

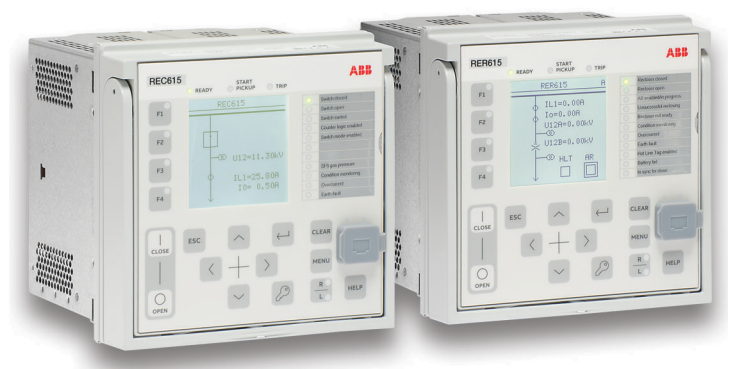
RELION® PRODUCT FAMILY

Grid Automation

REC615 and RER615

DNP3 Communication Protocol Manual





Document ID: 1MRS758757

Issued: 2018-08-31

Revision: A

Product version: 2.0

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Section 1 Introduction

1.1 This manual

The communication protocol manual describes a communication protocol supported by the protection relay. The manual concentrates on vendor-specific implementations.

1.2 Intended audience

This manual addresses the communication system engineer or system integrator responsible for pre-engineering and engineering the communication setup in a substation from a protection relay's perspective.

The system engineer or system integrator must have a basic knowledge of communication in protection and control systems and thorough knowledge of the specific communication protocol.

1.3 Product documentation

1.3.1 Product documentation set

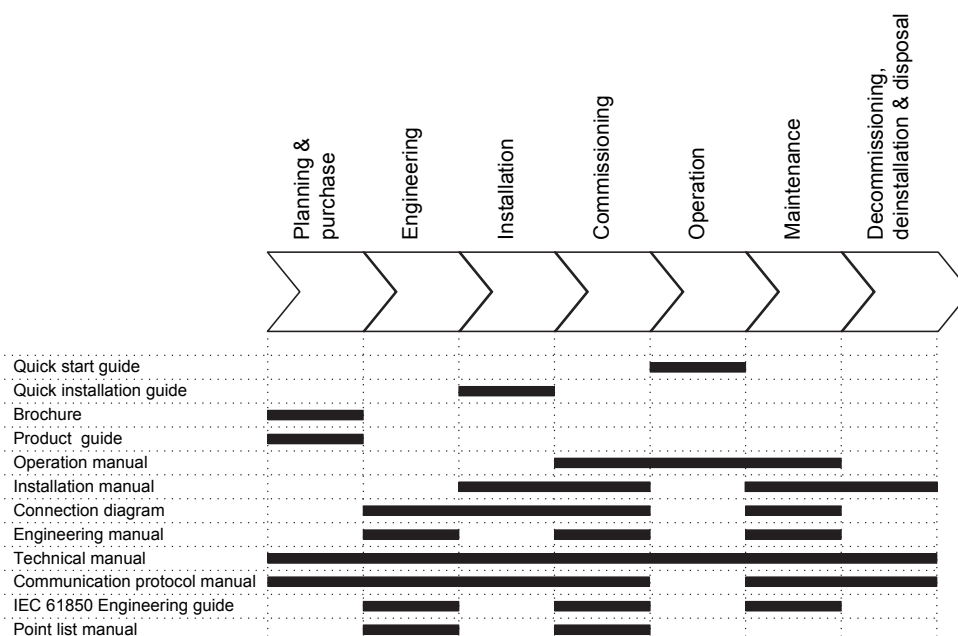


Figure 1: The intended use of documents during the product life cycle



Product series- and product-specific manuals can be downloaded from the ABB Web site <http://www.abb.com/relion>.

1.3.2 Document revision history

Document revision/date	Product version	History
A/2018-08-31	2.0	First release



Download the latest documents from the ABB Web site <http://www.abb.com/substationautomation>.

1.3.3 Related documentation

Name of the document	Document ID
Modbus Communication Protocol Manual	1MRS758758
IEC 60870-5-101/104 Communication Protocol Manual	1MRS758756
IEC 61850 Engineering Guide	1MRS757809
Engineering Manual	1MRS757810
Installation Manual	1MRS757799
Operation Manual	1MRS758754
Technical Manual	1MRS758755

Product-specific point list manuals and other product series- and product-specific manuals can be downloaded from the ABB Web site

<http://www.abb.com/substationautomation>.

1.4 Symbols and conventions

1.4.1 Symbols



The caution icon indicates important information or warning related to the concept discussed in the text. It might indicate the presence of a hazard which could result in corruption of software or damage to equipment or property.



The information icon alerts the reader of important facts and conditions.




The tip icon indicates advice on, for example, how to design your project or how to use a certain function.

Although warning hazards are related to personal injury, it is necessary to understand that under certain operational conditions, operation of damaged equipment may result in degraded process performance leading to personal injury or death. Therefore, comply fully with all warning and caution notices.

1.4.2 Document conventions

A particular convention may not be used in this manual.

-
- Abbreviations and acronyms are spelled out in the glossary. The glossary also contains definitions of important terms.
 - The example figures illustrate the IEC display variant.
 - Menu paths are presented in bold.
Select **Main menu/Settings**.
 - LHMI messages are shown in Courier font.
To save the changes in nonvolatile memory, select Yes and press .
 - Parameter names are shown in italics.
The function can be enabled and disabled with the *Operation* setting.
 - Parameter values are indicated with quotation marks.
The corresponding parameter values are "On" and "Off".
 - Input/output messages and monitored data names are shown in Courier font.
When the function starts, the START output is set to TRUE.

Section 2 DNP3 overview

2.1 DNP3 standard

The DNP3 protocol was developed by Westronic based on the early versions of the IEC 60870-5 standard telecontrol protocol specifications. Now the protocol specification is controlled by the DNP Users Group at www.dnp.org.

