SUMMARY OF OUR GOOSE RESPONSE TEST II

Key Conclusions

> Initial target time stamp testing results showed too much variation between the vendors (up to 10.5 ms), whereas time-stamping is expected to have a 1 ms resolution.

> Most of the vendor GOOSE action response times were within an acceptable range.

> Determining end–to-end performance is not difficult, but if there is a problem, new skills and software tools will be required by relay test techs to find weak links. A strong background in Ethernet and networking will be key.

> Information exchanges with various gateways and HMI applications was very fast (avg. 45 ms) using MMS connections from the GOOSE vendor devices.

Future Testing

> Ethernet priorities were set for our testing, though they appeared to have very little impact due to the low bandwidth network configuration we used.

> Future testing will focus on the impact of network configurations (e.g. injecting heavy traffic and multiple VLAN use v. flat network).

> We do not recommend anyone deploy their networks as shown in this experiment.

Welcome to the Q4 2014 edition of the NexStation Lab Report.

The past two quarters, we have been building on the preliminary GOOSE response testing we developed during the first part of 2014. Since that initial testing, we have performed in-depth testing to determine end-to-end information transfer times using IEC 61850 GOOSE messages in a multi-vendor system. We share our results below.

Note: What follows is a technical summary of the in-depth testing. The technical details are likely of interest mainly to engineers immersed in implementing IEC 61850. But since we do also have plenty of non-technical readers of the lab report, if you're looking for a quick summary, peek over to the left-hand sidebar. That will give you the gist of the results.

GOOSE Response Test II – Multi-Vendor Control and Status Response Times using GOOSE

GOALS

- Determine end-to-end information transfer times using IEC 61850 GOOSE messages in a multi-vendor system.
- Capture intermediate time stamps between internal device processes.
- Identify any differences between the various information paths.
- Determine IEC 61850 MMS report change notification response times from the same GOOSE test devices.
- Identify key information to capture in system documentation, testing tools and procedures.

TEST PLAN

- Use a protection relay to act as the breaker MU (IEC 61850 merging unit). In this test, it is designated D1. All breaker simulator control and feedback indication will go through this unit using IEC 61850 GOOSE messages.
- Configure a number of multi-vendor protection relays (D2 – D10) to have a user initiate an event to control the breaker by publishing a GOOSE message, subscribed by the breaker MU to control the breaker simulator.
- The breaker MU will publish a GOOSE message for each breaker position change. Each of the configured protection relays will subscribe to the breaker MU's published GOOSE message and perform an output pulse when received. This output pulse will simulate the protection relay performing a task based on the received GOOSE message.
- All key internal protection relay targets will be configured into the device's sequence of events recorder and be time stamped.
- Prior to testing, the feedback indication from the breaker simulator will be wired into an input of each of the protection relays used in the test. All but one of these relays has an IRIG B signal from a GPS clock managing its internal time. Only one of the relays has a connection to the GPS clock's Network Time Server for its time updates. The breaker simulator positions will be changed and the input time stamp recorded for each of the relays. We will use this information to determine the range of time tagging accuracy recorded by the relays for the same event. This test was performed to get a relative idea of how they compare. Later lab tests will focus more in this area.
- All of the protection relays, including the breaker MU, will have key internal targets mapped to an IEC 61850 MMS reports dataset. Other IEC 61850 MMS master station gateways and graphical user interface software applications will be connected to these reports. All key targets received using MMS will have their received time recorded.
- All GOOSE messages will be captured using the Wireshark Ethernet monitoring application and their embedded message times recorded.
- This test will use a single VLAN network that has very little traffic, with paths that only traverse up to two switches.

SOLICITING YOUR INPUT:
We value your feedback and welcome input. Send your testing ideas to: solson@powereng.com

