SCHWEITZER ENGINEERING LABORATORIES, INC.
WHITE PAPER

Automating Protection System Monitoring and Verification With the SEL RTAC

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INTRODUCTION

The North American Electric Reliability Corporation (NERC), under the direction of the Federal Energy Regulatory Commission (FERC), is responsible for improving the reliability of the North American bulk electric system (BES). This responsibility includes creating a compliance program to improve the protection system reliability of generation and transmission facilities that can impact the BES. Under NERC PRC-005-2, the definition of protection systems includes protective relays, associated communications systems, voltage- and current-sensing devices (including their circuits), dc control circuitry, and station dc supplies associated with protection functions. Proposed future revisions of the NERC PRC-005 standard expand the scope of the maintenance programs to include additional protection system components.

Compliance with the standard entails the creation of a comprehensive protection system maintenance program and the execution of maintenance activities on a time- or performance-based interval or a combination of both. Leveraging the inherent self-test functionality and communications capability of modern intelligent electronic devices (IEDs), engineers can implement an automated system to perform real-time monitoring, verification, and reporting for power system components. This provides the following benefits [1]:

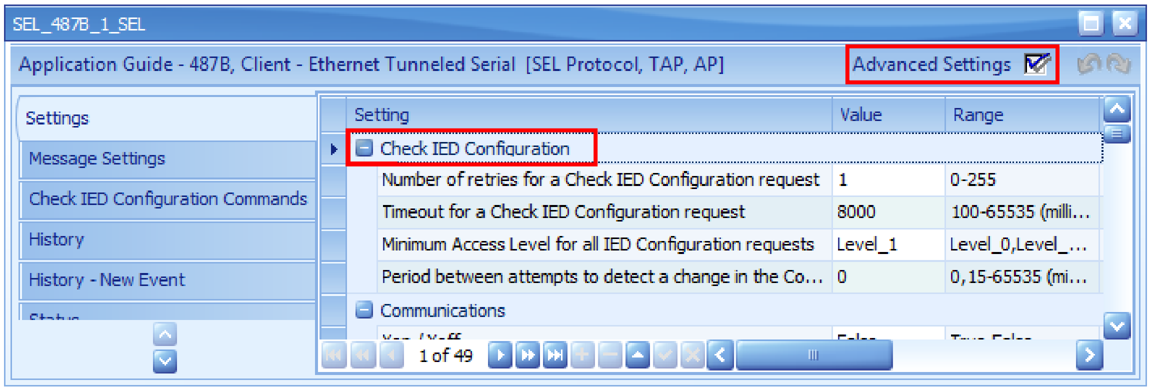
- Improves protection system awareness and identifies potential failed components that may otherwise go unnoticed.
- Supports maintenance and validation testing documentation requirements for each of the monitored critical protection system components.
- Documents the behavior of power system components during fault events and steady-state operations.

Beyond compliance, monitoring critical assets via predictive alarming gives engineers the necessary data to keep power system components online and avoid expensive downtime. This white paper describes how to use the SEL Real-Time Automation Controller (RTAC) to build an automated system to continuously monitor and validate many of the components identified in the NERC PRC-005 standard. This paper describes how to:

- Verify commissioned IED settings and firmware configurations.
- Verify CTs and PTs with continuous IED measurements.
- Verify communications-assisted protection channel integrity.
- Monitor IED diagnostics.
- Generate automated reports for both local and remote access.
- Identify and log maintenance conditions.

Verify Commissioned IED Settings and Firmware Configurations

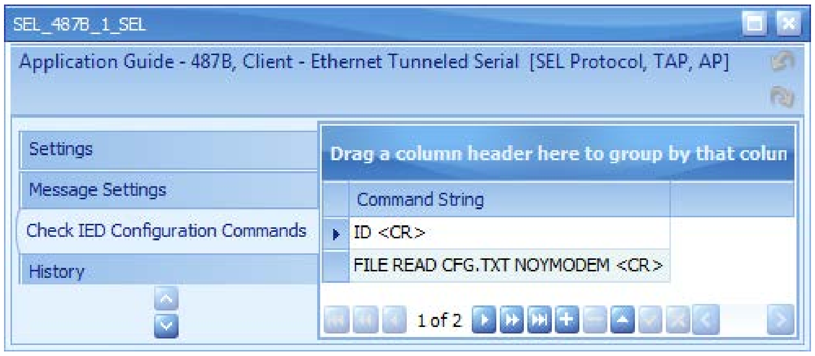
The Configuration Monitor is a feature in SEL clients that provides the capability to monitor ASCII command responses. With this feature enabled, SEL IEDs are continuously monitored to detect changes in configurations. Any ASCII command supported in the IED can be specified and sent on a periodic interval. When the RTAC receives a valid response, a 32-bit cyclic redundancy check (CRC) is calculated and stored in memory. If the RTAC receives a valid response in which the calculated CRC does not match the stored CRC, the **Check_IED_Configuration_Mismatch** POU pin pulses. Then, the most recent CRC is stored in memory. If the CRC cannot be calculated correctly, the **Check_IED_Configuration_Error** POU pin pulses. The settings for the Configuration Monitor are displayed by selecting the **Advanced Settings** check box in the upper-right corner of the IED view screen (as shown in Figure 1).


SEL_487B_1_SEL
Application Guide - 487B, Client - Ethernet Tunneled Serial [SEL Protocol, TAP, AP]
Advanced Settings
Settings
Message Settings
Check IED Configuration Commands
History
History - New Event
1 of 49

Setting	Value	Range
Check IED Configuration		
Number of retries for a Check IED Configuration request	1	0-255
Timeout for a Check IED Configuration request	8000	100-65535 (milli…
Minimum Access Level for all IED Configuration requests	Level_1	Level_0,Level_…
Period between attempts to detect a change in the Co…	0	0,15-65535 (mi…
Communications		

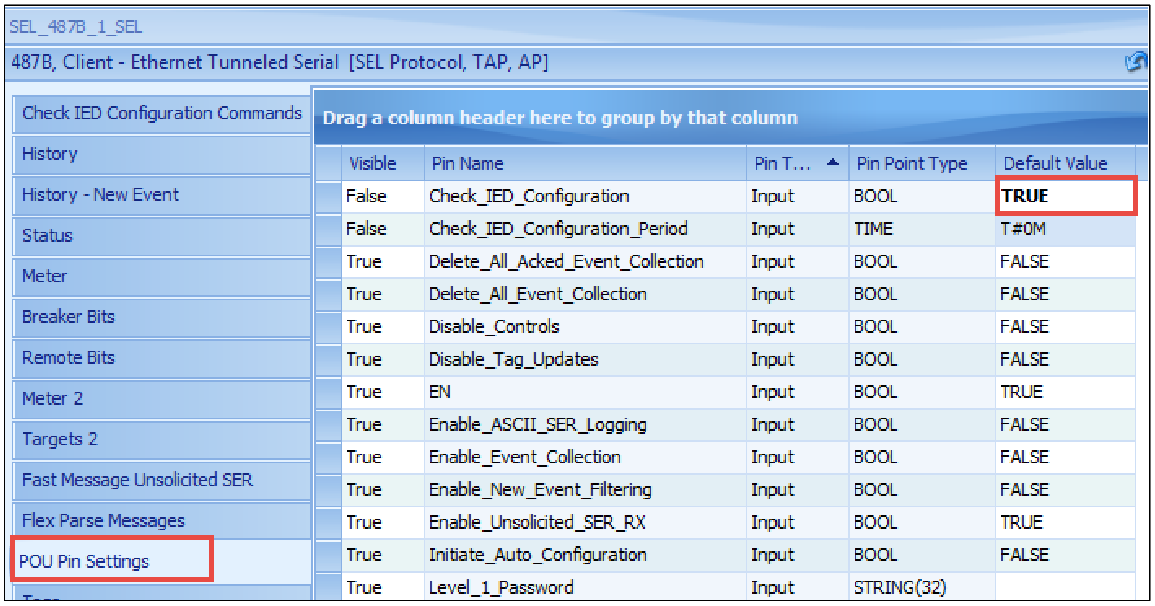
Figure 1 Check IED Configuration Settings in an SEL Client

The advanced settings are available to optimize the monitoring interval and command retry behavior. By default, messages are configured to allow users to monitor both the relay ID information and settings configuration. However, users should verify with the relay's manual that the commands are supported in the IED firmware version. Users can click on the **Check IED Configuration Commands** tab to view and edit the default messages (as shown in Figure 2). Additional messages can be added at the user's discretion. Also, by default, the Configuration Monitor is not enabled. To enable it, users click on the **POU Pin Settings** tab and change the **Check_IED_Configuration** POU pin to **TRUE** (as shown in Figure 3). In some instances, software flow control interferes with the Configuration Monitor. To avoid this, disable software flow control by toggling **Xon\Xoff** to **False** in the **Communications** section of the **Settings** tab.