The ISO/OSI based model supported by this protocol specifies physical, data link and application layers only. This reduced protocol stack is referred to as EPA. However, to support advanced RTU functions and messages larger than the maximum frame length as defined by the IEC document 60870-5-1, the DNP3 data link is intended to be used with a transport pseudo-layer. As a minimum, this transport layer implements message assembly and disassembly services.

2.2 Documentation

This implementation of DNP3 is fully compliant with DNP3 Subset Definition Level 2, and contains significant functionality beyond Subset Level 2.

Section 3 Vendor-specific implementation

3.1 Protocol server instances



The word "client" refers to the protocol master. The protection relay is referred to as "server" or a slave device.

The protection relay can communicate with several protocol clients simultaneously. Furthermore, it is possible to configure the protection relay to provide different protocol data and data outlook for different clients. A protocol server communication entity which is configured to operate against a specific master or client is called an instance.

There are three server instance scenarios.

1. One client - One protocol instance - One protocol mapping. The protection relay is intended to operate toward one protocol client. The default protocol data mapping or data outlook can be modified freely.
2. Several clients - Several protocol instances - One protocol mapping. The protection relay is intended to operate toward several protocol clients. All the clients should be able to access exactly similar data or similar data outlook. The default protocol mapping or data outlook can be modified freely.
3. Several clients - Several protocol instances - Several protocol mappings. The protection relay is intended to operate toward several protocol clients. Some or all of the clients may want to access protocol data in a different manner. For this purpose, several protocol mappings derived from the default protocol mapping need to be prepared.

3.1.1 Connection to clients

In the protection relay, it is possible to activate up to five protocol server instances. A function block represents the protocol on the protection relay's application configuration level. The block is named DNPLPRT1...5, depending on the instance in use. For each connected client, an instance has to be activated by dragging the function block to the configuration in the PCM600 Application Configuration tool.

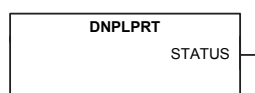


Figure 2: Function block

By default, instance 1 is always instantiated in the protection relay, but needs to be set “On” to be activated. Since the protection relay’s native IEC 61850 data model restricts client limit to five, the protection relay can have only five client connections in total, regardless of the protocols to which the clients belong. This includes the MMS clients and other communication protocol clients.

Protocol instances are identified with numbers 1...5. There are different and unique setting and monitoring parameters for each instance in the HMI menu. Instance numbers can be freely used. However, it is recommended to use the instances in the numerical order. For example, instance 1 is to be used if there is only one client connection and instances 1 and 2 when there are two clients.

3.1.2 Protocol server attachment to a client

After its activation, an instance should be attached to the intended client.

If the client is in a serial connection, the instance must be attached to the intended serial port.

In case of a TCP client, the instance must be first attached to the physical Ethernet port. If there are several TCP client connections, the protection relay must be able to distinguish between the clients. There are two setting parameters in an instance.

- *Client IP*: When the client makes the TCP connection, its IP address is checked. This instance is given to the client with this IP address. It is also possible to use the address “0.0.0.0” if no client IP address is to be defined. In this case, the client's IP address is ignored.
- *TCP port*: This parameter can be used in conjunction with the *Client IP address* setting, thus allowing only a certain IP address at a specific TCP socket port number.

3.1.3 Several identical client connections

If several clients access the same protocol data, the client connections must still be kept apart. Also the number of each instance used for each client must be noted so that if there are problems with the communication, the line diagnostic data for instances follows the same instance number rule.

In case of sequential event data transaction and a TCP client connection, it is essential that a reconnecting client is given back the same instance to which it was attached before disconnecting. This way, the event reading resumes from the point where the client left off, provided that no event overflow has occurred while the client was absent. If multiple client connections are used, the distinguishing between different client connections must be ensured by using the *Client IP* and *TCP port* parameters.

3.1.4 Protocol data mapping to server instances

There are two different type of data mappings for the protocol. The mappings are identified and numbered, starting from one. This number is not related to the protocol instance number.

In PCM600, it is necessary to always define the mappings to be edited or viewed.

Each protocol instance has the setting parameter *Mapping select*, which defines the protocol mappings to be used by this instance. Several protocol instances can use the same mapping. By default, the *Mapping select* parameter for all the instances is set to use the mapping number one.



Reboot the protection relay after changing the mapping number.

3.2 Link modes

DNP3 can be configured to operate in serial or Ethernet mode. The operation mode is configured with the *Port* parameter.

3.2.1 Serial link mode

DNP3 serial can be assigned to a serial communication port in the protection relay. Serial communication ports are named COM1...COMn, depending on how many serial ports the protection relay hosts.

DNP3 protocol ignores any parity setting in the COM settings group. DNP3 is defined as an 8 bit/no parity protocol with a 16-bit CRC every 16 bytes. These characteristics are automatically configured by the protection relay's software when a serial port is taken into use by DNP3. However, some characteristics of the serial port must be set: baud rate, serial mode (RS-232, RS-485 2/4-wire) and fiber mode. They are located in the serial port settings.

- **Configuration/Communication/COMn/Fiber mode**
- **Configuration/Communication/COMn/Serial mode**
- **Configuration/Communication/COMn/Baud rate**



For the serial port parameter settings and hardware setup, see the technical manual.



The COM port connection type, optical ST or EIA-485 connection, star or loop topology, idle state (light on or light off) and the bias and bus termination are selected with the COM port jumpers.

3.2.2 TCP/IP mode

DNP3 TCP/IP link mode is supported by the protection relay.

The protection relay listens for a connection from a DNP3 client on port specified by the user. Default values for TCP port number range from 20000...20004 depending on instance number. A different port can be selected with the *TCP Port* parameter.

DNP3 TCP/IP link mode and UDP broadcast are supported by the protection relay. UDP broadcast requires that there is an active TCP connection by the client.

Documentation on DNP3 TCP/IP communication is available on www.dnp.org.

3.3 Communication setup

3.3.1 Communication modes

DNP3 communication can be set up in two alternative modes.

