should be performed in order to give the confidence that the system protection features works properly. Typical fault conditions include earth fault protection test, phase loss test, ride-through function verification, auxiliary power loss, reference signal loss.

Due to the large power involved, some of these tests are preferably done at no load conditions and in some cases are simulated.

Earth fault test is one of the most important test to be carried out during ASDS testing since it may represent one of the most difficult to be detected on site. Typically, the ADSD earth fault protection embedded in the frequency converter control system covers any fault between the transformer secondaries and the motor winding. One way to perform such test is to ground one motor/transformer phase via a dedicated grounding switch during the no-load operation.

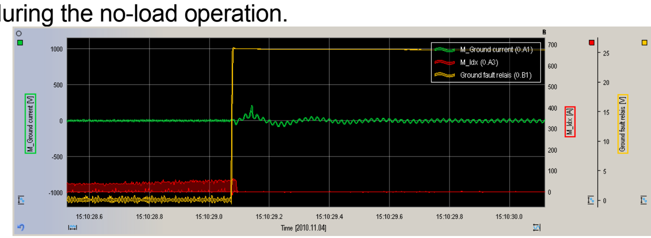


Figure 12: Earth Fault testing (LCI ASDS))

Another very important testing is the capability of the ASDS to ride through voltage dips. This test is very difficult to be effectively realized since it is impossible to easily recreate a voltage dip in a medium voltage network. However, at least two different methodologies may be used to run this test. The first option foresees the simulation of the voltage dip by acting on the ASDS undervoltage protection function setting: if this threshold is set well above the 100% voltage (i.e. 120%), any input voltage level will be seen as an intervention level and therefore the ASDS will start the ride-through function. By resetting the threshold to its original value, the ASDS will then drive the motor to its original setpoint. The second option foresees instead the intervention over an upstream circuit breaker, different from the one dedicated to the ASDS. Generally, the main circuit breaker dedicated to the ASDS shall be exclusively closed by the ASDS itself due to the need of DC-Link capacitor charging for VSI ASDS. If an upstream circuit breaker is available at the test bed, this can be open and closed in order to recreate a voltage loss condition.

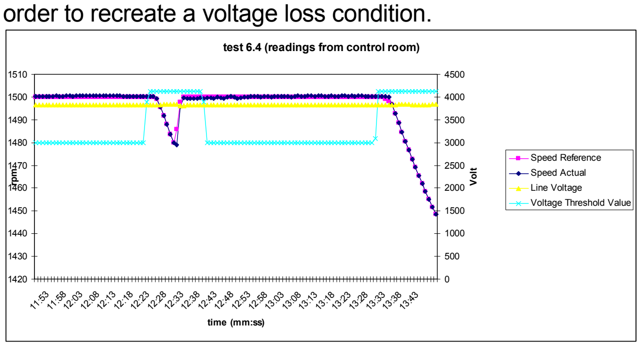


Figure 13: Voltage Dip Testing of an LCI ASDS, done with option one (simulation)

Other testing can be instead easily done. For instance, the loss of reference signal can be performed by short circuiting the 4-20mA signal; the low voltage auxiliary loss may be executed by opening the supply low voltage circuit breaker.

Finally, phase loss tests and short circuit tests may also be performed but these require the use of additional circuit breakers and medium voltage switchgears in order to execute these safely. Generally, phase loss tests can be executed by inserting in series of the supply cable a circuit breaker. These tests don't generally turn into dangerous transients. Instead, as far as short circuit tests are concerned, sometime these are requested to be performed on motor side and as such attention shall be paid not only on the electrical part but also and especially on the mechanical part, especially if performed at full load: the coupling shall withstand the short circuit torque or special fail safe coupling shall be used in order to avoid issues on the load machine.

H. Standard comparison

In Attachment A,

Table 3, the tests requested by IEC61800-4, IEEE1566 [9] and by a typical oil and gas specification are summarized and aligned basing on the similarity of test purpose.

When comparing IEC and IEEE, a first glance at the number of required tests may lead to the conclusion that IEEE specification is somewhat lighter than IEC one. However, by carefully looking at the specified tests, it pops up that IEEE strongly focuses on demonstrating the peculiar ASDS performances such as efficiency, vibrations, speed accuracy and protection devices. These are the key characteristic of this equipment.