SEL_487B_1_SEL
Application Guide - 487B, Client - Ethernet Tunneled Serial [SEL Protocol, TAP, AP]
Settings
Message Settings
Check IED Configuration Commands
History
Drag a column header here to group by that colun
1 of 2

Command String
ID <CR>
FILE READ CFG.TXT NOYMODEM <CR>

Figure 2 Default Messages Sent by the Configuration Monitor in the SEL Client


SEL_487B_1_SEL

487B, Client - Ethernet Tunneled Serial [SEL Protocol, TAP, AP]

Visible	Pin Name	Pin T...	Pin Point Type	Default Value
False	Check_IED_Configuration	Input	BOOL	TRUE
False	Check_IED_Configuration_Period	Input	TIME	T#0M
True	Delete_All_Acked_Event_Collection	Input	BOOL	FALSE
True	Delete_All_Event_Collection	Input	BOOL	FALSE
True	Disable_Controls	Input	BOOL	FALSE
True	Disable_Tag_Updates	Input	BOOL	FALSE
True	EN	Input	BOOL	TRUE
True	Enable_ASCII_SER_Logging	Input	BOOL	FALSE
True	Enable_Event_Collection	Input	BOOL	FALSE
True	Enable_New_Event_Filtering	Input	BOOL	FALSE
True	Enable_Unsolicited_SER_RX	Input	BOOL	TRUE
True	Initiate_Auto_Configuration	Input	BOOL	FALSE
True	Level_1_Password	Input	STRING(32)	

Figure 3 Enabling the Configuration Monitor in the POU Pin Settings Tab

ACSELERATOR RTAC LIBRARY EXTENSIONS INTRODUCTION

The ACSELERATOR RTAC® SEL-5033 Software library extensions are a set of libraries developed by SEL that offer additional functionality for programming applications in the RTAC's feature-rich, integrated IEC 61131 programming environment. Two libraries are used in this white paper: 1) ChannelMonitoring and 2) FileIO. FileIO is a paid library, and an RTAC upgrade package can be ordered by contacting your local sales or customer service representative.

To start programming with libraries, visit the ACSELERATOR RTAC software page at https://www.selinc.com/SEL-5033/ and download the ACSELERATOR RTAC library extensions. Once the library extensions are installed, navigate to the **IEC 61131-3** ribbon button in ACSELERATOR RTAC and select **Library** (as shown in Figure 4). From here, a wide range of libraries are available, including the ChannelMonitoring and FileIO libraries. Note that users can download and use the libraries in ACSELERATOR RTAC; however, if a paid library is uploaded to an RTAC without the correct model option table (MOT), a warning will appear that will prevent the project upload from completing.

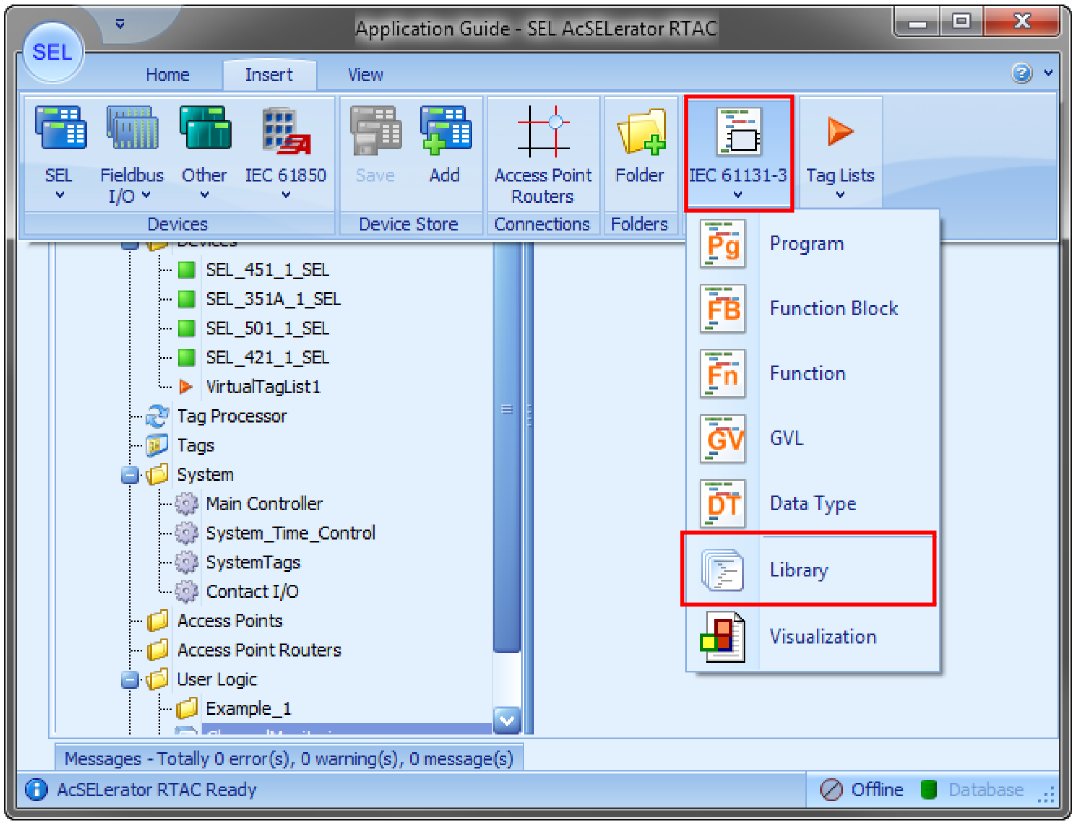


Figure 4 Adding a Library Through the IEC 61131-3 Menu in ACSELERATOR RTAC

Each library has a corresponding instruction manual that is accessible through the ACSELERATOR RTAC help button ( ) drop-down menu in the upper-right corner of the screen (see Figure 5). These manuals are installed automatically with the library extensions.

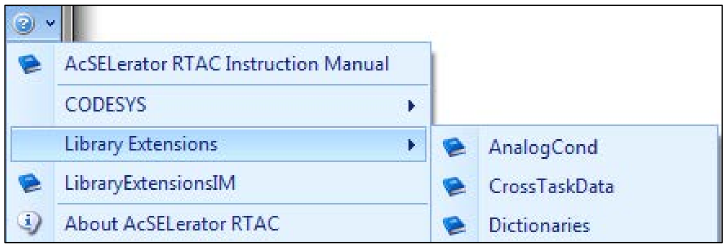


Figure 5 Accessing Library Documentation From the ACSELERATOR RTAC Help Menu

ChannelMonitoring Library Introduction

The RTAC is a data concentrator and communications gateway that includes an integrated IEC 61131 programming environment. The RTAC leverages these capabilities to monitor and validate IED measurements in a substation. The ChannelMonitoring library aids engineers in simplifying power system maintenance monitoring. The library includes tools that are used to create a monitoring system that works on any substation topology. The function block outputs provide Boolean alerts. The status outputs return information about the function block's current state. These outputs are assigned to enumerations provided in the library or to DINT data types. Functions are provided to convert the enumerated outputs to strings for logging purposes. For detailed information regarding the inputs, outputs, and information processing for the function blocks, refer to the library's instruction manual. In the following sections, brief examples are provided that demonstrate the functionality of each function block.

Example Assumptions

Communications protocol clients are configured in ACSELERATOR RTAC to communicate with IEDs. The phase measurements and the applicable relay status points are polled at user-defined polling intervals. These measurements and status points are passed to the function block inputs for processing. Input data are monitored by the function block, which determines if any significant difference is detected based on the user-specified parameters. Function block outputs are stored in tags configured in a virtual tag list (a virtual tag list is used in all of the following examples; however, any tag matching the data type of the function block output can be used to store the data). Example programs are constructed using Continuous Function Chart (CFC). Similar examples are provided in Structured Text (ST) in the library's instruction manual. For additional information regarding any of the topics described in this paper, refer to [2], or view the RTAC videos on the SEL website for quick tutorial videos produced by SEL automation engineers [3].