- Polled mode, called also “polled report by exception”. In this mode the DNP3 client always initiates the transaction with a read or write request to the DNP3 server. The server must reply with a response message.
- Unsolicited mode, called also “Unsolicited reporting mode”. In this mode the DNP3 server may spontaneously send changed class events to the client. The client can yet make additional read or write requests to the server.

By default, DNP3 operates in polled mode. Unsolicited reporting mode can be activated with the *UR mode* parameter.

3.3.2 DNP3 layer acknowledgements, retries and timeouts

It is possible to set up acknowledgements on both DNP3 link layer and application layer. The settings should be equal on both the client and the server sides of the communication. The timeouts must be set so that the other side has enough time to prepare a positive acknowledgement. If an acknowledgement is received after the configured timeout, it is discarded.

Confirmations, retries and timeouts can be configured via parameters.

- **Configuration/Communication/DNP3.0/DNP3.0n/Data link confirm**
- **Configuration/Communication/DNP3.0/DNP3.0n/Data link confirm TO**
- **Configuration/Communication/DNP3.0/DNP3.0n/Data link retries**
- **Configuration/Communication/DNP3.0/DNP3.0n/App layer confirm**
- **Configuration/Communication/DNP3.0/DNP3.0n/App confirm TO**

DNP3 link layer acknowledgements should not be used in TCP/IP link mode, since the DNP3 message transport (link) is then encapsulated and secured by the Ethernet protocol.

Link layer acknowledgements are seldom used in serial mode. The application layer acknowledgements also cover the link layer acknowledgements. This means that if the application message was successfully delivered, then the link layer must also have been successful. Furthermore, it is easier to perform a whole application layer retransmission rather than link layer retransmissions. Otherwise the application layer timeout must be prepared to cover all the timeouts and retransmissions performed by the link layer.

3.3.3 Polled mode

In the polled mode the client station initiates a connection and polls periodically for static data (Class 0), and events (Class 1/2/3) from the server. Data must be polled frequently enough, to prevent event overflow. If event overflow takes place, this is indicated in the IIN bits in the response message. This means that events have been lost.

3.3.4 Unsolicited reporting mode

Unsolicited mode can be enabled in the relay by the UR mode parameter. The operating principle is that the server sends event data spontaneously to the client. When the unsolicited mode has been activated by the setting parameter, the client station must activate UR reporting by *Enable unsolicited* Application function (20). After activation the server begins sending Class 1/2/3 events spontaneously.

Client must acknowledge unsolicited events reported by the server to ensure the communication is fully operative. If the server does not receive acknowledgement in time, defined by the *UR TO* and *App confirm TO* parameters, it does a count of resends defined by the parameter *UR retries*. If the client station does not respond acknowledgement during the count of retries, the server goes to offline mode. This means that spontaneous events are not sent for a period of time. The length of this period is defined by the parameter *UR offline interval*, (default 15 minutes). If it is not wanted that the server goes to offline mode, limitless retries can be achieved by setting the *UR retries* to “65535”.

Class event reporting can be buffered in the unsolicited mode by setting the parameters *UR Class x Min event* and *UR Class x TO*. The event parameter *UR Class x Min* defines how many events must be buffered in the device before unsolicited report is sent out. The *UR Class x TO* parameter in turn defines the minimum waiting

time the device buffers events before sending them out, after occurrence of an event. These parameters are useful for controlling the flow of events from the device and combining them into bigger reports.

Legacy master UR provides compatibility to some older DNP3 clients. When set to disabled, the server follows the DNP3 standard, sending its first unsolicited message after a connection has been established following relay reboot. The client is expected to send the Enable/Disable Unsolicited messages command to the relay. When *Legacy master UR* is enabled, the relay does not send the initial unsolicited message. Unsolicited responses are sent without the need of the Enable Unsolicited command. The client still needs to open a connection for the server to start sending unsolicited messages.

Unsolicited reporting mode is not recommended in half-duplex (RS-485 2-wire mode or optical ST mode) serial bus due to possibility of collisions in the serial bus. Especially in a system where event reporting is frequent, collisions can cause failed DNP3 requests/responses and thus retransmissions. If unsolicited mode is used, application level confirmations should be enabled to ensure that transmission is successful. In half-duplex serial bus, polled mode is recommended.

3.3.5 Communication supervision and diagnostics

3.3.5.1 Communication supervision status

The DNP3 protocol provides a link to a keep-alive mechanism which can be used in both Ethernet (TCP/IP) and serial communication modes. When the client has successfully established connection to the protection relay, keep-alive messages are sent periodically by the client or protection relay, depending on which one has a lower keep-alive interval setting. Keep-alive timer is also restarted by any normal DNP3 frame, so keep-alive messages are only being transmitted after a longer idle time between frames. In the protection relay, the keep-alive timeout can be set with the *Link keep-alive (seconds)* parameter.

Default value “0” means that no keep-alive messages are sent by the protection relay. Keep-alive requests sent by the client are still responded to. If a keep-alive message is not responded to, the connection is considered broken. In case of TCP/IP connection the protection relay closes the associated TCP socket connection, and a new connection must be initiated by the client.

The DNP3 link status (True/False) is updated in the Monitoring data Status, which also can be also used in Application Configuration tool in PCM600 for additional logic connection, for example, to a LED. DNP3 link status exists separately for each DNP3 protocol instance. True (value 1) means that the connection is active. False (value 0) means the connection has timed out. The status can be found via **Monitoring/Communication/DNP3.0/DNP3.0n/Status**.

On Application Configuration tool level, the DNP3 protocol instance is represented by a function block DNPLPRTn, where n is the protocol instance number 1...5.

Use of TCP/IP connection keep-alive timeout only

When the DNP3 link keep-alive mechanism is not used in TCP/IP case, the Ethernet stack TCP socket keep-alive mechanism is still in use. If there is a TCP socket keep-alive timeout, the protection relay closes the associated TCP socket connection and updates the DNP3 link status.