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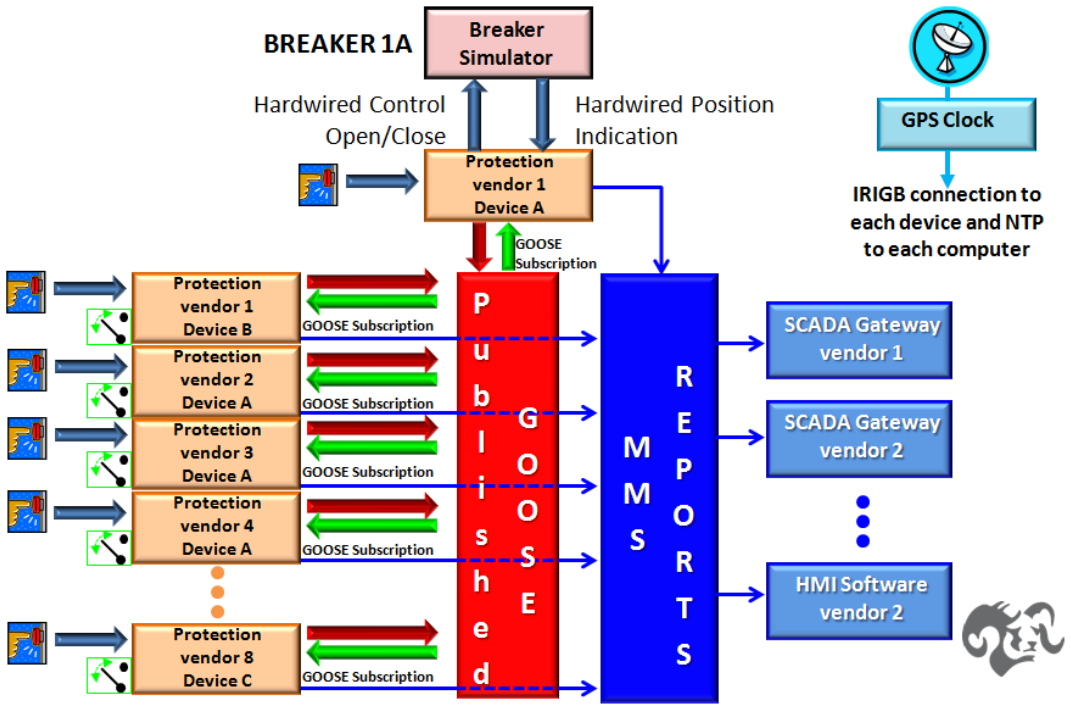


Figure 1. This figure gives a diagram representation of the lab test showing the breaker simulator hardwired connection to the merging unit, D1. All the other protection relays (D2 – D10) will initiate a GOOSE published message to trip the breaker simulator. When the merging unit (D1) sees the feedback indication change from the breaker simulator, it will publish a GOOSE message with that change. All the protection relays D2 – D10 will subscribe to this published GOOSE message and then pulse one of its outputs. SCADA gateways and HMIs will be connected to an MMS report from each of the relays, D1 – D10, and record the breaker simulator message received time.

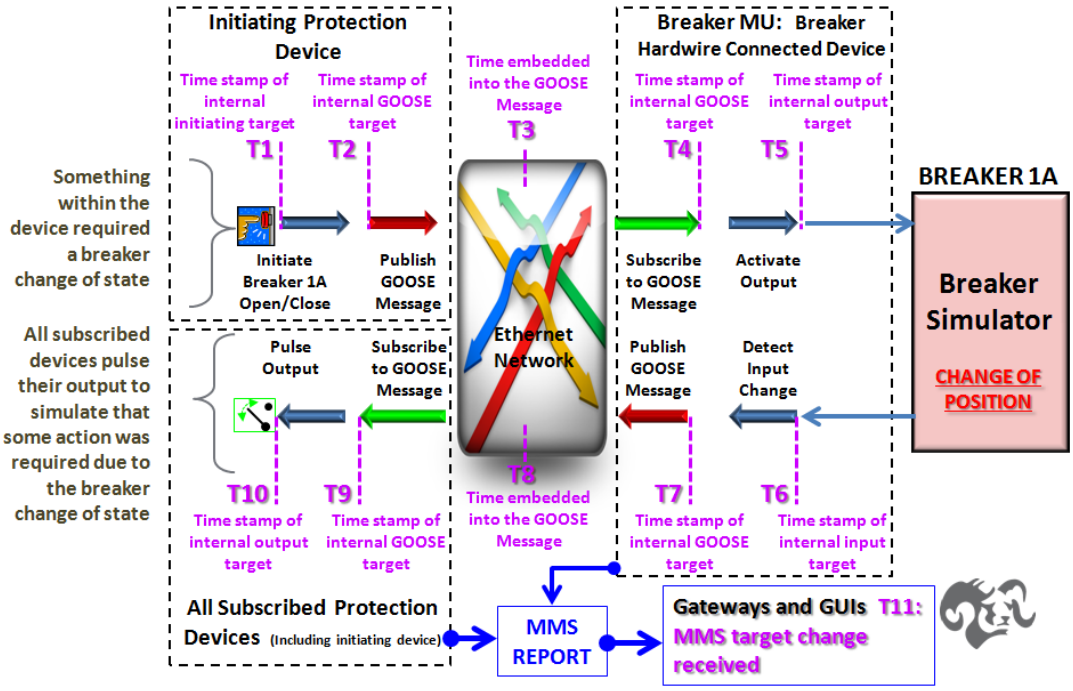


Figure 2. This figure provides a diagram representation of the various event time stamps that we will capture in our testing. The breaker merging unit (MU) will be device D1 throughout our testing. Later tests will use other vendor devices for the merging unit. Each of the remaining units will act as the initiating device to TRIP the breaker simulator with all devices monitoring its change of state.