The tags used in some of the following examples are complex measured value (CMV) data types. When an SEL IED is queried via SEL protocol, some of the data returned include both magnitude and angle; hence, a CMV data type is used to store that information. However, the function blocks that use analog quantities as inputs only accept measured value (MV) data types because, in most cases, the phasor magnitudes are compared to detect possible maintenance alert conditions. The following function logic converts a CMV data type to an MV data type through direct mapping of the magnitude quantity.

```
//////Declaration Section//////
FUNCTION fun_CMV_TO_MV_Mag : MV
VAR_INPUT
      CMV_IN : CMV;
END_VAR;

//////Start of function logic//////
fun_CMV_TO_MV_Mag.instMag := CMV_IN.instCVal.mag;
fun_CMV_TO_MV_Mag.q := CMV_IN.q;
fun_CMV_TO_MV_Mag.range := CMV_IN.range;
fun_CMV_TO_MV_Mag.rangeC := CMV_IN.rangeC;
fun_CMV_TO_MV_Mag.t := CMV_IN.t;
fun_CMV_TO_MV_Mag.zeroDb := CMV_IN.zeroDb;
fun_CMV_TO_MV_Mag.db := CMV_IN.db;
```

VERIFY CTS AND PTS WITH CONTINUOUS IED MEASUREMENTS

Two function blocks are provided in the ChannelMonitoring library that encapsulate logic to monitor MV data and determine if critical system components are operating as designed. The two function blocks alert on a test failure. The test failure indicates that either a sustained divergence between two inputs has occurred or repeated divergences were detected. Both function blocks also indicate the input information quality.

Example 1: Monitor for Deviations Between Phases on the High and Load Side of a Breaker

This example demonstrates the use of the **fb_MultiChannelAlert** function block. Both the high and load side of a breaker phase measurement are obtained from the IED. The IED has two terminals that are connected to two separate current transformers (CTs) located on both sides of a breaker, as shown in Figure 6. The function block monitoring is enabled when the high-side power measurements are greater than or equal to 5 percent of the nominal value. Phases are compared to detect a significant difference in measurements. The purpose is to detect any difference between the phases of each CT that may indicate a maintenance condition.

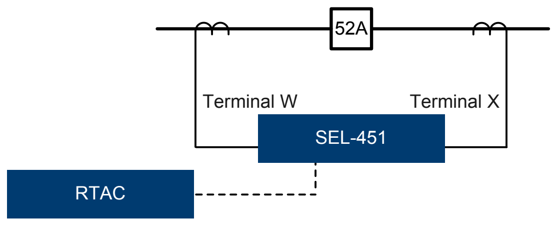
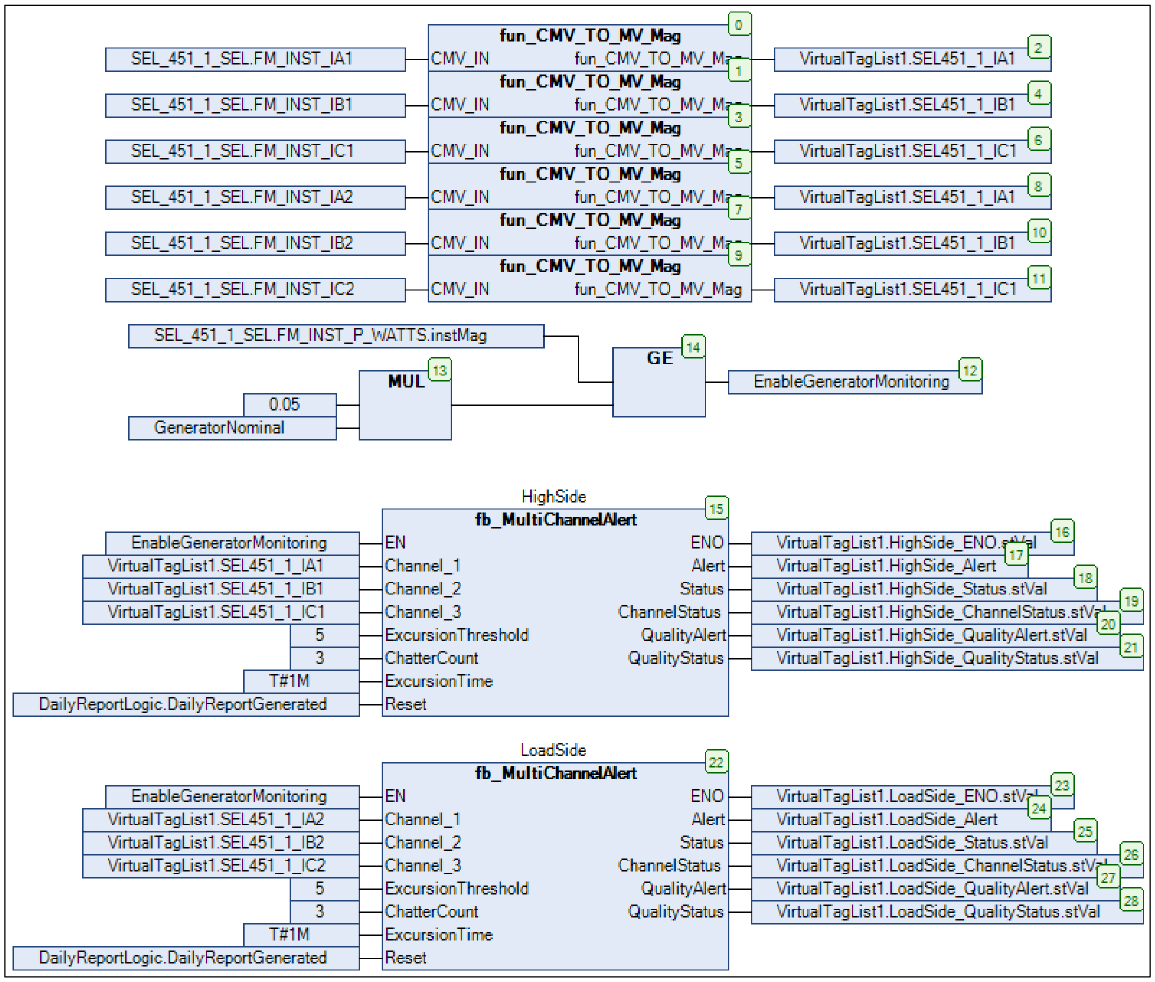


Figure 6 RTAC Polling Data From an IED Monitoring High and Load Sides of a Breaker

To configure this example, a CFC program (see the following PROGRAM Example1 logic) is added to the ACSELERATOR RTAC project [2] [3]. The code block shown in Figure 7 demonstrates how to instantiate two **fb_MultiChannelAlert** function blocks, each monitoring a three-phase CT, in the declaration section of the program. In the body of the program, the CMV data reported by the IED are converted to MV data types. A check is then performed to determine if the generator real power exceeds 5 percent of nominal before activating the instantiated **fb_MultiChannel** function blocks. Once activated, the function blocks compare all of the individual phases against one another to detect an abnormal condition.

```
PROGRAM Example1
VAR
      //Instantiate Function Blocks
      HighSide : fb_MultiChannelAlert;
      LoadSide : fb_MultiChannelAlert;

      //Function Block Parameters
      GeneratorNominal : REAL := 100;
      EnableGeneratorMonitoring : BOOL;

END_VAR
```



fun_CMV_TO_MV_Mag
SEL_451_1_SEL.FM_INST_IA1
CMV_IN
fun_CMV_TO_MV_Mag
VirtualTagList1.SEL451_1_IA1
SEL_451_1_SEL.FM_INST_IB1
VirtualTagList1.SEL451_1_IB1
SEL_451_1_SEL.FM_INST_IC1
VirtualTagList1.SEL451_1_IC1
SEL_451_1_SEL.FM_INST_IA2
SEL_451_1_SEL.FM_INST_IB2
SEL_451_1_SEL.FM_INST_IC2
SEL_451_1_SEL.FM_INST_P_WATTS.instMag
GE
EnableGeneratorMonitoring
MUL
0.05
GeneratorNominal
HighSide
fb_MultiChannelAlert
EN
Channel_1
Channel_2
Channel_3
ExcursionThreshold
ChatterCount
ExcursionTime
Reset
ENO
Alert
Status
ChannelStatus
QualityAlert
QualityStatus
5
3
T#1M
DailyReportLogic.DailyReportGenerated
VirtualTagList1.HighSide_ENO.stVal
VirtualTagList1.HighSide_Alert
VirtualTagList1.HighSide_Status.stVal
VirtualTagList1.HighSide_ChannelStatus.stVal
VirtualTagList1.HighSide_QualityAlert.stVal
VirtualTagList1.HighSide_QualityStatus.stVal
LoadSide
VirtualTagList1.SEL451_1_IA2
VirtualTagList1.SEL451_1_IB2
VirtualTagList1.SEL451_1_IC2
VirtualTagList1.LoadSide_ENO.stVal
VirtualTagList1.LoadSide_Alert
VirtualTagList1.LoadSide_Status.stVal
VirtualTagList1.LoadSide_ChannelStatus.stVal
VirtualTagList1.LoadSide_QualityAlert.stVal
VirtualTagList1.LoadSide_QualityStatus.stVal

Figure 7 Example 1 Configured in a CFC Program

Example 2: Monitor for Deviations in the Phase A Measurement From Multiple IEDs

This example demonstrates the use of the **fb_ChannelAlert** function block. Phase A measurements are obtained from four IEDs within the substation, as shown in Figure 8. The IEDs are connected to CTs located throughout the substation. Phase A measurements are compared against a chosen reference. By testing the measured values from an IED, the function blocks also provide validation for additional critical protection system components, including the CT circuits and the IED analog-to-digital converters. The monitoring function blocks enable when the reference measurement has good quality. The purpose is to detect any difference between CT measurements that may indicate a maintenance condition.

