IEC 61850 Sampled
Values Configuration

Megger

IEC 61850 Sampled Values Configuration - Application Guide

Objective: This application guide will help users configure the Sampled Values Analyser (SVA) for use in a variety of applications in a digital substation environment.

Introduction to Sampled Values:

IEC 61850-9-2 Sampled Values (SV) standardise the transmission of instantaneous power system data over an Ethernet/fibre optic communication channel using a publisher/subscriber mechanism. In a move towards digitalisation of substation architecture, analogue signals transmitted on copper wires are getting replaced with digital signals on fibre optic Ethernet networks. These digital signals are either generated by standalone merging units (MU) or compliant IEDs with digital signal processing capabilities.

Data gathering starts at the process level with instrument transformers. Current transformers (CTs) and voltage transformers (VTs) measure analogue currents and voltages, respectively, and send the outputs to MUs. Typically, analogue filters in MUs receive analogue signals from CTs/VTs which are then pushed to the sample and hold circuitry. Analogue to digital converters then transform analogue signals into digital counts. Once converted, MUs will add a timestamp from a time reference and then the count in timestamp becomes part of the dataset. Once the data is ready, MUs broadcast it to the process bus which can then be received by relays, controllers, and metering equipment simultaneously, if they are subscribed to receive the data. Figure 1 provides a visualisation of how a merging unit samples the data and how a subscriber re-samples based on the first sample (sample count = 0). It also displays the significance of high accuracy time synchronisation.
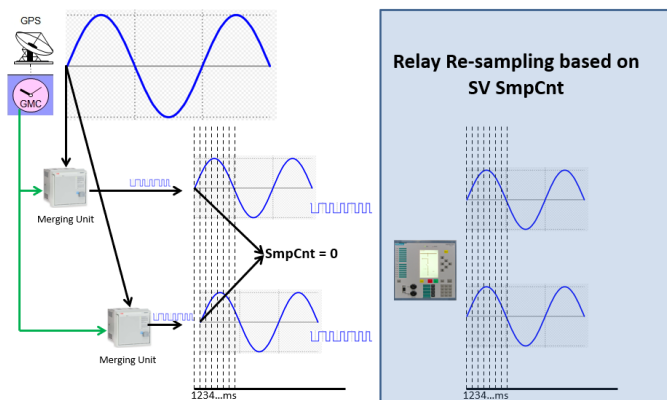
Megger's SMRT/FREJA test instruments and the SVA software are compliant with IEC 61850 9-2 Light Edition (LE), which is NOT a standard. Rather, it is a Utility Communication Architecture (UCA) profile that has been widely accepted across the world for use in digital substations. Some points worth noting as per the LE edition:

- **Datasets carried by the SV message are fixed to 4 voltages and 4 currents**
- **Sampling frequency is 80 samples per cycle (4000 samples for 50 Hz and 4800 samples for 60 Hz systems, respectively) for all protection applications**
- **Time synchronisation is 1-PPS. There is formally no support for IEEE 1588 PTP time synch, which is typical of Edition 2 of the IEC 61850 standard. Regardless, some users move forward to deploy IEEE 1588 PTP (IEC 61850-9-3) with the consideration of future standards and higher accuracy. PTP to 1-PPS converters can be used in such cases with SMRT/FREJA to satisfy the need. We recommend Meinberg SyncBox/N2X.**
- **The quality string has one 'extra bit', the 14th bit, for deriving or measuring the analogue quantity, which differs from the usual 'normal' quality string of 13 bits for IEC 61850 and IEC 61869.**

Required equipment:

Depending on the tests that the user wants to perform, the following is some of the equipment that may be needed:

- **Test unit: SMRT/FREJA with the two-app firmware (>6.252) and bootloader > 1.052 version**
- **Software: RTMS and SVA**
- **Managed Ethernet switch: To connect various IEDs and clocks**
- **High accuracy clock for time synchronisation: 1-PPS or IEEE 1588 PTP**
- **PTP to 1-PPS converter: Only if IEEE 1588 PTP is used as the external clock**
- **IEC 61850 9-2 LE compliant IEDs (relays, RTUs, controllers etc.)**

Note: SVA on on-board units can also be used if the customer PC has restricted access within the network. One crucial point to remember is that SVA follows 2 out of 3 communication principles, which means that only two of the following can be active at any point of time: On-board RTMS/SVA, RTMS on PC, and SVA on PC. If working from a PC, it is advisable to switch the on-board mode to remote mode.

Figure 1: Merging unit sampling

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Conversion of SMRT/FREJA into digital mode:

After downloading the correct firmware and activating the soft key to enable the Sampled Values feature in the SMRT/FREJA, the user can launch Relay Testing Management Software (RTMS) to switch back and forth between analogue (normal) and digital (SV) mode as per the requirements.

RTMS set-up: After launching RTMS, the user should go to the SYSTEM CONFIGURATION button and select DISPLAY VERSIONS to verify if the SV feature is enabled. "IEC-61850 Enabled" must be equal to 2 to use Sampled Values.