3.3.5.2

Diagnostic communication counters

Protocol instance n dependent diagnostic communication counters are provided in the protection relay. These counters can be accessed via **Monitoring/Communication/DNP3.0/DNP3.0n**.

Table 1: *Diagnostic communication counters*

Diagnostic counter	Description
Received frames	Total amount of received DNP3 frames
Transmitted frames	Total amount of transmitted DNP3 frames
Physical errors	Total amount of Physical layer errors noticed
Link errors	Total amount of Link layer errors noticed
Transport errors	Total amount of Transport layer errors noticed
Mapping errors	Total amount of Protocol mapping errors noticed
Status	Shows the value "True" if the TCP/IP or serial instance is active. This means that a DNP3 client has connected to the TCP socket and DNP3 messages are received regularly at least within <Link keep-alive> second interval or faster. In all other cases this value shows "False".
Reset counters	True = Reset all diagnostic counters

For non-activated instances n, no communication diagnostic values are shown by the HMI. Diagnostic counter values are initially set to "-1" to indicate that no messages have yet been processed by the active instance. As soon as a message is received or transmitted, the counters initialize to "0".

In a serial-bus troubleshooting case, if no DNP3 diagnostic counter is running, the COMn serial driver settings and driver diagnostic counters should be checked.

3.4

Data objects

3.4.1

Readable data objects

DNP3 data objects in the protection relay are all unmapped as default. Using the Communication Management tool in PCM600, the objects can be freely added and located into the DNP3 memory map.

The available DNP3 data objects are taken (mapped) entirely from the native IEC 61850 application data available in the protection relay. Mainly the IEC 61850 data that resides in IEC 61850 default dataset is included in the DNP3 object mapping. Objects within IEC 61850 datasets produce time tagged events. IEC 61850 events and time stamps are propagated into DNP3 class events.

Some IEC 61850 objects, which do not reside in any IEC 61850 dataset, have also been mapped to DNP3. Since these objects do not create any events upon change, it is not possible to assign them into any event class (1...3) in DNP3. The Communication Management tool prevents this kind of assignment. These objects are in the point list referred to as “Static-only” objects. The controlling station can read them on demand directly from the object group in question, or they can be assigned to DNP3 Class 0.

The protection relay includes a predefined set of available function blocks, which in turn includes data objects that are visible for the DNP3 protocol. However, only a part of these function blocks can be used by the protection relay's application configuration. The Communication Management tool shows only the DNP3 objects that are active in the configuration. Not all the available function blocks are included in the default application configuration.

It is impossible to make the DNP3 point configuration before the protection relay's application configuration has been created.

- If a function block is removed from the configuration, the DNP3 objects belonging to this function block are automatically removed from the DNP3 point list. If points are mapped to a DNP3 object address, a “hole” in the mapping occurs. In such case, the remaining map can be modified with the Communication Management tool.
- If a function block is added, the DNP3 points from this function block appear as unmapped in the Communication Management tool.

3.4.2

Class events

DNP3 objects that are not of “Static-only” type can be assigned by the Communication Management tool in PCM600 into DNP3 event classes 1...3. Event buffering is defined per DNP3 object type and not by DNP3 event class.

The DNP3 standard does not define or suggest any specific usage of the different classes. In polled mode, the controlling station could prioritize the polling of a specific class. However, this is not used very often, since the chronology of events is considered more important than the prioritization of certain objects.

Different DNP3 object types are often assigned to different DNP3 event classes. This has no meaning if the client performs class polling simultaneously to all the three classes. Outstation still responds to the events in chronological order. However, there are some advantages.

- The event buffering is handled by DNP3 object type, but a possible event overflow signal is in turn given from the DNP3 event class. If a class only contains a particular object type, the overflow occurs for that DNP3 object type.
- In unsolicited reporting mode, the controlling station enables the classes that should start the spontaneous event reporting. One or some of the classes could then be left disabled.

3.4.3 Writable data objects

Writable objects belong to object types 10 (binary outputs) and 40 (analog outputs). Outputs are controlled through the control relay output block or analog output block commands. From the DNP3 output objects, the commands are propagated further to the native IEC 61850 control objects.

3.4.3.1 Control relay output block parameters

Controlling of the native IEC 61850 objects differs from the way that an RTU control operation is defined by the DNP3. In DNP3 standard, it is assumed that the controlling station decides the control type (pulse or persistent), pulse lengths and possible pulse trains (number of pulses). These control parameters are given to the RTU outstation in the CROB command. In IEC 61850 standard, the same parameters and few additional parameters are configured as properties of the control objects. The control command issued to the control object is only a trigger. In a protection relay, the control object knows how to perform the physical control operation.

In CROB data, the given pulse type and pulse length values are ignored by the outstation. The only data that is checked by the outstation is the direction (ON or OFF). If the IEC 61850 data object is of persistent type, OFF is also possible. When controlling a double-pole IEC 61850 data object, the direction information is used.

3.4.3.2 Direct operate and select before operate

Both direct operate and select before operate DNP3 control functions are supported for binary outputs.

In the native IED IEC 61850 data, these control operation differences are referred to as the control model. The control model is in turn configured as a property of the control object. Thus an IEC 61850 control object can be either in “Direct” or “SBO” mode. This is applicable for double-point control objects. Single point control objects in the protection relay always work in “Direct” mode. Depending on the control model setting of the native IEC 61850 control object, various DNP3 control functions can be performed.

Table 2: Available control models

IEC 61850 control model	Supported DNP3 control function
Direct	Direct only
SBO	Direct or SBO ¹⁾

1) Configurable with the Communication Management tool

In case of making a DNP3 direct command to a SBO configured object, the desired behavior can be defined in the Communication Management tool. In case the direct control mode property is set to “Always allowed”, the DNP3 stack automatically performs the two needed commands to the native control object. Direct control is always allowed. In case the direct control mode property is set to “Control model”, the DNP3 control command must follow the native 61850 objects control model. SBO control must be used in the SBO mode.

