

IEEE C37.115-2003 Standard Test Method for Use in the Evaluation of Message Communications between Intelligent Electronic Devices in an Integrated Substation Protection, Control, and Data Acquisition System

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A standard test method, including evaluation criteria, performance measures, and test scenarios for communication between intelligent electronic devices (IEDs) that implement substation integrated protection, control and data acquisition is defined in IEEE C37.115-2003 [1]. Test scenarios are used to describe what data is exchanged between IEDs to perform a specific function that may be distributed between IEDs. All test scenarios use a standard Unified Modeling Language and a core reference model to build-out an implementation.

1 INTRODUCTION

The Power System Relaying Committee (PSRC) of the IEEE Power Engineering Society sponsored the development of a standard test method for evaluation of communication performance between Intelligent Electronic Devices used in electric power substations. After several years of development and peer review through the IEEE standards process, IEEE C37.115 [1] "Standard Test Method for Use in the Evaluation of Message Communications between Intelligent Electronic Devices in an Integrated Substation Protection, Control, and Data Acquisition System." was approved as a standard in 2003.

This paper describes functional/performance requirements, application response time evaluation criteria, and general test requirements. Test scenarios are used to describe what data is exchanged between IEDs to perform a specific function that may be distributed between IEDs. All test

scenarios use a standard Unified Modeling Language (UML) and a core reference model to build-out an implementation. An overview of the modeling tools and an example – synch check to close a breaker – is described to illustrate how the functionality is specified with sufficient detail to apply the standard test method of C37.115.

2 OVERVIEW

There are currently no coherent communication modeling, terminology and communication test scenarios for the evaluation of one or more implementation concepts for communication between substation IEDs within a substation or between a substation and remote IEDs. C37.115 developers addressed this issue by focusing their attention on mapping the functional and performance requirements to an abstract object model. Using the object model, transaction sequences were developed to characterize the interaction between IEDs. From the analysis of the transaction sequences, C37.115 developers were able to identify and characterize the test concept and requirements, as well as develop a specification for application response time testing.

Several communication network structures are used in C37.115. Near real-time information transfer between IEDs within a substation, over the substation Local Area Network (LAN), is one communication network structure. Another structure for control and monitoring uses the utility's Wide Area Network (WAN) for communication between the control center or technical services center and the substation. And a third structure includes the transfer of information between two utility communication networks or between the utility WAN and the customer's WAN. All three structures are used in the scenarios described in the annexes of C37.115.

Another PSRC working group developed a wide range of future applications that could take full advantage of the information available from substation automation and the use of advanced communications. Their results were

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reported in an IEEE report [2], “Application of Peer-to-Peer Communications for Protective Relaying.” Each of these applications included a functional description of the architecture and the communication performance requirements unique to that application. A more comprehensive list of communication performance requirements is available in IEEE 1646 “Standard Communication Delivery Time Performance Requirements for Electric Power Substation Automation” [3].

To illustrate the process, one example from C37.115 is discussed in this paper: Synch check to close a breaker uses a high performance substation LAN for the transmission of synch check voltage information to the synch check relay IED, and the transmission of the “Synch Close” message to the breaker IED.

Consider this case in a breaker and a half substation with conventional wiring. Assuming redundant bus voltage transformers (VTs), and that the center breaker in a breaker and a half substation is the one to be closed, four sets of bus voltages would have to be wired to the dedicated synch check relay for that breaker. In a ring bus, the possibilities are even greater for multiple VT sources. In either case, without a substation host, it would be difficult for the synch check relay to determine which bus voltage source to use for synch check information. Further, a separate synch check relay would be required for each breaker to be synch check closed.

With the LAN approach, one or two (for redundancy) synch check relay IEDs can serve the entire station. The benefits are simplified wiring to synch check relays, and added flexibility in selecting bus side VTs.

3 FUNCTIONAL AND PERFORMANCE REQUIREMENTS

The use of distributed voltage measurements for synch (synchronism) check over a substation LAN can only be achieved if a number of requirements are met. The hypothetical substation in question includes the following:

- An IED (Intelligent Electronic Device) hard wired⁴ to each breaker for control (trip and close)
- Protection IEDs hard wired to their input VTs
- Measurement IEDs hard wired to bus VTs
- IED to IED communication is via a substation LAN
- A LAN delivery time performance, application to application, of 4 milliseconds or less
- A substation host with up-to-date topology information of the substation components

The synch check function is used to ensure that a breaker will not be closed if the power systems on both sides of the breaker are not already synchronized. The function measures the angle between single-phase voltages on each

side (bus and line) of the breaker, and the slip rate, to determine if they are within the limits set. The function may be programmed to allow closing if there is either a dead bus or a dead line condition.