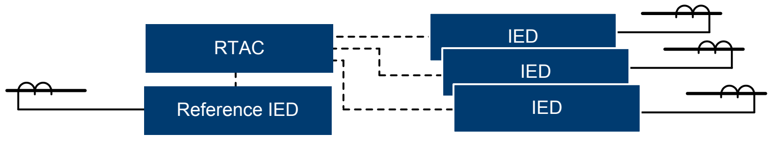
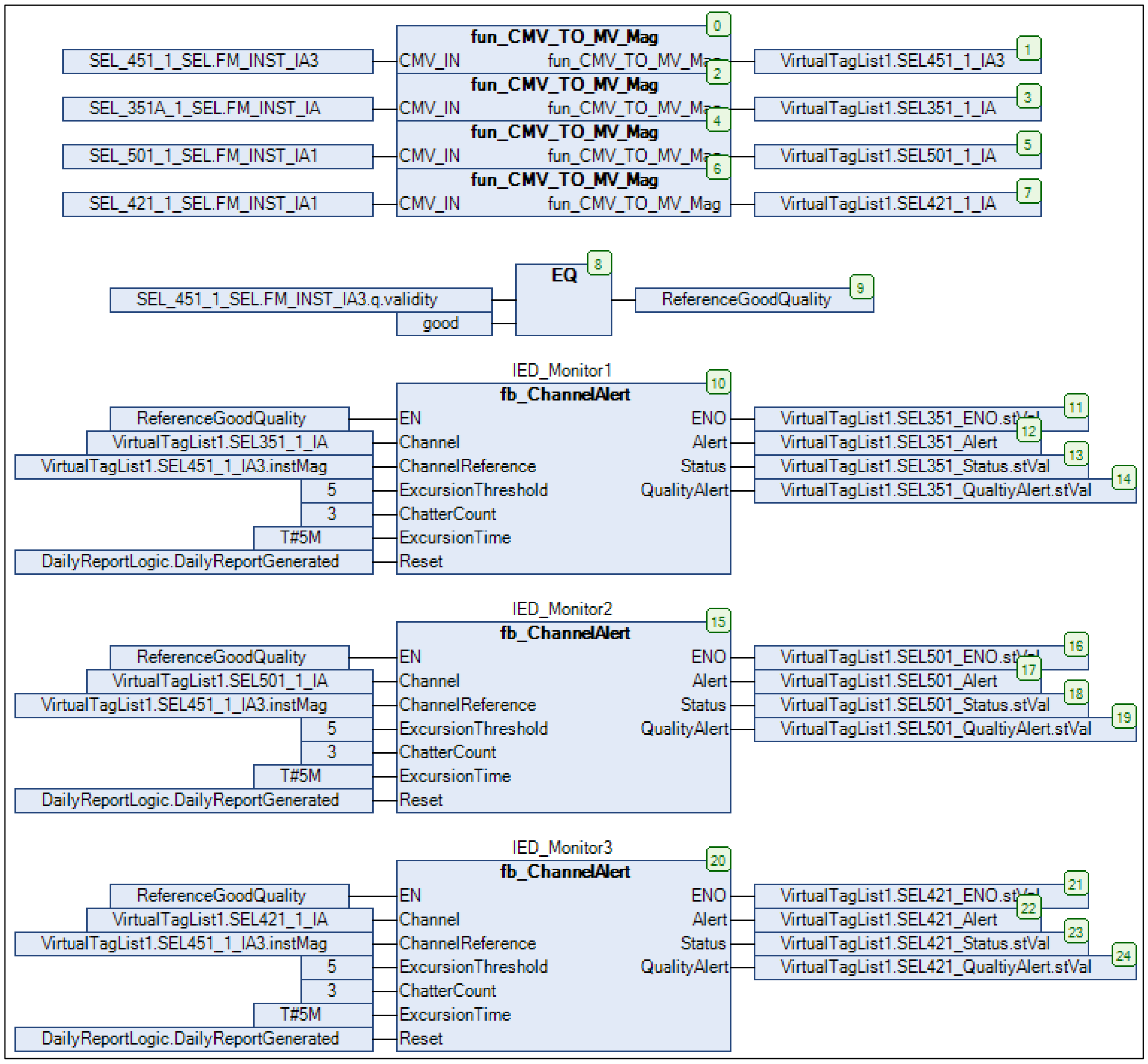


Figure 8 RTAC Polling Data From a Reference IED and Three IEDs Connected to Substation CTs

To configure this example, a CFC program (see the following PROGRAM Example2 logic) is added to the ACSELERATOR RTAC project [2] [3]. The code block shown in Figure 9 demonstrates how to instantiate three **fb_ChannelAlert** function blocks, each monitoring a CT's

Phase A measurements, in the declaration section of the program. As in the previous example, in the body of the program the CMV data reported by the IED are converted to MV data types. A check is then performed to determine if the reference value has good quality (i.e., the RTAC is receiving valid data from the IED) before activating the instantiated function blocks. Once activated, the function blocks compare the input channel and reference data to determine if an abnormal condition is detected.

```
PROGRAM Example2
VAR
      //Instantiate Function Blocks
      IED_Monitor1 : fb_ChannelAlert;
      IED_Monitor2 : fb_ChannelAlert;
      IED_Monitor3 : fb_ChannelAlert;

      //Function Block Shared Parameters
      ReferenceGoodQuality : BOOL;
END_VAR
```



SEL_451_1_SEL.FM_INST_IA3
SEL_351A_1_SEL.FM_INST_IA
SEL_501_1_SEL.FM_INST_IA1
SEL_421_1_SEL.FM_INST_IA1
fun_CMV_TO_MV_Mag
CMV_IN
fun_CMV_TO_MV_Mag
VirtualTagList1.SEL451_1_IA3
VirtualTagList1.SEL351_1_IA
VirtualTagList1.SEL501_1_IA
VirtualTagList1.SEL421_1_IA
EQ
SEL_451_1_SEL.FM_INST_IA3.q.validity
good
ReferenceGoodQuality
IED_Monitor1
fb_ChannelAlert
EN
Channel
ChannelReference
ExcursionThreshold
ChatterCount
ExcursionTime
Reset
ENO
Alert
Status
QualityAlert
ReferenceGoodQuality
VirtualTagList1.SEL351_1_IA
VirtualTagList1.SEL451_1_IA3.instMag
5
3
T#5M
DailyReportLogic.DailyReportGenerated
VirtualTagList1.SEL351_ENO.stVal
VirtualTagList1.SEL351_Alert
VirtualTagList1.SEL351_Status.stVal
VirtualTagList1.SEL351_QualtiyAlert.stVal
IED_Monitor2
VirtualTagList1.SEL501_1_IA
VirtualTagList1.SEL501_ENO.stVal
VirtualTagList1.SEL501_Alert
VirtualTagList1.SEL501_Status.stVal
VirtualTagList1.SEL501_QualtiyAlert.stVal
IED_Monitor3
VirtualTagList1.SEL421_1_IA
VirtualTagList1.SEL421_ENO.stVal
VirtualTagList1.SEL421_Alert
VirtualTagList1.SEL421_Status.stVal
VirtualTagList1.SEL421_QualtiyAlert.stVal
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

Figure 9 Example 2 Configured in a CFC Program

VERIFY COMMUNICATIONS-ASSISTED PROTECTION CHANNEL INTEGRITY

Protection communications channels require high availability and reliability to ensure that critical signals are available to other substation IEDs that participate in coordinated protection and control schemes. Continuously monitoring these channels for communications errors provides information on the health of the channel. Early alerting on a potential maintenance condition can aid engineers in identifying conditions that may result in a misoperation.

Example 3: Monitor a MIRRORED BITS® Communications Channel for Data Transmission Errors

This example demonstrates the use of the **fb_IndicatorAlert** function block. The RTAC and an IED exchange critical control information over a serial MIRRORED BITS communications channel. The channel health is monitored by the RTAC's built-in diagnostic information included in all communications instances. The **Rx_OK_Instantaneous** POU pin is monitored by the function block. This pin deasserts the instant any of several types of transmission errors are detected or any time that a MIRRORED BITS message is not received in the time required to transmit three messages. Monitoring this pin provides a good indication of channel health. Note in the example that a **NOT** block inverts the **Rx_OK_Instantaneous** POU pin because the **fb_IndicatorAlert** function block detects a **TRUE** condition. Because the goal is to monitor the deasserting of the pin, a NOT is included in the logic.