The DNP3 stack has a protocol dependent parameter setting for the timeout between Select and Operate commands. The default value is “10 seconds” but it can be changed via *CROB select timeout* parameter. Also the native control object have a configured timeout for the SBO operation. Since the control object may also be available for Local (manual) control, a longer timeout is often required. The DNP3 timeout should be set lower than the native control object timeout.

3.4.3.3

Command blockings

According to the DNP3 standard, an outstation is considered to have the states “Local” or “Remote”. The IEC 61850 IED in turn can be in “Local”, “Station”, “Remote”, “Off”, or “All” state. A DNP3 controlling station can perform control operations in “Station”, “Remote”, and “All” protection relay states. However, it is the controlled protection relay's application in the outstation that rejects or accepts control operations based on the control allowance states and not the DNP3 protocol stack. In an RTU (non-intelligent outstation) application, the DNP3 stack rejects the commands.

3.4.4

Accessing of non-protocol-mapped data

The protection relay application includes a number of general-purpose I/O data. By default, these data are mapped to this protocol. See the point list manual for the exact mappings.

The general-purpose objects can be connected to any internal object in the protection relay configuration application using the Application Configuration or Signal Matrix tool. This gives additional opportunities for the protocols.

Example 1

Due to security reasons, protocols do not contain mappings for the direct control of physical outputs. This way, the client cannot accidentally write a change to a physical output.

It is possible to connect general-purpose outputs to physical outputs using the Application Configuration tool. The general-purpose output can also be controlled from the protocol.

Example 2

The legacy protocol default mappings are a selection of the most important signals produced by the IEC 61850-based protection relay applications. The manufacturer's selection of important signals may not always serve every customer.

Any non-protocol-mapped internal signal can be freely connected to a general-purpose input object via the Application Configuration tool. This object can then be accessed by the legacy protocol as regular protocol application data.

Example 3

The basic IEC 61850 application model of the protection relay produces a great amount of information. In some cases, this is more than what is feasible to transport through a legacy protocol. Via the PCM600/Communication Management tools, unnecessary data objects can be excluded from the legacy protocol.

However, in some cases a better solution is to OR together several internal signals into one general signal. This OR output can be connected to a general-purpose input and accessed by the legacy protocol as regular protocol application data.



General-purpose input object and OR function block may cause delays to time stamps.

3.5

Standard data object types

3.5.1

Binary inputs

DNP3 object type 1, binary input objects are derived from IEC 61850 data object's boolean type attributes, mainly from data classes SPS, SPC, ACD and ACT. Also, few binary input objects has been converted from enumerals INS and INC classes (ENS and ENC classes in Edition 2).



The circuit breaker and disconnector double point data objects, containing open and close bits, also exist in the DNP3 map as normal single binary input alternatives. These are intended for DNP3 controlling stations that do not support the double bit input DNP3 data type alternative (Object group 3).

DNP3 object type 2, binary input change events can buffer up to 200 events. When the buffer becomes full, the new events are discarded until more space is available in the event buffer.

Binary inputs which are not of “Static-Only” type can be assigned to any DNP3 event class. Furthermore, it is possible to invert the signals if necessary, for example, generic input data.

The default variation for all binary input values can be set with the *Default Var Obj 01* parameter.

3.5.2 Double point inputs

Double Bit input (object type 3) is supported by the protection relay. Double point objects are derived from the protection relay's internal data class DPC, that is, circuit breaker and disconnector position data. An alternative DNP3 analog input data always exists for the double point data. If the DNP3 client does not support object type 3, the analog input is the only other alternative for representing the double point value in one DNP3 data object.

The DNP3 Double Bit input event buffer size is 100.

3.5.3 Analog inputs

DNP3 analog input data (Object type 30) is mainly derived from the protection relay's IEC 61850 measurand object classes MV and CMV. Since the MV and CMV source values are of float32 type, the default setting for the default variation of DNP3 analog data is float32.

If needed, the default variation can be changed to integer 16 or 32 bit types. In such case, re-scaling of the original data has to be applied.

There are four scaling options associated with analog input reporting.

- None: The value is presented as is. None of the configured values in the Communication Management tool columns Min Source Value, Max Source Value, Min Dest Value and Max Dest Value has any effect.
- Multiplication: The process value is multiplied by a constant. An offset is added producing the reported value. In the Communication Management tool the constant is found in the Max Dest Value column and the offset in the Min Dest Value column.
- Division: The process value is divided by a constant. An offset is added by producing the reported value. In the Communication Management tool the constant is found in the Max Dest Value column and the offset in the Min Dest Value column.
- Ratio
 - Configuration-time ratio scaling: Find R for new set of {source_min, source_max, Dest_min, Dest_max}
 - $R = (out_max - out_min) / (in_max - in_min)$
 - Reported value = $(inval - in_min) * R + out_min$.

Some DNP3 analog input points, such as CT/VT measurement values, support primary and secondary scaling. This selection can be done in PCM600 by selecting either "Primary value" or "Secondary value" for *Representation*. If the analog input object does not support primary and secondary scaling, the selection does nothing.

The DNP3 analog input event buffer size is 150.

In case of analog events, the IED system produces changed analog events with a specific sampling rate and deadband. The sampling rate and deadband can be additionally modified for DNP3 AI points through the Communication Management tool in PCM600. If a DNP3 analog input points' additional *Deadband* value is set to "0.0", the IED system analog events are propagated as such through the DNP3 protocol. Sampling rate of the DNP3 AI value can also be reduced through the points' *Deadband Time* setting. This means that the events are transmitted less frequently. If *Deadband Time* is for example set as "2", then analog events are not produced more frequently than with two seconds interval from the DNP3 AI object.

3.5.4 Counter objects

DNP3 counter objects (object type 20) are derived from the relay's IEC 61850 object class BCR. For each counter, there is also a frozen counter value available for reading as object type 21.

There are two types of counters in the relay.

- BCR class is an integrated totals type counter, typically used for energy values.
- INC class counters are operational counters, for example, circuit breaker control counters.