A utility’s overall transmission system design and operating procedures define which breakers, when commanded to be closed, must first be subjected to synchronism check. This is pre-established and, in today’s substations, the synch check relays are hard wired to the correct VTs and breakers.

For our example of synch check to close a breaker, the performance required is dictated by time tagging the positive going voltage waveform zero crossings to the nearest 100 microseconds and to a common time reference (100 microseconds corresponds to approximately 2° on a 60 hertz sine wave). Note: This requires the clock in the VT IED to be set to $\pm 10 \mu\text{s}$, which may require a separate timing wire from the substation master clock to the VT IEDs or the use of IEEE 1588 [4] to set the IED clocks.

The high performance LAN in Figure 1 is shown with only those IEDs necessary for the synch check of a selected breaker.

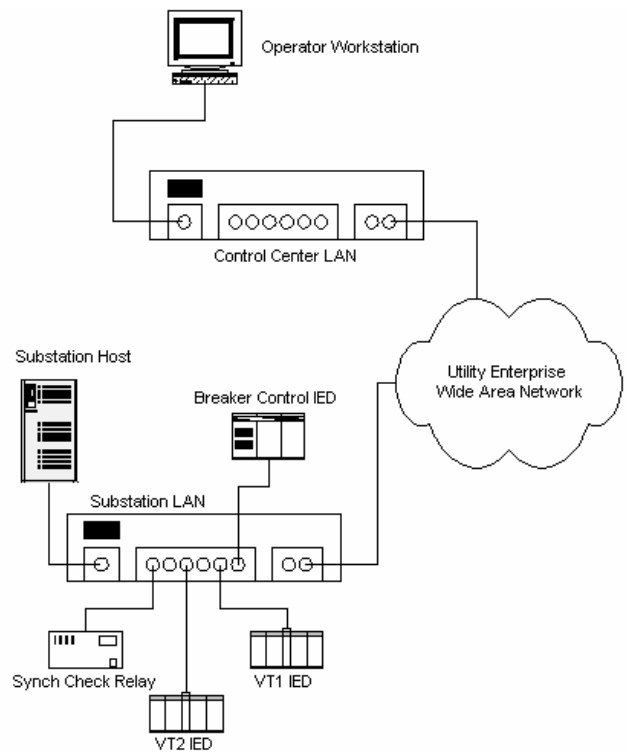


Figure 1 Synch check to close a breaker

The synch check function requires the following capabilities from each substation component.

- The substation host determines the proper VTs to be used.
- The VT IEDs time tag the zero crossings of the two voltages (bus and line) to $\pm 0.1 \text{ ms}$, calculate the voltage and frequency information, and send the required messages.

⁴ Direct metallic connection via individual wires

- The synch check relay IED interprets the time tag messages and issues the required Synch Close message.
- The breaker control IED receives and properly responds to the required messages.

Only the breaker IED and the two VTs needed are shown in Figure 1. In an actual substation, there will be many breaker, relay, and VT IEDs. Depending on which breaker is to be synch check closed and the substation topology, a unique pair of VT IEDs would be used for bus and line side voltages.

4 APPLICATION RESPONSE TIME EVALUATION CRITERIA

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”. Time requirements are specified in IEEE 1646 [3] .

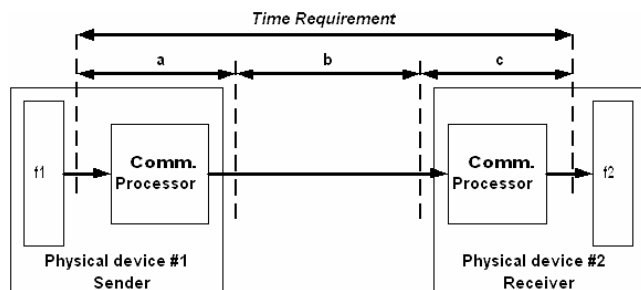


Figure 2 Application to application communication times

C37.115 requires that application response time testing 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). Testing should include:

- Measurements of how long it takes to switch between different applications tasks or to load new software 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 opens, reads, writes, searches, and closes to provide a

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 GENERAL TEST REQUIREMENTS

C37.115 requires that interoperability tests be conducted to evaluate product communication capability. Testing to evaluate the product for its performance, as a power system device, is not within its scope. C37.115’s interoperability test method defines:

- Test concepts and requirements, performance measures for testing the device(s)-under-test (DUT)
- Evaluation requirements for determining whether or not the DUT performed its communication functions correctly
- Information that should be provided in the procurement specification
- Information that should be provided by the device vendor

While a single set of communication interoperability tests applied to all products might seem an ideal approach to testing power system devices, the wide range of products required for substation automation precludes the application of a blanket test set. However, there are sets of services required for all products and those services will be tested in all cases. Beyond the required services, interoperability testing should be customized for each product based on the services identified in the Protocol Implementation Conformance Statement (PICS), Protocol Implementation Extra Information for Testing (PIXIT) and Model Implementation Conformance Specification (MICS) provided by the vendor.

