



# Operation and Maintenance Manual - Naxys AECM AN11903

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## 1 ABBREVIATIONS

AECM	Acoustic Electric Condition Monitoring
AN	Article Number
DCS	Distributed Control System
DNV	Det Norske Veritas
EPC	Engineering Procurement Construction
GUI	Graphical User Interface
HMI	Human Machine Interface
ISD	Intelligent Subsea Device
KPI	Key Performance Indicator
OPC	Open Platform Communications
OS	Operating System
RP	Recommended Practice
SAS	Safety Automation System
SCM	Subsea Control Module
SIIS	Subsea Instrumentation Interface Standardization
SW	Software
UEP	Underwater Electric Potential
VSD	Variable Speed Drive
TCP	Transmission Control Protocol

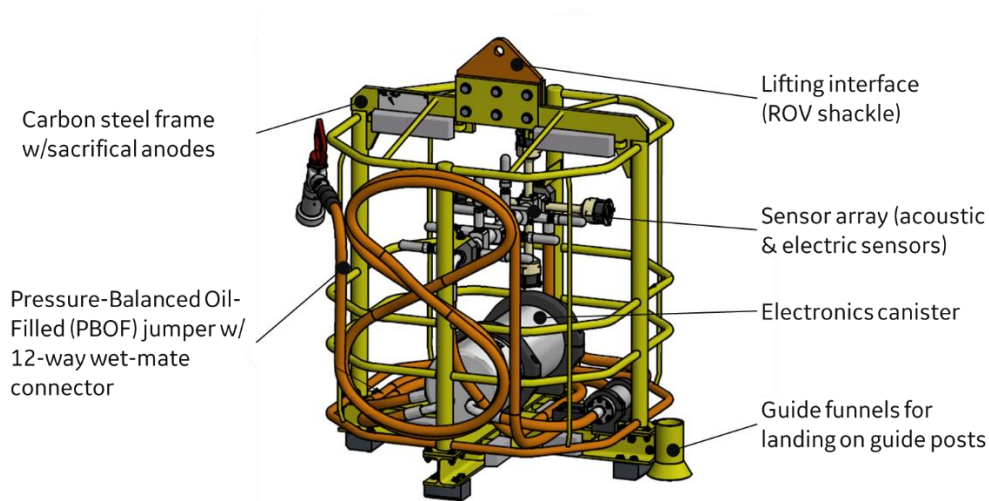
## 2 INTRODUCTION

This document describes operation and maintenance for Naxys Acoustic Electric Condition Monitoring system (Naxys AECM) for monitoring Subsea Boosting Systems (pumps and compressors) including wide area leak detection for the Boostingstation. This document is structured as follows:

- Section 3 - General description of Naxys AECM
  - Introduction to Naxys AECM system
  - Overview of data flow, software and HMI
- Section 4 - Operation of Naxys AECM for Compressor/Pump condition Monitoring
  - Description of Key Performance Indicators data
  - Daily operation and handling of warnings
- Section 5 - Operation of Leakage detection system
  - Description of warning/alarms
  - Daily operation and handling of warnings/alarms
- Section 7 - Maintenance
  - Maintenance of subsea sensor
  - System maintenance
- Section 8 - Competence and Training
  - Competence level for relevant personnel categories and training required for personnel involved with operation of Naxys AECM

### 3 GENERAL DESCRIPTION OF NAXYS AECM

Subsea rotating machinery radiates electric and acoustic fields generated by electric supply and mechanical motion. These fields provide valuable information about the condition of the subsea rotating machinery.



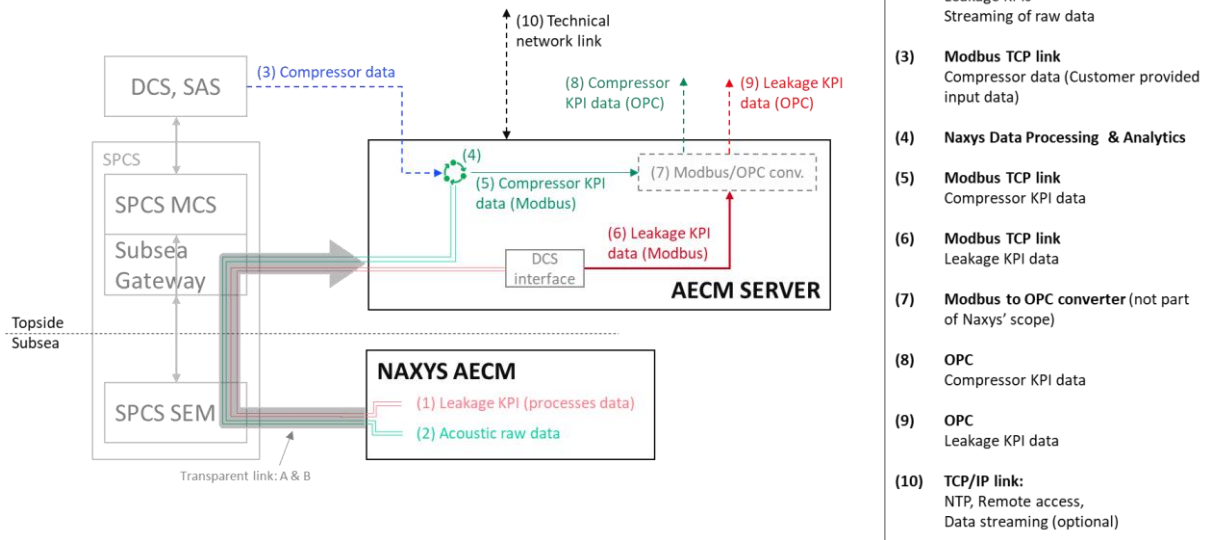
**Figure 1: Naxys Acoustic Electric Condition Monitoring system (AECM) for monitoring of subsea rotating machinery (compressors and pumps)**