T1: The user initiated target
T2: The initiating device-published GOOSE dataset target
T3: The GOOSE message-embedded time stamp
T4: The breaker MU subscription GOOSE dataset target
T5: The breaker MU physical output target (controls breaker simulator)
T6: The breaker MU physical input target (breaker simulator position)
T7: The breaker MU-published GOOSE dataset target
T8: The GOOSE message-embedded time stamp
T9: The initiating device subscription GOOSE dataset target
T10: The initiating device physical output target
T11: MMS client change of state receive times

For the test described in this lab report, we focus on the following time intervals:

- T1 to T5: This time interval will give us data on the time it takes from the internal initiating relay target to the time stamp of the merging unit's output target time stamp.
- T3 to T4: This time interval gives us the data on the time it takes from the published GOOSE message time stamp to the internal merging unit's GOOSE target time stamp.
- T1 to T10: This is the total round trip time from the initiating targets' time stamp through the breaker simulator's operation back to a subscribed device to perform a control action.

EXECUTION

- We first performed a relative device time tagging test to determine time differences when seeing the same event on an input from each device. We connected control wires from the breaker simulator interpose relay contact to inputs on each of the devices. We then closed the contact and observed the input closure times captured by the sequence of events recorder.
- Each device was triggered to publish a GOOSE message to trip the breaker simulator. All of the target time stamps were extracted from the device's event recorders and recorded. The GOOSE message times were observed and recorded using the Wireshark network monitoring software.
- This test used IEC 61850 protection relays from five different vendors and in some cases different models from the same manufacturer.

TEST RESULTS

Time Stamp Test

Six separate runs of the same time test were conducted and recorded. All the device input time stamp data was recorded. The minimum and maximum differences between the input time stamps are shown for each test on the following pages. The data below only includes the IRIG B-connected units. We found that the NTS time synchronized unit differed by an average of 9.3 ms from the maximum IRIG B difference.

(ms)	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Avg
Min Difference	1	1	1	1	0	0	0.7
Max Difference	11	10	8	9	12	13	10.5

GOOSE Test #1: Device D7 is the initiating unit

TEST #1	Time for operation of breaker simulator TS01-TS05 (ms)	Time from GOOSE message to receive target TS03-TS04 (ms)	Init Function to End Function time TS01-TS10 (ms)
D7 (Initiating Unit)			26
D1 (Merging Unit)	8	6	
D2			25
D3			28
D4			25
D10			22
D5			24
D6			26
D9			22
D8			26

GOOSE Test #2: Device D6 is the initiating unit

TEST #2	Time for operation of breaker simulator TS01-TS05 (ms)	Time from GOOSE message to receive target TS03-TS04 (ms)	Init Function to End Function time TS01-TS10 (ms)
D6 (Initiating Unit)			30
D1 (Merging Unit)	10	6	
D2			32
D3			35
D4			31
D10			33

D5			32
D7			35
D9			29
D8			33

GOOSE Test #3: Device D2 is the initiating unit

TEST #3	Time for operation of breaker simulator TS01-TS05 (ms)	Time from GOOSE message to receive target TS03-TS04 (ms)	Init Function to End Function time TS01-TS10 (ms)
D2 (Initiating Unit)			27
D1 (Merging Unit)	9	4	
D3			28
D4			26
D10			23
D5			25
D7			29
D6			23
D9			24
D8			27

GOOSE Test #4: Device D3 is the initiating unit

TEST #4	Time for operation of breaker simulator TS01-TS05 (ms)	Time from GOOSE message to receive target TS03-TS04 (ms)	Init Function to End Function time TS01-TS10 (ms)
D3 (Initiating Unit)			27
D1 (Merging Unit)	7	4	
D2			24
D4			23
D10			20
D5			22
D7			27
D6			24
D9			21
D8			24

GOOSE Test #5: Device D8 is the initiating unit

TEST #5	Time for operation of breaker simulator TS01-TS05 (ms)	Time from GOOSE message to receive target TS03-TS04 (ms)	Init Function to End Function time TS01-TS10 (ms)
D8 (Initiating Unit)			25
D1 (Merging Unit)	6		
D2			23
D3			26
D4			23
D10			20
D5			24
D7			29
D6			22
D9			22

