Hardware in the Loop Testing (HIL)

JULY 2011

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FOREWORD

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The Society reserves the exclusive right to interpret, decide equivalence or make exemptions to this Standard for Certification.
Main changes:
This is a new document.
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1. General

1.1 Preamble

1.1.1 The safe operation of a vessel is more and more depending on complex and critical shipboard control systems. In this context end users are requesting improved performance and safety of the vessels. Independent Hardware in the Loop (HIL) testing is a test method which can be utilized to assist in the verification of adequate performance and safety levels of such systems. The end-users may in addition require a 3rd party certification from classification societies of the HIL testing in order to align this new type of testing into the traditional maritime certification and classification regime. The motivation for this Standard for Certification is to establish generic requirements to this new certification concept for HIL testing of a wide range of Control and Monitoring systems.

1.1.2 In addition to the generic requirements given in this standard, application specific requirements (e.g. dynamic positioning) to HIL testing are necessary for completing HIL certification. Reference to such additional requirements should e.g. be found in the HIL test packages to be developed by the HIL suppliers.

1.2 Objectives

1.2.1 The objective of a HIL test certificate is to document that a third party certification has been carried out in compliance with requirements stated in this Standard for Certification of HIL testing for the specified target system.

1.2.2 The objective of HIL testing is to test the specified target system in order to provide objective evidence of acceptable functionality (during normal, abnormal and degraded condition) according to given functional requirements. Functional requirements for the target system may originate from e.g. class rules for the target system. General and specific requirements given in this Standard for Certification of HIL testing will apply as applicable.

1.3 Definitions and abbreviations

1.3.1 Control computer system: A system consisting of at least one computer or processor with CPU processing and I/O capacity, and one or several operator stations. The control computer system includes also network, interface, and cabling for signal communication, and the HW/SW platform with the controllers containing both basis software and application specific software.

Guidance note 1:
The control computer system also includes control and management networks and interface used for integration with other control systems and decentralized command and monitoring terminals.

Guidance note 2:
The operator stations constitute the command and monitoring functionality of the control system, consisting usually of human machine interfaces (HMI’s), Visual Display Unit’s (VDU’s), alarm panels, joysticks, switches, printers, etc.

1.3.2 Failure: [IEEE610.12-1990] The inability of a system or component to perform its required functions within specified performance requirements.

1.3.3 Failure mode: [IEEE 610.12-1990] The physical or functional manifestation of a failure. For example, a system in failure mode may be characterized by slow operation, incorrect outputs, or complete termination of execution.

1.3.4 Failure testing: To test the functions of a target system by inducing relevant failures in the system in order to verify compliance with the stated requirements.

Guidance note:
This may be done by inducing relevant failures in the system or components connected to it, either simulated or real, and observing and reporting the effects of these failures on the behaviour of the target system.

1.3.5 Function: [IEEE 610.12-1990] A defined objective or characteristic action of a system or component.
1.3.6 **Functional testing:** Testing functions of a system to verify compliance with the stated functional specification and requirements. The main objective is to reveal failures occurring in design, implementation, integration, and configuration.

1.3.7 **HIL:** Testing by “Hardware-In-the-Loop” simulation.

1.3.8 **HIL simulator:** A real-time simulator constructed by hardware and software, which is configured for the control system under consideration and interfaced to the target system or component through appropriate I/O. During testing with an HIL simulator the target system or component will not experience significant difference from being connected to the real system.

1.3.9 **HIL test-package:** A test-package including HIL simulator(s) as testing tools and all documentation required for description and reporting of the HIL testing.

**Guidance note:**
An HIL test package normally consists of the following elements:

- one or several HIL simulators for the specific testing to be carried out
- all documentation required for planning and approval of the specified testing to be carried out
- all documentation required for execution and reporting
- all analysis and test results including findings and conclusions.

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1.3.10 **HIL test package maker:** The part responsible for making the HIL test package.

1.3.11 **HIL tester:** The part responsible for carrying out the HIL tests.

1.3.12 **HW:** Hardware (computer hardware).

1.3.13 **SW:** Software (computer software).

1.3.14 **Repeatability:** A test case is repeatable if the outcome of the specified test case for several test runs is unchanged.

1.3.15 **Target system:** An identified set of equipment with hardware and software that is subject to analysis, testing and verification.