Naxys AECM is a non-intrusive subsea instrument for leakage detection and condition monitoring of subsea rotating machinery (subsea compressors and pumps). The AECM utilizes acoustic sensors and underwater electric potential (UEP) sensors for measuring electric and acoustic stray fields emitted by the subsea rotating machinery. The acoustic and electric signals received by the sensors are digitized and transmitted to a topside unit for processing and analytics. The topside processing unit has interface to the topside control system and presents Key Performance Indicators (KPIs). The KPIs provide valuable information about the condition of the subsea rotating machinery, and unwanted conditions are detected and automatically reported to the Operator. The AECM data further guides the Operator to take necessary measures for optimizing compressor operation and minimizing non-productive time.

In addition, the AECM system is used for subsea leak detection by utilizing the acoustic sensors (hydrophones) for detection of acoustic energy emitted by subsea leaks).

#### 3.1 DATA FLOW AND COMMUNICATION OF KEY PERFORMANCE INDICATORS

The communication interfaces are based on SIIIS Level 3 Data aware connection. Typical communication interfaces are illustrated in Figure 2.



**Figure 2: Data communication – Naxys AECM and AECM server**

Key performance indicators are made available to EPC and Operator. See section 4.1 for description of KPI and user levels.

## 4 OPERATION OF NAXYS AECM FOR COMPRESSOR/PUMP CONDITION MONITORING

### 4.1 KEY PERFORMANCE INDICATOR (KPI) AND PRESENTATION OF NAXYS AECM DATA

Naxys AECM system produces KPI data that is made available to the operator through the connection to the topside control system and the Operator’s Technical network (see Figure 2). The KPI data includes information about the compressor/pumps’s condition and technical status for the AECM system, and the data shall be presented to the different users involved in operation of the compressor/pump. This manual considers the following user levels:

1. **Control room user (Level 1, Basic user):** User information is limited to warnings only.
2. **Technical operations user (Level 2, Trained user):** User is defined as onshore technical support involved in daily operation of the compressor/pumps. User has access to KPI data presented in Operator/EPC’s Condition Monitoring System or Naxys AECM topside software. See section 8 for competence and training.
3. **Technical Expert users (Level 3, Expert user):** User is defined as Operator’s expert users and Vendor’s expert support. User has access to KPI data and raw data for in-depth analysis, support, and long-term trending. See section 8 for competence and training.

A description of KPI data is presented in Table 1 below together with recommended user level. Detailed description of the KPIs and recommendation for HMI/GUI implementation is presented in section 4.1.1 to 4.1.5. For details about data registers, please see ref. **Error! Reference source not found.**

**Table 1: Description of compressor/pump monitoring Key Performance Indicators (KPI)**

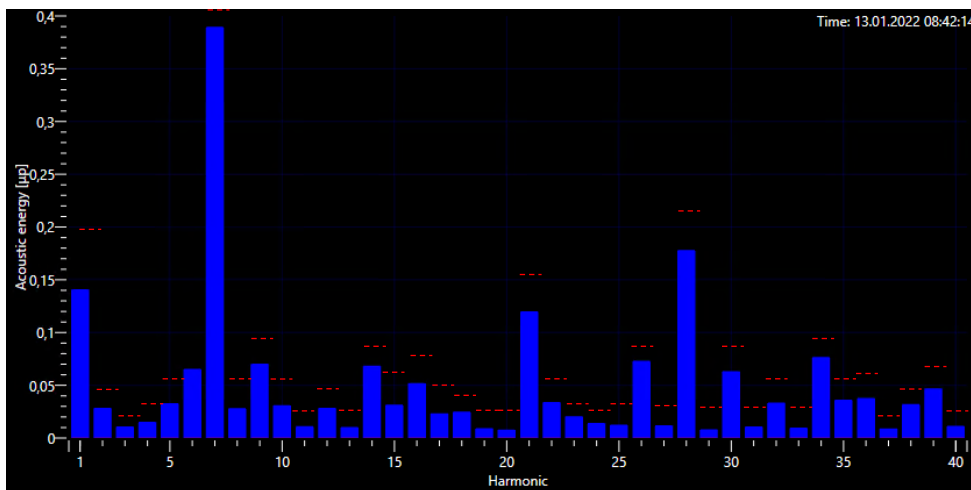
KPI#	Title	Data description	User level		
			Control room (L1)	Technical Operation (L2)	Expert (L3)
1	Harmonic levels	Acoustic compressor/pump signature represented by 1-40 <sup>th</sup> harmonic values (commonly referenced as 1x, 2x, 3x, ...etc.). AECM monitors the harmonic signature, builds statistics for the measured speed envelope and sets a threshold for normal behaviour. The harmonic signature is directly related to the mechanical behaviour of the compressor/pump, and a change of the acoustic signature outside normal threshold levels, indicates a change of the mechanical behaviour. For instance, special attention is made to 1x (1 <sup>st</sup> harmonic) which is an indicator of imbalance. Note that the 1x is also the fundamental compressor/pump rotational frequency.		X	X
2	Sub-sync level	The energy in a configurable band below 1x. Typically 0.47-0.53 x, where x is the shaft frequency. Sub-synchronous vibrations occur at frequency less than the rotational frequency. Monitoring of energy at approx. 0.5x of the fundamental rotational frequency identifies and gives an early		X	X