Figure 2: Display versions

After it is verified that IEC-61850 Enabled = 2, the user must find and select the NORMAL MODE button, (this is set to "Normal Mode" by default), as shown in Figure 3 under the HARDWARE tab of the system configuration window.
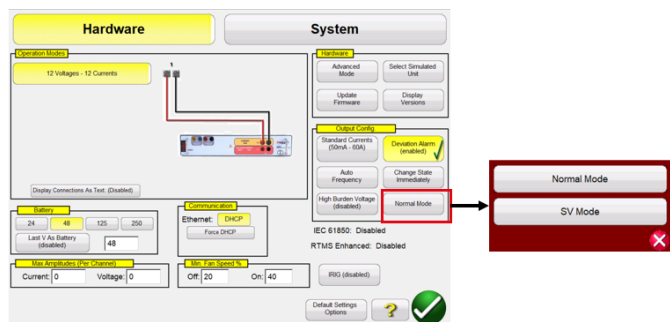
Figure 3: System configuration setting to program Normal/SV Mode

Change the setting to "SV Mode" by pressing the SV MODE button and then select the green check/tick button. A message box will appear advising the user to power cycle the test set. Once powered up and the RTMS is searching for the connected unit, the user should see the serial number of the test set and the text "SV" as prefix. Select the unit with the correct serial number and "SV" prefix and the home screen of the RTMS should appear, as shown in Figure 4.
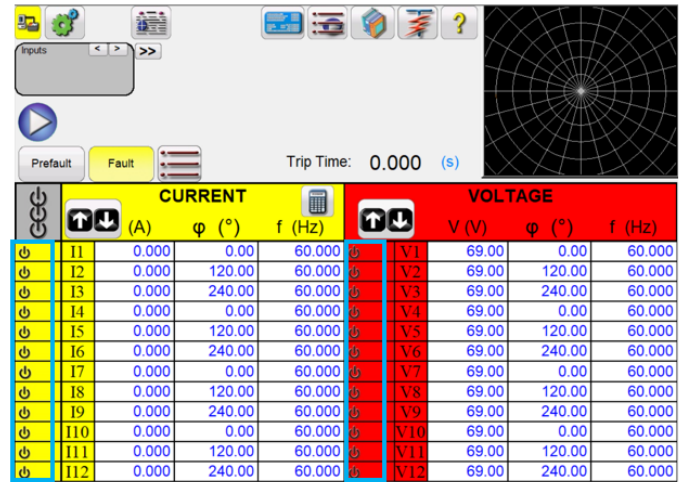
Figure 4: Home screen in SV Mode

IEC 61850-9-2 LE specifies 4 currents and 4 voltages as one single SV stream. With the current version of the software, the SVA and RTMS can accommodate the configuration of a total of 3 SV streams. The RTMS home screen in Figure 4 shows 12 currents and 12 voltages to simulate 3 SV streams. To enable the publishing of SV streams, users will first need to arm the channel(s) by clicking on the button(s) in the blue outlined boxes in Figure 4. If only one stream is needed, only arm the channel associated with that stream.

Special note: SMRT/FREJA units can either decode IRIG-B or 1-PPS. If IEEE 1588 PTP is used as the master clock in the network, the user may need a PTP to 1-PPS converter. The SV mode in RTMS has "Binary Input-1" as the default input to receive 1-PPS signal. Users can monitor the LED on "Binary Input-1" to validate the sensing of 1-PPS. The LED should flash once every second.

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SV 9-2 LE configurator

This screen allows users to set some crucial parameters related to Sampled Values testing. The SVA allows the user to set parameters for all the streams on one screen, thereby eliminating the need to switch screens. The user can either manually enter the settings or import an SCD file to auto-populate the settings.
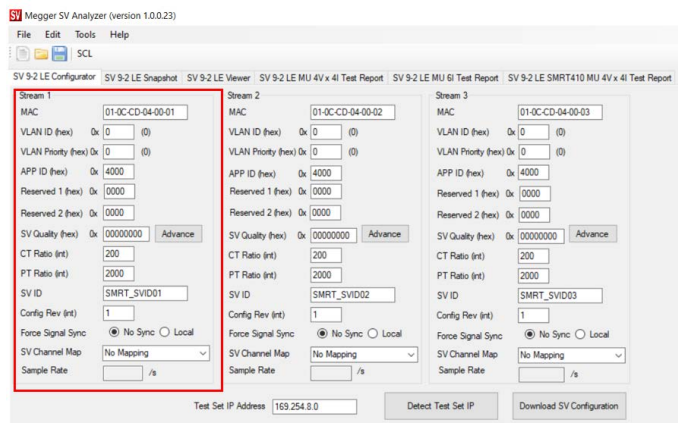

Figure 5: SV configurator

Import SCL

By selecting the SCL button outlined in blue in Figure 5, users can select an existing SCD file from their network. SVA allows the import of all SCL file types - CID, SCD, XML, ICD, SCL, IID, and SED. Select the appropriate file and follow the steps as below:

1. **The imported file will be launched as a new tab with its name and file type as an extension. In the example in Figure 6, the REX640_2SV.cid tab, highlighted in yellow, can be seen after the import. If there is no SV data available in the file, an error message will appear indicating there was no SV data.**
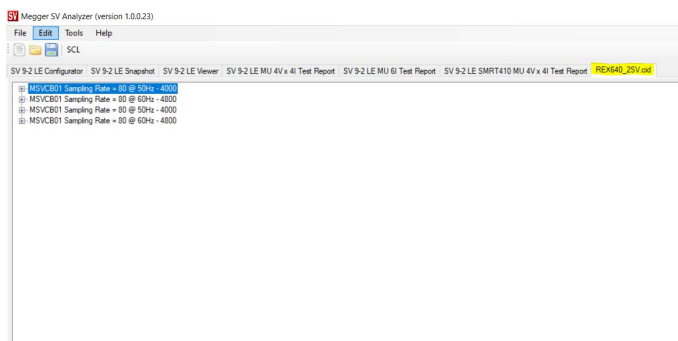

Figure 6: Import SCD Tab

2. **Data sets can be expanded to see which one needs to be used for monitoring or testing. Once decided, right click and copy to either Stream 1, Stream 2, or Stream 3.**
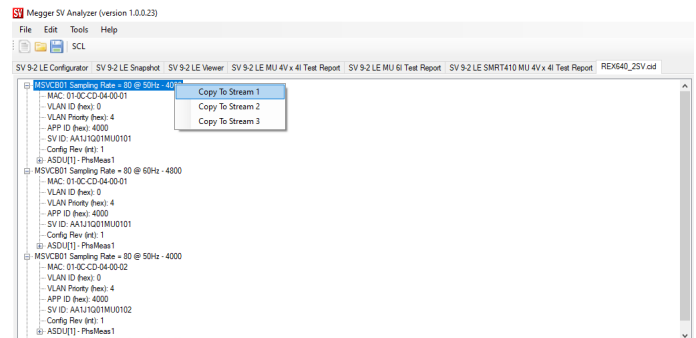

Figure 7: Method to map MSVCB01 to desired streams

3. **Select the SV 9-2 LE configurator tab to see the imported parameters. A description of each field is provided as follows:**

Configurator Settings

MAC – A MAC address is a unique identifier assigned to a network interface controller (NIC), in this case – IEDs, for use as a network address in communications within the network segment. It is a 12-digit HEX that is most often displayed with a colon or a hyphen separating every two digits. In IEC 61850 GOOSE and Sampled Value messages, destination multicast MAC addresses are used. This means that if a packet is received by the Ethernet switch, the switch will forward the message to all other ports in case no recipient groups are specified at the switch. For Sampled Values, the fourth octet is equal to 04 and the range of addresses could be 01-0C-CD-04-00-00 to O1-0C-CD-04-01-FF. Each port on the IED has a different MAC address.

VLAN ID - The VLAN identifier can be used if the Ethernet switches in a station/process bus that supports VLAN and can play an important role in segregating Ethernet traffic in a substation LAN. For example, GOOSE traffic and SV could both be isolated to their own VLANs. This has the significant advantage of reducing the traffic load for IEDs not participating in GOOSE or SV. VLANs provide a way to avoid multicast SV messages being sent to any devices not intended to receive it, like RTUs, SCADA, or corporate networks. The value "000" means a non-configured VLAN and switches do not filter these messages in port basis. This value is recommended if VLAN is not configured in the network. The VLAN identifier is a 3-character HEX value with range 000...FFF.

VLAN Priority - VLAN priority is a priority the customer assigns to outbound packets containing the specified VLAN ID. Priority tagging is defined in IEEE 802.1Q/IEEE 802.1p standard for further study. The value range is 0 to 7 in decimal format. 4 to 7 is high priority and 1 to 3 is low priority. The value 1 is the priority of untagged frames, thus 0 should be avoided when connected to a network as it may cause unpredictable delays due to normal traffic.

App ID – Application Identifier, or APPID, is a unique HEX value identifier used to select ISO/IEC 8802-3 frames containing Sampled Value messages and to distinguish the application association. The reserved value range for sampled values is 0x4000 to 0x7FFF. If no APPID is configured, the default value shall be 0x4000. The default value is reserved to indicate lack of configuration. It is strongly recommended to have unique, source orientated SV APPID within a system. This should be enforced by the configuration system.

Reserved 1 and Reserved 2 – Reserved 1 and Reserved 2 were set for future standardised applications in the first edition of IEC 61850 9-2. It was recommended that Reserved 1 be set to 0. With the introduction of Edition 2, there was better clarification on simulation mode, and it provided more flexibility for interoperability tests. An SV stream is "Simulated" if the first bit of the reserved bits is set to 1. There are 16 reserved bits in the SV message. Reserved 1 field in SVA can be used to send simulated SV streams. Since the standard defines Reserved 1 in hexadecimal format, the user will be required to enter '8000' to send simulated SV streams. By default, SVA is sending real SV streams because the Reserved 1 field is set to 0.

SV Quality – Quality is an attribute defined in the IEC 61850 standard in a HEX format that contains information on the quality of the information from the server. With this setting in SVA, users can force quality bits such as valid, questionable, invalid, and test to publish the stream as per the needs. For detailed information on quality bits, please refer to IEC 61850-7-3.