To configure this example, a CFC program (see the following PROGRAM Example3 logic) is added to the ACSELERATOR RTAC project [2] [3]. The code block shown in Figure 10 demonstrates how to instantiate an **fb_IndicatorAlert** function block in the declaration section of the program. Although not shown in Figure 10, the function block **EN** value can be tied to the **ENO** POU pin of a MIRRORED BITS communications instance. This ensures that the MIRRORED BITS channel is enabled before activating the instantiated function block. Once activated, the function block monitors for a **TRUE** condition, which indicates that errors were detected in the communications channel.

```
PROGRAM Example3
VAR
      //Instantiate Function Blocks
      MirrorBitsMonitor : fb_IndicatorAlert;

      //Function Block Shared Parameters
      EnableMonitoring : BOOL := TRUE;
END_VAR
```

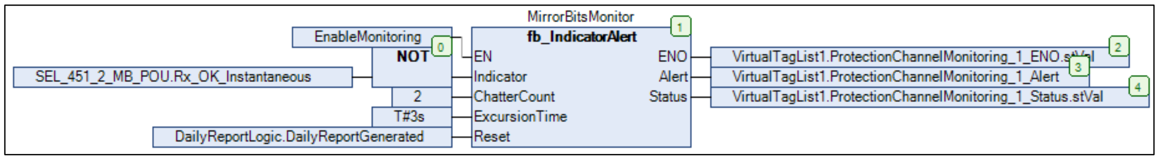

MirrorBitsMonitor
fb_IndicatorAlert
EnableMonitoring
NOT
SEL_451_2_MB_POU.Rx_OK_Instantaneous
2
T#3s
DailyReportLogic.DailyReportGenerated
EN
Indicator
ChatterCount
ExcursionTime
Reset
ENO
Alert
Status
VirtualTagList1.ProtectionChannelMonitoring_1_ENO.stVal
VirtualTagList1.ProtectionChannelMonitoring_1_Alert
VirtualTagList1.ProtectionChannelMonitoring_1_Status.stVal
0
1
2
3
4

Figure 10 Example 3 Configured in a CFC Program

MONITOR IED DIAGNOSTICS

Each SEL IED runs continuous self-tests to monitor the internal health of its major components. If an out-of-tolerance condition is detected, the relay generates a warning or failure alarm. When a self-test determines that one or more internal components have exceeded an expected limit but have not compromised the relay operation, a warning alarm is generated and a contact pulsed. For a severe out-of-tolerance condition, a failure alarm is issued and the relay enters a protection-disabled state.

Example 4: Monitor the HALARM Relay Word Bit in an SEL IED

This example also demonstrates the use of the **fb_IndicatorAlert** function block. The RTAC is polling an IED for the HALARM Relay Word bit. Many SEL IEDs have additional configurable alerts that can also be monitored. Monitoring this Relay Word bit provides assurance that the IED is functioning as designed. Using both the chatter and sustained event capability of the function block, alerts can be generated when multiple warnings are received (which indicates an out-of-tolerance condition) or if a failure alarm is generated. This example only monitors the HALARM bit when communication with the IED is good.

To configure this example, a CFC program (see the following PROGRAM Example4 logic) is added to the ACSELERATOR RTAC project [2] [3]. The code block shown in Figure 11 demonstrates how to instantiate an **fb_IndicatorAlert** function block in the declaration section of the program. The **SEL IED Offline** POU pin is monitored to ensure that the IED is responding correctly to poll requests. If the **Offline** POU pin is **FALSE**, the function block enables monitoring. This ensures that a false condition does not trigger the alert output. Once activated, the function blocks monitors for a true condition, which would indicate a hardware warning or failure.

```
PROGRAM Example4
VAR
      //Instantiate Function Blocks
      SEL_451_HardwareMonitor : fb_IndicatorAlert;

      //Function Block Shared Parameters
      EnableMonitoring : BOOL;
END_VAR
```

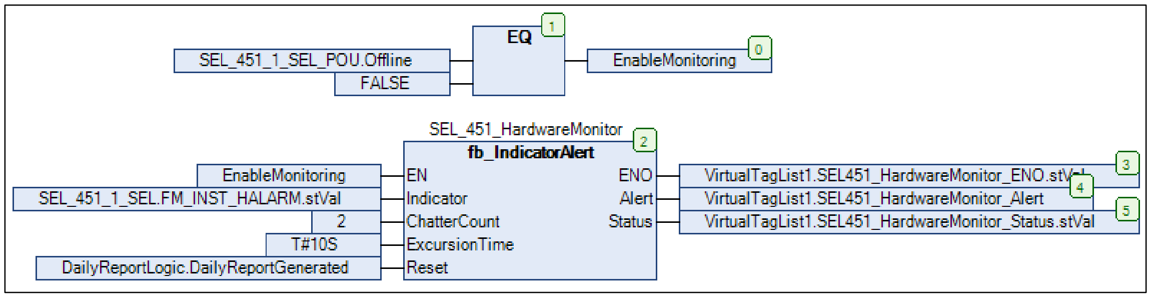

EQ
1
SEL_451_1_SEL_POU.Offline
FALSE
EnableMonitoring
0
SEL_451_HardwareMonitor
fb_IndicatorAlert
2
EnableMonitoring
SEL_451_1_SEL.FM_INST_HALARM.stVal
2
T#10S
DailyReportLogic.DailyReportGenerated
EN
Indicator
ChatterCount
ExcursionTime
Reset
ENO
Alert
Status
VirtualTagList1.SEL451_HardwareMonitor_ENO.stVal
3
VirtualTagList1.SEL451_HardwareMonitor_Alert
4
VirtualTagList1.SEL451_HardwareMonitor_Status.stVal
5

Figure 11 Example 4 Configured in a CFC Program

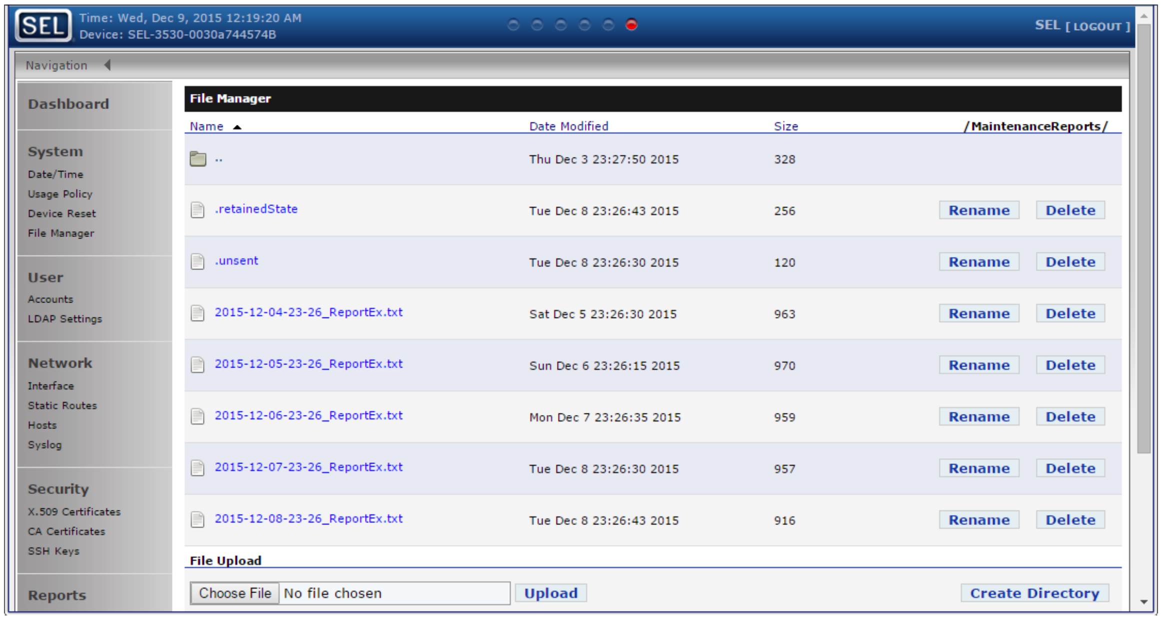
Generate Automated Reports

Note that users must purchase the FileIO library option in the SEL RTAC for the example in this section to work.

Alert conditions are monitored and reported daily. An alert could be associated with an IED self-test, bad CT and or potential transformer (PT) data values, a relay firmware or setting change, or bad data quality. If a component alert is generated, the RTAC identifies which of the components generated the alert, logs the failure time, and includes the status of the failed component in the daily report. This is accomplished by continually monitoring and processing the data required to identify if a monitored component parameter exceeds the user-specified limits. The status of all monitored protection system components is documented in a single automated report that can be downloaded through the RTAC web interface or sent to a centralized server via File Transfer Protocol (FTP).

Example 5: Daily Maintenance Report Generation

The logic in this example demonstrates how to create a report that can be downloaded through the RTAC's web interface, as shown in Figure 12, or sent to an FTP server. Sending the report via FTP is not shown in this example, but examples are included in the FileIO instruction manual.



Name ▲	Date Modified	Size	/MaintenanceReports/
..	Thu Dec 3 23:27:50 2015	328	
.retainedState	Tue Dec 8 23:26:43 2015	256	Rename Delete
.unsent	Tue Dec 8 23:26:30 2015	120	Rename Delete
2015-12-04-23-26_ReportEx.txt	Sat Dec 5 23:26:30 2015	963	Rename Delete
2015-12-05-23-26_ReportEx.txt	Sun Dec 6 23:26:15 2015	970	Rename Delete
2015-12-06-23-26_ReportEx.txt	Mon Dec 7 23:26:35 2015	959	Rename Delete
2015-12-07-23-26_ReportEx.txt	Tue Dec 8 23:26:30 2015	957	Rename Delete
2015-12-08-23-26_ReportEx.txt	Tue Dec 8 23:26:43 2015	916	Rename Delete

Figure 12 The RTAC Web Interface File Manager Menu Displaying Five Reports Generated Over a Five-Day Time Frame

The following logic shows Example 5 configured in an ST program. The logic can be divided into four general steps:

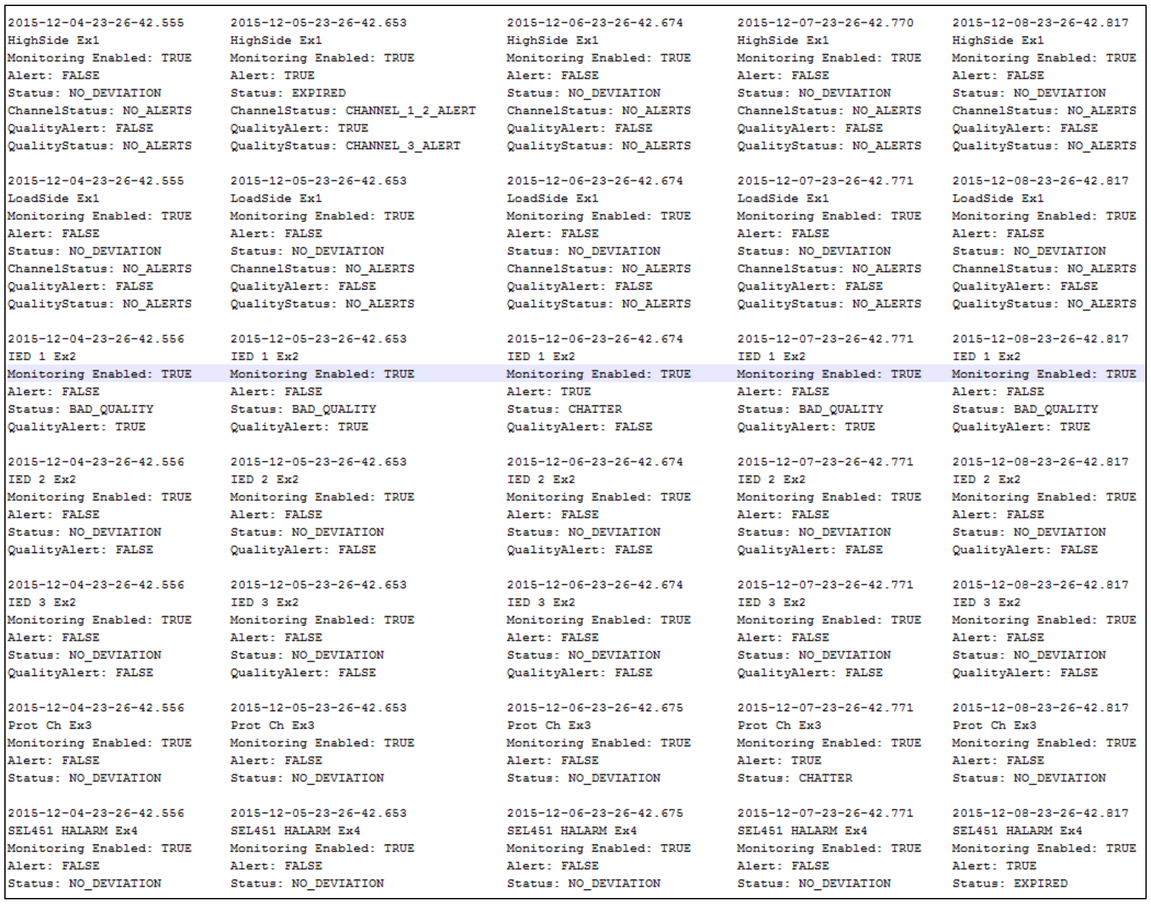
1. Monitor the time that has elapsed since the last report.
2. Convert the data from the examples into human-readable strings.
3. Construct and format message strings to log in the report.
4. Trigger the report creation.

```
PROGRAM Example2
VAR
      //Report generated every interval: user-defined seconds
      ReportInterval : REAL := 86400; (*day*)

      //Variables used to control program flow
      NewDownload : BOOL := TRUE;
      GenerateReport : BOOL;
      DailyReportGenerated : BOOL;
      TimeSinceLastReport : REAL;
      LastReportGenerated : timestamp_t;

      //FileIO library LogDirectoryManager class
      MaintenanceReportManager : class_LogDirectoryManager(
      folderName := '/MaintenanceReports',
      logPostfix := 'ReportEx.txt',
      MaxFolderSize := 512000,
      maxNumFiles := 30,
      autoStartNewLogDaily := FALSE);
      //Report messages
      HighSideMessage : STRING(255);
      LoadSideMessage : STRING(255);
      IED_1_Ex2_Message : STRING(255);
      IED_2_Ex2_Message : STRING(255);
      IED_3_Ex2_Message : STRING(255);
      ProtChMessage : STRING(255);
      SEL451_HALARM_Message : STRING(255);
END_VAR

//Program generates a report based on a user-defined report interval//

//Reset variables
IF NOT Simulation.Reset THEN
      GenerateReport := FALSE;
      DailyReportGenerated := FALSE;
ELSE
      DailyReportGenerated := TRUE;
END_IF


//Calculate time in seconds since last report
TimeSinceLastReport := TS_DIFF(System_Time_Control_POU.System_Time.value,
LastReportGenerated.value);

//Report trigger logic
IF NewDownload THEN
      NewDownload := FALSE;
      (*This resets the report time after a new project is downloaded *)
      LastReportGenerated := SYS_TIME();
ELSIF TimeSinceLastReport > ReportInterval THEN
      GenerateReport := TRUE;
END_IF

//Generate a report
IF GenerateReport THEN

      //Report Formatting
      HighSideMessage := '';
      HighSideMessage := Concat('$NHighSide Ex1', '$NMonitoring Enabled: ');
      HighSideMessage := Concat(HighSideMessage,
BOOL_TO_STRING(VirtualTagList1.HighSide_ENO.stVal));
      HighSideMessage := Concat(HighSideMessage, '$NAlert: ');
      HighSideMessage := Concat(HighSideMessage,
BOOL_TO_STRING(VirtualTagList1.HighSide_Alert.stVal));
      HighSideMessage := Concat(HighSideMessage, '$NStatus: ');
      HighSideMessage := Concat(HighSideMessage,
fun_GetAlertString(VirtualTagList1.HighSide_Status.stVal));
      HighSideMessage := Concat(HighSideMessage, '$NChannelStatus: ');
      HighSideMessage := Concat(HighSideMessage,
fun_GetChannelString(VirtualTagList1.HighSide_ChannelStatus.stVal));
      HighSideMessage := Concat(HighSideMessage, '$NQualityAlert: ');
      HighSideMessage := Concat(HighSideMessage,
BOOL_TO_STRING(VirtualTagList1.HighSide_QualityAlert.stVal));
      HighSideMessage := Concat(HighSideMessage, '$NQualityStatus: ');
      HighSideMessage := Concat(HighSideMessage,
fun_GetChannelString(VirtualTagList1.HighSide_QualityStatus.stVal));
      HighSideMessage := Concat(HighSideMessage, '$N');

      LoadSideMessage := '';
      LoadSideMessage := Concat('$NLoadSide Ex1','$NMonitoring Enabled: ');
      LoadSideMessage := Concat(LoadSideMessage,
BOOL_TO_STRING(VirtualTagList1.LoadSide_ENO.stVal));
      LoadSideMessage := Concat(LoadSideMessage, '$NAlert: ');
      LoadSideMessage := Concat(LoadSideMessage,
BOOL_TO_STRING(VirtualTagList1.LoadSide_Alert.stVal));
      LoadSideMessage := Concat(LoadSideMessage, '$NStatus: ');
      LoadSideMessage := Concat(LoadSideMessage,
fun_GetAlertString(VirtualTagList1.LoadSide_Status.stVal));
      LoadSideMessage := Concat(LoadSideMessage, '$NChannelStatus: ');
      LoadSideMessage := Concat(LoadSideMessage,
fun_GetChannelString(VirtualTagList1.LoadSide_ChannelStatus.stVal));
```

```
      LoadSideMessage := Concat(LoadSideMessage, '$NQualityAlert: ');
      LoadSideMessage := Concat(LoadSideMessage,
BOOL_TO_STRING(VirtualTagList1.LoadSide_QualityAlert.stVal));
      LoadSideMessage := Concat(LoadSideMessage, '$NQualityStatus: ');
      LoadSideMessage := Concat(LoadSideMessage,
fun_GetChannelString(VirtualTagList1.LoadSide_QualityStatus.stVal));
      LoadSideMessage := Concat(LoadSideMessage, '$N');

      IED_1_Ex2_Message := '';
      IED_1_Ex2_Message := Concat('$NIED 1 Ex2','$NMonitoring Enabled: ');
      IED_1_Ex2_Message := Concat(IED_1_Ex2_Message,
BOOL_TO_STRING(VirtualTagList1.SEL351_ENO.stVal));
      IED_1_Ex2_Message := Concat(IED_1_Ex2_Message, '$NAlert: ');
      IED_1_Ex2_Message := Concat(IED_1_Ex2_Message,
BOOL_TO_STRING(VirtualTagList1.SEL351_Alert.stVal));
      IED_1_Ex2_Message := Concat(IED_1_Ex2_Message, '$NStatus: ');
      IED_1_Ex2_Message := Concat(IED_1_Ex2_Message,
fun_GetAlertString(VirtualTagList1.SEL351_Status.stVal));
      IED_1_Ex2_Message := Concat(IED_1_Ex2_Message, '$NQualityAlert: ');
      IED_1_Ex2_Message := Concat(IED_1_Ex2_Message,
BOOL_TO_STRING(VirtualTagList1.SEL351_QualtiyAlert.stVal));
      IED_1_Ex2_Message := Concat(IED_1_Ex2_Message, '$N');

      IED_2_Ex2_Message := '';
      IED_2_Ex2_Message := Concat('$NIED 2 Ex2','$NMonitoring Enabled: ');
      IED_2_Ex2_Message := Concat(IED_2_Ex2_Message,
BOOL_TO_STRING(VirtualTagList1.SEL501_ENO.stVal));
      IED_2_Ex2_Message := Concat(IED_2_Ex2_Message, '$NAlert: ');
      IED_2_Ex2_Message := Concat(IED_2_Ex2_Message,
BOOL_TO_STRING(VirtualTagList1.SEL501_Alert.stVal));
      IED_2_Ex2_Message := Concat(IED_2_Ex2_Message, '$NStatus: ');
      IED_2_Ex2_Message := Concat(IED_2_Ex2_Message,
fun_GetAlertString(VirtualTagList1.SEL501_Status.stVal));
      IED_2_Ex2_Message := Concat(IED_2_Ex2_Message, '$NQualityAlert: ');
      IED_2_Ex2_Message := Concat(IED_2_Ex2_Message,
BOOL_TO_STRING(VirtualTagList1.SEL501_QualtiyAlert.stVal));
      IED_2_Ex2_Message := Concat(IED_2_Ex2_Message, '$N');

      IED_3_Ex2_Message := '';
      IED_3_Ex2_Message := Concat('$NIED 3 Ex2','$NMonitoring Enabled: ');
      IED_3_Ex2_Message := Concat(IED_3_Ex2_Message,
BOOL_TO_STRING(VirtualTagList1.SEL421_ENO.stVal));
      IED_3_Ex2_Message := Concat(IED_3_Ex2_Message, '$NAlert: ');
      IED_3_Ex2_Message := Concat(IED_3_Ex2_Message,
BOOL_TO_STRING(VirtualTagList1.SEL421_Alert.stVal));
      IED_3_Ex2_Message := Concat(IED_3_Ex2_Message, '$NStatus: ');
      IED_3_Ex2_Message := Concat(IED_3_Ex2_Message,
fun_GetAlertString(VirtualTagList1.SEL421_Status.stVal));
      IED_3_Ex2_Message := Concat(IED_3_Ex2_Message, '$NQualityAlert: ');
      IED_3_Ex2_Message := Concat(IED_3_Ex2_Message,
BOOL_TO_STRING(VirtualTagList1.SEL421_QualtiyAlert.stVal));
      IED_3_Ex2_Message := Concat(IED_3_Ex2_Message, '$N');

      ProtChMessage := '';
      ProtChMessage := Concat('$NProt Ch Ex3','$NMonitoring Enabled: ');
      ProtChMessage := Concat(ProtChMessage,
BOOL_TO_STRING(VirtualTagList1.ProtectionChannelMonitoring_1_ENO.stVal));
      ProtChMessage := Concat(ProtChMessage,'$NAlert: ');
      ProtChMessage := Concat(ProtChMessage,
BOOL_TO_STRING(VirtualTagList1.ProtectionChannelMonitoring_1_Alert.stVal));
      ProtChMessage := Concat(ProtChMessage,'$NStatus: ');
      ProtChMessage := Concat(ProtChMessage,
fun_GetAlertString(VirtualTagList1.ProtectionChannelMonitoring_1_Status.stVal));
      ProtChMessage := Concat(ProtChMessage, '$N');

      SEL451_HALARM_Message := '';
      SEL451_HALARM_Message := Concat('$NSEL451 HALARM Ex4','$NMonitoring Enabled: ');
      SEL451_HALARM_Message := Concat(SEL451_HALARM_Message,
BOOL_TO_STRING(VirtualTagList1.SEL451_HardwareMonitor_ENO.stVal));
      SEL451_HALARM_Message := Concat(SEL451_HALARM_Message,'$NAlert: ');
      SEL451_HALARM_Message := Concat(SEL451_HALARM_Message,
BOOL_TO_STRING(VirtualTagList1.SEL451_HardwareMonitor_Alert.stVal));
      SEL451_HALARM_Message := Concat(SEL451_HALARM_Message,'$NStatus: ');
      SEL451_HALARM_Message := Concat(SEL451_HALARM_Message,
fun_GetAlertString(VirtualTagList1.SEL451_HardwareMonitor_Status.stVal));
      SEL451_HALARM_Message := Concat(SEL451_HALARM_Message, '$N');

      //Write the formatted reports
      MaintenanceReportManager.WriteLogEntryString(HighSideMessage);
      MaintenanceReportManager.WriteLogEntryString(LoadSideMessage);
      MaintenanceReportManager.WriteLogEntryString(IED_1_Ex2_Message);
      MaintenanceReportManager.WriteLogEntryString(IED_2_Ex2_Message);
      MaintenanceReportManager.WriteLogEntryString(IED_3_Ex2_Message);
      MaintenanceReportManager.WriteLogEntryString(ProtChMessage);
      MaintenanceReportManager.WriteLogEntryString(SEL451_HALARM_Message);

      //Update report time
      LastReportGenerated := SYS_TIME();

      //Reset the function blocks
      DailyReportGenerated := TRUE;
END_IF

//This has to be included every scan for the manager to process actions
MaintenanceReportManager.Run();
```

This example shows the creation of five daily reports (see Figure 13). Each daily report demonstrates an alert condition in one or more of the function blocks. The maintenance report includes the function block outputs from the previous examples and examples for monitoring the following protection system component attributes:

- Relay configuration.
- IED, CT (PT), and associated circuitry.
- Protection communications.
- Relay hardware alarms.



```
2015-12-04-23-26-42.555   2015-12-05-23-26-42.653           2015-12-06-23-26-42.674   2015-12-07-23-26-42.770   2015-12-08-23-26-42.817
HighSide Ex1              HighSide Ex1                      HighSide Ex1              HighSide Ex1              HighSide Ex1
Monitoring Enabled: TRUE  Monitoring Enabled: TRUE          Monitoring Enabled: TRUE  Monitoring Enabled: TRUE  Monitoring Enabled: TRUE
Alert: FALSE              Alert: TRUE                       Alert: FALSE              Alert: FALSE              Alert: FALSE
Status: NO_DEVIATION      Status: EXPIRED                   Status: NO_DEVIATION      Status: NO_DEVIATION      Status: NO_DEVIATION
ChannelStatus: NO_ALERTS  ChannelStatus: CHANNEL_1_2_ALERT  ChannelStatus: NO_ALERTS  ChannelStatus: NO_ALERTS  ChannelStatus: NO_ALERTS
QualityAlert: FALSE       QualityAlert: TRUE                QualityAlert: FALSE       QualityAlert: FALSE       QualityAlert: FALSE
QualityStatus: NO_ALERTS  QualityStatus: CHANNEL_3_ALERT    QualityStatus: NO_ALERTS  QualityStatus: NO_ALERTS  QualityStatus: NO_ALERTS

2015-12-04-23-26-42.555   2015-12-05-23-26-42.653           2015-12-06-23-26-42.674   2015-12-07-23-26-42.771   2015-12-08-23-26-42.817
LoadSide Ex1              LoadSide Ex1                      LoadSide Ex1              LoadSide Ex1              LoadSide Ex1
Monitoring Enabled: TRUE  Monitoring Enabled: TRUE          Monitoring Enabled: TRUE  Monitoring Enabled: TRUE  Monitoring Enabled: TRUE
Alert: FALSE              Alert: FALSE                      Alert: FALSE              Alert: FALSE              Alert: FALSE
Status: NO_DEVIATION      Status: NO_DEVIATION              Status: NO_DEVIATION      Status: NO_DEVIATION      Status: NO_DEVIATION
ChannelStatus: NO_ALERTS  ChannelStatus: NO_ALERTS          ChannelStatus: NO_ALERTS  ChannelStatus: NO_ALERTS  ChannelStatus: NO_ALERTS
QualityAlert: FALSE       QualityAlert: FALSE               QualityAlert: FALSE       QualityAlert: FALSE       QualityAlert: FALSE
QualityStatus: NO_ALERTS  QualityStatus: NO_ALERTS          QualityStatus: NO_ALERTS  QualityStatus: NO_ALERTS  QualityStatus: NO_ALERTS

2015-12-04-23-26-42.556   2015-12-05-23-26-42.653           2015-12-06-23-26-42.674   2015-12-07-23-26-42.771   2015-12-08-23-26-42.817
IED 1 Ex2                 IED 1 Ex2                         IED 1 Ex2                 IED 1 Ex2                 IED 1 Ex2
Monitoring Enabled: TRUE  Monitoring Enabled: TRUE          Monitoring Enabled: TRUE  Monitoring Enabled: TRUE  Monitoring Enabled: TRUE
Alert: FALSE              Alert: FALSE                      Alert: TRUE               Alert: FALSE              Alert: FALSE
Status: BAD_QUALITY       Status: BAD_QUALITY               Status: CHATTER           Status: BAD_QUALITY       Status: BAD_QUALITY
QualityAlert: TRUE        QualityAlert: TRUE                QualityAlert: FALSE       QualityAlert: TRUE        QualityAlert: TRUE

2015-12-04-23-26-42.556   2015-12-05-23-26-42.653           2015-12-06-23-26-42.674   2015-12-07-23-26-42.771   2015-12-08-23-26-42.817
IED 2 Ex2                 IED 2 Ex2                         IED 2 Ex2                 IED 2 Ex2                 IED 2 Ex2
Monitoring Enabled: TRUE  Monitoring Enabled: TRUE          Monitoring Enabled: TRUE  Monitoring Enabled: TRUE  Monitoring Enabled: TRUE
Alert: FALSE              Alert: FALSE                      Alert: FALSE              Alert: FALSE              Alert: FALSE
Status: NO_DEVIATION      Status: NO_DEVIATION              Status: NO_DEVIATION      Status: NO_DEVIATION      Status: NO_DEVIATION
QualityAlert: FALSE       QualityAlert: FALSE               QualityAlert: FALSE       QualityAlert: FALSE       QualityAlert: FALSE

2015-12-04-23-26-42.556   2015-12-05-23-26-42.653           2015-12-06-23-26-42.674   2015-12-07-23-26-42.771   2015-12-08-23-26-42.817
IED 3 Ex2                 IED 3 Ex2                         IED 3 Ex2                 IED 3 Ex2                 IED 3 Ex2
Monitoring Enabled: TRUE  Monitoring Enabled: TRUE          Monitoring Enabled: TRUE  Monitoring Enabled: TRUE  Monitoring Enabled: TRUE
Alert: FALSE              Alert: FALSE                      Alert: FALSE              Alert: FALSE              Alert: FALSE
Status: NO_DEVIATION      Status: NO_DEVIATION              Status: NO_DEVIATION      Status: NO_DEVIATION      Status: NO_DEVIATION
QualityAlert: FALSE       QualityAlert: FALSE               QualityAlert: FALSE       QualityAlert: FALSE       QualityAlert: FALSE

2015-12-04-23-26-42.556   2015-12-05-23-26-42.653           2015-12-06-23-26-42.675   2015-12-07-23-26-42.771   2015-12-08-23-26-42.817
Prot Ch Ex3               Prot Ch Ex3                       Prot Ch Ex3               Prot Ch Ex3               Prot Ch Ex3
Monitoring Enabled: TRUE  Monitoring Enabled: TRUE          Monitoring Enabled: TRUE  Monitoring Enabled: TRUE  Monitoring Enabled: TRUE
Alert: FALSE              Alert: FALSE                      Alert: FALSE              Alert: TRUE               Alert: FALSE
Status: NO_DEVIATION      Status: NO_DEVIATION              Status: NO_DEVIATION      Status: CHATTER           Status: NO_DEVIATION

2015-12-04-23-26-42.556   2015-12-05-23-26-42.653           2015-12-06-23-26-42.675   2015-12-07-23-26-42.771   2015-12-08-23-26-42.817
SEL451 HALARM Ex4         SEL451 HALARM Ex4                 SEL451 HALARM Ex4         SEL451 HALARM Ex4         SEL451 HALARM Ex4
Monitoring Enabled: TRUE  Monitoring Enabled: TRUE          Monitoring Enabled: TRUE  Monitoring Enabled: TRUE  Monitoring Enabled: TRUE
Alert: FALSE              Alert: FALSE                      Alert: FALSE              Alert: FALSE              Alert: TRUE
Status: NO_DEVIATION      Status: NO_DEVIATION              Status: NO_DEVIATION      Status: NO_DEVIATION      Status: EXPIRED
```

Figure 13 Five Daily Reports Downloaded From the SEL RTAC Web Interface and Displayed in Columnar Form

IDENTIFY AND LOG MAINTENANCE CONDITIONS

Tracking and archiving events is an important function provided by a data concentrator. In the event that a potential maintenance condition is detected, it can be logged into the Sequence of Events (SOE) record, which provides a nonvolatile storage location for maintenance alerts. The SOE log in the SEL RTAC can store up to 30,000 log items. These logs are accessible through the web interface or an ODBC connection and can be sent via Syslog protocol to a syslog server for archiving. This provides a mechanism to store maintenance report results without the addition of the FileIO library. For detailed information on how to log and collect SOE data into the SEL RTAC, refer to [2] and/or [4]. Both resources provide detailed instructions on logging SOE records and methods to retrieve that information.

CONCLUSION

Generator and transmission protection relays can be described as silent sentinels that only demonstrate their designed function when a protection event occurs. Typically, an event may not happen for an extended period of time. This can increase the possibility of a false operation or a failure to operate on a protection event due to an undetected critical protection system component failure, noncommissioned setting, or other potential issues. The RTAC helps mitigate these possibilities by continuously monitoring many critical protection system components, recording their statuses through daily reports, and increasing protection system engineering awareness through data aggregation and logging tools.

References

[1] D. Stewart, R. Jenkins, and D. Dolezilek, "Case Study in Improving Protection System Reliability With Automatic NERC PRC-005 Inspection, Testing, Reporting, and Auditing," proceedings of the 66th Annual Conference for Protective Relay Engineers, College Station, TX, April 2013. Available: http://dx.doi.org//10.1109/CPRE.2013.6822050.

[2] ACSELERATOR RTAC SEL-5033 Software Instruction Manual. Available: https://www.selinc.com.

[3] Schweitzer Engineering Laboratories, Inc., "SEL Video," January 2016. Available: https://video.selinc.com.

[4] D. Kite, "Leveraging Security – Using the SEL-RTAC's Built-In Security Features," January 2016. Available: https://www.selinc.com.

Biography

Darrin Kite received his Bachelor of Science in Renewable Energy Engineering from the Oregon Institute of Technology in 2012. Before joining Schweitzer Engineering Laboratories, Inc. (SEL) in 2012, he worked as an engineering intern at Bonneville Power Administration. He is presently working as an automation engineer in SEL research and development.

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