KPI#	Title	Data description	User level		
			Control room (L1)	Technical Operation (L2)	Expert (L3)
		warning of instabilities caused by fluid dynamic pressure around the rotor (e.g. oil whirl causing sub-sync. vibrations).			
3	Measured RPM	The shaft speed measured from the acoustic AECM data.		X	X
4	Measured VSD freq.	The VSD frequency measured from the electric AECM data.		X	X
5	Slip ratio	The slip ratio calculated as the difference between measured VSD and shaft speed. Slip ratio indicates the compressor/pump load.		X	X
6	Band energy (10 bands)	Acoustic energy in 10 different frequency bands.		X	X
7	KPI warning reg.1	<p><b>Overall warning:</b> Warning is issued if any of the 1-4 below is set.</p> <p><b>Harmonic warning:</b> A warning is issued if any of the harmonic registers are above the configured threshold, i.e. outside of normal operational limits.</p> <p><b>Sub-sync warning:</b> A warning is issued if the sub-sync. level is above the configured threshold.</p> <p><b>Slip ratio warning:</b> A warning is issued if the slip ratio is above the configured threshold.</p> <p><b>Band energy warning:</b> A warning is issued if any of the 10 bands' acoustic energy is above the configured threshold</p>	X	X	X
8	KPI warning reg.2	Spare register for future functionality.		X	X
9	Topside processing technical status register	<p>Technical status for the topside processing.</p> <ul style="list-style-type: none"> <li>• 0 - OK</li> <li>• 1 - Communication fault internal DSP</li> <li>• 2 - Memory fault</li> <li>• 4 - Sensor fault</li> <li>• 8 - Ring buffer fault</li> <li>• 16 - Communication fault internal FPGA</li> <li>• 32 - ADC fault</li> <li>• 64 - Raw data stopped due to flash programming</li> <li>• 128 - Receiving data fault</li> <li>• 256 - Watchdog fault</li> </ul>	X	X	X

4.1.1 KPI #1 - HARMONIC LEVELS

**Bar plot:** This is the most common way of presenting the harmonic levels (1x to 40x). The bar plot is a real-time plot of the compressor/pump’s acoustic signature, illustrated in

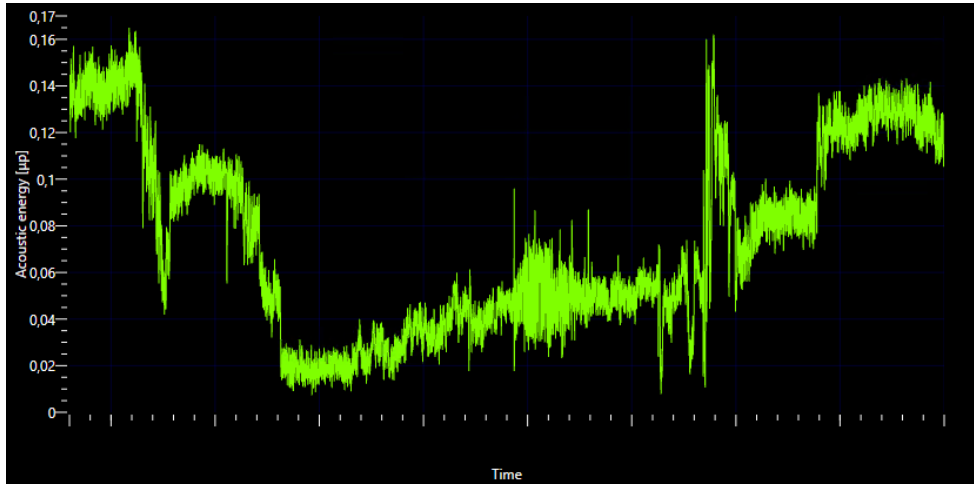
- Figure 3. Each harmonic is associated with a certain warning threshold, illustrated by the red dotted lines. The harmonic plot is the acoustic signature for a given compressor speed. At a different compressor/pump speed, the acoustic signature and the warning threshold will change (dynamic warning threshold).