True interoperability testing requires that each vendor’s product 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. Therefore, the test concept must provide an environment simulating the target environment using products from the vendors of the communications software.

- Given these initial conditions, products developed to operate in the role of a Client should be tested with simulated servers to verify that they perform the required messaging functions in that role.

- Products developed to operate in the role of a Server should be tested with simulated Clients to verify that they perform the required messaging functions in that role.
- Products developed to operate as a Server under specified conditions, and as a Client under other specified conditions would be tested with simulated Clients and simulated Servers that emulate the specified conditions of each.

6 SYNCH CHECK LAN OPERATION OBJECT MODEL

C37.115 describes in elaborate detail the full development of the object model for each scenario. Object models are described for remote operation and substation operation. The component models for substation operation include line side and bus side transformers IEDs, synch check relay and breaker IEDs, and substation LAN interfaces.

For example, Figure 3 shows the substation LAN operation for the synch check scenario. SubstationHost is required to provide an interface to the WAN, and to maintain all knowledge of the substation's topology, device operating parameters and configuration data.

EmbeddedDeviceController is implicitly part-of each BusSideVT, LineSideVT, Relay, and Breaker to provide the communication interface to the substation LAN for all IEDs.

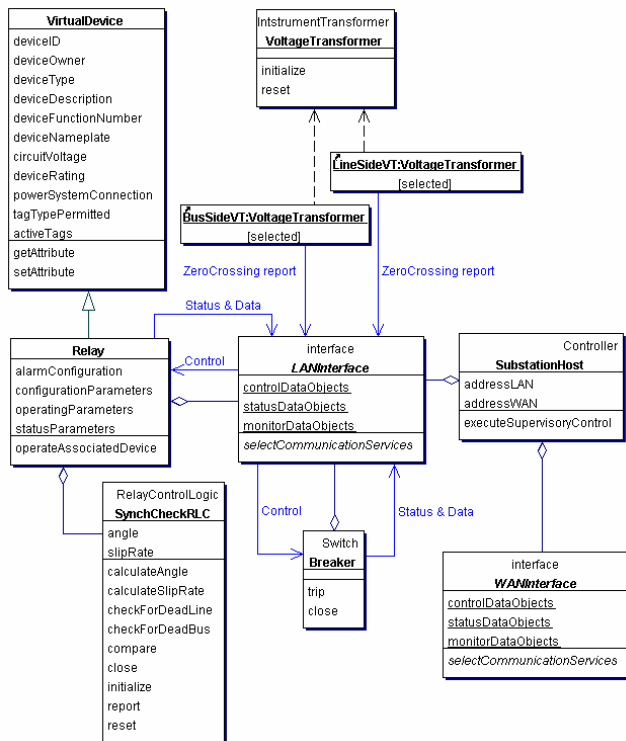


Figure 3 LAN operation object model

The two instrument transformers IEDs (LineSideVT and BusSideVT) are selected by the SubstationHost to provide voltage measurements to the SynchCheckRCL IED to

calculate the single-phase angle between the voltages and slipRate. The Breaker IED is responsible for responding to the close command issued from the SynchCheckRCL IED to close the breaker.

7 SYNCH CHECK TRANSACTION SEQUENCES

Several transaction sequences are described in C37.115 to implement the synch check scenario. Each sequence is shown graphically with descriptive text. The first two sequences show the operator-initiated SBO transactions to select the breaker for close followed by enabling a permissive close.

Select-before-operate (SBO) is a two-step procedure. First, the device must be selected. Second, after confirmation that the device has been selected, the device can be operated. For the synch check scenario, operate is defined as an operator-initiated permissive close. SBO may be implemented in one of two ways: Local SBO and End-to-End SBO.

If Local SBO is implemented, both steps of SBO are processed within RemoteController before a message is sent to SelectedBreaker. Or if End-to-End SBO is implemented, then each step is completed with SelectedBreaker in the loop. For the synch check scenario, End-to-End SBO is used so that after SelectedBreaker receives and validates the 'select', all other operators are locked out of operating breaker close. All operator displays will be updated to show that the breaker is selected and cannot be operated except by the validated Operator. This condition will exist until the breaker is closed or the operation has timed-out.

