

236

CONFORMANCE TESTING GUIDELINE FOR COMMUNICATION IN SUBSTATIONS

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Conformance Testing Guideline for Communication in Substations

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1 General

1.1 Scope

Modern *substation automation systems* (SAS) built up with intelligent electronic devices (IEDs) became more and more common in a wide range of MV and HV applications. The interaction between those devices is not restricted to hard-wired information exchange but is going to use serial communication as a backbone of the complete system.

This communication in the application domain substation will be based in the future on international standards, which are replacing supplier dependent or regional solutions.

The rules for standardized communication are defined by standardized communication protocols. Standard protocols are commonly described by the ISO/OSI model (Open System Interconnection model of the International Standard Organisation) which structures the rules in 7 layers:

Layer 7 Application	: Meaning of data (voltage, position, time, etc.)
Layer 6 Presentation	: Coding (ASCII, double bit indication, 16-bit analogue, etc.)
Layer 5 Session	: Start/stop of talking, allowed/included communication partners
Layer 4 Transport	: Connection, sequence/order of telegrams, completeness
Layer 3 Network	: Address in the communication network
Layer 2 Data link	: Telegram length, error detection/correction
Layer 1 Physical	: Medium, connectors, and signal level

These layers are called very often the (communication) stack.

An examples for such a standard under development for communication in substations is:

- IEC 61850: Communication networks and systems in substations
This standard is stack independent, i.e. it may be mapped to any stack. Nevertheless, a mapping to a very restricted number of stacks will be provided as part of this standard also. The standard is restricted by definition to the substation domain. It excludes the remote control interface to the NCC and the dedicated teleprotection link outside the substation. But IEC TC57 has started the discussion (TC57 meeting, Oslo, 2001) how to use IEC61850 also outside the substation, e.g. between the substation and the network control center.

An example of a requirements specification under development is:

- IEEE 1525: Standard for Substation Integrated Protection, Control and Data Acquisition Communications
This standard is focused on the IP protocol suite and has no general restriction for the utility communication network. It includes the remote control interface to the NCC and the dedicated teleprotection link outside the substation also. The document is a requirements specification, and does not define a complete protocol stack, thus not specifying interoperability.

The goal of certain communications standards is to have interoperability between the IEDs from different suppliers in one common system. Therefore, these standards have to be compatible including the complete stack up to the application level (level 7) and additionally to be based on an application domain specific model (common data objects and services). Compatibility at all

lower level is a prerequisite for any higher level. Note that Interoperability implies not only standardization of syntax but also of semantics.

Such a standard has a strong impact on cost also, since it defines by its structure and facilities how easy communication and system engineering will be. To facilitate communication engineering or plug-and-play behavior, the standard has to provide a standardized device and system description also which is understandable by the non-standardized engineering systems of the different providers.

System interfaces to the utility WAN with semantic content may have some impact on the communication standards in substations. This refers e.g. to

- IEC 61968: System interfaces for distribution management
- IEC 61970: Energy management system application program interface
- IEC 61400-25: Wind Turbine Generator Systems - Communications for monitoring and control of wind power plants

1.2 Summary

Modern communication technologies have a strong impact on future equipment in substations. Open interfaces, interoperability and experiences with previous ranges of products and systems lead to the necessity to ensure operation of devices in heterogeneous environments. Due to a large variety of combinations a stepwise test structure is appropriate for conformance testing of devices. Device level tests and system level tests are specified and guidelines given for performing them.

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2 Glossary

ACSI	Application Communication Service Interface
DTD	Data Type Definition
DUT	Device Under Test
EMC	Electromagnetic Compatibility
EMS	Energy Management System
FAT	Factory Acceptance Test
GOOSE	Generic Object Oriented Substation Event
GSSE	Generic Substation State Event
HMI	Human Machine Interface
ICS	Implementation Conformance Statement
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IEEE	Institute of Electric and Electronic Engineers
IPP	Independent Power Producer
ISO	International Standardisation Organisation
IUT	Implementation Under Test
LAN	Local Area Network
MICS	Model Implementation Conformance Statement
NCC	Network Control Center
OSI	Open System Interconnection
PICS	Protocol Implementation Conformance Statement
PIXIT	Protocol Implementation Extra Information for Testing
RTP	Real Time Protocol
SAS	Substation Automation System
SAT	Site Acceptance Test
SCL	Substation Configuration Language
WAN	Wide Area Network
XML	Extended Markup Language

3 Introduction to testing

3.1 Overview

Since there is a long way from the development and production of a device to the proper running of a system designed according the dedicated needs of a customer, a long sequence of testing steps applies.

The basics of reliable testing in development and production today is the **quality system** of the producer/supplier according to ISO 9001/9002 as far as applicable.

A lot of **internal tests** during the *development* of a device (or a system kit) result in a **type test** (unit level test) performed at least by the provider and – as far as standards apply – by an independent test authority. In the context of this paper, the term type test is restricted to the functional behavior of the device excluding communication.

In addition, **routine tests** in the production chain are necessary to ensure a constant quality of delivered devices in accordance with the quality procedures of the producer.

The **conformance test** is the type test for communication and – since communication establishes a system – the basic system test of the IEDs. For a global communication standard, the conformance test applies to all related suppliers worldwide and, therefore should be standardized also. If an independent authority shall do this testing and certify will be discussed in chapter 8

Although **type test** and **conformance test** does not completely guarantee that all functional and performance requirements are met, properly performed they reduce significantly the risk of costly problems occurring in system integration in the factory and on-site.

Conformance testing is not replacing the project specific system tests like **factory acceptance test** (FAT) and **site acceptance test** (SAT) based on customer requirements of a dedicated ordered substation automation system which are done by the manufacturer with the testimony of customer normally. These tests increase the confidence level that all potential problems in the system have been addressed and solved. In addition, by these tests it is proven that the delivered individual substation automation system is running as specified.

Periodic testing for the installed substation automation system to ensure a constant quality over the life cycle is more and more replaced by the continuous **self-supervision** on the system. The result is **maintenance on demand** only.

3.2 Limits of testing

The application and communication software is running on the most devices without direct access to any of the ISO/OSI layers. Only the input and outputs (binary, analogue, serial, etc.) are visible. Therefore, the complete device has to be tested as a black box. This is in line with the view of the user, which is interested on the confirmed interoperability only.