**Figure 3: Harmonic bar plot.**

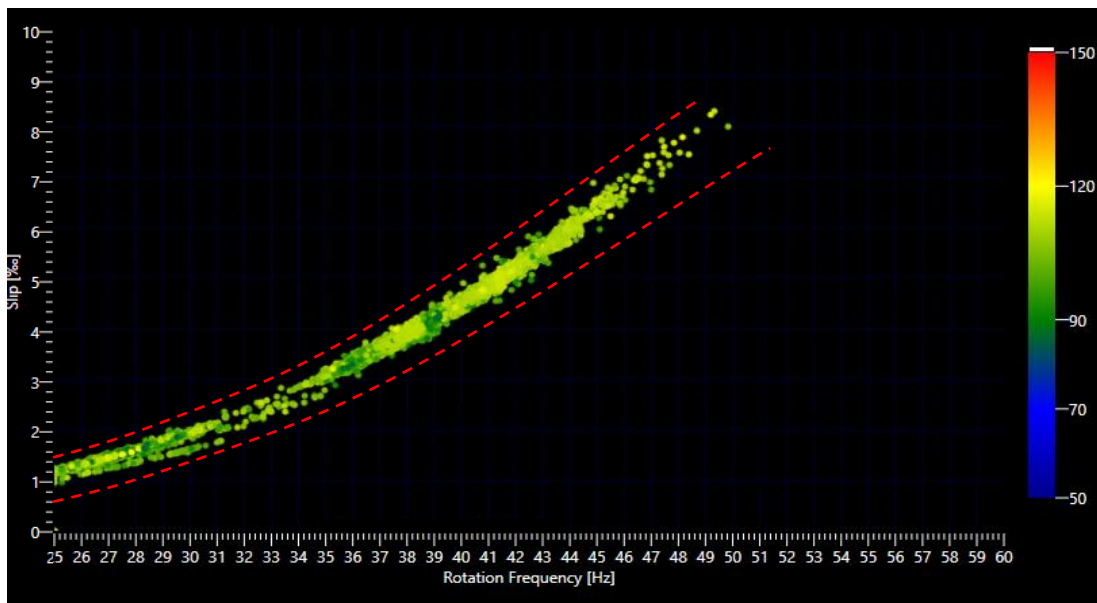
- Trend plot: This shows a specific harmonic value (e.g. 1x) presented as a time series plot and is primarily used for long term trend monitoring.





**Figure 4: Illustration of trend plot showing a certain harmonic value (here 1x) trend as a function of time**

- Cross plot: A specific harmonic value is presented as a function of two other parameters (e.g. RPM & slip, etc.). Figure 5 illustrates harmonic value (1x) scatter (warmer colour – higher harmonic value) plotted as function of measured compressor speed (RPM) and measured slip.

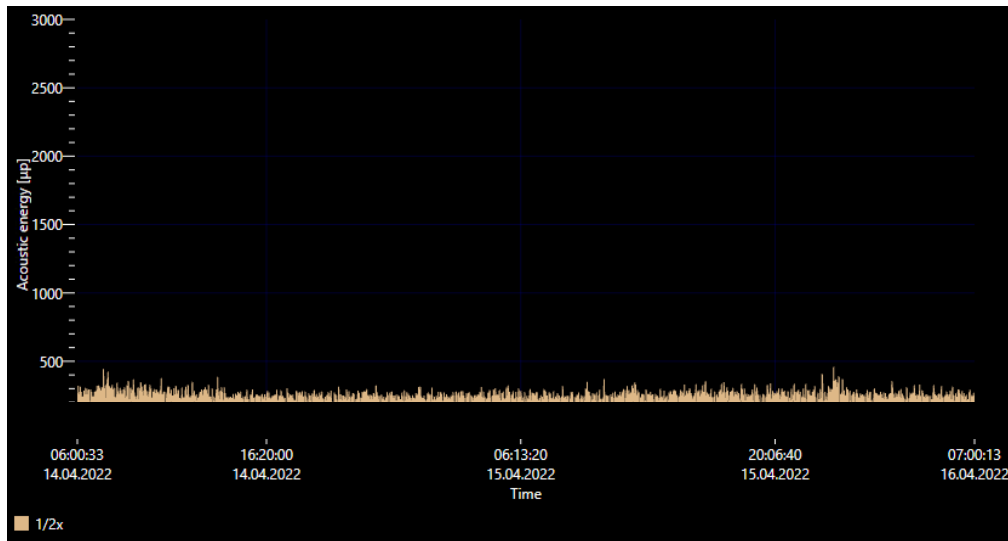


**Figure 5: Illustration of cross plotting slip (y-axis) and harmonic vibration level (here 1x – warmer colour – higher vibration level) as function of RPM. Envelope for normal slip by dotted red lines.**

For harmonic level warning description, see KPI#7 and handling of warnings described in section 4.2.