Quality is a 13-bit bit string (the 14th bit is the derived bit) with various sorts of information attached. IEDs can be put into "Test" mode by enabling the bit associated with test (the 11th bit) in quality string. This change will force the IED to publish test data in the network. SVA provides the setting to enable SMRT/FREJA to send test data in the network. This is very crucial in testing IEC 61850 SV systems and is clarified in IEC 61850 9-2 Ed. 2 standard. By default, SVA is publishing

"valid" SV streams (0x 00000000). By changing the quality to 0x 00000800, users can either enable all channels to be sent with test data or they can choose a particular channel in a stream. Click ADVANCE to set quality for individual channels.
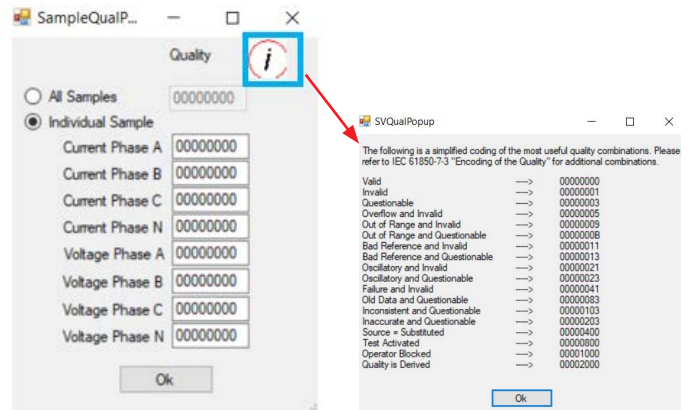

Figure 8: SV Quality window

The user may select the RADIO button for Individual Sample and enter quality for individual channels as desired. For user convenience, SVA provides the quality chart as per IEC-61850-7-3. Click on the information icon as outlined in blue in Figure 8 to see the right bits to enter. The "SV Quality" field in the configurator will display "SPECIAL" if individual quality bits are set.

The SV quality field is useful only when SMRT/FREJA is used to publish SV streams. When monitoring or sniffing streams from the network or from an IED, the SV data pop-up under the SV Snapshot tab should be observed. The SV data pop-up provides the live status of a captured stream.

CT Ratio – Sampled Values are designed to be in primary values. The test set injects current in secondary values. The CT Ratio setting in SVA allows the user to program the CT ratio associated with IED under test to be able to monitor primary values from the relay

PT Ratio – Sampled Values are designed to be in primary values. The test set injects voltage in secondary values. The PT Ratio setting in SVA allows the user to program the PT ratio associated with IED under test to be able to monitor primary values from the relay.

SV ID – SV ID is a user-defined unique string identifier used for subscription/publishing. If the user wants to monitor SV

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streams subscribed/published by an IED in the "SV Snapshot" tab, the SV ID of the IED must be entered. If the traffic of SMRT/FREJA needs to be monitored in the "SV Snapshot" tab, enter SMRT_SVID01, SMRT_SVID02, SMRT_SVID03 as SV ID.

Config Rev – ConfRev increases when the referenced data set is modified. Config Rev is a counter indicating the number of configuration changes. Both the SV sender and the receiver must have the same ConfRev value. This ensures that both IEDs have the same configuration level in the substation configuration. If the receiver has a different ConfRev than the sender, the receiver may treat the message as invalid and reject the message. ConfRev usage is done automatically by tools. If the latest system configuration is not downloaded to all required IEDs, the configuration revision may differ between sender and receiver.

Force Signal Sync – Time synchronisation is of utmost importance in the world of Sampled Values. Merging Units and all IEDs as subscribers should be synchronised to a common clock, and it is recommended to have redundant clocks for back-up. The time synchronisation mechanism of the clock when sending SV messages in IEC 61850 is defined by an attribute called "SmpSynch", available in SV buffer. In IEC 61850 9-2 Ed 1 2004, SmpSynch can either be "TRUE" or "FALSE". When it is "TRUE", SVs are synchronised by a clock signal. As per IEC 61850 9-2 LE, clock signal is standardised to 1-PPS. No synchronisation source available if "FALSE".