It is possible to freeze and reset the DNP3 counters in this relay. However, the original BCR counters will also be reset. Another method is to read the cumulative values and not reset the counters.

The DNP3 Counter, and Frozen Counter event buffer size is 30.

3.5.5 Binary outputs and control relay output block

DNP3 binary outputs (Object group 10) are cross-coupled with the protection relay's IEC 61850 control data classes SPC and DPC. The DNP3 stack automatically handles the conversion between the two protocols' control models.

DNP3 control is never done directly to the binary outputs but rather indirectly using the Control Relay Output Block (CROB) function. The CROB function contains some additional information regarding the control sequence, for example, pulse-length and number of control pulses. These parameters are intended for RTU type (non-intelligent) DNP3 devices. However, in this protection relay, all the required control parameters are already configured properties of the control object. Therefore most control parameters given in the DNP3 CROB command are neglected by the protection relay. Only the control direction is noticed. Most single point objects, like

resets and acknowledgements, can only be controlled using ON. However, there may also be single point objects that have two states, ON or OFF. Double point objects may be controlled using ON or OFF.

3.5.5.1 Control modes

All DNP3 binary outputs support direct control at any time. Double-point objects (circuit breakers and disconnectors) also support select before operate controls, provided that the native IEC 61850 control objects are in SBO control model mode. A double-point control is represented with one binary output point on DNP3 even if there are two separate control relay outputs (open and close) from the protection relay.

3.5.5.2 Accessing of physical outputs

As opposite to an RTU device, it is impossible to control the protection relay's physical output relays directly from remote communication. However, using generic control points and dedicated Application Configuration tool application connections this is possible.

3.5.5.3 Control feedback

When the binary output values are read from the protection relay, the last written value is returned. However, while controlling an object, the final status change of the object should be verified from the corresponding binary input object, if available.

In case of double-point control, the IEC 61850 standard defines a value attribute named *stSeld* to be always available for the control object. In case of SBO, this value shows if the control object is actually selected, for example, if it is already selected by another controlling source. This value is found in the DNP3 memory map as a regular DNP3 binary input. The *stSeld* value also goes on ("1") and off ("0") during a direct control operation. The *stSeld* value is always held in true state ("1") by the protection relay until the control operation is terminated.

In case of a long lasting control operation, for example, a motor controlled disconnector, the *stSeld* value can stay true for several seconds after the control operation is acknowledged and started. A new control operation cannot be started by the protection relay until the previous one has finished.

3.5.6 Analog outputs

Analog outputs are cross-referenced to the *.Oper.ctlVal* attribute of the protection relay's object class INC, controllable integer. If the INC object is readable, the *.stVal* attribute of the object is mapped to DNP3 AI data.

The protection relay platform contains a few controllable analog objects, for example, parameter setting group selection, tap changer control and fault record read selection. All analog objects are of integer type. The values do not have to be scaled.

The Analog Output Block DNP3 object group (41) is used for writing to a DNP3 analog output. Analog output can be also read from the protection relay, as object group 40. Reading an analog output returns the last written value to the object.

Class events are generated for changed Analog Output values. The DNP3 Analog Output event buffer size is 100.

3.6 Fault records

Fault record data objects contain registered values captured simultaneously by the relay's protection at the moment of a fault. The fault record objects internally belong to IEC 61850 logical node FLTRFRC1.

The FLTRFRC1 objects can be found as DNP3 analog input values in the DNP3 point list. There are two alternative DNP3 data objects for each captured fault record object in the point list. A different trailing text for the objects is shown in the object's name, either "Ev-Upd" (event updated) or "Record" (read on demand).

3.6.1 Ev-Upd type objects

A freely selectable part of the "Ev-Upd" objects, or alternatively all objects can be added to the DNP3 analog input data memory map. These objects can also be enabled for DNP3 class events. Each time a new fault record capture is done by the protection relay, the objects are sent as DNP3 class events to the controlling station. Every object captured at the same time (belonging to the same record) has the same time tag. The controlling station can also, at any time, read fault record objects from the outstation. The most recent (newest) captured value is always returned.

The deadband setting for the "Ev-Upd" objects should be "0". This means that every update of the object from the protection relay level is propagated as a DNP3 class event, regardless of the change in value. As a default setting, all analog inputs have deadband setting of 0.0, that is, the event is always reported when a system event is generated. In the fault record, the next captured value can be identical to the previous one, therefore the recommended deadband value is 0.0.

3.6.2 Record type objects

The protection relay saves the 128 latest captured fault records internally. On demand, these (older) records can be read by the DNP3 controlling station.

A freely selectable part of the "Record" objects can be added to the DNP3 analog input data memory map. These objects are as default defined as 'Static only'. This means that they can only be read on demand by the controlling station. Also notice the analog output object from the same logical node named FLTRFRC1.SelRowctlVal '-Select record'. This object should be added to the DNP3 analog output area.

The stored fault records are internally saved in indexes numbered 1...128. When the controlling station writes a value 1...128 to the “Select record” object, the entire set of fault record values belonging to that record is copied to the “Recorded” fault record DNP3 AI values. Thereafter, the controlling station can read the fault record values.

3.6.3 Time stamp for record type objects

One disadvantage of the DNP3 protocol is that static data read does not include any time stamps for the static values. It is impossible to know when the DNP3 data object was updated to its value. Therefore, the time stamp of the record itself is re-coded into a set of seven DNP3 analog input objects. The objects separately contain the year, month, day, hour, minute, second, and millisecond values of the time stamp.

3.6.4 Additional fault record implementation details

The protection relay’s native fault record application can be configured to make captures at an operate situation only, or during start situations (not leading into operate). The latter alternative most often causes more captures. The DNP3 protocol has no part in the setup of the fault record application. The chosen fault record setup is reflected to all readers of the fault record data, including HMI. If the values are intended to be available for several readers, a fault record clear operation from any reading source is not recommended. There are several alternatives for any remote client, including DNP3, to access the captured fault record data.