#### 4.1.2 KPI #2 - SUB-SYNCHRONOUS LEVEL

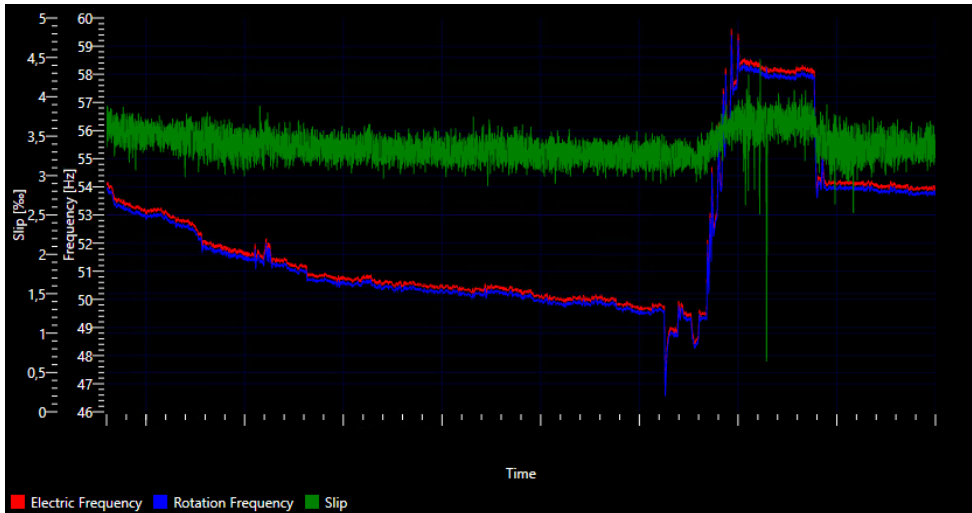
- Trend plot: This shows the sub-sync. level as a time series plot and is primarily used for long term trend monitoring.



**Figure 6: Illustration of trend plot showing the sub-sync. level as a function of time**

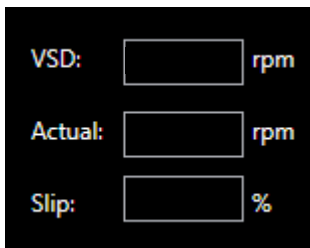
4.1.3 KPI 3, 4 & 5 – MEASURED ROTATION SPEED/FREQ, VSD FREQ. AND SLIP RATIO

Trend plot: This shows the measured speed, measured electric freq. and calculated slip ration as a time series plot, primarily used for long term trend monitoring and comparison (Figure 7). Note that the value is the electric supply frequency. To achieve electric supply RPM this value must be multiplied by 60.



**Figure 7: Measured rotation speed/freq., electric frequency and calculated Slip ratio**

Values should also be shown as real-time instantaneous numerical values (Figure 8).



**Figure 8: Measured electric freq. (VSD), rotation speed (Actual) and Slip ratio presented with instantaneous (real-time) values**

4.1.4 KPI 6 – BAND ENERGY (10 BANDS)

- Trend plot: The band energy is presented as time plot series for long term trend monitoring.

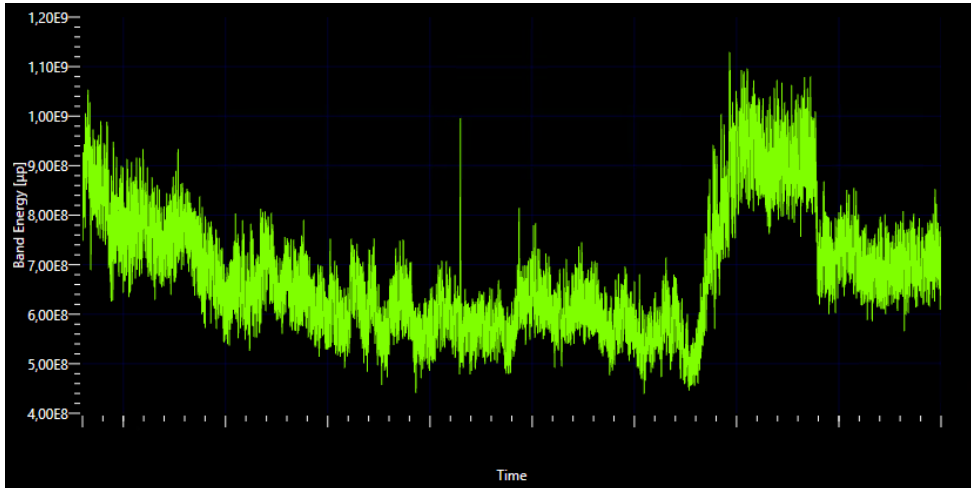


Figure 9: Illustration of trend plot showing the band energy (for band #x, where x is between 1 to 10) as a function of time.

4.1.5 KPI 7, 8 & 9 - WARNING REGISTERS AND TOPSIDE PROCESSING TECHNICAL STATUS REGISTER

**Minimum solution: Control room (basic user):** As a minimum, KPI #7 (Overall warning for ‘Compressor/pumpcondition’) and KPI#9 (Technical status) shall be presented to the control room user. This is recommended implemented as “led indicator” (green/red).

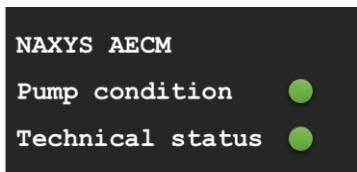


Figure 10: Recommended display for Control Room Operator (basic user). KPI #7 (Overall warning for ‘Compressor/pump condition’) and KPI #9 (Technical status, see below)

**Recommended solution: Control room (basic user), Technical operations (Trained user):** Warning registers in KPI#7 (harmonic, sub-sync., slip ratio, band energy) and KPI#9 (Technical status) shall be presented in the condition monitoring HMI/GUI. These are recommended implemented as “led indicator” (green/red).