IEC 61850 9-2 2011 provides more clarity on SmpSynch attributes, which can be equal to any of the following:
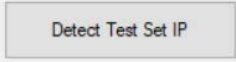
- **0 – None – With this setting, the system is running on free-wheeling mode with no time synchronisation of the Sampled Values.**
- **1 – Local – This setting allows local synchronisation. The device accepts Sampled Values that are locally synchronised to the degree required to meet the measuring accuracy class phase error limit and forwards them to the protection applications. If the unique identifier of the specific local area clock is known, the "SmpSynch" attribute can be set to that value. A local area clock is a source that provides time that advances at essentially the correct attribute, which may have a time offset from global area clocks. When 1-PPS is used and if the pulse length is >= 0.9 us and <= 1.1 us, then 1-PPS is a local signal and SmpSynch = 1.**
- **2 – Global - This setting allows global synchronisation. The device accepts Sampled Values that are globally synchronised to the degree required to meet the measuring accuracy class phase error limit and forwards them to the protection applications. A global area clock is a source that provides time that is traceable to the international standards labs maintaining clocks that form the basis for the International Atomic Time (TAI) and UTC**
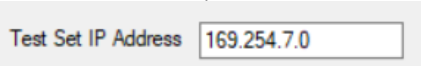
timescales. Examples of these are GPS, NTP, and NIST servers. Since 1-PPS is the standard for IEC 61850 9-2 LE, UCA states that if the pulse length >= 5 us and < 500 ms then PPS signal is the global signal and SmpSynch = 2.
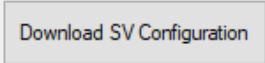
SVA allows the streams to be forced to a particular SmpSynch attribute when SMRT/FREJA is used as publisher or Merging Unit. "No Sync" is chosen by default. The user can toggle between "No Sync" and "Local" as per the requirements. Note that if 1-PPS with global length requirements is sensed on BI-1, then the "SV Snapshot" tab will automatically detect "Global sync" and will display that in the window. In that case, the "Force Signal Sync" setting is overridden.

SV Channel Map – Through this setting, SVA allows the user to select channel 1-4, channel 5-8, or channel 9-12 to be mapped to any of the streams. Each stream needs unique mapping otherwise an error will appear. If a stream is not desired, do not map it with any channels but rather select "No Mapping".

After all the parameters are set, either manually or through the import of a SCD feature, the user can click the DETECT TEST SET IP button on the bottom left to auto-detect any units in the network. If the auto-detect function does not work, there is a provision to manually enter the IP address . It is important to remember that the IP address of the SMRT/FREJA on the test set label or in the normal mode may differ from its IP address in the SV mode. Once the correct unit is selected, press the DOWNLOAD SV CONFIGURATION button to download all the mapped parameters to the SMRT/FREJA. A successful message will pop-up with information on the number of streams downloaded.

Sample Rate – Based on the frequency profile, 50 Hz or 60 Hz in the installed firmware, SVA auto-calculates the sample rate after the DOWNLOAD SV CONFIGURATION button is pressed and displays the value in this field. The value must be 4000 Hz for a 50 Hz profile and 4800 Hz for a 60 Hz profile.

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SV 9-2 LE Snapshot

After the SV settings are downloaded, the user can launch the "SV 9-2 LE Snapshot" tab to monitor the downloaded streams. If the network has a stream not mapped in the "SVA configurator", it will be displayed and can be monitored only if there is room available. It means that SVA Snapshot only allows monitoring of a maximum of three streams. If all streams are mapped, SVA will not display unmapped existing stream during the sniffing process.
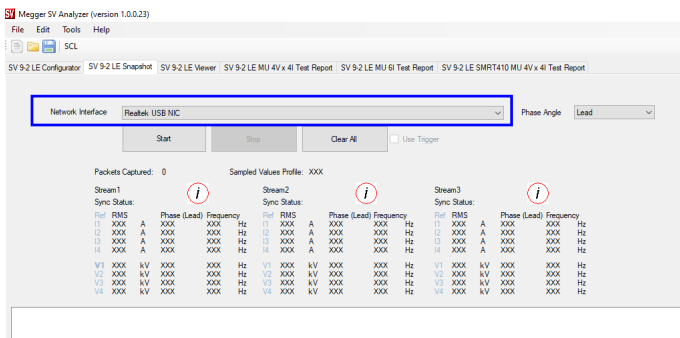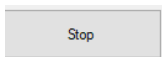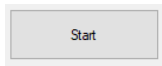

Figure 9: SV Snapshot in idle state

Network Interface – The network interface field, outlined in blue in Figure 9, is used to configure the interface on which SV will be monitored. It does not auto-select the interface and the user needs to manually choose this option. If the connected network interface is not found in the list, it is recommended to first check with IT to see if your PC has admin rights enabled. If the network interface is still not visible, manually assign an IP address for the respective port and choose a lower interface metric (<5) under Advanced TCP/IP settings of the network and internet settings on the PC.

If there are no Sampled Values in the network, which is expected to be the case before the user downloads SV data to the unit, all the data in all the streams is displayed with "xxx". That is an indication of the absence of SV.

After the correct interface is selected, press the START button to start monitoring. The STOP button will stop the monitoring. It is advisable to clear the cache by pressing the CLEAR ALL button before the monitoring is restarted. After START is pressed, the user will notice the total number of packets captured by the Sampled Values Profile, as outlined
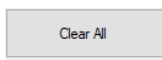
in blue in Figure 10 (depends on the installed FW) and the Sync Status can be monitored. Based on the SmpSynch, "No Sync", "Local Sync", and "Global Sync" will display for each stream.