Alternative 1, buffering on the DNP3 client side

The easiest alternative is that the client receives the time tagged fault record values as events at the moment when they are captured in the protection relay. The client system must then observe that all fault record values with identical event time tag belong to the same capture. A new fault record capture can take place in the protection relay right after the previous one. The new fault record values are again sent as events to the client. The client system is responsible for buffering up these values, in case it is necessary to later look at older captures.

Alternative 2, buffering on the DNP3 outstation side

If fault records' values not are sent as events to the client, the latest record capture values can be read directly from the outstation DNP3 AI-area. In this case, also the older captures are to be read out from the outstation than the latest one, the client must perform a control action towards the server.

There are up to 128 fault records stored inside the protection relay. The records are located chronologically in a circular buffer indexed from 1...128. If the client makes a DNP3 AO-write with an index value (1...128) to the object FLTRFRC1.SelRow.ctlVal, the values from that particular record are internally copied into the FLTRFRC1 fault record values. Thereafter the DNP3 client can read them using regular DNP3 AI reading.

The latest record is stored at index (row) 1, and the oldest record at index 128. Records are stored in a FIFO buffer, that is, the oldest record is dropped out from index 128, and latest record always stored to index 1.

The fault record also has an increasing counter for record number which can be used to track different fault records. This value is derived from data FLTRFRC1.OpCnt.stVal and it counts 1...999999, and rolls over after maximum. If OpCnt = 0, there is no fault record data available.

If the FLTRFRC1.OpCnt.stVal object is added as an “Ev-Upd” object to the DNP3 AI-data, and then enabled for Class events, it serves as an indication on the client side that a new fault record has been captured.

It is also possible that the client had stored the latest fault record index value it used in the previous reading. While starting to read out new records, it could simply continue from the memorized index + 1 onwards.

3.7 Troubleshooting

Table 3: *Troubleshooting*

Condition	Cause	Remedy
Slow or no update of data, reports disabled	Protocol data is available for active IED applications and the IED system. Active IED applications mean the function blocks that have been added into the protection relay's configuration using Application Configuration in PCM600. The IED system data is always available and is not dependent on the application configuration. A protection relay variant has a standard application configuration that has been done in advance. This configuration can be modified with PCM600. It is also possible to start a completely new configuration from an emptied configuration state in Application Configuration. When a new IED configuration is created from an empty configuration state, an additional PCM600 check must be done at the end.	Select manually the check boxes for clients of all visible 61850 data sets in the IEC 61850 Configuration tool, see the engineering guide for detailed instructions. This procedure enables reporting for the data sets, and report control blocks should appear on the Report Control tab.
CMT data point updating from Application Configuration	When some AFLs are added to the ACT logic, the related data points are again synchronized to the Communication Management tool although the data are already in the selected list.	Verify the DNP3 mapping if a new AFL has been added to the ACT logic as some signals may have disappeared.

Section 4 DNP3 parameters

4.1 Parameter list

The DNP3 parameters can be accessed with PCM600 or via the LHMI path **Configuration/Communication/DNP3.0n**.



Some parameters are not visible in the “Basic” setting visibility mode. To view all parameters use “Advanced” setting visibility mode in Parameter Setting tool in PCM600 and LHMI.



Power must be cycled to the unit after making changes to the DNP3 parameters. The LHMI or WHMI do not notify that this action must be taken.

Table 4: *DNP3 settings*

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			5=off	Operation Off / On
Port	1=COM 1 2=COM 2 3=Ethernet - TCP 1 4=Ethernet TCP +UDP 1			3=Ethernet - TCP 1	Communication interface selection
Unit address	1...65519		1	1	DNP unit address
Master address	1...65519		1	3	DNP master and UR address
Mapping select	1...2		1	1	Mapping select
ClientIP				0.0.0.0	IP address of client
TCP port	20000...65535		1	20000	TCP Port used on ethernet communication
TCP write authority	0=No clients 1=Reg. clients 2=All clients			2=All clients	0=no client controls allowed; 1=Controls allowed by registered clients; 2=Controls allowed by all clients
Link keep-alive	0...65535	s	1	0	Link keep-alive interval for DNP
Validate master addr	1=Disable 2=Enable			1=Disable	Validate master address on receive
Self address	1=Disable 2=Enable			2=Enable	Support self address query function
Need time interval	0...65535	min	1	30	Period to set IIN need time bit
Table continues on next page					