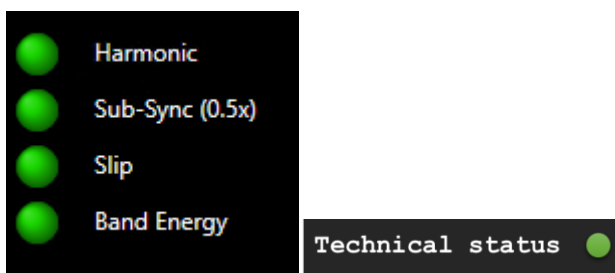


Figure 11: Recommended display for Control room and technical operations KPI #7 (Harmonic warning, Sub-sync. Warning, Slip warning, Band Energy warning)

KPI#8 is reserved for future functionality and is currently not applicable.

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## 4.2 WARNING DESCRIPTION AND HANDLING OF WARNINGS

<p>The Operator is encouraged to report to Vendor about warnings issued from the Naxys AECM system. This to ensure that warnings are swiftly handled in collaboration with the Operator to early detect any unwanted compressor/pump conditions and to fix any system upsets.</p>
---

Warnings produced by the AECM system is represented by KPI #7, KPI #8 and KPI #9 in Table 1.

### 4.2.1 WARNINGS RELATED TO COMPRESSOR/PUMP CONDITION

KPI #7 is related to the condition of the compressor/pump. If a warning is issued, the control room operator shall report to the supporting functions in the organization (e.g. onshore technical support). The supporting function shall evaluate the cause for the warning and contact Naxys for assistance.

### 4.2.2 WARNINGS RELATED TO AECM TECHNICAL STATUS

KPI #9 is related to the technical status for the AECM condition monitoring system. If a warning is issued, Naxys shall be contacted for assistance.

## 5 OPERATION OF LEAKAGE DETECTION SYSTEM

### 5.1 ALARM DESCRIPTIONS

#### 5.1.1 LEAKAGE ALARM

The system will trigger a leakage warning/alarm if the detected acoustic signature satisfies several predefined parameter settings such as:

- Magnitude: Acoustic emissions are above a given threshold
- Frequency content: Acoustic emissions from a leakage is recognized with a certain frequency signature
- Stationary source: Acoustic emissions are stationary (i.e. not moving)
- Persistent source: Acoustic emissions are persistent for a certain time

The alarm together with indication of leakage location is presented in one of the many AECM status registers, which is available for DCS for upload to the control room and display. It is recommended that leakage alarms are given high priority in DCS. Recommendations for integration and visualization of Naxys AECM data in Operator Control Room (HMI) is described in section 5.2. Recommended actions for alarm handling are described in section 6.2.

#### 5.1.2 ROV DETECTOR ALARM

ROV activity is a potential source for false alarm. Naxys AECM has implemented detection of ROV to inform the Operator that an ROV is detected and that handling of potential leakage warning/alarms should take this into account (see section 6.2 for handling of alarms)

#### 5.1.3 TECHNICAL SYSTEM ALARM

The Naxys AECM acoustic leak detector runs continuous self-diagnostics and system status is made available to the Operator through DCS using the Naxys AECM internal registers, for instance:

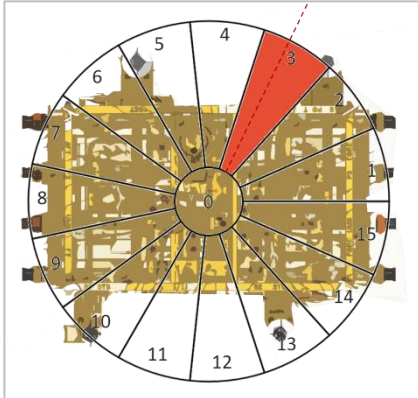
- Sensor failure
- Communication error
- Processing error
- etc.

Depending on the Operator's operating philosophy, system alarms can be given lower priority than leakage alarm. In case of system alarm the Operator is recommended to act per section 6.3.

### 5.2 OPERATOR USER INTERFACE – RECOMMENDATIONS FOR HMI/GUI

Operational parameters, status and configurations are stored in the Naxys AECM registers which are available for readout from the DCS. The following data is deemed the most relevant registers to read and display by the user:

Data name	Data description	HMI/GUI implementation
Leakage Alarm	Bitwise 16-bit register. Bit 0 = sector 0...Bit 15 = Sector 15	<p><b>Leakage status using sector indication:</b></p> <p>It is recommended to implement a sector diagram for displaying leakage status. The sector diagram should preferably overlay the subsea installation for easy identification of possible leakage locations. (illustrated in Figure 12).</p> <p>Sector 1-15 are highlighted with colors white (no leakage), orange (warning) or red (alarm) based on leakage warning and alarm register bit 1 to bit 15. Each sector indicates direction towards the leakage.</p> <p>Sector 0 indicates that leakage is detected but no direction can be given. This sector is highlighted using white (no leakage), orange (warning) or red (alarm) based on warning and alarm register bit 0.</p>
Leakage Warning	Bitwise 16-bit register. Bit 0 = sector 0... Bit 15 = Sector 15	
ROV detector	0 → No ROV present 1 → ROV present	No ROV = Green light indicator ROV detected = Red light indicator
Technical status	= 0 → OK > 0 → Fault	System OK = Green light indicator System fault = Red light indicator
Options (detailed alarm/warning information)		
Elevation (Phi)	Angle in vertical plan towards leakage	Detailed alarm/warning information recommended to be displayed as values. Angle information (azimuth) can also be used in the sector diagram for detailed localization of leakage. When 2 or more sensors are installed, the azimuth angle can be used for cross-bearing to indicate leakage position.
Azimuth (Theta)	Angle in horizontal plan towards leakage	
Magnitude	Acoustic magnitude value	Detailed alarm/warning information recommended to be displayed as values.



**Figure 12: Illustration of alarm/warning sector overlay the subsea installation. Alarm sector indicates direction towards leakage. Dotted line represents the azimuth angle (optional detailed alarm information)**



## 6 OPERATIONS

Operation involves daily monitoring and control of the leak detection system. It is typically handled by the control room operator with supporting functions from onshore operations and expert support from Naxys. This section describes the alarms that are generated by the Naxys AECM subsea leak detector and recommended actions for handling of alarm and events.

### 6.1 DAILY OPERATION OF LEAKAGE DETECTION SYSTEM

#	Description	Frequency	Performed by	Topside Control System	Service Computer
1	Alarm monitoring (technical system alarms, leakage alarms) Alarm handling See section 5.1 and 6.2 for alarm description and alarm handling.	Continuously	Basic user*	X	

\* See section 8 for description of competence and training of personnel.

### 6.2 HANDLING OF LEAKAGE ALARM/WARNING

With reference to DNV Recommended Practice for Subsea Leak Detection, the person responsible for alarm handling shall seek an understanding of the situation and investigate the nature of the alarm/warning. It is recommended to run the following checkout routine:

#	Purpose	Checkout	Action
1	Confirm alarm type	Is the alarm reported as a leakage alarm?	<ul style="list-style-type: none"> <li>- If alarm is related to leakage, continue to run checkout routine below (#2-4)</li> <li>- If alarm is related to technical alarm, please see section 6.3.</li> </ul>
2	Confirm leakage location	In which sector(s) is the leakage alarm indicated?	Sector no.: ____  If sector 0 is indicated this implies that the system has not been able to estimate leakage location. Checkout routine shall still be continued (#3-4).
3	Rule out possible sources for false positive alarm	Operational changes	The Operator shall investigate if the alarm sector indication corresponds to the spatial position of the operational change, e.g. well intervention, drilling, choke cavitation etc.  The Operator shall evaluate situation and contact expert user for assistance if leakage alarm is related to operational changes.
4		Presence of an ROV at the time of the alarm?	Presence of ROV in fixed position may cause leakage alarm. The sensor will automatically detect presence of ROV, but not automatically deactivate alarms when ROV presence is detected.  Operator shall confirm if leakage alarm location corresponds to ROV position.  Operator to move ROV to verify that alarm is cleared.

If the above rules out potential sources for false positives and the Naxys Subsea Leak Detector indicates that there is a leakage, the Operator is recommended to follow the steps below in addition to the Operator's own procedures:

- 1) Further investigate parallel systems (other leak detectors, process pressure, mass balance, etc.)
- 2) Contact Expert User (Company's Expert User or Supplier) for further assistance with detailed interpretation of the acoustic data.

Please note that the suggested actions are general and must be tailored to each specific installation.

### **6.3 HANDLING OF TECHNICAL SYSTEM ALARM**

When a technical system alarm is reported, the Operator shall contact Supplier for further investigation of the initiated alarm.

## 7 MAINTENANCE

The Naxys AECM subsea leak detector has been designed with focus on minimizing requirements for maintenance. Required maintenance is related to verifying that the system is running and operating as expected, and it is recommended that the system is maintained on a regular basis. The following sections describes the maintenance requirements for

- a) The Naxys AECM subsea unit installed on the subsea structure (section 7.1)
- b) Naxys AECM system (section 7.2)

### 7.1 SUBSEA UNIT

#### 7.1.1 MAINTENANCE PLAN – SUBSEA UNIT

No periodic maintenance is required for the Naxys AECM subsea unit. It is however recommended that when an ROV is available, e.g. annually or bi-annually, the Naxys AECM subsea unit is inspected for structure damage and foreign objects

Inspection item	How	Frequency	Performed by
Naxys AECM subsea unit	Inspect Naxys AECM subsea unit visually with ROV for identification of damages or foreign objects.	During ROV inspection	Customer

Recommended frequency of maintenance is only a guideline and must be adjusted as required to the actual installation.