The user can set the reference as desired. By default, "V1" of "Stream 1" is the reference for phase angle calculation. As outlined in red in Figure 10, the label "V1" is bold and it acts as the reference for phasors. Click any other label to change the reference. The RTMS home screen is used in the example (Figure 11) to publish SV streams from SMRT/FREJA.
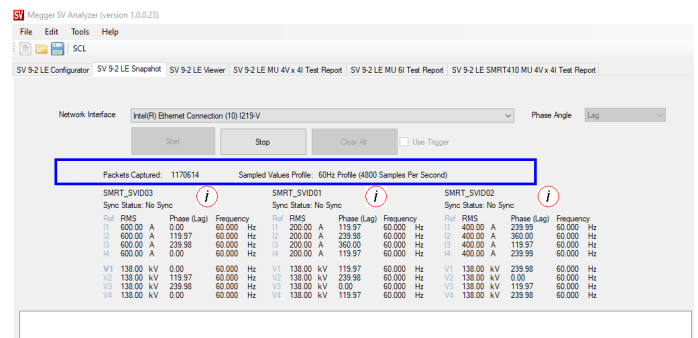

Figure 10: SV Snapshot in monitoring state. SMRT is acting as SV Publisher

Figure 11: Use of RTMS home screen to publish SV Streams

Phase angle – Phase angle orientation (Figure 10) can be chosen as either "Lead" or "Lag" orientation depending on the IED settings, which helps with troubleshooting, provided that the "Lead" and "Lag" orientation match the IED under test.

SV Data Window – The user can select (i) button on any stream to visualise the live status of various parameters in the stream.
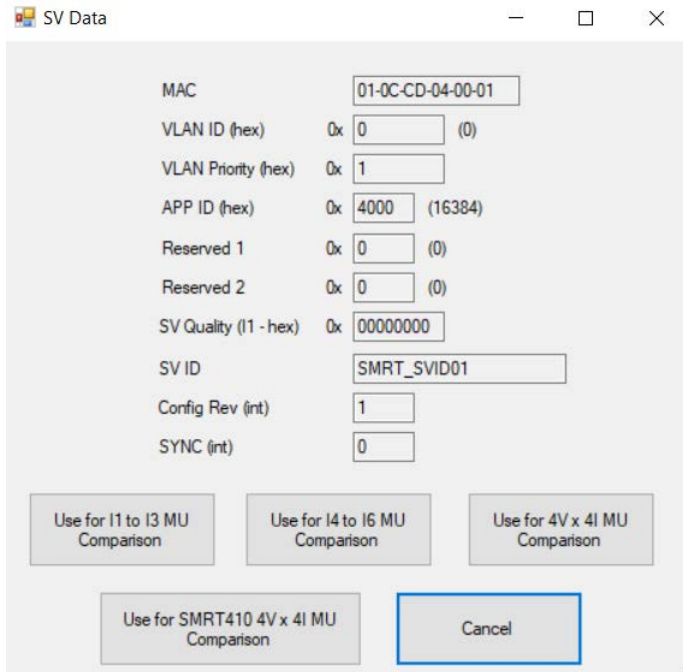
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Figure 12: SV Data pop-up

This data is the captured data from the network during the monitoring state.

Another application is when one injects analogue quantities into a Merging Unit and monitors the published SV stream out of that Merging Unit. In that setup, the user is not required to press DOWNLOAD SV. All the user needs to do is to set the desired stream in the SVA configurator, choose the right network interface in SV Snapshot, and press START in the "SV Snapshot" tab. The example in Figure 13 shows the traffic. Stream-1 was programmed to sniff any SV streams coming out of a Merging Unit. SMRT/FREJA in normal mode was used to inject analogue three-phase voltages into the Merging Unit.
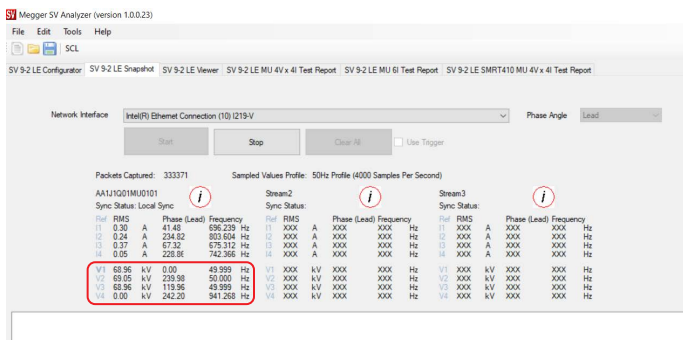
Figure 13: SV Snapshot in monitoring state, ABB REF 615 is the Merging Unit and SV Publisher

If stream data is lost due to Ethernet disconnection, loss of time sync, or other unavoidable conditions, the values for the stream will turn red indicating lost data. If the data for the stream comes back, then the values will switch to black colour. Loss of time sync will be accompanied by a hold-over period, which is usually around 4 to 5 secs. In this hold-over mode, the stream will still behave as if time synchronised. If the time sync signal comes back, "Sync Status" will display the mode based on the sensing of SmpSynch. Re-connecting to the time sync source is also quite fast, less than 3 seconds. The example in Figure 14 shows data loss for SMRT_SVID01:
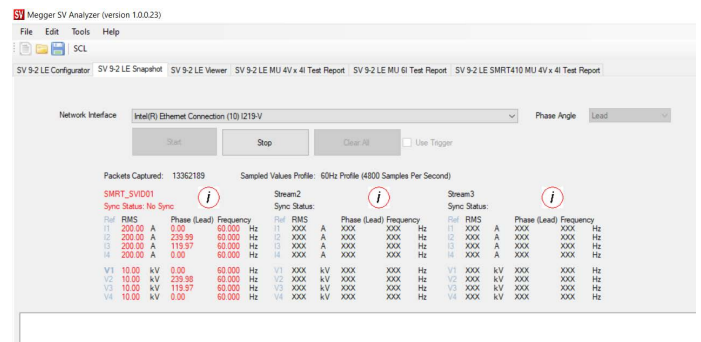

Figure 14: Data loss state due to either loss of sync or packet loss

Simulating derived quality bit set for neutral quantities –

The combination of SVA and RTMS provides the user with the flexibility to either simulate derived bits or real measured quantities for neutral current and voltages. The fourth channel in any IEC 61850 9-2 LE based SV stream is a neutral quantity.

If the fourth channel in any stream is not armed in RTMS, then we automatically send derived quantity and calculated zero sequence values to the fourth channel. It is crucial to note that the derived value is I0/V0 and not 3I0/3V0. The example in Figure 15 shows that SMRT_SVID01 is publishing derived bits on I4 and V4 if I4/V4 is not armed in RTMS. Calculation of I4/V4 is simple.

I4 at I4 angle = (I1 at I1 angle + I2 at I2 angle + I3 at I3 angle)/3

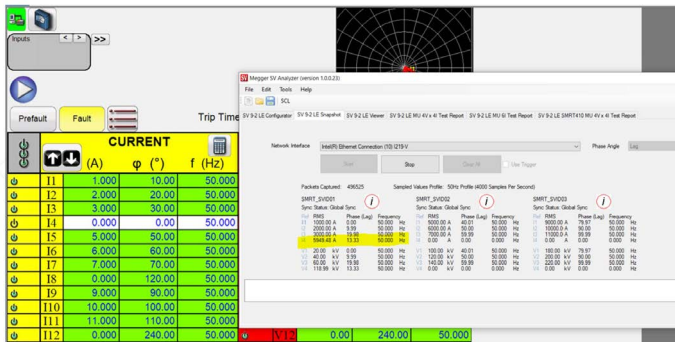V4 at V4 angle = (V1 at V1 angle + V2 at V2 angle + V3 at V3 angle)/3

Figure 15: Simulating SV publishing with derived bits active

If simulation of derived bits is not needed and the fourth channel is needed to simulate measured neutral quantities, then arm the fourth channel for the stream under test in RTMS. The example in Figure 16 shows that the sniffed data is the same as the published data, even though the summation of three phases is not accounting for a balanced system.
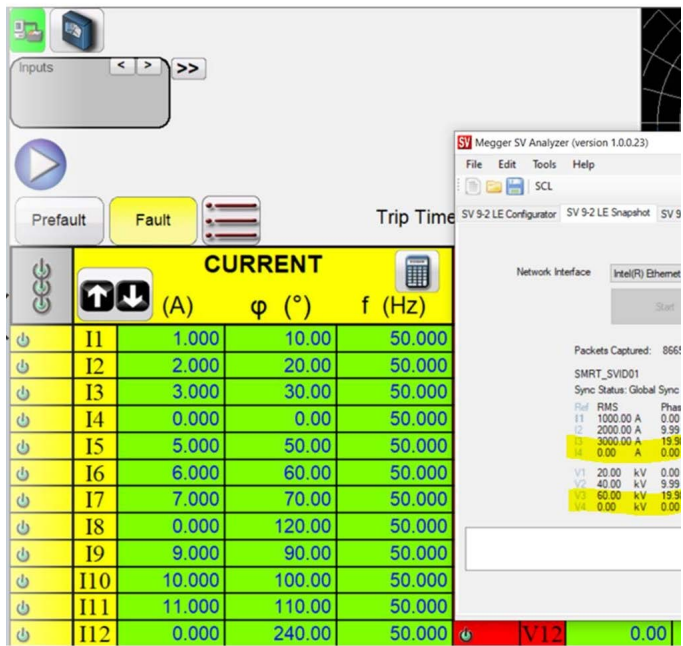

Figure 16: Simulating SV publishing with actual data on the neutral channel of the stream

SV 9-2 LE Viewer

This tab allows users to view waveforms of the monitored SV. Users can zoom in on the waveform portion by holding down the left mouse button and highlighting the area they wish to view or by clicking on the ➕ or ➖ buttons shown in the red outlined box in Figure 17. To view the measurement, select "Cursor 1" and left click in the waveform area where it is desired to start the measurement capture. Select "Cursor 2" and left click again in the waveform area where the measurement capture is wished to end. It will snip the waveform based on the cursor positions. We also show delta sample count, delta time, and delta degrees between the two cursors. When SVA is in the capture mode, the START button will not be visible since the software is accumulating all the packets. Click STOP to stop the capture in the waveform window and then define cursor positions. The yellow outlined box allows the ability to zoom in and zoom out as well as move left or right for the captured waveforms. The blue outlined box in Figure 17 shows the channels that are displayed in the viewer. Uncheck the channels not desired to be seen, and the viewer will hide them in the waveform display window.
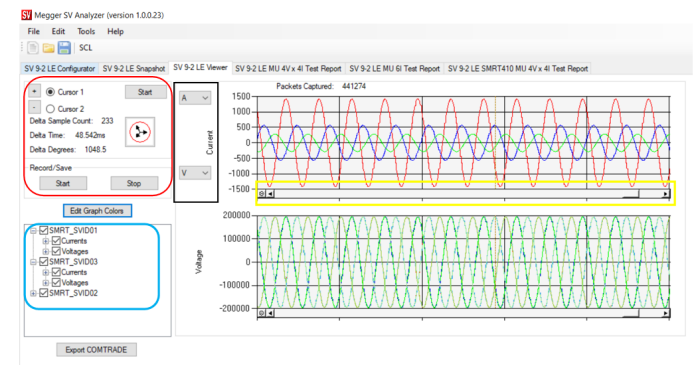

Figure 17: SV Viewer

The example given in Figure 18 demonstrates where the waveforms were meticulously snipped to 80 samples. As you can see, delta time = 16.667 ms which is coherent with the 60 Hz profile. Delta degrees show 360, meaning one complete cycle is captured.

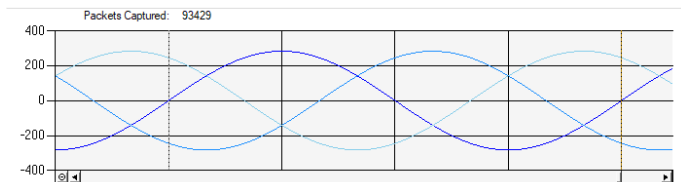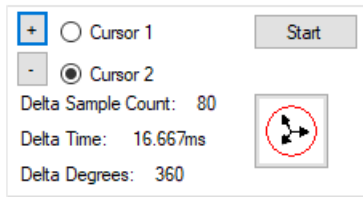# IEC 61850 Sampled Values Configuration

Figure 18: Snipped waveform on "SV Viewer" tab

The user can also edit the colours shown on the graph by clicking on the EDIT GRAPH COLORS (Edit Graph Colors) button. Selection of colour for each stream's respective voltage and current channel is recommended.
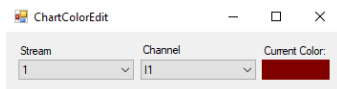

Figure 19: Graph colour dialogue

The user can also select which streams, current channels, and voltage channels are displayed in the graph area by checking or un-checking the boxes in the tree view as seen in the blue outlined box in Figure 17. There is also an option to view the data in "mA", "A", "kA", "mV", "V", and "kV" by choosing the desired setting in the drop-down menu as shown in the black outlined box in Figure 17.

The recording feature for future analysis and data storage is also available within this tab. The user can record and save the data into an ASCII 2013 COMTRADE (Common format for Transient Data Exchange for power systems) ".cfg" file by clicking on the START (Start) button in the "Record/Save" area.

The monitor must be running for data to be recorded. If the data is being recorded the user will see **Recording...** in the bottom left of the graph area. Clicking on the Stop (Stop) button will stop the recording.

If needed, COMTRADE can be exported by selecting the Export COMTRADE (Export COMTRADE) button on the bottom left. It is worth remembering that the exported COMTRADE is in primary values because of the nature of SV streams. Secondly, the CT/PT ratio of the exported COMTRADE is 1:1. The user can manually enter the ratios in a viewer tool they own.

SV Viewer phasor diagram

Clicking on the ⟨↦⟩ will display a phasor diagram of the monitored SV. Phasors of any two SV streams with respect to a particular sample count can be compared.
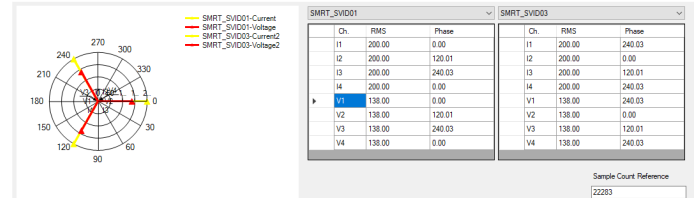

Figure 20: Phasor view

Menu options

New Session

The user can start a new session by either clicking on FILE -> NEW SESSION or the ▤ button. Starting a new session will reset all the data and restart the GUI.

Open

The user can load a saved SVA configuration by clicking on FILE -> OPEN or the 📂 button.

Save

The user can save their SVA configuration by clicking on FILE -> SAVE or the 💾 button. All values that the user configured will be saved (SV Configurator fields, Network Interface, Phase Angle, Capture Frequency, Graph Colours, Selected Stream, and Current/Voltage channels).

RTMS tools that are functional with SV Mode

PowerDB D100.53.15 and above allow the following screens to be functional in SV mode:

- ■ **Home screen**
- ■ **Ramp screen – Simple and advanced**
- ■ **TOC screen – Timing (directional not tested)**
- ■ **Click-onto-fault screen**

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