As stated in [1], exhaustive testing is impractical because of technical and economic reasons.

Note: the testing in this document refers to communication testing only.

3.3 Specifics of testing for application domain substation

Any kind of comprehensive testing looks costly. Regarding the consequential damages of improper running substation automation systems some testing effort is very reasonable as in some other industrial applications. A layered or step-wise approach may keep the effort and the costs at a reasonable level.

4 Conformance testing

To ensure the intended interoperability between all related IED's from different suppliers, proper **conformance testing** of the implementation of the international communication standard is necessary.

4.1 ISO testing methodology

Communication testing in a lot of standards is restricted to the conformance testing of the stacks according to the ISO/OSI methodology [1].

According to [2] conformance tests are performed in a controlled environment and are disregarding factors like network load, time elapsed since power-up and the communication port status. Therefore, this type of conformance tests does not guarantee interoperability.

This paper refers to testing of standards dedicated to interoperability. Therefore, this testing guideline goes beyond the above mentioned conformance testing methodology. Some of the ISO/OSI terms defined in [1] have to be reinterpreted and new terms have to be introduced.

Since the different ISO/OSI layer may be tested separately or group-wise and a lot of implementations refer to these standards, in [1] the term "Implementation under Test" (IUT) is used. Regarding the black box testing mentioned above, the term "Device under Test" (DUT) is more appropriate.

The goal is to test interoperability. Therefore, the stack implementation has to be assumed in conformance, which may be proven e.g. by supplied documents. Effort shall be invested to guarantee interoperability as far as possible based on the domain specific model level and its mapping to the application level (level 7) of the stack. This kind of conformance testing will guarantee interoperability to a large extent in contrast to the pessimistic view of [2].

4.2 Activities to test communication standards for substation

There are activities regarding conformance testing dedicated to the two above-mentioned standard approaches.

- In IEC 61850 there is a part 10 (IEC 61850-10) in preparation (status 2002) which will define conformance testing for this standard.
- An IEEE working group has balloted the standard IEEE C37.115 "Standard Communication Test Scenarios for performance testing" which is focused on IEEE 1525 (status 2002).

4.3 Basic considerations to conformance testing

In general, conformance testing of IEDs communication behavior should address the functional requirements (static test) and performance requirements (dynamic test) of typical applications supported by these devices in a Substation Automation System (SAS). IEC 61850-4 defines a general classification of quality tests, which are used within this report.

Conformance testing demonstrates the capability of the device under test (DUT) to operate with other IEDs in a specified way according to an international standard like IEC 61850.

The role of institutions and test bodies for conformance testing and certifying the results will be discussed in chapter 8.

For conformance testing the following points have to be considered:

- The problem of any testing is the **completeness** of the tests. The number of all possible situations could be very large. To cover all normal operating cases looks possible, but this holds not for the failure cases.
- Since by no means all system configurations possible with IEDs from different suppliers worldwide may be tested, a standardized **test system** with device simulators has to be used. The use of such a test system implies both agreements about its configuration and the test procedures applied to get compatible results.
- A communication standard does not standardize the **functions** of the communicating equipment. Therefore, the failure modes of the functions are outside the scope. But both the existence of distributed functions and the impact of function response in devices on the data flow create some **interdependence**.
- Depending on the definition range of the standard some properties of the device may be proven not by the conformance test itself but by information and **documents** to be provided with the DUT for the conformance testing.

5 Conformance testing procedure

5.1 Introduction

The conformance test has to prove that the communication of the IED under test (DUT = Device Under Test) works according the standard. To prove interoperability **static** and **dynamic** tests have to be performed. Static tests refer mainly to the **device testing**, dynamic tests to the **system level testing**. Both tests together cover also the **functionality** of the communication system.

As mentioned already above, the most existing test descriptions for communication standards are focussed on the stack up to the application layer. There is an explicit warning that also with the conformance tests described interoperability is not provided since the impact of network load, time-out definitions, etc. are not covered by these tests [2].

Modern communication standards, especially IEC 61850, are focussed on the data, function and device models including all services above or at application level (Abstract Communication Services Interface of IEC 61850). The goal of these standards is **interoperability** by definition and, therefore, has to be proven in conformance testing.

Since the IEC 61850 defines no new stacks, the conformance to all 7 ISO/OSI levels may be proven by documentation that certified stack software is implemented according to the selection rules of the standard and pre-tested also. In the standard specific conformance test, the application according to ACSI has to be tested only. But, if the standard defines a direct access to lower layers of the stack for some functions like time synchronization, the relevant features of the lower stack levels have to be tested also. Nevertheless, the proper and unambiguous operation of the complete stack is the prerequisite for interoperability.

5.1.1 Stack conformance

As long as mapping on existing stacks defines the lower layers, certificates of the following classes may cover stack implementation conformance [2]:

- Class 1: physical conformance
- Class 2: Link-Layer conformance
- Class 3: Real-time protocol (RTP) conformance
- Class 4: application interface conformance

- Class 5: network management conformance
- Class 6: profile conformance

The classes are defined in a hierarchical structure: for example, to achieve class 3 conformance, class 1 and 2 should be achieved a prerequisite. To ensure **interoperability** it is necessary to achieve class 6 conformance.

5.1.2 The use of test scenarios and test configurations

Using well-defined scenarios, both the functional and dynamic behavior may be tested properly. Therefore, interoperability is proven with a very high confidential level.

Note 1: For testing the communication capabilities **messages** have to be generated. This means that also for communications testing the (non-standardized) application functions of the device have to be operated in a proper way. This includes hardwired **stimuli** (contacts, voltages, currents, etc.) and stimuli coming over a serial link if applicable. This holds both for static tests and dynamic tests.

Note 2: Testing explicitly the **lower levels of the stack** may be part of an **overall conformance testing procedure** also, but is beyond the scope of this document.

Communication testing needs at least two devices to communicate with each other. True interoperability testing requires that each vendor's product has to be tested with complementary and/or competitive products from all other vendors. The problem is that complementary or competitive products will not always be available for testing, at least not in a comprehensive way. Also if these devices would be available, the endless number of combinations makes a complete testing impossible. Therefore, the test concept has to include **test devices**, **test configurations**, and **test scenarios**. These features will be addressed both in the static device test (see 5.2.5) and the dynamic system level test (see 5.5.2).