GOOSE Test #6: Device D4 is the initiating unit

TEST #6	Time for operation of breaker simulator TS01-TS05 (ms)	Time from GOOSE message to receive target TS03-TS04 (ms)	Init Function to End Function time TS01-TS10 (ms)
D4 (Initiating Unit)			19
D1 (Merging Unit)	6	4	
D2			23
D3			26
D10			
D5			22
D7			23
D6			20
D9			20
D8			24

GOOSE Test #7: Device D10 is the initiating unit

TEST #7	Time for operation of breaker simulator TS01-TS05 (ms)	Time from GOOSE message to receive target TS03-TS04 (ms)	Init Function to End Function time TS01-TS10 (ms)
D10 (Initiating Unit)			21
D1 (Merging Unit)	6	4	
D2			23
D3			26
D4			22
D5			22
D7			23
D6			22
D9			20
D8			23

GOOSE Test #8: Device D5 is the initiating unit

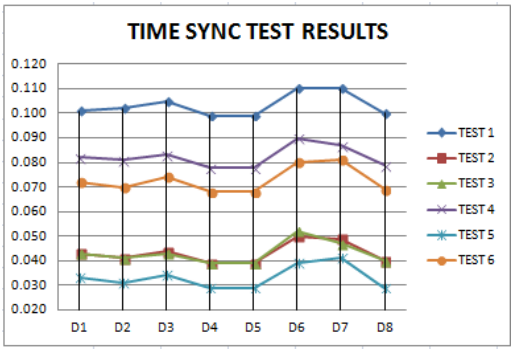
TEST #8	Time for operation of breaker simulator TS01-TS05 (ms)	Time from GOOSE message to receive target TS03-TS04 (ms)	Init Function to End Function time TS01-TS10 (ms)
D5 (Initiating Unit)			23
D1 (Merging Unit)	6	4	
D2			24
D3			25
D4			23
D10			20
D7			25
D6			24
D9			21
D8			23

SUMMARY

Time Test

The IEC 61850 message performance times we recorded were referenced from the top of the published message Ethernet stack to the top of the subscribed message stack. Trying to get accurate time stamps to record this performance is impossible. The best we can do is using the device targets and sequence of events recorders provided. The results of our time test show an average minimum time stamp difference between devices of 0.7 ms and a maximum difference of 10.5 ms. This is a large difference given that we are looking for a resolution of 1 ms in our results. We will look into this issue in further detail in future testing.

The graph below shows the differences between devices for each of the six test runs. From the shape of the traces, we can see that each of the devices had a difference that was consistent in each test run.



GOOSE Message Performance Test

Despite the mixed results noted above, this time stamping test provided a good picture of the overall performance of the multi-vendor system we configured. We will need to use a more rigorous statistical approach in future analysis to determine the validity of the results.

The table below shows the average time of 7.3 ms (TS01 – TS05) for a protection relay to internally start a breaker trip action and operate the output contact on a subscribed protection relay to trip the breaker. Given that the IEC 61850 standard specifies a 3 ms stack to stack performance time and the additional internal process times for the two devices, the 7.3 ms does not seem out of line; however, we were expecting a lower average number. The variance in the time stamp testing may play a role in this increased time.

Test #1-8	Time for operation of breaker simulator TS01-TS05 (ms)	Time from GOOSE message to receive target TS03-TS04 (ms)	Init Function to End Function time TS01-TS10 (ms)
Avg.	7.3	4.6	24.8
Max.	10.0	6.0	35.0
Min.	6.0	4.0	20.0

We examined the TS03 to TS04 time interval to determine the IEC 61850 stack-to-stack performance time. We assume that the GOOSE message time stamp would be close to the published transmit time and that the device-received GOOSE target time stamp would be close to the receive time. The average of 4.6 ms is very close to the IEC 61850 message type 1A 3 ms performance mark.

The TS01 to TS10 total round trip time average of 24.8 ms is the time from a device initiated trip target through the breaker simulator operation and back to other protection devices that performed an internal function to operate their outputs. We found that the average breaker simulator operation time was 12.1 ms. This means that it took an average of 12.7 ms for three devices to perform internal functions and make two GOOSE publish–subscribe message information exchanges.

We were also surprised to see an average MMS report message response for the breaker simulator change of state of ~45 ms while the GOOSE testing was being done. This suggests very fast SCADA gateway and HMI data update response times.