1.3.16 **Testability:** The extent to which a test objective and feasible test can be designed to determine whether a requirement is met. Testability of a function in a system requires controllability and observability of that function:

- **Controllability:** A function in a system is controllable if for each possible behaviour of the function, i.e. each possible output data value, condition, or state, there exist a set of actions that can be applied to the inputs of the system such that the corresponding behaviour is achieved.
- **Observability:** A function in a system is observable if any arbitrary behaviour of the function can be determined from the outputs of the system.

1.3.17 **Test activity:** An activity for testing a specified target system according to a defined test scope and test program in order to partly or fully meet the overall objective of HIL testing. Test activities may range from testing of isolated modules or subsystems in laboratory conditions, testing of integrated modules, integration testing of complex systems consisting of equipment from many makers, to full-scale testing of an integrated control system.

**Guidance note:**
A test activity may be divided into one or several test sessions due to practical considerations of the availability of the target system. Typically, each test activity has a documented Test Program to be carried out in one or several test sessions.

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1.3.18 **Validation:** [ISO 9000] Confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled.

1.3.19 **Verification:** [ISO 9000] Confirmation, through the provision of objective evidence, that specified
requirements have been fulfilled.

2. Scope of Verification
The scope of verification shall include all relevant functions in computer hardware and software implemented in the target system.

3. Application
1) The requirements of this standard for certification apply to systems which shall undergo Hardware-In-the-Loop testing.

Guidance note:
The requirements in this specification are additional to the rules for classification. The standard may however be used in conjunction with traditional Certification of Materials and Components (CMC) and classification testing activities.

2) Functional requirements for the target system shall be referred and form the basis for the tests in the HIL test package.

3) This standard does not include requirements or recommendations in regard to the vessel's operation or other characteristics.

4) Application of HIL testing shall provide additional objective evidence of functionality and quality according to stated requirements during normal, abnormal and degraded condition in accordance with the relevant requirements.

Guidance note:
The objective is to test the specified target system in order to provide objective evidence of acceptable functionality and quality according to stated requirements. Application of HIL test method should provide an additional broader and/or deeper and/or earlier verification of the applicable requirements when compared to normal classification test activities required for the target system(s).

5) In addition to the generic requirements given in these rules, functional requirements and any stated quality requirements for the stated system(s) shall be specified. In this context all relevant main and additional classification requirements applicable for the target system applies.

Guidance note:
Upon special agreement other rules and requirements may be made applicable if relevant. In the case that rules and requirements have conflicting requirements, such conflicts shall be clarified, concluded, and documented in each case.

4. HIL Test Certificate
1) Systems that have successfully undergone HIL testing in compliance with the requirements in this specification may be assigned an HIL Test Certificate.

2) The HIL Test Certificate shall specifically identify the target systems that have been tested, by listing of specific HW type, serial numbers, and specific SW version identification. References to the specific HIL test package and HIL test report shall also be provided.

Guidance note:
For hardware this could typically imply manufacturer delivery identification, serial and type numbers on cabinets and main components like computers and controllers. For application software, this should typically include the complete software version including identification of software build version and date with timestamp. For operating system software, the main version must be identified. It must be possible to identify these version numbers on the installed equipment and software onboard. Example of certificate format is given in annex A.

3) Before the HIL test certificate can be issued, all findings shall be concluded.
5. Owner Obligations with Regard to Alterations and Additions

1) The HIL certificate shall refer to a given target system with specific hardware and software versions. Changes made to software and/or hardware after HIL testing implies that the HIL certificate may become invalid.

2) It is the obligation of the owner to notify the HIL certification body about any changes to the target system in case the certificate shall be valid after the changes. Information about such changes shall also be submitted to users of the HIL test certificate.

6. Requirements for the Maker of the HIL Test Packages

1) The company which makes the HIL test packages shall be independent from the other involved parties.

   Guidance note:
   In general the following issues should be addressed, in order to verify the organisational independency of the HIL test package maker:
   - the company should have testing and verification as one of its main activities
   - involvement in the design and development process, in terms of delivering design propositions and solutions for the target system to be HIL tested
   - independency with respect to personnel and technology
   - ownership and other business relationships.

2) The HIL test simulator technology shall be based on other (diverse) technology than the target system technology. This means that:
   — the HIL simulator shall be implemented by means of a separate hardware unit
   — the HIL simulator application software shall be sufficiently diverse from the target system application software, and testing tools used in design and development of the target system.

3) The maker of HIL test packages shall have a documented quality management system.

   Guidance note:
   This may be a recognized system such as e.g. ISO 9001 or equivalent.