Special attention has to be given to **communication equipment** like star-couplers, hubs, etc. which shall support all requested features of the standard but not introduce additional contingencies and limitations.

Also the impact of the **communication method** (client-server, GOOSE, GSSE etc.) used by the standard under test has to be considered properly in the test procedures. Verification of function engineering (use of GOOSE messages) is not part of a conformance test even if advanced tools may offer such analyses.

5.2 Static device tests

With the assumption that the ISO/OSI methodology is focussed on stack testing only, the **static device tests** cover in terms of ISO/OSI [1] the following points.

- **Basic interconnection tests** provide limited testing of a DUT in relation to the main features in a base or a profile specification, to establish that there is sufficient conformance for interconnection to be possible, without trying to perform thorough testing
- **Capability tests** provide limited testing of each of the static conformance requirements in one or more base specifications and if appropriate a profile specification, to ascertain which capabilities stated in the Implementation Conformance Statement (ICS) can be observed, and to check that those observable capabilities are valid with respect to the static conformance requirements

5.2.1 Device hardware

For a review, basic documents have to be provided to show conformance with basic requirements like EMC, safety etc. as found in recommendations or requirements inside and

outside the communication standard. The content is given normally by the specification (data sheet) of the device with a reference to applicable product standards.

5.2.2 Device communication interfaces and the protocol stack

The hardware interface(s) of the DUT must be compliant with the interface specifications cited for the device; e.g., a specification defined in the profile as described for IEC 61850 in part 8-x and 9-x. The hardware interface refers to level 1 of the ISO/OSI model. Same conformance requirements hold also for the other layers of the implemented communication stack.

This part of the device test may be passed by

- answering a Questionnaire
- providing a Protocol Implementation Conformance Statement (PICS)

The contents of the Questionnaire and the PICS have to be standardized.

There may be device specific information outside the scope of the standard to be used for testing, e.g. internal test access points in the device. Also the type of device for testing must be clear. All this is covered by

- providing a description of the Test Configuration of the device hardware
- providing a Protocol Implementation Extra Information for Testing (PIXIT)

5.2.3 Configuration test

Since the modern communication standards are focused on the user application ("user layer") with its data model and services, the proper implementation of this application has to be tested. Since the devices may have a lot of fixed or flexible configurations these configurations have to be accessible and to be tested.

- providing a Model Implementation Conformance Statement (MICS)

Since the formal description of the device configuration (device type description DTD) is a prerequisite for setting up interoperable systems, the static part of this description has to be provided by the device specification and the dynamic part (actual implementation in the system) has to be provided in line with the system configuration as described e.g. by the Substation Configuration Language (SCL) in part 6 of IEC 61850. A device and vendor specific configuration tool may generate this formal description. This tool has to be included to some extent in the conformance test also.

- Prove that the device specific *configuration tool* supplied by the vendor complies with the specifications for device configuration management. This means to test the configuration files on conformity regarding syntax and contents as defined e.g. in IEC 61850-6.
 - Generate configuration file with the device configuration tool according to the standard, e.g. according to IEC 61850-6
 - Check the syntax by an editor with checking facilities

Example for IEC 61850-6: XML Note Pad with DTD (data type definition) check

5.2.4 Verification of communication capabilities

- Prove that all *communication capabilities* (services) are implemented in accordance with the specification for the device; e.g., connection-oriented modes of communication, connectionless modes (multicast or broadcast) modes of communication, file transfer mechanisms as defined e.g. in IEC 61850-7 and IEC 61850-8/9.

- Demonstrate that all required device functions and related *data objects* can be properly managed in accordance with the specification for the device as defined e.g. in IEC 61850-7.
- Feature testing should be used to verify individual commands and capabilities of the application. Feature testing should be performed with minimal to light loads to measure the IEDs interface and application operations or transactions invoked by the client IED.
- Functional testing should be used to verify that the application's multi-IED characteristics and background functions work correctly under heavy loads. Functional testing should be performed under loading that closely models the substation's real-world operating environment.
- Throughput testing should measure data transfer rates (e.g., kilobits per second or packets per second) to evaluate performance and find bottlenecks.

5.2.5 Test equipment

Testing the conformance of the configuration means a tool to read and analyze the configuration files. Testing the communication capabilities means a tool, which simulates the communication network at least in a simple way to test the network access of the DUT. These tools have to provide the communication link to the DUT as a physical point-to-point connection.

These tools may be very compact (PC/Laptop with test SW). Beyond conformance testing this SW may be implemented as part of a maintenance tool used on-site by the supplier (commissioning) and the user (maintenance).

5.3 The impact of dedicated communication methods

The communication method used has some impact on the test setup. This clause applies to communication standards based on the very common server-client approach only.

Products developed to operate in the role of a server have to be tested with a client simulated by the test tool to verify that they perform the required messaging functions in that role. The most points mentioned above refer to server type of devices.

Products developed to operate in the role of a client have to be tested with a server simulated by the test tool to verify that they perform the required messaging functions in that role.

Products developed to operate as a server under some specified conditions, and as a client under some other specified conditions have to be tested with simulated clients and simulated servers that emulate the specified conditions of each.

5.4 Dedicated tests for communication equipment

The basic test steps for communication equipment are the same as mentioned above. Typical communication equipment are the following devices if applicable.

- **Repeaters** provide a signal refreshing on both directions on ISO/OSI layer 1 only (minimum two ports).
- **Star Couplers** behave same as repeaters but are used as physical star with n ports (commonly with o/e and e/o conversion supporting an optical LAN).
- **Bridges** provide all repeater features but additionally perform an address filtering on ISO/OSI layer 2.
- **Hubs** connect as physical star the legs of a LAN with the same features as a bridge; in simple cases they have no more functionality than a star coupler.
- **Routers** provide all bridge features but do also an address based routing on ISO/OSI layer 3 (minimum three ports).

- **Switches** behave like a router but are used as physical star with n ports requiring a very fast operation.
- **Gateways** connecting a LANs with a communication system with a different protocol handling/converts therefore all 7 ISO/OSI layers (minimum 2 ports, never used as star).

Functionality of the communication equipment should be tested to ensure that the proper message handling/routing occurs without errors. Specific tests should include virtual path identifier and virtual channel handling, response to header error control, and verifying proper alarm generation and response.

When checking the performance of the communication system, special test equipment should be used to emulate message traffic and data streaming traffic to verify proper routing through the communication equipment. Special test equipment should also be used to identify all communication traffic at the input and output by scanning the messages and previewing all addresses that are active and storing them for use¹.

The proper testing of switches and hubs cannot be done with the above-mentioned type of tool providing one physical point-to-point link but a complete test system is needed connecting all ports of the communication equipment.

Depending on the communication method used some basic behavior like collision detection in Ethernet type LANs has to be guaranteed also in case of using this communication equipment. These requirements belong to the lower levels of the stack and may be proven by a Protocol Implementation Conformance Statement (PICS). One result may be the maximum allowed number of such communication equipment in series.

For dedicated application in substation automation systems, the data throughput and time delay is important for the system performance, the time jitter for the accuracy of time synchronization. These features have to be tested in the Dynamic system level tests below.

5.5 Dynamic system level tests

To test the conformance with the standard and, therefore interoperability with more than one device, a test system, which simulates the distributed architecture of a substation automation system, is needed.

With the restriction that the ISO/OSI methodology is focused on stack testing only, the **dynamic device tests** cover in terms of ISO/OSI [1] the following points

- **Behavior tests** testing an implementation as thoroughly as is practical, over the full range of dynamic conformance requirements specified in one or more base specifications and, if relevant, within the restrictions of a profile.

5.5.1 System configuration

True interoperability testing requires that each vendor's product has to be tested with complementary and/or competitive products from all other vendors. The problem is that complementary or competitive products will not always be available for testing, at least not in a comprehensive way. Therefore, the test concept must provide a test configuration simulating the target environment. Such a test configuration is shown in [Figure 1](#).

¹ The scan identifies mapping problems up front, providing easy analysis.

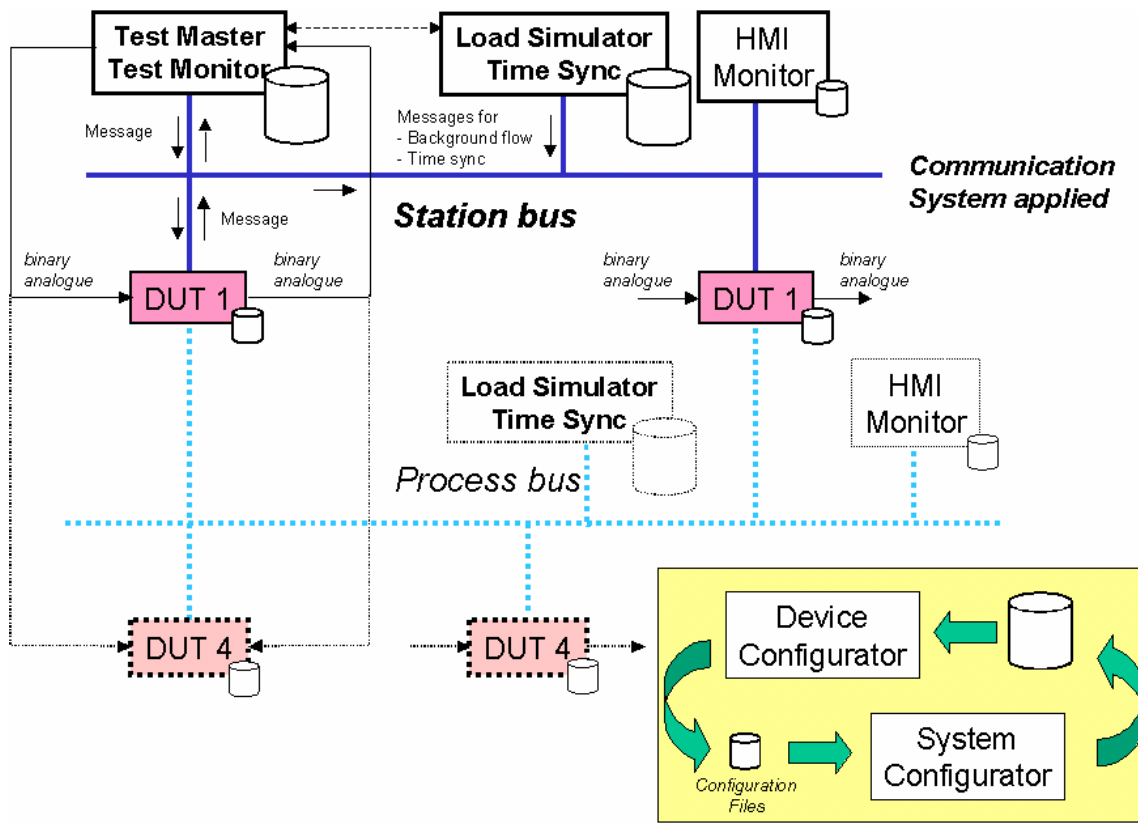


Figure 1 – Test system configuration

5.5.2 Test system

In order to be able to perform a device and system test a minimum test setup is necessary (see Figure 1). Beside the DUT, a simulator which acts as a client and server is required to initiate / generate messages and is recording / processing receiving information. The role of the simulator is described in 5.5.3. Background load on the network should be provided by an additional load simulator, which may also contain a master for time synchronization (the time sync master). Requirements for both parts of the test system are defined in section 5.5.4 and 5.5.5. An optional HMI on the network may be used for an independent monitoring of the test system. It may include a network monitoring facility and the engineering software on system and device level. System tests are based on the data flow between distributed functions. Therefore at least a second DUT has to be included in the test system.

In case of a standard with a client-server approach the test system has to provide connection points for server devices, for client devices and for devices acting as both.

The test system has to be documented regarding the following points:

- Test configuration of the test system hardware
- Test configuration of the test system software

- Test simulator / Background load simulator / Time sync master

5.5.3 Test simulator

The test simulator must be able to create **messages** to stimulate the DUT and other **stimuli** (binary and analogue inputs if applicable). These messages may be created by user control, batch processes, on events from physical inputs or any combination. Parallel physical outputs should be provided in order to trigger DUTs by physical state signals if applicable. Those outputs must provide state changes without bouncing effects. The transfer of information has to follow the mechanism of the network; e.g. client/server architectures have to use the subscribe/report procedure.

As the test system is running in a closed loop the data flow on the network during the test sequence has to be monitored by the device. In addition physical inputs have to be monitored if the DUT is providing physical state signals. Those signals have to be time tagged with an appropriate resolution and accuracy. Each test sequence should provide a test report with the related data flow and physical I/O states.

To ensure correct behavior of DUTs regarding message contents, the test simulator must be able to create messages with freely configurable attributes (quality, timestamp, value).

5.5.4 Background load simulator

To establish a proper data flow for various network load conditions, the simulated network load must be adjustable to defined load figures. In case of non-deterministic networks the average load must be settable. The range should be adjustable to maximum applicable load. The background load simulator may be integrated into the test simulator or work as a stand-alone device.

5.5.5 Time Sync Master

The master for time synchronization (time sync master) is a key element in the test system. All tests concerning performance and time resolution/accuracy are based on the accuracy of this master. The accuracy of the time sync master should be ten times better than the expected accuracy of the DUT. This statement is also valid for internal clock accuracy of the test simulator or the network monitor. The time sync master may be a part of the test simulator, the background load simulator or an external device.

5.5.6 Engineering tool as part of the test system

To build up the test system with simulators and to connect properly all DUTs, an engineering tool is needed. This tool has to be able to import, process and export the configuration and system data according to the standardized formal configuration description if applicable. In case of IEC 61850, this description is defined as Configuration System Language (SCL) in part 6.

The prerequisite to handle the DUT in a system is that it has passed the static device test, especially according to 3.1.3. In the case of device specific setting tools data exchange of settings between the engineering tool and the setting tool has to use the standardized configuration description as well.

5.5.7 Test of connectivity

Loss of communication due to power-off, blocking of devices etc. must be detected by the communication system in order to avoid faulty system behavior. Depending on the communication system the algorithms to detect loss of communication may vary in a wide range. The test of connectivity should force a DUT in a system test to block the communication link. All other devices inside the system which are using information provided by this DUT should recognize the loss of communication within a specified time period. The behavior of applications following a detected loss of communication is depending on the application itself and not part of the test described here.

5.5.8 Interoperability testing and its limits

Statements on interoperability must be based on the communication behavior and could not guarantee the correct operation of a distributed function with two different devices due to incompatible algorithms inside applications. The interoperability in this sense is achieved, if a DUT is acting as specified on external messages/events with the desired performance. The test of compatibility of full applications in ordered/delivered systems is subject to FAT and SAT.

5.5.9 Performance tests

Performance tests are the most critical tests inside conformance tests. The following sections are describing general requirements for this kind of tests. To ensure that those tests are not influenced by the application tests should be carried out from stack to stack. In reality, this approach will be difficult to realize. It would require specific device behavior to allow access to the internal interfaces between applications and communication stack inside a DUT. This interface should be a part of the standard, which is not achievable. Due to this, the tests have to be performed in a more realistic environment, which allows monitoring the overall DUT response (state change/message) on external information (message/event).

Due to event driven messages, non-deterministic stack latencies and variant bus loads performance tests should be repeated to evaluate statistical parameters (variance, standard deviation) of the results. The accepted limit for these figures should be part of the acceptance criteria.

5.5.9.1 Test requirements

- Communication *response time* must be measured from the time that an IED application sends a message to the time that another IED application receives the message.
- Test drivers and background environments may be simulated or induced by other instrumentation, which is not part of the DUT (*test simulator*).
- Reaction with test set
- Since the communication behavior is dependent on the communication activities in the system, any dynamic testing has to be based on proper *scenarios* (test cases)

All performance measures should be defined in accordance with a standardized or agreed specification. In general, the following communication times should be measured:

- Message delivery time should be measured in terms of the time required to send a message from the sending application interface to its receipt at the receiver application interface (this is the sum of a + b + c described in [Figure 2](#)).
- Functional performance should measure the time required to communicate, from the sender to the receiver, the information needed to execute the specified function, plus the time to execute the function



Nevertheless due to practical reasons those measurements have to be performed on accessible indications. Time tagging of information entering a stack of a receiving application might be possible during development of a device but not in a real installation. Therefore, all test must be done with a strong link to the device/system application. While the user of a system is interested in the overall system performance and application dependant functional performance, the supplier or integrator might be interested in the performance of the communication system. Both views could be covered by the same test setup. In the first case, user defined functions could be monitored under reference conditions while the communication system test should use test applications with a negligible or well defined response time. Therefore all devices should provide such standard functions which allow creating a time-tagged message on a configurable event with a specified response time. Monitoring the initial event and the response allows evaluation of the DUT system performance. To achieve the initial approach, the supplier has to specify delay

times of applications, which will be taken into account in the final evaluation of the response time. Due to real time behavior of DUTs more than one test should be performed to evaluate mean and maximum values. Statistical methods should be used for final reporting.

5.5.9.2 Response time definition

Response time is specified in terms of the time when the message leaves the sending IED application to the time when the receiving application gets the message. Figure 2 shows time components that define the time requirement. Application-to-application time is defined as the sum of the times required for the sending IED communication processor to accept the data from the sending application and exit the output queue of the sender “a”, plus time over the communication network (including processor time required by routers, bridges, gateways, etc.) “b”, plus the time required for the receiving IED communication processor to extract the message content and present it to the receiving application “c”.

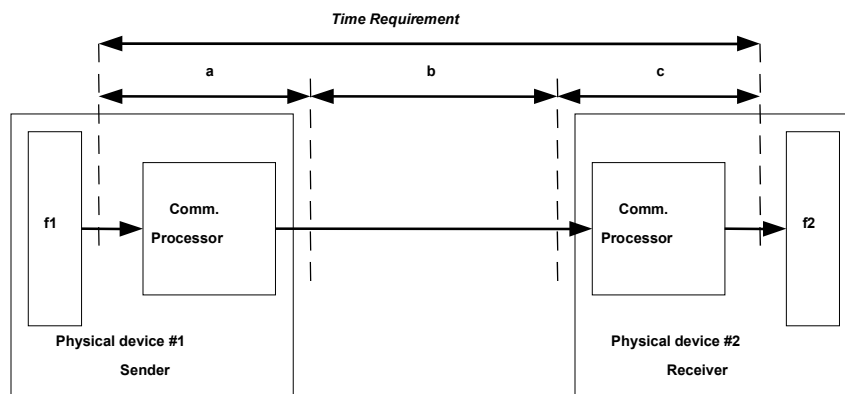


Figure 2 – Definition of Response Time ($a + b + c$)

Application response time testing should be used to measure how long it takes an application to complete a series of tasks, and best represents the utility's perception of the network system (application network operating system and network components).

For a presentation layer, the test should measure how long it takes to switch between different applications tasks or to load new overlays.

Tests should be run at various loads, numbers of real or emulated IEDs, to create a load versus response time curve for each application tested.

Application tests should use a series of commands that execute typical network activity, such as file open, read, write, search, and close to provide an representative load model. The time it takes to complete commands should be measured for each workstation or IED running under test.

Response time testing should include monitoring the system for reliability. A reliability problem, such as a high number of dropped packets at a router or server, or a high number of bad packets

because of a malfunctioning network component, can significantly impact response time measurements.

Network analyzers should be used to monitor the system for errors during testing.

5.5.10 Reliability testing

Reliability testing forces the DUT or the communications network to handle in a compressed time period the activity it would normally experience over weeks, months, or years in a production network. Reliability testing attempts to accelerate failure of the IED communication processors or other communication network devices caused by:

Cumulative errors that result from repeating an operation multiple times in a fashion that result in an error.

Timing errors caused by two time-dependent operations that occur out of sequence or without the proper delay.

Statistical errors resulting from the probability that a highly unusual error condition will occur or a seldom-invoked sequence of events will occur².

Tests should be performed to check the reliability of the communication network's ability to handle faulty traffic. Graceful recovery from a loss of signal, loss of synchronization, or discarded traffic should be included in these tests.

Reliability tests should be run for an extended period of time (24 to 72 hours), under medium to heavy load to monitor the network for errors and failures.

5.5.11 Test cases and test scenarios

The real situation in a substation automation system on-site may be very complex with a lot of parallel processes. To make a realistic dynamic conformance testing, the most common standard situations have to be covered by **test cases**. The **abstract test cases** shall be defined according to real world **scenarios**. How the abstract test cases are transformed into **executable test cases** depends on the test system. The test cases shall be defined in such a way that the results are independent of the test system as far as possible.

Same holds also for reliability testing.

5.5.11.1 Determining the range of parameters, input and output values

The following chain of three data groups represents the complete communication dynamics of an IED: Input → IED (Parameter) → Out

Each **parameter** that defines the characteristic to be tested should be defined in terms of its operational range of values.

Input values for each parameter should be selected on the basis that the output results are deterministic.

The **output values** may not be known precisely, but it should be described in terms of expected results.

Input/output on the serial communication link are deterministic or stochastic message flows.

Input and output values may be realized by physical contacts and wires also if applicable.

² In developing and testing a complex substation automation system, it is virtually impossible to test and verify every possible path through the software code. Reliability testing increases the probability that a statistical error will occur.

5.5.11.2 Rules for scenarios

There is a need to verify that the rules are “correct” by applying them to selected scenarios. The examples that demonstrate the verification of rules should be taken from the standard if applicable (e.g. Appendix of IEC 61850-5) and include

- Background and test drivers (functions-not-under-test)
- Function-under-test and the background (functions-not-under test)

5.5.11.3 Definition of Scenarios

The scenarios (abstract test cases) have to be defined in such a way that they

- are easily applicable for testing all dynamic requirements,
- support the evaluation criteria,
- cover the definitions and requirements of the standard in a representative way.

5.5.12 Evaluation/Acceptance Criteria

The intent is to show how all requirements are **testable** under specified background loads.

Evaluation criteria for testing the Device-Under-Test (DUT) include:

- Specific design characteristics to be validated.
- Checkpoints identified for anomalous conditions.

There are always three possibilities for a test result according to [1] i.e.

Pass (verdict) - A test verdict given when the observed test outcome gives evidence of conformance to the conformance requirement(s) on which the test purpose of the test case is focused, and when no invalid test event has been detected.

Fail (verdict) - A test verdict given when the observed test outcome either demonstrates nonconformance with respect to (at least one of) the conformance requirement(s) on which the test purpose of the test case is focused, or contains at least one invalid test event, with respect to the relevant specification(s).

Inconclusive (verdict) – A test verdict given when the observed test outcome is such that neither pass nor fail verdict can be given. Such a result should be always resolved to find out if this behavior results from the standard, from the implementation or from the test procedure.

6 Feedback

Because of the possible complexity of the systems and changing technologies and applications, both the test experience and field experience shall be reported back either for future revisions of the standard or for improvements of the test system or the test procedure. Independent who is doing conformance testing, the feedback procedure has to be formalized in some way. Feedback should be shared between all interested vendors, test bodies and users and used to create recommendations. Setting up a user group may be an appropriate method to allow future improvements of the communication standard. In addition, this could help to manage uncertain items on implementation or certification.

7 Tests beyond conformance testing

In the ISO/OSI methodology the Conformance resolution test [1] is also restricted on stack testing only. For Conformance testing according this report, it may be re-defined in the following way.

Conformance resolution tests being non-standardized, possibly system-specific tests to fulfill test purposes for which standardized abstract tests cases are not defined. They may be used to complement the standardized tests used in the conformance assessment process, in order to investigate the behavior of a DUT with respect to particular conformance requirements. Because of its special conditions it is outside the Conformance testing.

In the overview, the **Factory acceptance test (FAT)** and the **Site acceptance test (SAT)** of an ordered/delivered system is mentioned. These tests are outside the scope of this conformance testing guideline.

8 Certification

Conformance testing should be done according well-defined and widely accepted procedures. To facilitate these definitions and to get this acceptance testing should be standardized together with the communication standard itself. Standardized testing will also support the production of comparable results in test laboratories all over the world.

The result of conformance testing will be always a certificate. The legal aspects of the certification procedures are outside the scope of this guideline and controlled by regional or national bodies.

There may be a costly impact of non-conformant devices in a system on human safety, device integrity and power delivery, certification by independent laboratories is highly recommended. Certification gives no 100% guarantee but is reducing the risk on non-interoperability with all consequences considerably.

9 Conclusion

There is a lot of sophisticated task involved in conformance testing, i.e.

- general aspects related to testing,
- basic aspects related to application domain substation,
- dedicated conditions depending on the standard under consideration.

According to the definitions of the standard(s) for communication in substations, the goal of conformance testing is

- to prove interoperability (which really cuts cost down)
- to test with reasonable costs (not to jeopardize the cost cutting)

The real world supplies scenarios which have been translated into

- abstract test cases and implemented as executable test cases.
- step-wise testing to control the cost
- comprehensive test set-ups

The testing has to be based on a

- test plan with pass criteria

Independent test laboratories for certification may help

- to reduce risks and fights on site regarding interoperability
- to reduce consequential damages

Annex

A1 Test Plan with Pass Criteria

The test plan should consist of two sections. A general section should contain information about the test laboratory, the test system and the general test procedure.

The test specific section of the test plan lists all test steps applied to the DUT. Each test step is identified by an individual designation, the version control of the test step and a reference to the basic documents. A short description of the test step, the related test setup, a reference to the scenario and acceptance criteria applied are necessary to ensure traceability of the test. The result of each test step should be recorded and may be accomplished by comments.

A2 Test cases

A2.1 Substation Example

1. Voltage levels 380 kV/110 kV (see Fig.2)
2. 380 kV
 - 2.0 Double busbar with bypass
 - 2.1 Measuring bay C1
 - 2.2 Line bay C2
 - 2.3 Bus coupler C3
 - 2.4 Transformer bay C4
3. 110 kV
 - 3.0 Double busbar
 - 3.1 Transformer bay E1
4. Logical Nodes of the related Substation Automation System (simplified example)
 - 4.1 Measuring bay C1
 - Busbar CT and VT (TCTR and TVTR)
 - Measuring unit (MMXU)
 - 4.2 Line bay C2
 - Circuit breaker (XCBR)
 - Isolators and grounding switches (XSWI)
 - Line CT and VT (TCTR and TVTR)
 - Switch controller (CSWI) per switch
 - Measuring unit (MMXU)
 - Distance protection (PDIS)
 - 4.3 Bus coupler C3
 - Circuit breaker (XCBR)
 - Isolators and grounding switches (XSWI)
 - Line CT and VT (TCTR and TVTR)
 - Switch controller (CSWI) per switch
 - Measuring unit (MMXU)
 - Overcurrent protection (PIOC)
 - 4.4 Transformer bay C4
 - Circuit breaker (XCBR)
 - Isolators and grounding switches (XSWI)
 - Line CT and VT (TCTR and TVTR)
 - Switch controller (CSWI) per switch
 - Transformer (YPTR) *not considered in what follows*
 - Measuring unit (MMXU)

A2.2 Communication system

The communication system is assumed to consist of one Station bus and one Process Bus (see Figure 3). The consequences both of a breakdown of the process bus in many and the merger between the station bus and process bus can easily be derived from the example.

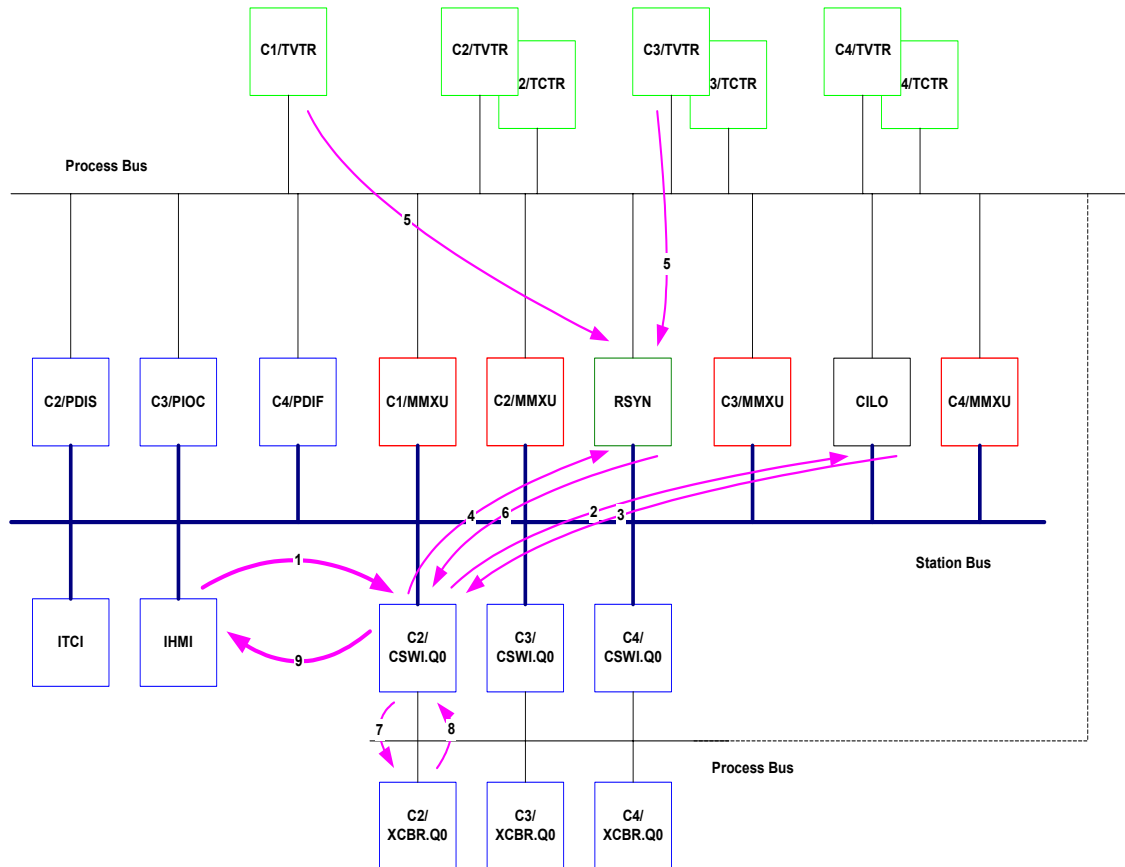


Figure 4 – Principle scheme of communication scheme in substations both with station bus and process bus. The abbreviation for the functions are according to the Logical Node names from IEC 61850

A2.2.1 Station bus

connected to
IHMI, ITCI, RSYN, CSWI, MMXU, PDIS, PIOC, PDIF, CILO
for transmission e.g. of
Position indications, Commands, Releases/blockings, Measurands, etc.

A2.2.2 Process bus

connected to
XSWI, MMXU, PDIS, PIOC, CSWI, XCBR, XSWI, TCTR, TVTR
for transmission e.g. of
Samples, Trips, Commands, etc.

A2.3 Message flow in the Communication System

A2.3.1 Station bus

Command from IHMI to CSWI

Single status changes of the switchgear from CSWI to IHMI

Single status change from CSWI to CILO

Release/block from CILO to CSWI

All actions results all in one message independent from the number of IEDs connected to the bus.

In terms of IEC 61850 these messages are named GOOSE/GSSE. One of these GOOSE/GSSE is started per device (IED) at any change with repetitions with increasing time interval, i.e. from 1 ms (min) to 1 s (max) → only the first GOOSE/GSSE contributes to the load/performance → low load.

Note: If there are very many GOOSE/GSSE messages in the background with the maximal repetition time, these may contribute heavily to the total load on the bus → high load

b) In case of a busbar trip

- GOOSE/GSSE messages from protection devices and from circuit breakers via CSWI are started nearly at the same time with min. repetition time → high load dependent on the number of bays (one bay controller per bay).

- GOOSE/GSSE messages from the central CILO are restarted in a very short time following the fast changing interlocking conditions having all the min. repetition distance of 1 ms → high load dependent from the number of bays.

Note: therefore, RSYN is representative also for Busbar protection (PDIF/*busbar*), Interlocking (CILO) or, more generally, for all topology dependent functions (logical nodes).

A2.3.2 Process bus

a) Samples from TCTR and TVTR to PDIS, MMXU, etc.

Sample rate constant → load constant for constant number of CTs and VTs

Depending on the number of devices producing samples

One process bus per substation or one process bus per bay

Minimum number of messages:

One merging unit per bay → one message per bay and sample → load depending on number of bays

Maximum number of messages

CTs and VTs connected directly to process bus → one message per CT and VT and per sample → load depending on number of CTs and VTs

b) Command or trip or status indication

- additional load neglectable

- response time to be guaranteed at any load situation

A2.4 Other services running over the bus

- Standard client-server dialogs are not time critical compared with the message traffic mentioned above.
- Maintenance operations like file transfer are not time-critical at all.
- System services like time synchronization are contributing to the background traffic on the bus

A2.5 General requirement for test cases

- The number of devices per bus has to be standardized for conformance testing
- The behavior of the system with the delivered number of devices per bus has to be verified at the factory and/or site acceptance test

A3 Acceptance criteria

Acceptance criteria for performance tests could be grouped into five categories. These categories are based on overall performance requirements given by power network behavior, human behavior or implemented algorithms.

A3.1 Automatic functions (Example: Synchrocheck)

Coupling of two independent power networks requires previous synchronizing (active by f/V regulation or passive by condition monitoring). The overall requirement is given by the max. time span when specific conditions ($\Delta\phi$, Δf , ΔV) are fulfilled. The following equation is detailing this condition:

$$(1) \quad t_{\text{syn}} = (2 \cdot \Delta\phi) / (360 \cdot \Delta f) \geq t_{\text{CB}} + t_{\text{RSYN}} + t_{\text{CSWI}} + t_{\text{XCBR}} + t_{\text{comm}}$$

As t_{syn} is strongly dependant on the power network characteristics (topology, short circuit power,...) t_{comm} has to be defined according to predefined parameters. Two examples are given below:

- $\Delta\phi = 30^\circ$; $\Delta f = 0,1 \text{ Hz}$ $\Rightarrow t_{\text{syn}} = 1,7 \text{ s}$ (transmission networks)
- $\Delta\phi = 30^\circ$; $\Delta f = 1 \text{ Hz}$ $\Rightarrow t_{\text{syn}} = 170 \text{ ms}$ (IPP interconnection)

Assuming a closing time of a circuit breaker of approximately 80 ms the relationship between the time delays within logical nodes and communication became quite important in the second case.

In this specific case of an automatic function the acceptance criteria is derived from the result of the equation (1) given above.

A3.2 Protection function (Example: Intertripping)

Hard-wired schemes for conventional intertripping between protection relays are providing a delay of approx. 8...15ms due to the closing time of the relay and the delay of binary inputs. Therefore intertripping via serial links based on GOOSE/GSSE messages has to be transmitted within 4ms to allow a first recognition of the message by the receiving logical node of the second repetition.

A3.2.1 Command response time

The command to operate a switch (circuit breaker/isolator) shall be performed within the human operator time scale, i.e. **1 s**. It refers to the complete time communication chain including back indication

IHMI $\rightarrow$ (station bus) $\rightarrow$ CSWI $\rightarrow$ (process bus) $\rightarrow$ XCBR/XSWI and reverse
It is assumed that all external block/release information is provided without additional time delay to CSWI.

A3.3 EMS support time

The substation automation system has to provide rms values of current and voltage for the support the remote energy management system (EMS) for state estimation. This means that the values at the telecontrol interface (ITCI) have to be not older than an agreed value.

This value is normally **15 s**. It refers to the complete communication chain:

TCTR/TVTR → (process bus) → MMXU → (station bus) →ITCI

A3.4 Background repetition limit

If there are very many GOOSE/GSSE messages in the background with the maximal repetition time, these may contribute heavily to the total load on the bus → background load. This load is depending on the number of GOOSE messages.

Bibliography

[1] ISO/IEC 9646-1 (1994-12) Information technology – Open Systems Interconnection – Conformance testing methodology and framework – Part 1: General concepts

[2] IEC 61375-1 (1999-09) Electric railway equipment – Train bus – Part 1: Train Communication Network

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