Eight sequences are described next to show the synch-check transactions supervised by SubstationHost that result in the synch-check relay sending a command to close the breaker.

7.1 Operator-initiated select for breaker close

First, consider an operator initiated breaker close command. The breaker in question is one previously identified as requiring synch check before closing. The operator might be at the remote SCADA master or at a substation console. In either case, the command is sent to the substation host.

From the one-line diagram on the remote workstation computer, Operator selects the breaker to be closed. For this scenario, the operatorID (and security keys) are predefined as 'valid' to execute breaker close.

RemoteController then issues a 'close.select' message over the WAN to SubstationHost to select the breaker to be closed. From its database, the substation host knows that the breaker requires synch check and the synch check parameters for that breaker. From its database of substation topology, it also knows which VTs should be used for the synch check function for the present topology. Then SubstationHost sends a 'close.select' message over the LAN to SelectedBreaker. After receiving the message from SubstationHost, SelectedBreaker internally verifies that

Operator (operatorID) has the authority to close the breaker. If not, SelectedBreaker would return an error message and the breaker would not be selected.

Operator access is verified, and SelectedBreaker sends a multicast message 'report (close.select=enabled)' over the LAN to SubstationHost and over the WAN to RemoteController that Operator selected it for breaker close. When the 'report (close.select=enabled)' message is received, RemoteController internally update the display for Operator. Operator now knows that SelectedBreaker has been selected for breaker close.

When an IED's state changes, it sends a multicast message defining its new state. The state change multicast message is repeated for reliability, at geometrically increasing intervals out to a maximum of 1 minute. Thus, every IED in the substation will report its state at least every minute. Any state change will cause a new state change message to be multicast on the LAN. The substation host receives all these multicast messages to maintain its database.

As stated earlier, the multicast state change message is sent from the breaker IED indicating that it is in the "Selected" state. This is the first step in an SBO sequence. In this state, the breaker is locked out from any other SBO operation, and will not respond to a close command from any other SBO source. If the "Select" operation had been initiated from a remote HMI, the substation host would forward the new state information to that HMI.

The last step of the transaction sequence is to initialize an internal countdown timer within RemoteController. This countdown is a time-out for the operator to send the close permissive message to SelectedBreaker. If the operator does not send the close.permissive message within the time-out, RemoteController will automatically send a message to SubstationHost to deselect the breaker.

7.2 Operator-initiated permissive close

C37.115 describes the transaction sequence for an operator-initiated permissive close. When permissive close is enabled, the synch check function is initiated. When specific conditions are satisfied, SynchCheckRCL will issue a close command to the selected breaker.

The transaction sequence to verify and enable the object SelectedBreaker (of class Breaker) for 'close.permissive' is very similar to the sequence previously described. When SelectedBreaker receives the message to 'close.permissive', it must first verify that the Operator is authorized to initiate this action. If not, SelectedBreaker returns an error message. If Operator is authorized, then close.permissive is enabled.

A time-out (predefined in RemoteController) is included in the message to SubstationHost. When SubstationHost selects SynchCheckRelay it will pass the timeout to SynchCheckRelay. After SelectedBreaker enables 'close.permissive', the countdown to close the breaker begins. If SynchCheckRelay does not send a breaker.close message to SelectedBreaker within the timeout,

SubstationHost will cancel the synch check operation by sending the appropriate messages to the selected VTs, SynchCheckRelay and SelectedBreaker.

7.3 Select synch check parameters

Within the substation, only SubstationHost knows the detailed topology and state of all IEDs. Based on predefined conditions, SubstationHost will select the appropriate SynchCheckRelay, LineSideVT and BusSideVT to perform the synch check function. These IEDs will exchange data over the substation LAN only.

Four internal procedures are executed by SubstationHost to select the synch check parameters, LineSideVT, BusSideVT and SynchCheckRelay. After selecting these IEDs, SubstationHost will initiate synch check.

7.4 Initiate synch check

A transaction sequence is initiated by SubstationHost to begin the synch check function. Both voltage transformers begin sending ZeroCrossing information to the SynchCheckRelay as soon as they receive the initiate message from SubstationHost.

The first two messages initialize synchCheck reporting by telling the LineSideVT and BusSideVT to send their ZeroCrossing information to a selected SynchCheckRelay. These two messages also specify the refreshRate for updating the VT ZeroCrossing data.