IEC testing procedure if on one hand is aligned to IEEE one, on the other hand adds other important punch items such as power factor and EMC measurement as well as auxiliary devices checking. Especially when dealing with large ASDS, power factor line side and EMC compliance (intended as conformity to IEC 61800-3 standard in terms of THD compliance) is very important for plant operability.

Moreover, IEC requires the measurement of torque pulsation. This measurement be performed by means of devices that uses exclusively the acquisition of the stator currents and voltages and computes the electromagnetic torque with the help of the Park transformation. This method eliminates mechanical measuring shafts which lead to some advantages. No costly mechanical insert has to be made and a use for a wide range of alternating machines, regardless of their speed range, size and supply waveforms is provided. Most of all the transient torques are visible. A graphical analysis of the instantaneous torque versus time indicates the stress of bearings and windings [10].

When finally looking at the typical oil&gas specification, it appears that both standards are taken into account. The testing schedule is pretty demanding because in addition some functional and fault tests are included in order to prior demonstrate the ASDS performance under abnormal conditions that may occur at site. As final request, the oil&gas specification reserves a paragraph for the visual Inspection of the ASDS components, in line with strict quality requirements of oil & gas industry.

III. CONCLUSIONS

In this paper the major challenges of testing a large ADSD have been addressed.

Testing the system before delivery at site is the way forward to ensure that the system performances are met (e.g.: true losses, efficiency and actual temperature rise).

How to carry out the system test depends on the Drive topology (e.g. VSI, LCI), the standards define the guidelines and the scope of testing, but every time is important to define in a proper test procedure the list of the test to be carry out for a specific job.

Special care has to be taken checking the protection devices: these tests shall be carried out without stressing the components above their rated value.

Another important topic is the measurement devices for distorted voltage and current.

The main points have been explained, the reference list for deepen of specific topic has been presented and practical examples has been illustrated.

IV. REFERENCES

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ATTACHMENT A

TEST REQUIREMENTS IN INTERNATIONAL AND OIL AND GAS STANDARDS COMPARISON TABLE

IEC 61800-4	IEEE 1566	Typical oil & gas specification
Light load test	-	No load tests
Load characteristic test (Load envelope test)	Unit under load	Load tests
Load duty test (Intermittent load test)	-	110% nominal current test for at least 10 minutes
Allowable full load current versus speed test	-	-
Temperature rise tests	Verification of converter temperature rise	Motor winding temperature rise Converter temperature rises
Efficiency	Demonstration of the efficiency	Overall efficiency determination at full and half load curve
Line-side current distortion content	-	Harmonic distortion in the current on the line side
Power factor	-	Power factor determination at full and half load curve
Checking of auxiliary devices	-	-
Checking co-ordination of protective devices	Demonstration of the proper operation of all protective functions, both trip and alarm	Test of all protection, alarm and trip functions
Checking properties under unusual service conditions	-	Fault condition tests (earth fault, phase interruption…)
Shaft current/bearing insulation	-	Motor shaft voltage
Audible noise	-	Noise test
Torque pulsation	-	-
Motor vibration	Demonstration of vibration levels during start-up, when operating under load in the speed range and when loads are suddenly applied or removed	Shaft vibration Vibration severity at bearing housing
EMC tests	-	Harmonic distortion in the current on the line side
Current limit and current loop test	-	Linearity between setpoint signal and output
Speed loop test	Demonstration of minimum and maximum speed adjustments Demonstration of acceleration and deceleration rates Demonstration of speed control from an external signal Demonstration of the accuracy of the monitoring panel speed indication meter by comparison with a frequency counter	Test the response times and the adjustability (ramp times) within the operational speed range
Automatic restart/re-acceleration	-	Test capability to restart VSDS and resynchronize converter onto a running motor after a voltage interruption
-	Demonstration of undervoltage disturbance ride-through and restart	Test capability to ride through voltage dips less than 20%
-	Demonstration of voltz/hertz relationship from minimum to maximum speeds	-
-	Verification of all control parameters	
-	Exciter supply voltage waveform shall be inspected to ensure compatibility with the machine exciter insulation voltage rating	-
-		Visual Inspection

Table 3: IEC 61800-4, IEEE 1566 and typical oil & gas specification comparison