#### 7.1.2 MAINTENANCE OPERATIONS –SUBSEA UNIT

Marine growth does not affect system functionality or sensitivity and no program is defined for removing of sea growth or adding/maintaining any anti fouling. Washer beam shall never be aimed against any hydrophones, electric sensor or cable as this may permanently damage the sensor.

### 7.2 SYSTEM MAINTENANCE

The Operations Program described in the previous section relates to daily operation including alarm and event handling, which is performed by operator personnel. This section describes the routine maintenance program to be performed by trained personnel with the overall goal to:

- Ensure that the system is operating as expected and identify system upsets
- Check of system performance and identify system improvements
- Minimize false alarm rates and maximize Operator’s confidence to the system

System maintenance is recommended to be performed monthly using the Naxys Service Software installed on a Service Computer. The section below describes the recommended maintenance activities.

### 7.3 MAINTENANCE PLAN AND MAINTENANCE OPERATIONS – NAXYS LEAK DETECTION TOPSIDE SYSTEM

**Table 2: Naxys Leak Detection System maintenance schedule**

Item	Description	Frequency	Performed by	Topside Control System	Service Computer
1	<p><b>SYSTEM STATUS:</b></p> <ul style="list-style-type: none"> <li>Verify that system is running and operating as expected</li> <li>Detect early if system is out of function and initiate system recovery</li> </ul> <p>Depending on how the system is set up and which registers are being read from the DCS, the Operator may or may not be automatically noticed if a system is out of function. If the Operator is not automatically noticed it is recommended that system operability is checked daily.</p>	Monthly	Trained user *		X
2	<p><b>SENSOR STATUS</b></p> <ul style="list-style-type: none"> <li>Check of sensor status</li> <li>Detect sensor failure, assess cause and criticality to system performance</li> </ul>	Monthly	Trained user *		X
3	<p><b>COMMUNICATION STATUS</b></p> <ul style="list-style-type: none"> <li>Check system communication status</li> <li>Detect communication problems, initiate cause analysis and work required to fix problem</li> </ul>	Monthly	Trained user *		X
4	<p><b>HISTORY LOG:</b></p> <ul style="list-style-type: none"> <li>Review systems history log with status messages for last period</li> <li>Identify and investigate events of interest, e.g. sensor failure, warning/alarm issued</li> </ul>	Monthly	Trained user *		X
5	<p><b>PERFORMANCE &amp; IMPROVEMENTS</b></p> <ul style="list-style-type: none"> <li>Review data from last period and analyze if warning/alarm thresholds should be adjusted to improve system performance. Configure system.</li> </ul>	Monthly	Expert user *		X

\* See section 8.2 below for description of training levels

## 8 COMPETENCE AND TRAINING

### 8.1 COMPETENCE

Reference to DNV Recommended Practice for Subsea Leak Detection that recommends that *“The system should be manned by a trained operator who knows what the detectors measure and the system limitations.”* The following competence matrix is recommended for operation and maintenance activities related to Naxys AECM system.

User level	Relevant personnel categories			Competence	Relevant training level*
	Control room operator	Controls/SAS eng./onshore support eng.	Operator expert, Supplier		
Basic user	X	X	X	User has undergone L1 training comprising of introduction to daily operation and handling of warnings from Naxys AECM	L1
Trained user		X	X	User has undergone L2 training comprising: <ul style="list-style-type: none"> <li>• Introduction to Naxys AECM compressor condition monitoring system and use of KPI data for daily operation</li> <li>• Introduction to Naxys Acoustic Leak Detection system and daily operation.</li> </ul>	L2
Expert user		X	X	User has undergone L3 training comprising: <ul style="list-style-type: none"> <li>• Introduction to Naxys AECM compressor condition monitoring system and use of KPI data for daily operation</li> <li>• Introduction to Naxys Acoustic Leak Detection system and daily operation.</li> <li>• Use of Service Computer to view data for regular maintenance of system.</li> <li>• In depth knowledge of system and capable of configuring Naxys AECM parameters based on extraction and analysis of acoustic and electric data.</li> </ul>	L3

\* See section 8.2 below for description of training levels

### 8.2 TRAINING

Further to the describes above, DNV Recommended Practice states that *“Personnel responsible for alarm and event handling shall be trained and competent in the leak detection system implemented on board. The training shall cover the operating procedures for the leak detection system.”*

Naxys offers training for Operator personnel:

- Introduction to Naxys Acoustic & Electric Compressor Condition Monitoring system
- Introduction to Naxys Subsea Acoustic Leak Detectors
  - o Passive acoustics for subsea leak detection
  - o Technology Capabilities and Limitations
- System Architecture
- System Alarms
- Operation and alarm handling
- System Maintenance
- Naxys support

Training is divided into 3 levels depending on required user level (see competence matrix in section 8.1 and required user levels for operation and maintenance activities described in section 7.3).

Training level	Training description
L1	Basic training with introduction to Naxys Acoustic & Electric Condition Monitoring and Acoustic Leak Detection and daily operation of the system including basic warning and alarm handling.
L2	L1 training + monitoring of KPI data for daily operation.
L3	L1 & L2 training + training for advanced data analysis and configuration of system using Service Computer and system maintenance

Training can be arranged by contacting Naxys.