Section 4

DNP3 parameters

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Parameter	Values (Range)	Unit	Step	Default	Description
Time format	0=UTC 1=Local			1=Local	UTC or local. Coordinate with master.
CROB select timeout	1...65535	s	1	10	Control Relay Output Block select timeout
Data link confirm	0=Never 1=Only Multiframe 2=Always			0=Never	Data link confirm mode
Data link confirm TO	100...65535	ms	1	3000	Data link confirm timeout
Data link retries	0...65535		1	3	Data link retries count
Data link Rx to Tx delay	0...255	ms	1	0	Turnaround transmission delay
Data link inter char delay	0...20	char	1	4	Inter character delay for incoming messages
Data link frame length	50...292	bytes	1	292	Data link maximum frame length
App layer confirm	1=Disable 2=Enable			1=Disable	Application layer confirm mode
App confirm TO	100...65535	ms	1	5000	Application layer confirm and UR timeout
App layer fragment	50...2048	bytes	1	2048	Application layer fragment size
UR mode	1=Disable 2=Enable			1=Disable	Unsolicited responses mode
UR retries	0...65535		1	3	Unsolicited retries before switching to UR offline mode
UR TO	0...65535	ms	1	5000	Unsolicited response timeout
UR offline interval	0...65535	min	1	15	Unsolicited offline interval
UR Class 1 Min events	0...999		1	2	Min number of class 1 events to generate UR
UR Class 1 TO	0...65535	ms	1	50	Max holding time for class 1 events to generate UR
UR Class 2 Min events	0...999		1	2	Min number of class 2 events to generate UR
UR Class 2 TO	0...65535	ms	1	50	Max holding time for class 2 events to generate UR
UR Class 3 Min events	0...999		1	2	Min number of class 3 events to generate UR
UR Class 3 TO	0...65535	ms	1	50	Max holding time for class 3 events to generate UR
Legacy master UR	1=Disable 2=Enable			1=Disable	Legacy DNP master unsolicited mode support. When enabled relay does not send initial unsolicited message.
Legacy master SBO	1=Disable 2=Enable			1=Disable	Legacy DNP Master SBO sequence number relax enable
Default Var Obj 01	1=1:BI 2=2:BI&status			1=1:BI	1=BI; 2=BI with status.
Default Var Obj 02	1=1:BI event 2=2:BI event&time			2=2:BI event&time	1=BI event; 2=BI event with time.
Default Var Obj 03	1=1:DBI 2=2:DBI&status			1=1:DBI	1=DBI; 2=DBI with status.
Default Var Obj 04	1=1:DBI event 2=2:DBI event&time			2=2:DBI event&time	1=DBI event; 2=DBI event with time.
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Default Var Obj 20	1=1:32bit Cnt 2=2:16bit Cnt 5=5:32bit Cnt noflag 6=6:16bit Cnt noflag			2=2:16bit Cnt	1=32 bit counter; 2=16 bit counter; 5=32 bit counter without flag; 6=16 bit counter without flag.
Default Var Obj 21	1=1:32bit FrzCnt 2=2:16bit FrzCnt 5=5:32bit FrzCnt&time 6=6:16bit FrzCnt&time 9=9:32bit FrzCnt noflag 10=10:16bit FrzCnt noflag			6=6:16bit FrzCnt&time	1=32 bit frz counter; 2=16 bit frz counter; 5=32 bit frz counter with time; 6=16 bit frz counter with time; 9=32 bit frz counter without flag; 10=16 bit frz counter without flag.
Default Var Obj 22	1=1:32bit Cnt evt 2=2:16bit Cnt evt 5=5:32bit Cnt evt&time 6=6:16bit Cnt evt&time			6=6:16bit Cnt evt&time	1=32 bit counter event; 2=16 bit counter event; 5=32 bit counter event with time; 6=16 bit counter event with time.
Default Var Obj 23	1=1:32bit FrzCnt evt 2=2:16bit FrzCnt evt 5=5:32bit FrzCnt evt&time 6=6:16bit FrzCnt evt&time			6=6:16bit FrzCnt evt&time	1=32 bit frz counter event; 2=16 bit frz counter event; 5=32 bit frz counter event with time; 6=16 bit frz counter event with time.
Default Var Obj 30	1=1:32bit AI 2=2:16bit AI 3=3:32bit AI noflag 4=4:16bit AI noflag 5=5:AI float 6=6:AI double			5=5:AI float	1=32 bit AI; 2=16 bit AI; 3=32 bit AI without flag; 4=16 bit AI without flag; 5=AI float; 6=AI double.
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Default Var Obj 32	1=1:32bit AI evt 2=2:16bit AI evt 3=3:32bit AI evt&time 4=4:16bit AI evt&time 5=5: float AI evt 6=6:double AI evt 7=7:float AI evt&time 8=8:double AI evt&time			7=7:float AI evt&time	1=32 bit AI event; 2=16 bit AI event; 3=32 bit AI event with time; 4=16 bit AI event with time; 5=float AI event; 6=double AI event; 7=float AI event with time; 8=double AI event with time.
Default Var Obj 40	1=1:32bit AO 2=2:16bit AO 3=3:AO float 4=4:AO double			2=2:16bit AO	1=32 bit AO; 2=16 bit AO; 3=AO float; 4=AO double.
Default Var Obj 42	1=1:32bit AO evt 2=2:16bit AO evt 3=3:32bit AO evt&time 4=4:16bit AO evt&time 5=5:float AO evt 6=6:double AO evt 7=7:float AO evt&time 8=8:double AO evt&time			4=4:16bit AO evt&time	1=32 bit AO event; 2=16 bit AO event; 3=32 bit AO event with time; 4=16 bit AO event with time; 5=float AO event; 6=double AO event; 7=float AO event with time; 8=double AO event with time.

4.2 Monitored data

Table 5: DNP3

Parameter	Values (range)	Description
Received frames	-1...2147483646	Total amount of received DNP3 frames
Transmitted frames	-1...2147483646	Total amount of transmitted DNP3 frames
Physical errors	-1...2147483646	Total amount of Physical layer errors noticed
Link errors	-1...2147483646	Total amount of Link layer errors noticed
Transport errors	-1...2147483646	Total amount of Transport layer errors noticed
Mapping errors	-1...2147483646	Total amount of Protocol mapping errors noticed
Status	True, False	Status of communication
Reset counters	True, False	True = Reset all diagnostic counters

Section 5 Glossary

ACD	Start/pickup status
ACT	1. Application Configuration tool in PCM600 2. Trip status in IEC 61850
AI	Analog input
CMT	Communication Management tool in PCM600
DNP3	A distributed network protocol originally developed by Westronic. The DNP3 Users Group has the ownership of the protocol and assumes responsibility for its evolution.
DPC	Double-point control
EMC	Electromagnetic compatibility
EPA	Enhanced performance architecture
Ethernet	A standard for connecting a family of frame-based computer networking technologies into a LAN
HMI	Human-machine interface
IEC	International Electrotechnical Commission
IEC 60870-5	IEC standard for telecontrol equipment and systems. Part 5 defines transmission protocols.
IEC 61850	International standard for substation communication and modeling
IED	Intelligent electronic device
IP	Internet protocol
IP address	A set of four numbers between 0 and 255, separated by periods. Each server connected to the Internet is assigned a unique IP address that specifies the location for the TCP/IP protocol.
ISO	International Standard Organization
LHMI	Local human-machine interface
OSI	Open systems interconnection
PCM600	Protection and Control IED Manager
RTU	Remote terminal unit
SBO	Select-before-operate
SPC	Single-point status of a controllable object

SPS	Single-point status
TCP	Transmission Control Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
WHMI	Web human-machine interface



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