The third message initializes the SynchCheckRelay by specifying which breaker has been selected to close. The message also tells the SynchCheckRelay which LineSideVT and which BusSideVT will send ZeroCrossing information. Timeout is also passed to SynchCheckRelay if it is needed for executing the synch check function.

When the SynchCheckRelay receives the message to initiate synchCheck from the SubstationHost, it enables synchCheck and sends a multicast state change message to the SubstationHost, SelectedBreaker, and Remote controller.

Both the LineSideVT and BusSideVT begin sending ZeroCrossing information (unsolicited reports) to the SynchCheckRelay as soon as they are initiated. Each VT will send ZeroCrossing data periodically in accordance with the refreshRate specified by SubstationHost. The ZeroCrossing data object is a data structure comprised of six data items: controllerID (LineSideVT or the BusSideVT), measurementTime, voltageMagnitude, frequency, frequencyRateOfChange, and positiveZeroCrossingTime.

7.5 Check for dead line or dead bus

A transaction sequence is initiated by SynchCheckRelay to check for dead line or dead bus. If dead line or dead bus conditions exist, SynchCheckRelay sends a close message to SelectedBreaker. Because SelectedBreaker has enabled

close.permissive, it will respond to the close command from SynchCheckRelay.

After verification, SelectedBreaker closes the breaker and deselects the breaker. This action will disable synchCheck and close.permissive, and deselect close.select. Because its state has changed, SelectedBreaker immediately sends SynchCheckRelay and SubstationHost a multicast change of state message. SubstationHost will change the operatingParameters accordingly.

SubstationHost then sends a multicast message to the RemoteController (not shown), LineSideVT, and BusSideVT to reset synchCheck=disabled. Each VT will then stop sending zeroCrossing voltage information, and the RemoteController will refresh the operator's display

7.6 Check for high voltage difference

Checking for high voltage difference produces the same transaction sequence except for one constraint. If SynchCheckRelay detects a highVoltageDifference conditions between the two VTs which persists beyond the preset time out, it sends a message to SelectedBreaker to change the breaker state to close.select=disabled. After verifying the command request, SelectedBreaker deselects the breaker for close (close.select=disabled and close.permissive=disabled), and SelectedBreaker remains in the open state condition (breakerState=open).

7.7 Perform synch check

A transaction sequence is initiated to perform the synch check function. First, SynchCheckRelay calculates the difference in angle between LineSideVT and BusSideVT from the supplied ZeroCrossing information. When these parameters (angular difference and slipRate are within preset limits, then SynchCheckRelay sends a close message to SelectedBreaker. Again, because SelectedBreaker has enabled 'close.permissive', it will respond to the close command from SynchCheckRelay.

When SelectedBreaker verifies that SynchCheckRelay is authorized to close the breaker, it closes the breaker and changes its state to breakerState=closed. This action will also set close.select=deselected and close.permissive=disabled. SelectedBreaker then sends a multicast message to SynchCheckRelay and to SubstationHost notifying them of its state change, and that synchCheck is disabled.

After SubstationHost receives the message from SelectedBreaker, it sends a multicast message to each VT with the notification that synchCheck=disabled. Each VT will stop sending its zeroCrossing voltage information, and the RemoteController will refresh the operator's display. Each VT sends a "reset" message to the SubstationHost, confirming that its state has changed to synchCheck=disabled.

7.8 Update remote controller

Transaction sequences were described for selecting synch check parameters and devices, initiating synch check, checking for dead line or dead bus, checking for high voltage difference, verifying that synch check parameters are within limits, and closing the breaker. For each of the transaction sequences SubstationHost sends a multicast message to all instances of RemoteController. When received, operator displays are refreshed and local databases are updated.

8 HOW UTILITIES SHOULD USE C37.115

This paper only presents an overview of IEEE C37.115. Utilities using C37.115 in a procurement specification should identify and tailor those clauses required to meet the utility's requirements for compliance. Vendors and system integrators need to provide the measurement tools.

9 REFERENCES

- [1] IEEE C37.115-2003, "Standard Test Method for Use in the Evaluation of Message Communications between Intelligent Electronic Devices in an Integrated Substation Protection, Control, and Data Acquisition System."
- [2] IEEE Report: "Application of Peer-to-Peer Communications for Protective Relaying", December 22, 2000
- [3] IEEE P1646-2003, "Draft Standard Communication Delivery Time Performance Requirements for Electric Power Substation Automation". At the time of this transaction paper, P1646 was in the balloting and IEEE approval stage.
- [4] IEEE-1588-2002 Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems