Bay Control Unit in an IEC 61850 Environment: A Generalized and Systematic Process Flow for Optimized Configuration

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***Abstract*—The bay control unit (BCU) is a fundamental component of an electric power substation that is required to perform various bay operations based on predefined control logic. It acts as an interface between the operator and the field devices in the bay. With the advent of substation automation systems (SASs), especially in IEC 61850 environments, communications settings have become a core requirement for data exchange among the devices. In order for a BCU to perform the required automation and control functions in an IEC 61850 environment, communications settings need to be based on an optimized process flow. This paper presents an optimized procedure for configuring a BCU in an IEC 61850-based SAS with emphasis on referring to the right engineering document to set a given parameter. This paper is based on a commissioned 110/13.8 kV substation with a double-busbar scheme and an SAS that uses IEC 61850 protocols. The paper discusses practical aspects of configuring an intelligent IEC 61850-based BCU and explains the role and importance of required engineering documents.**

Keywords—Bay control unit, engineering documents, IEC 61850, SCADA, substation automation system.

I. Definitions

ac	Alternating current
APP ID	Application identifier
BCU	Bay control unit
CB	Circuit breaker
CID	Configured IED Description
CT	Current transformer
dc	Direct current
DO	Direct Operate
DSW	Disconnect switch
GOOSE	Generic Object-Oriented Substation Event
GPS	Global Positioning System
IED	Intelligent electronic device
I/O	Input/output
IP	Internet Protocol
LAN	Local-area network
LCC	Local control cubicle
MAC	Media access control
MMS	Manufacturing message specification
NTP	Network Time Protocol
RCB	Report control block
SAS	Substation automation system
SBO	Select Before Operate
SCADA	Supervisory control and data acquisition
SNTP	Simple Network Time Protocol
UTC	Coordinated Universal Time
VID	VLAN identifier
VLAN	Virtual LAN
VT	Voltage transformer

II. Introduction

Modern substation automation systems (SASs) are generally based on IEC 61850. Major components of a complete SAS solution include Global Positioning System (GPS) clocks, database servers, gateways, Ethernet switches, intelligent electronic devices (IEDs) such as protective relays and bay control units (BCUs), and a supervisory control and data acquisition (SCADA) platform. Though each component is important for optimal SAS performance, BCUs play a vital role because they are the interface between the field components in the switchgear and the SAS human-machine interface via the SAS communications network. BCUs that are compliant with the IEC 61850 standard contain an enormous number of useful data structures. However, only by using the available data in a professional and optimized way is the SAS able to perform the desired operations. Given the importance of BCU configuration, a consolidated configuration procedure based on an optimized process flow is required. Such a procedure should highlight the various stages of configuring a BCU.

III. Background

Substation control and protection entered a new age when the first IED was introduced in the 1980s. The advent of IEDs introduced new characteristics to BCUs, including the capacity to control field equipment, a simplified panel architecture, and (more importantly) an increase in control reliability and flexibility [1] [2]. The development of IEDs and the introduction of the IEC 61850 standard for SASs opened a new area of research and engineering. Reference [3] provides an excellent example of IED modeling based on IEC 61850. It presents a general method for bay-level IED modeling and explains in detail the data structure models of IEC 61850. However, it does not discuss the data models required for a BCU in an SAS. Reference [4] briefly compares different IED configurations in intelligent substations while discussing IEC 61850-based information models for controlling and monitoring IEDs.

References [5] and [6] target the practical aspects of configuring BCUs. Reference [5] presents an overview of IEC 61850-based SASs and briefly explains the conceptual basics of a standard bay solution. Reference [6] presents detailed information on bay control using IEC 61850. It is based on a simulator containing commercial BCUs programmed for a sample feeder bay, mostly at the medium-voltage level. It details interlocking concepts and diagrams and compares a traditional BCU circuit with one based on IEC 61850.

Reference [6] provides an excellent overview of BCU basics; however, there is a gap in terms of explaining the required engineering documents and specific details, such as the logic and time-synchronization settings, of BCUs. Furthermore, with reference to IEC 61850, there is an obvious gap of not identifying the manufacturing message specification (MMS) reporting and Generic Object-Oriented Substation Event (GOOSE) messaging requirements and configuration. Also, [6] is based on a simulated system rather than an actual substation.

IV. Objective

This paper addresses the gaps identified in Section III and serves as a reference document for optimized configuration of a high-voltage or extra-high-voltage BCU in an IEC 61850 environment. The paper is based on a typical 110/13.8 kV electric power substation with a double-busbar scheme.

V. BCU Concept

Generally, the high-voltage or extra-high-voltage portion of an electric power substation contains four different types of bays: overhead/underground line feeder, outgoing transformer feeder, bus section, and bus coupler (see Fig. 1 through Fig. 3).

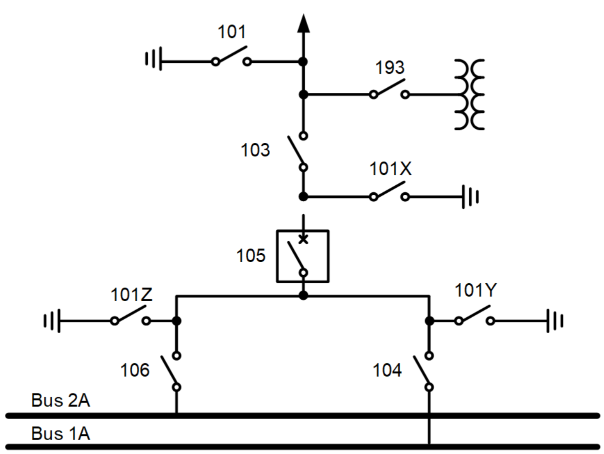


Fig. 1. Typical 110 kV Line Feeder

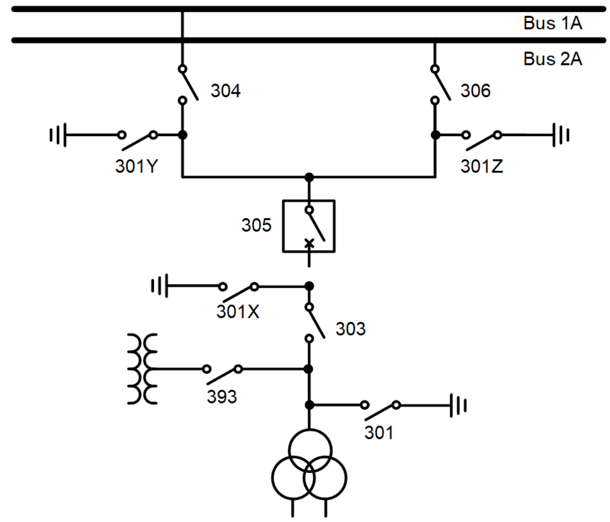


Fig. 2. Typical 110 kV Transformer Feeder

To achieve ease of operation, each gas-insulated switchgear bay has a dedicated local control cubicle (LCC). In modern-day IEC 61850-based SASs, BCUs and input/output (I/O) modules (if required) are installed in the LCC. The LCC also contains all of the required direct current (dc) and alternating current (ac) circuitry to provide an ac power supply for the cabinet lighting and a dc power supply for turning on the installed equipment and powering the BCU and the I/O modules. The LCC has a mimic diagram complemented with emergency local control pushbuttons and position indicators for all field components, and it is designed to take care of all necessary hardwired electrical interlocking schemes. The BCU acts as an interface between the data acquisition server and the field components of a bay and carries out peer-to-peer communication with other BCUs. The BCUs are engineered to contain soft electrical interlocking that is redundant with the hardwired interlocks of the LCC. Hardwired interlocking must be satisfied for any switching operation to take place, independent of the LCC mode of operation.

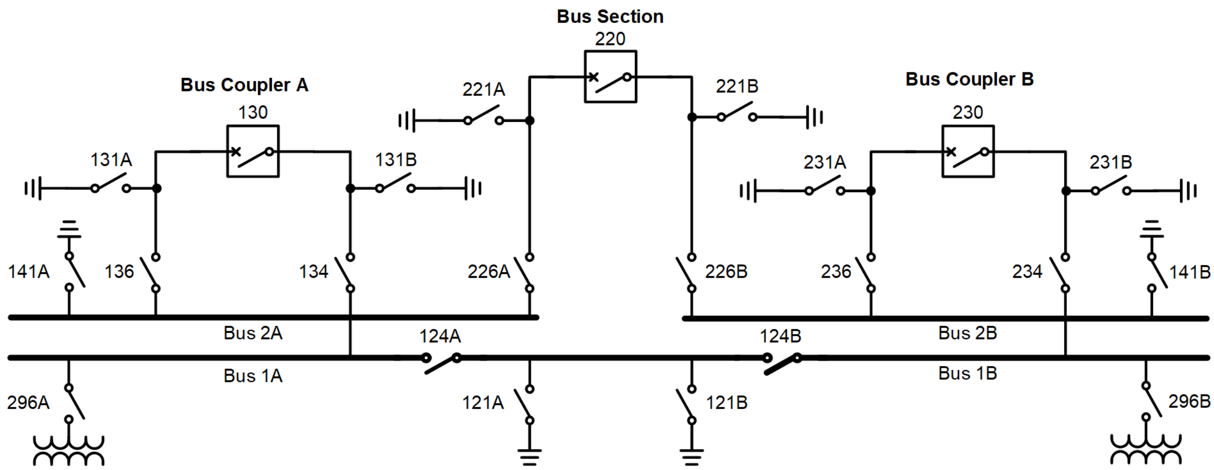


Fig. 3. Typical 110 kV Bus Coupler and Bus Section

VI. Process Flow for BCU Configuration

To achieve the defined objective in Section IV, this section presents a process flow for optimized BCU configuration.

A. Collecting the Engineering Design Documents

The configuration process requires a complete package of user-approved engineering design documents, which are provided to the automation engineer as a reference for applying all necessary settings. These documents and their uses are described in the following subsections.

1) Internet Protocol (IP) Address List

The IP address list provides the IP addresses for all SAS devices, including the subnet mask and default gateway. An example is shown in Table I.

2) Substation Single-Line Drawing

This document is required to understand various parameters, including current transformer (CT) and voltage transformer (VT) ratios, substation busbar schemes, the number and arrangement of bays, and the equipment in each bay (including its arrangement and naming convention).

3) LCC Schematic Drawing

A schematic drawing of the LCC panel is required to identify and/or validate the hardwired inputs for a specific bay. This drawing also provides the interlocking scheme, which is vital information for preparing the BCU logic.

4) BCU I/O List

This document consolidates all of the hardwired inputs and outputs of a specific BCU. An example is shown in Table II.

5) GOOSE Signal List

The GOOSE signal list contains the signals that are exchanged between BCUs using the IEC 61850 GOOSE protocol. These signals play an important role in completing the interlocking scheme and making it successful. An example is shown in Table III.

6) Voltage Synchronization Settings Document

The voltage synchronization settings document provides the synchronization parameter values that are applicable to line feeders, bus couplers, and bus sections.

7) SAS Network Architecture

The SAS network architecture document shows the Ethernet connections between different SAS devices and whether single or redundant Ethernet paths are used to connect the IEDs. It is used in BCU Ethernet port configuration. It also provides information on database servers and gateways and consequently serves as reference to decide the number of MMS reports in the IEC 61850 configuration of a specific BCU.

TABLE I. Example IP Address List

Bay/Panel Reference	Feeder Description	IEC 61850 Name	Device Name	IP Address	Local-Area Network (LAN) Configuration
=E01	Line Incomer	E01_XXX_BCU	XXX	111.11.1.1	Parallel Redundancy Protocol

TABLE II. Example BCU I/O List

Source	Switchgear No.	Circuit Breaker (CB) No.	Tag Name	Signal Description	Physical I/O	Word Bit	IEC 61850 Tag Name
ABC123	B01-S01-SG-001	CB001	XYZ_G01_B001S451_CBO	CB001 Open Command	OUTPUT 101	XX01	ABC123CON/XXGGIO1/SPCSO01/ctlVal[CO]

TABLE III. EXAMPLE GOOSE LIST

ABC_123_BCU GOOSE List

Publish

Relay Element	Description	Data Set Name	VLAN Identifier (VID)	Media Access Control (MAC) Address	Application Identifier (APP ID)
INXXX	CB Open	GOOSE	0x004	01-0C-CD-01-01-0F	0x00F

Subscribe

Virtual Bit	Publisher	Relay Element	Description
VB001	ABC_456_BCU	INYYY	CB Close

B. Control and Metering Logic Configuration

This section provides a detailed explanation of the parameters required to implement BCU logic, including control, metering, and time synchronization. The discussion is based on a typical 110 kV line feeder (see Fig. 1).

The control settings can be divided into three categories: interlock scheme logic, BCU outputs to send control commands to different bay equipment, and voltage synchronization settings.

1) Interlocking Logic

Usually, relays are programmed with different types of internal logic variables (discrete and/or analog). These include virtual bits for receiving GOOSE messages from other BCUs and predefined word bits for the statuses of hardwired digital and analog inputs and outputs wired to the BCU. All of these variables are collectively used to create the complete interlocking logic of the BCU using LCC schematic drawings, as discussed in Section V. Examples of interlocking schemes for a 110 kV CB on an incoming line feeder are shown in Fig. 4 and Fig. 5.

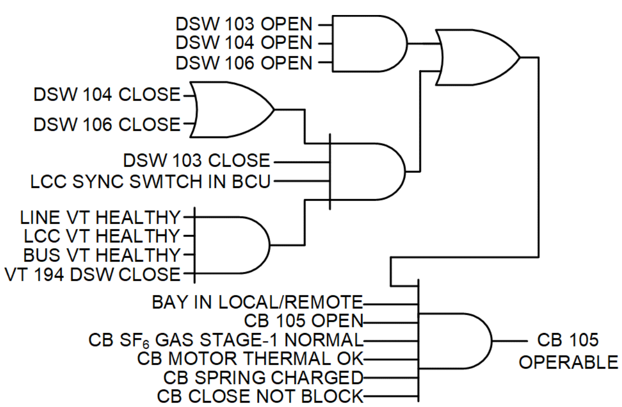


Fig. 4. Interlocking Scheme of a Close Proceed for a 110 kV CB on a Line Feeder

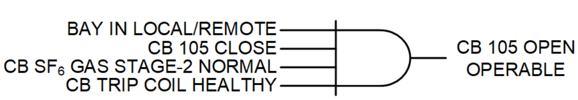


Fig. 5. Interlocking Scheme of an Open Proceed for a 110 kV CB on a Line Feeder

Fig. 6 shows an example of interlocking logic for a CB.

```
###########(Q0)105 CB INTERLOCK ##########################
#105 – CB TEST INTERLOCK LOGIC
PSV35 := 89OPN01 AND 89OPN03 AND 89OPN05
#105 – CB SERVICE INTERLOCK LOGIC
PSV32 := (89CL01 OR 89CL03)
PSV40 := 89CL05 AND PSV32 AND IN102 AND PSV33
# CB CLOSE LOGIC
PSV43 := PSV40 OR PSV35
PSV48 := ASV038 OR ASV039
PSV45 := PSV43 AND PSV31 AND (NOT 521CLSM) AND (NOT IN305) AND (NOT IN308)
AND (NOT IN312) AND IN224 AND PSV48
# CB OPEN LOGIC
PSV46 := PSV31 AND 521CLSM AND (NOT IN306) AND (NOT IN314)
```

Fig. 6. Example of Interlocking Logic for a 110 kV CB

As shown in Fig. 6, the final binary value will be stored in internal variables PSV45 and PSV46 for a close or open command, respectively. When the value of a variable is high (1), it is termed “interlock satisfied” or “permissive received,” which means that all interlocking conditions are satisfied and the CB can either be closed or opened, depending upon its present state. When the value of a variable is low (0), it is termed “interlock not satisfied” or “permissive not received,” which means that one or more interlocking conditions are not satisfied and the CB can neither be closed nor opened, depending upon its present state.

2) Output Contacts

In a BCU, two hardwired output contacts are associated with each operable device. For instance, one of a CB’s output contacts is wired to the CB closing coil to send a close command and the second output contact is wired to the CB opening/trip coil to send an open command. Thus, to relate the command of closing or opening with the interlocking condition, the word bit of the close or open command and the related internal variable (PSV45 or PSV46, in this case) are combined using AND logic. The result is mapped to the BCU output contact, which is wired to the closing or opening coil of the CB, as shown in (1) and (2).

$$\text{OUT205} = \left(\text{CB Close Command}\right) \text{AND PSV45} \quad (1)$$

$$\text{OUT206} = \left(\text{CB Trip Command}\right) \text{AND PSV46} \quad (2)$$

The explanations in the preceding two subsections apply in the exact same manner for isolators and earth switches for any specified bay.

3) Synchronization Logic Settings

A live incomer cannot be switched onto a live bus without verifying that certain parameters (voltage magnitude [kV], voltage angle [degrees], and frequency [Hz]) are within permissible limits on both ends. The various cases for synchronization are line-line, live bus-live line, dead bus-dead line, and live bus and dead line-dead bus. Table IV and Table V show example settings for various parameters related to the synchronization check. These settings should be based on the voltage synchronization settings document discussed earlier in Section VI.

TABLE IV. EXAMPLE SYNCHRONIZATION CHECK PARAMETERS (REFERENCE)

Parameter Type	Parameter Options	Parameter Selected
Synchronization reference voltage	VAY, VBY, VCY, VAZ, VBZ, VCZ	VBY
Voltage low threshold (V)	20–200	53
Voltage high threshold (V)	20–200	73

TABLE V. EXAMPLE SYNCHRONIZATION CHECK PARAMETERS (SOURCE)

Parameter Type	Parameter Options	Parameter Selected
Synchronization source voltage	VAY, VBY, VCY, VAZ, VBZ, VCZ	VBZ
Maximum slip frequency (Hz)	0.005–0.5	0.05
Maximum angle difference (degrees)	3–80	10

4) Measurement Settings

The measurement settings of a BCU usually consist of CT and VT ratios and the assignments of the measured current and voltage values from word bits to internal analog variables. An example is shown in Table VI.

TABLE VI. EXAMPLE MEASUREMENT PARAMETER SETTINGS

Parameter Type	Parameter Value
CT ratio	2000 / 1
VT ratio	110,000 / 115
Dead line voltage (V)	5.8
Live line voltage (V)	46.2

5) Time-Synchronization Settings

Time synchronization is a vital feature of an SAS that matches the times of events recorded in a BCU and those published to SCADA. This requires setting an IP address for the time server (e.g., a GPS clock), setting a Coordinated Universal Time (UTC) offset, and setting daylight-saving time, per the geographical location of the substation. Table VII shows example time-synchronization settings where the Simple Network Time Protocol (SNTP) primary and backup IP addresses are for the main and redundant SNTP servers and are taken from the approved IP address list discussed in Section VI.

TABLE VII. SAMPLE SNTP PARAMETER SETTING

Parameter Type	Parameter Options	Parameter Selected
SNTP operation mode	OFF, UNICAST, MANYCAST, BROADCAST	UNICAST
Request update rate (seconds)	15–3,600	60
SNTP time-out (seconds)	0–20	5
SNTP primary server	aaa.bbb.ccc.ddd/yz	111.11.1.2
SNTP backup server	aaa.bbb.ccc.eee/yz	111.11.1.3
UTC offset (hour)	–15.5 to +24	+3
Daylight-saving time	OFF, ON	OFF

To optimize the network traffic, the appropriate SNTP operation mode must be selected. Of the three modes, UNICAST fulfills this requirement well because it does not send the broadcast messages on the network, unlike the other two modes, which broadcast Network Time Protocol (NTP) requests.

C. IEC 61850-Based Configuration

Development of the IEC 61850 configuration is a vital stage in BCU configuration. This stage either follows the BCU logic settings or takes place in parallel, depending on how detailed and efficiently designed the BCU I/O and GOOSE lists are. This configuration produces a Configured IED Description (CID) file that is downloaded to the BCU to provide communication between the BCU and SCADA as well as peer-to-peer communication among the BCUs to share required status and analog values based on the control and measurement settings.

This section of the paper discusses IEC 61850 configuration parameters along with the practical aspects of an optimized configuration.

1) Controllable Point Control Model

In IEC 61850, there are two major control models: Direct Operate (DO) and Select Before Operate (SBO). The preferred model is SBO because it ensures that after a client (e.g., a data acquisition server) selects a control object, it will be the only device allowed to perform control actions; hence, conflicting control actions from multiple clients are prevented by the server (i.e., the BCU).

2) IEC 61850 Name

In an IEC 61850-based SAS, every IED has an IP address and a unique IEC 61850 name. This name should be the same both on the BCU and in SCADA; otherwise, IED communication will fail. An IEC 61850 name could be **ABC_123_BCU**, for example.

3) Data Sets

A data set is a list of IEC 61850 addresses (data items) associated with relay elements that are transmitted together using GOOSE messaging (described in the following subsections) or MMS reporting. Although every IED provides a number of data sets, from the optimization point of view, at least three data sets should be created: one to contain all status points (hardwired inputs and outputs, internal logic variables, equipment status and controllable points, general alarm points etc.), one to contain all required analog points (mainly used for measurements), and one to contain interlocking signals to be published via GOOSE messages.

Data items related to status points have three attributes:

- Status value (*stVal*), which indicates the state of the specific relay element as either 0 or 1.
- Quality flag (*q*), which is used to represent the health of the data item.
- Time stamp (*t*), which provides the time associated with a change in *stVal*. This time is taken from the BCU.

Fig. 7 shows an example status points data set.

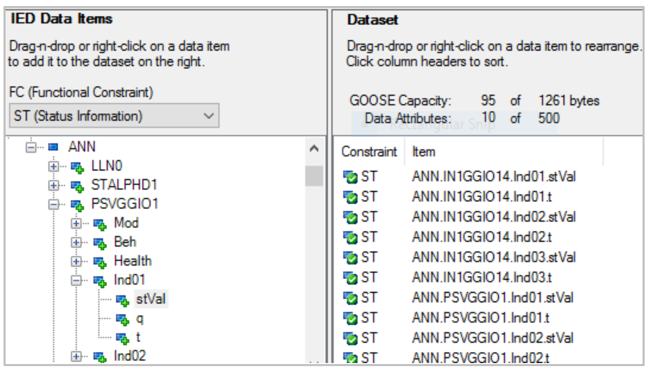


Fig. 7. Status Points Data Set

Data items related to analog points also have three attributes, two of which are the same *q* and *t* as in the status points data set. However, instead of *stVal*, the analog points data set has instantaneous magnitude (*instMag*), which depicts the real-time measurement of the associated relay element. See Fig. 8 for an example analog points data set.

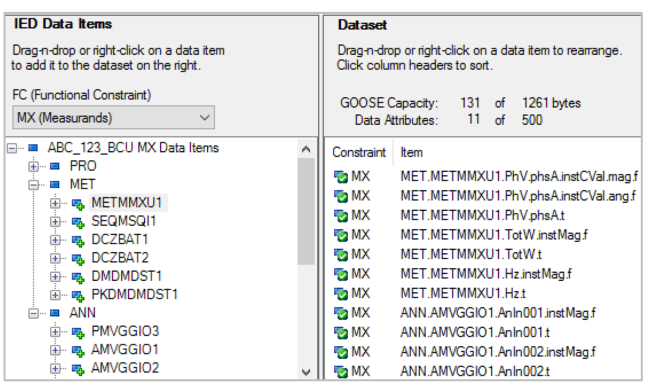


Fig. 8. Analog Points Data Set

Every data set is designed to have a limited number of data attributes, which has to be respected to avoid data loss during information transfer from an IED to the database server. This limitation is handled by selecting only the required data attributes for a data set based on the I/O list and by selecting only *stVal* and *t* for the status points data set and *instMag* for the analog points data set. The *q* flag is added only for critical signals.

Only the *stVal* data attribute should be included in the GOOSE publishing data set to keep the message size and number of data items to a minimum for optimum message processing performance at the subscriber end.

4) Report Control Blocks (RCBs)

Each data set discussed earlier is linked with RCBs that are responsible for transferring the unsolicited data messages from the BCU to data acquisition servers. Each report can be locked with a single IEC 61850 client. Reports can be classified as buffered or unbuffered. In buffered reporting, events are logged and stored for a specific amount of time after the associated client is disconnected, and these events are sent once this client is reconnected. In unbuffered reporting, this functionality is not available.

As a best practice, the status points and analog points data sets are assigned to a required number of buffered and unbuffered RCBs, respectively.

As described in the previous subsection, the status points data set has information about individual bays and the substation as a whole. Because each change of these data is critical for understanding power system events, it is necessary to buffer these data changes and include associated time stamps. This requirement is fulfilled by using IEC 61850 buffered reporting [7].

Because analog measurements are less critical, they are usually updated by configuring appropriate deadbands (a way of optimizing SAS network traffic) and/or updated through integrity polling. Therefore, unbuffered reporting suffices for detecting changes in analog values.

The number of RCBs that need to be configured in the BCU is based on the number and arrangement of database servers and gateways, as represented by the SAS network architecture document. Fig. 9 shows a sample configuration for a buffered RCB.

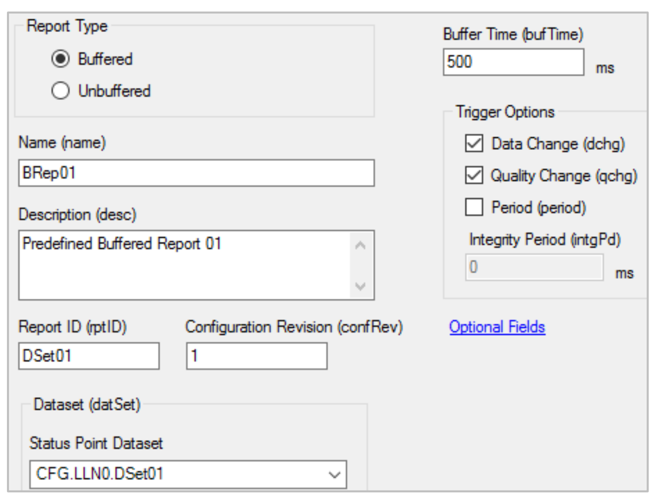


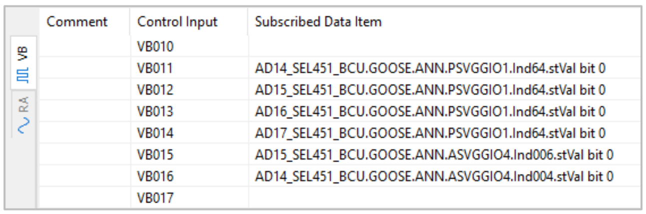
Fig. 9. Buffered RCB

5) GOOSE Transmit Configuration

A GOOSE data set is created with variables to be shared with other BCUs and IEDs. This data set is the payload of the GOOSE transmit message.

6) GOOSE Receive Configuration

When every BCU in an SAS has GOOSE transmit enabled, GOOSE receive can be configured for each BCU. One BCU or IED can be configured to receive GOOSE messages from multiple BCUs and IEDs. The GOOSE messages to be received are mapped to internal virtual bits available in the BCU. These virtual bits should be the same as those used for the logic settings in the BCU. Fig. 10 shows an example GOOSE receive configuration. Because of the connectionless publish and subscribe nature of GOOSE messaging, it is very important to check the message quality at the subscriber end. The message quality needs to be mapped to a virtual bit in the subscriber IED and used to supervise the quality status of all the other information contained in that GOOSE message.



Comment	Control Input	Subscribed Data Item
	VB010	
	VB011	AD14_SEL451_BCU.GOOSE.ANN.PSVGGIO1.Ind64.stVal bit 0
	VB012	AD15_SEL451_BCU.GOOSE.ANN.PSVGGIO1.Ind64.stVal bit 0
	VB013	AD16_SEL451_BCU.GOOSE.ANN.PSVGGIO1.Ind64.stVal bit 0
	VB014	AD17_SEL451_BCU.GOOSE.ANN.PSVGGIO1.Ind64.stVal bit 0
	VB015	AD15_SEL451_BCU.GOOSE.ANN.ASVGGIO4.Ind006.stVal bit 0
	VB016	AD14_SEL451_BCU.GOOSE.ANN.ASVGGIO4.Ind004.stVal bit 0
	VB017	

Fig. 10. GOOSE Receive Configuration

VII. Conclusion and Future Work

The configuration of the BCU is a vital part of ensuring proper operation of an SAS and fulfilling all necessary technical requirements. Because of the diversity of the inputs and outputs in relation to the functionality implemented in BCUs, the design input documentation must be well-defined and thorough. The configuration steps and the design inputs must also be well-defined to enable efficient and accurate implementation.

The methodology presented in this paper was developed based on actual commissioning experience with an SAS implementation for a 110/13.8 kV substation, and it has been proven to be optimized. The proposed method is advantageous as it provides a defined process flow to perform step-by-step engineering of the BCU and enables a much defined and robust review process.

This paper will be extended in the future with more technical details on setting parameters related to IEC 61850 configuration of a BCU by providing a procedure for integrating a BCU with a SCADA platform and by providing an overall testing methodology.

References

[1] D. Proudfoot, “Innovative Substation Design-The Bay Controller Concept,” proceedings of the 34th Annual IEEE Industrial Applications Conference, Phoenix, AX, October 1999.

[2] L. Hossenlopp, “Perspectives for the Substation Digital Bays,” proceedings of the IEEE Power Engineering Society Winter Meeting, Singapore, January 2000.

[3] T. Xu, X. Yin, D. You, H. Yu, Y. Wang, and H. Hou, “Bay Level IED Modeling and Realizing Using IEC 61850,” proceedings of the IEEE Transmission and Distribution Conference and Exposition, Chicago, IL, April 2008.

[4] Y. Liu, H. Gao, X. Wei, Z. Teng, P. Wei, N. Li, and M. Xiang, “Study on New Type of IED With Integrated Functions in Intelligent Substation,” proceedings of the International Conference on Advanced Power System Automation and Protection, Beijing, China, October 2011.

[5] D. Otto, R. Zhang, and H. Li, “IEC 61850 Configuration Strategy for Substation Control and Protection,” proceedings of the 10th IET International Conference on Developments in Power System Protection, Manchester, UK, March 2010.

[6] J. C. Miranda, U. C. Netto, D. V. Coury, M. Oleskovicz, E. C. Gurjão, N. S. D. Brito, and B. A. de Souza, “Bay Control Using Commercial Digital Relays Via IEC 61850,” proceedings of the 2010 IEEE/PES Transmission and Distribution Conference and Exposition, Sao Paulo, Brazil, November 2010.

[7] R. L. O’Fallon, D. A. Klas, T. Tibbals, and S. Shah, “IEC 61850 MMS SCADA Network Optimization for IEDs,” proceedings of the DistribuTECH Conference, San Diego, CA, February 2011.

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