4) The quality management system of the HIL test package maker, shall have documented procedures for:
   — operation as an independent maker of HIL test packages
   — verification and validation
   — preparation of HIL test packages including a statement of the intended use of the test packages
   — preparation of the HIL test interface to the target system
   — software development and software quality assurance
   — maintaining special competence in the target system domain
   — identification of hazards and risks related to HIL testing
   — preparation of instructions for risk control measures to other involved parties
   — preparation of reports, results evaluation, and retesting
   — archiving of HIL test packages including reports with version control of tests carried out for specific vessels and systems during the system life cycle
   — competence requirements and training for personnel involved in all phases of HIL testing
   — requirements verification
   — design and version control.

5) Upon request the maker of the HIL test package shall demonstrate and document that the procedures in the quality management system are applied in its HIL test package deliveries.

6) The certification body shall be informed about organisational and technical dependencies. The certification body may request documentation to verify independency.
7. Documentation

7.1 Documentation requirements

The following documentation shall be submitted for approval:

— Hardware-in-the-loop test package documentation. A set of documents as described in Table 7-1.
— Hardware-in-the-loop test package report. A set of documents as described in Table 7-2.

Guidance note:
For general requirements to documentation, see DNV’s Rules for Classification of Ships Pt.0 Ch.3 Sec.1.

<table>
<thead>
<tr>
<th>Table 7-1 Definition of - Hardware-in-the-loop test package documentation</th>
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<tr>
<td><strong>Applicable system</strong></td>
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8. Tests

8.1 General

HIL testing shall be carried out at the target system manufacturers works, and onboard the vessel. The HIL testing shall assure that the target system has been configured, and completed according to relevant functional specifications and requirements.

Guidance note:

HIL testing at the manufacturers works or onboard the vessel are the main sites where witnessing of the tests are assumed. However, upon agreement, other sites may be accepted. This also implies that e.g. tests planned at the manufacturers works could upon agreement be carried out at the dock or at a dedicated test laboratory. Parts of the onboard testing may be accepted carried out during dock and/or quay trials. In other cases, it may be agreed to omit the requirement for onboard testing when it can be justified that the testing at manufacturers works is sufficient.

The tests shall be performed according to the approved test programs in the HIL test package. The test programs shall be approved by the certification body upfront the HIL test sessions. The test program shall be prepared for testing of the target system at the target system manufacturers works. The onboard testing test programme shall be prepared for testing of the onboard installed target system. When deemed necessary by the attending surveyor, tests additional to those specified by the test program will be required.

Before the HIL test session and survey commences, an opening meeting should be arranged between the responsible parties. The following items should be clarified:

— responsibilities related to the HIL test session
— emergency procedures and responsibilities for potential hazardous situations during the HIL test session
— the test setup and objectives of the HIL tests to be carried out
— the schedule and sequence for carrying out the HIL testing.

The test results for each test shall be recorded. The conclusion of each single test shall be documented into the HIL test report.

Testing as described in Sec.8.1, item 4 shall be carried out in the presence of a surveyor from the certification body. Upon special agreement, parts of the testing may be carried out without the presence of the surveyor. Each single test outcome shall be presented to the surveyor, if requested. The surveyor may request any test to be repeated. Due to this, the HIL test simulator shall not be disconnected before the surveyor has confirmed that no more testing will be requested to be witnessed in the current test session.

After an HIL test activity is completed, the complete set of results shall be compiled into an HIL test report. Each test or
conclusion shall be documented and signed. In the case that some tests have become not applicable or is not possible to carry out or it is decided to postpone the tests to a later HIL test activity, such conclusions shall also be documented.

After the HIL test activity, a closing meeting shall be arranged between the responsible parties. The purpose of the meeting is to agree upon the findings from the testing. For each finding a responsible party for follow up within a set due date shall be agreed, documented, and signed as applicable.

The finding shall be categorised into defined categories. As a minimum the finding shall be categorised into safety critical and non-safety critical groups. This categorization shall be agreed with the certification body.

The conclusions from the closing meeting shall be documented in an HIL test summary report as described in Table 7-2. The HIL test summary report shall be distributed to all parties and the agreed actions shall be followed up. The HIL tester shall keep track of the agreed actions and update the report as the actions are handled.

After completion of an HIL test activity, the HIL test report shall be prepared. The HIL test report shall be submitted to the certification body.

The personnel responsible for performing the HIL testing shall be qualified according to the quality requirements in Sec.6, item 4. Documentation of completed training shall be available on request from the certification body.

Guidance note:
The HIL testing may be carried out by personnel from e.g. the maker of the HIL test package, the system manufacturer, the yard, the vessel owner, or a marine consultant provided that this personnel have been qualified according to the quality requirements in Sec.6, item 4.

8.2 Testing at manufacturer

1) HIL testing at the manufacturer works shall be carried out based on an approved HIL test package.

Guidance note:
The HIL testing at the manufacturers works may, upon agreement be combined with other certification activities.

2) The HIL testing at the manufacturers' works shall verify closed loop functionality and response of the target system when connected to the HIL simulator. Both normal, degraded and abnormal operation shall be simulated.

Guidance note:
The HIL testing at the manufacturers works may, upon special agreement, be carried out on replica hardware.

3) The HIL testing at the manufacturer works may be limited in test scope or omitted when the target system is HIL Type Approved.

Guidance note 1:
The requirement to the scope of the HIL testing at the manufacturer works will be based on the total system functionality and the degree of configuration and customisation for the specific target system delivery.

Guidance note 2:
The certification requirements according to main class requirements and other optional class notations will not be omitted based on HIL Type Approval.

4) For an HIL Type Approval to be valid, the delivered hardware and software must be covered by the HIL Type Approval Certificate.

Guidance note:
This means that the HIL Type Approval certificate will specify the hardware components and the software versions. Note that the HIL Type Approval certificate does not imply that the hardware in itself is type approved and tested according to the DNV Standard for Certification No. 2.4 or other standards stating environmental requirements. However, relevant environmental requirements will always apply.
8.3 Onboard testing

1) HIL testing of the installed target systems onboard the vessel shall be carried out based on an approved HIL test package in order to assure that the target system has been configured, and installed according to relevant functional specifications and requirements for the vessel.

2) The HIL testing shall verify normal closed loop functionality and response of the total system upon normal, degraded and abnormal operation.

   Guidance note:
   The requirement for normal closed loop functional testing, may in some cases give situations which are harmful to the equipment under test. The requirement for closed loop functionality may upon special consideration be omitted and/or replaced by other types of testing.

3) The target system and other possible influenced systems, shall be re-instated and set back to normal operational mode after completion of the HIL testing.

9. HIL Test-packages

9.1 General

1) The HIL test-package shall include HIL simulator(s) as testing tools and all documentation required for description and reporting of the HIL testing.

2) The certification body shall approve the relevant parts of the HIL test-package upfront each HIL test activity. The approval will in addition to these rules also be based on the specified functional requirements for the target system.

3) The HIL test-package shall refer to the specific functional requirements to the target system which has formed the basis for the HIL test scope. Reference to these functional requirements shall be stated in the HIL test certificate.

4) The applicable parts of the HIL test-package documentation shall be prepared for serving as working documents during the HIL tests.

5) The intended use of the HIL test-package shall also be stated. The intended use statement shall give directions for the HIL test scope.

   Guidance note:
   The intended use of the HIL test-package may be to verify specific functional requirements for a specified type of future vessel operation. The intended use may also include statements of methods for selection of the verification and test scope.

6) The HIL test-package shall describe the target system and possible interfaced systems as necessary.

   Guidance note:
   The required documentation for the HIL test-package can be found in Table 7-1 and Table 7-2.

7) The HIL test-package shall contain test cases related to the normal, degraded and abnormal operation of the target and simulated systems. Normally single and common failure modes and common components should be extensively analysed and tested. Multiple failures should be tested if found relevant.

   Guidance note 1:
   Operation in all normal modes and transfer between operational modes and the corresponding functional requirements, should be the basis for establishing the HIL test scope. In addition, failure testing is also to be included in the test scope. General types of failures to be simulated could be, but not limited to:
   - sensors or input devices failure modes (dropout, noise, calibration
   - errors, drift, bias, signal freeze, wild point, …)
   - failure mode of actuators, drives, power system components
   - or other electro-mechanical components
   - feedback from sensors on actuator failure modes
   - failure modes in computer networks
   - failure modes related to overload of networks
   - failures affecting weighting and voting mechanisms
   - failures affecting protective safety functions
   - failures affecting alarms, monitoring, and analysis functions
   - failures causing and/or otherwise affecting switch-over in redundant systems
- common mode failures affecting several components and/or signals
- emergency handling (special emergency functions required during emergency handling could be tested)
- reconstruction of relevant reported failures/incidents related to the system and/or operations.

Guidance note 2:
When establishing the HIL test scope, verification planned to be carried out by other methods (e.g. FMEA), should be considered. The purpose should be to give input to the HIL test scope and to align the execution of the tests in an efficient manner.

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8) Testing shall be performed for all relevant operational modes of the target system. The need for testing in different operational modes of relevant equipment and systems connected to the target systems shall also be evaluated.

9.2 Risk assessment
A risk assessment for each test activity shall be a part of the HIL test-package.

Guidance note:
The intention is to ensure that the responsible parties have addressed that there may exist possible hazards and risks related to HIL testing and that sufficient overall actions for emergency handling have been planned and agreed. Items which typically should be considered if appropriate:
- specification of equipment to be tested
- specification of personnel required for the HIL testing
- specification of required environmental conditions during the HIL test
- hazard identification for the equipment during the HIL test operation
- hazard identification (personnel safety) for the personnel during HIL testing
- hazard identification for the ship and the ship environment
- availability of an emergency procedure for handling possible hazardous situations.

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9.3 Verification and validation
1) The HIL test-package shall contain procedures for verification and validation of the configured HIL simulator. The scope of verification and validation shall be based on the specific intended use of the HIL testing.

2) Functional suitability and accuracy of the simulator shall be documented according to procedures (ref.1 above) in order to ensure sufficiently accurate and valid test results. This must as a minimum include:
   — verification tests to document that the simulator functions are correct and sufficiently accurate
   — validation tests to document that the functional suitability of the simulator is according to the intended use of the HIL testing. Verification and validation activities and/or assessments shall be documented in the HIL test summary report as required in Sec.7.

Guidance note:
The key element for planning the validation activities is to analyse the intended use statement and identify possible critical factors/elements in the simulator/test package which may leave the test results not representative. A set of relevant validation activities for the HIL simulator and HIL test package should be identified and measures for limiting possible inaccuracies and uncertainties should be described. In case the objective of the HIL testing is to test the qualitative behaviour of functions and failure handling, it must be validated that the accuracy of the simulator is sufficient to obtain testability of the target functions. If, on the other hand, the objective of the HIL testing is to test both the qualitative and quantitative behaviour of functions in the target system, it must be validated that the performance of the simulator is sufficiently accurate and realistic to assess the target system performance. It is recognized that some validation tests can only be carried out by full-scale trials. In order to collect information supporting the correctness of the simulator such validation tests are advised.

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Appendix A
Example Certificate for Dynamic Positioning - Target System

This certificate consists of X pages

This is to certify that the Dynamic Positioning (DP) computer system (target system) installed on board: “Vessel Name” has undergone HIL Testing in compliance with:

— DNV’s Standard for Certification No. 2.24 “Hardware in the Loop Testing (HIL)“*)

The system is tested with respect to the following functional requirements:

— DNV’s Rules for Ships Pt.6 Ch.7 “Dynamic Positioning Systems”

The “Target System” is tested and found to be in compliance with the above specification(s) at the date of issue of the Certificate. The issue date must be evaluated by the user of the HIL Certificate. For renewal of the HIL Certificate testing according to the standard must be witnessed by DNV.

Place and date
Høvik, YYYY-MM-DD
for Det Norske Veritas AS

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<td>Yard / Hull no:</td>
<td>Yard name/hull no</td>
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<tr>
<td>Build year:</td>
<td>YYYY</td>
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</table>

*) Change in HW or SW may render this Certificate invalid. Reference is made to Sec.5, Owners Obligations in the Standard for Certification.

Target System:
Dynamic Positioning computer system: DP2 delivery number..., consisting of:

Hardware:
— DP A: Serial:...
— DP B: Serial:...
— Main controller A: Serial:...
— Main controller B: Serial:...
— Operator station computer A: Serial:...
— Operator station computer B: Serial:...
— ...

DP software:
— DP controller SW version:...
— DP HMI SW version:....
— Operating system SW version:....
— ...

HIL test package maker:
HIL test maker company ltd

HIL test package delivered by the HIL test package maker:
HIL Simulator:
— Software identification
— Configuration files

HIL documentation package “Package reference DP-HIL Function and Failure Testing”, dated YYYY-MM-DD, consisting of:

—

DNV examination letter: NACNO372/SIGN/DXXXXX-J-XXX, dated YYYY-MM-DD

HIL Test Organisation:
HIL tester company ltd

Testing:
Testing is performed as documented in the above referenced HIL test documentation package, including the required HIL test reports.
This documentation package is intended to be kept onboard the vessel.

END OF CERTIFICATE