Boston University

National Emerging Infectious Disease Laboratory

Building Automation System Network Performance Review

July 21, 2016

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Appendices

Executive Summary:

The National Emerging Infectious Diseases Laboratories (NEIDL) is part of a national network of secure facilities studying infectious diseases that are, or have the potential to become, major public health concerns. These laboratories are dedicated to the development of diagnostics, vaccines, and treatments to combat emerging and re-emerging infectious diseases. In addition to BSL2 and BSL3 laboratories, NEIDL also houses a BSL4 laboratory for work with especially dangerous pathogens. Research and diagnostics performed at NEIDL add to the growing prominence of life sciences industry in the region, throughout the Commonwealth of Massachusetts, and across the United States[1].

At the request of Boston University, Merrick and Company was engaged to evaluate and assess circumstances surrounding a failure of the Building Automation System (BAS) and the network infrastructure that occurred March 21, 2016. This report addresses the incident's cause, response and provides recommendations to reduce the risk of future such events from occurring.

The cause of the event was an uplink failure in the control network dedicated to the Building Automation System (BAS). The BAS is an integrated monitoring and control system that receives input from numerous subsystems in the facility and among other features, provides alarms in the event of a failure in any subsystem. In this case, a fiber module on a Cisco network switch experienced intermittent failure beginning approximately 15:00h on March 21st.

The fiber module completely failed at approximately 20:00h in such a manner that it created a loop in the network propagating a flood of network traffic which overwhelmed the throughput capacity of the network architecture, an occurrence commonly known as a "Broadcast Storm". The storm sustained this level of network traffic until the failed fiber module was ultimately identified and replaced at approximately at 01:45h the following morning.

The Broadcast Storm effectively crippled operation of the BAS in several ways. First, individual Siemens microprocessor-based controllers within the BAS were overwhelmed by the level of network traffic resulting in the inability of the BAS control panel to transmit data across the network. Either due to levels of network traffic above their design throughput as described above or due to continuous

[1] www.bu.edu/neidl/about

dropping and reconnection to the network, the panels ceased to operate normally, preventing them from executing programmed responses.

Secondly, with the BAS impaired, systems being controlled could not function as intended, including the critical ventilation system. Beginning within seconds of the initiation of the Broadcast Storm, ventilation systems serving the containment laboratories failed. Key elements of the ventilation systems consisting of supply air handling units and exhaust fans (which require careful balancing), were impacted over the duration of the event. As the BAS signals were compromised, the "ON" command signals and speed commands registered on the BAS as "Failed". Operating normally, the BAS's response should have been able to stop the Air Handlers in response to the shutdown of the exhaust fans. This response was not achieved since it relies on network communications for this coordination.

The BSL4 laboratory's local response to the failure of the exhaust system appears to have operated as intended. These laboratory modules each operate as individual zones and maintain a predetermined operational negative pressure set-point. The failure of the exhaust system affected the ability to achieve these set-points. The normal response by the laboratory module when sensing higher than appropriate negative pressure is to lockout if the airflow control valves cannot maintain the threshold. A lockout closes an isolation damper (air / bubble tight), closing off any supply air to the suite. Several suites locked out at 20:00 while others remained below the threshold All of the suites maintained a steady state negative pressure throughout the event duration. Individually, several rooms experienced positive pressures spikes for brief durations, however these spikes were preceded by the room going into Lockout and initiating closure of the isolation dampers. The positive pressure experienced for a few seconds when the room enters lockout mode is not unexpected as the dampers although fast acting are not instantaneous. As they should, the pressures in these rooms rapidly dropped below neutral pressure and remained negative for the duration of the event.

The BSL3 and ABSL3 suites do not have individual bubble tight dampers/control devices or the extra layer of protection that is provided for the BSL4 suites such as the air pressure resistant doors. The continued operation of the supply air handlers coupled with the lack of operating exhaust fans created a reversal air flow (positive pressure) out of the BSL3 suites. None of the BSL3 or ABSL3 suites were in use with BSL3 agents at the time of this event. The programmed response for the BSL3 suites when loss of inward directional airflow is encountered is to enter into a Stage 1 or a Stage 2 lockout. The condition in which there is inadequate exhaust to overcome the supply within a suite engages a Stage 1 lockout. In this scenario the air control valves are commanded to move to a predetermined flow to overcome a local failure. Several suites went into Stage 1 lockout during the event however not all suites that should have registered the Stage 1 lockout did so due to the loss of network communications. In these suites the exhaust flow was not adequate to prevent the reversal of airflow. When this occurs, a Stage 2 lockout is the expected response. A Stage 2 lockout shuts down all supply air handlers and reduces the number of operable exhaust fans to only one. No suites registered a Stage 2 lockout as expected during the event until the network was restored. After network restoration, all air handlers were commanded off by the Stage 2 lockout.

In summary, the effect of the Broadcast Storm on the BAS effectively eliminated network communications between devices on the network which directly affected the ability of individual BAS panels to operate in a standalone mode. This impaired the ability of the BAS control panels to communicate with each other and with ventilation system devices and also hindered the ability of systems to remaining operational with proper responses. Given the magnitude of the impacts of the Broadcast Storm, we recommend alterations to the BAS network, including a permissive interlock that would require the exhaust system to be operational in order for the supply air handlers to operate independent of the BAS network.

Event Chronology and Assessment of Incident:

The Boston University NEIDL Building Automation System (BAS) Network experienced an uplink failure on March 21, 2016 at approximately 15:00 hours. This failure created a flood of network traffic, known as a "Broadcast Storm," which rendered the network inoperable, causing sustained airflow reversals in BSL3and ABSL3, and brief positive pressure spikes in BSL4.

Meetings were held at the NEIDL on April 13/14, 2016 to determine the cause of the reversal of airflow. Multiple teleconferences and the transmitting of BAS trend data to Merrick from the NEIDL BAS system occurred in the weeks that followed the initial meeting of April 13/14.

At the initial meeting, Boston University IT (IS&T) group was represented and described the incident from a network perspective. IS&T provided an After-Action Report which stated, "An uplink failure notification was logged on the sixth floor switch of the BAS network at 17:01. The failure continued to log every 5 minutes for the next 3 hours. At 19:59, all four network switches (three physically located in the NEIDL and one located in the BUMC Control Center) that support the BAS network indicated 'Notification Errors'. This started a Broadcast Storm making the BAS network useless and unreachable."

Ultimately, remediation action was taken including replacement of a fiber module, replacement of a switch and troubleshooting of other switches on the network. The network was brought back on-line in the early morning (01:40) of March 22, 2016.

The IS&T After-Action report concluded that a fiber module on the sixth floor BAS network switch had failed and created the Broadcast Storm.

An additional BU IS&T report indicated that the fiber module failure did not fail in a "normal" way. In their conversations with Cisco technicians, the switch manufacturer, Cisco stated that they have only seen this type of module failure once in the past 8 years.

The NEIDL Facilities group was represented and described the incident timeline from an airflow/HVAC equipment perspective:

Monday, March 21, 2016

> 20:33 BUMC Control Center contacted NEIDL Facilities stating that they could not see the BAS network.
>
> 20:36 NEIDL Facilities reached out to NEIDL IT who physically went to the NEIDL to investigate the BAS network. NEIDL IT investigated issues and restarted the server and the mechanic on duty reviewed the systems.

20:48 NEIDL IT reported that Siemens (the BAS system vendor) could not communicate with its panels and suspected a network switch problem.

21:36 A conference call was initiated to coordinate response for the event. A re-affirmation was made that the event posed no safety or health risk as no active BSL3 or BSL4 research was ongoing and all BSL3 labs had not been used since formal decontamination was conducted upon conclusion of their previous research studies.

22:06 BUMC IS&T called NEIDL IT and checked the BAS network switches.

22:55 BUMC IS&T arrived on campus.

23:58 NEIDL IT reported that the BSL3 suites were experiencing positive pressure and all the exhaust fans were off.

Tuesday March 22, 2016

00:11 BUMC IS&T informed NEIDL Facilities that the BAS network switch at the Power Plant has been replaced.

00:48 NEIDL Facilities informed BUMC IS&T that the BAS is still not receiving information.

00:51 BUMC IS&T reported that they were not able to remote into the NEIDL and went over to the NEIDL.

01:32 BUMC IS&T shut uplinks to switches, replaced the faulty fiber module in one of the Cisco network switches, and reset switches and the BAS network came back on-line.

03:00 NEIDL Facilities cleared all the alarms and the system returned to normal.

Review of the series of events indicate a failure of the fiber module on the sixth floor switch was the beginning of the incident. Per the BUMC IT After-Action report:

> *These (fiber) modules convert optical light from an optical fiber end into electronic pulses that the network switch uses to send and receive network data traffic. This particular module started to flap up and down starting around 5PM which caused the switch to think it had two separate uplinks, when in fact the central node switch still thought the uplink ports were combined together as a logical group. In this type of scenario, a loop can occur causing the switches to become confused. When this happens, they start to flood traffic out all of their ports since they are unsure of the correct destination for each packet. When different nodes are sending/broadcasting data over all of the ports in the same network domain, the other switches are rebroadcasting the data back in response. This causes a*

Broadcast Storm and the whole network melts down leading to a complete failure of network communication.

The failure of the fiber module and the subsequent rebroadcasting of data flooded the network and according to Siemens' Assessment Report (full report in Appendix C):

....it is believed that the root cause was the failure of a fiber module at the Cisco Ethernet switch that caused heavy network traffic on the network that the Siemens sides on. This network traffic has been referred to as a 'Broadcast Storm'. The volume of data being passed on the network, and through the Siemens BMS panels well surpassed the design specifications of the Siemens BMS control panels prohibiting some panels from performing properly.

After Merrick's review of the Siemens' report and trend data, it was determined that the Siemens system was sending an "ON" command to the exhaust system panels, but due to the heavy traffic being passed through the BAS panels, the panels did not execute these commands . Some of the Air Handling Units (AHU's) were running and the BAS was providing an "ON" command attempting to start the corresponding exhaust fans. This failed command resulted in the ABSL3 and BSL3 suites going positive and the BSL4 having momentary positive spikes.

In further correspondence with Siemens, it was confirmed that the issue with the panels not executing the "ON" command was due to the inability of the panel to execute its programing resulting from the overwhelming amount of data created by the Broadcast Storm.

Another observation relates to the configuration of the BAS network, again from the Siemens Assessment Report:

The original design of the network was a stand-alone flat Ethernet network that utilized Netgear switches. This configuration was commissioned and tested for network communication failure, and designed to maintain the integrity of the design in this failure mode. The network layout was changed approximately one year ago by BU IT to managed Cisco switches through redundant routers that met the campus standard. A Broadcast Storm was not a failure mode that the system was designed or tested for during commissioning. This level of communication traffic is not recommended.

After further discussions with BU IS&T and the "*Report on NEIDL Incident of 3/21/2016*" the updated configuration of the network is not believed to have contributed to the Broadcast Storm.

From the report:

> *This redundant network was (and is) still designed as a flat network. The redundancy eliminates the single point of failure scenario but does not segment the network. The network is still seen as a single big loop with everything connected to everything else. The distribution routers are not configured to route network traffic and are simply serving as a pass through.*
>
> *In the scenario that occurred on March 21, 2016 the redundancy worked as it was designed. Every time the SFP module "flapped" off, the network failed over to the other link and continued normally. When the SFP module flapped back on, network traffic resumed normally. Both routers performed normally throughout the entire event and evidenced no failures of any kind. They simply passed network traffic back and forth. Very shortly after 19:59 on the 21st, the SFP module entered into an unanticipated error state (which) precipitated a Broadcast Storm. There was no failure of the network itself or the routers. They simply became overwhelmed with network traffic. It is our opinion that redundancy did not contribute to the Broadcast Storm. In conversations with professionals from Cisco they shared their opinion that based on the IS&T account of the events and the support case notes from the troubleshooting performed during this incident it did not appear the network topology (design) had any kind of adverse effect on the network during this incident. A Broadcast Storm was possible in the old network configuration as it was in the new. It has been suggested that the SFP module failure in the old network would have caused it to fail more quickly. It is true that had the SFP module failed in a normal manner then the network would have failed in the old design. But the SFP module did not have a normal or anticipated failure. The SFP module didn't just stop working. It precipitated a flood of broadcast traffic that neither network topology was designed to handle and is not routinely tested for in normal business practice.*

BSL4 Areas – Air Handling Units

The air systems serving the BSL4 consist of 4 Air Handling Units (AHU-BSL4-1 thru AHU-BSL4-4) and 4 Exhaust Fans (EFBSL4-1 thru EFBSL4-4). All four AHUs and exhaust fans are designed to operate continuously 24 hours per day/ 365 days per year.

The last time the units were operating under normal conditions was 19:45, and this was before the Notification Errors were indicated on the network switches. The network switches indicated Notification Errors at 19:59, and this was just before the status was reading "off." These events line up in the timeline.

Time Stamp	BSL4 AHU-1	BSL4 AHU-2	BSL4 AHU-3	BSL4 AHU-4
Mon 19:45	operating normally	operating normally	operating normally	operating normally
Mon 20:00	showing normal voltage (5.88 v)	No data showing	No data showing	No data showing
Mon 20:11	Showing normal voltage readings	Showing some voltage readings		Showing some voltage readings
Mon 20:13; and 20:15 thru 20:18	Failed execution status (not executing commands)	Failed execution status (not executing commands)	Failed execution status (not executing commands)	Failed execution status (not executing commands)
Mon 20:52 to Tues 01:30	Showing some voltage readings	Failed execution status (not executing commands)	Failed execution status (not executing commands)	Failed execution status (not executing commands)
Tues 01:45	0 voltage reading	0 voltage reading	0 voltage reading	0 voltage reading
Tues 02:23	Unit is coming back on-line	Unit is coming back on-line	Unit is coming back on-line	Unit is coming back on-line
Tues 02:30	Unit operating normally at pre-failure voltage	Unit operating normally at pre-failure voltage	Unit operating normally at pre-failure voltage	Unit operating normally at pre-failure voltage

See Appendix A for trend data for AHU-BSL4 units

<u>BSL4 Areas – Exhaust Fans</u>

Per trend data, the BSL4 exhaust fans were operating normally up until 20:00.

See chart below for fan operation during the event:

Time Stamp	BSL 4 Exhaust Fans
Mon 20:20	All 4 fans operating normally
Mon 20:15	No data recorded
Mon 20:18	All 4 fans show failed execution status

Mon 20:18 thru 20:52	No data recorded
Mon 20:52	Voltage indicated to all 4 fans; but failure status is also shown for all 4 fans
Mon 21:00	Voltage indicated to all 4 fans; but failure status is also shown for all 4 fans
Mon 21:00 thru Tues 1:44	No data recorded
Tues 1:45	All fans indicate "on", but only two fans show voltage
Tues 2:00	All fans indicate normal and are approaching normal operating voltage
Tues 2:30	All fans operating normally at 8 volts

See Appendix A for BSL4 trends and graphs.

Based on available information, the BSL4 rooms experienced very brief moments of positive pressure spikes. The pressure monitors and all the controls for each room are contained on a dedicated room controller. The room controller was monitoring the room pressure and properly reacted to the fan failures by shutting down the room. While the rooms indicated positive spikes, with the doors closed/sealed and HEPA filters on both the supply and exhaust, no threat was believed to be posed to health and safety.

BSL4 Air Pressure Resistant (APR) Doors

Two types of Air Pressure Resistant (APR) doors are installed in the BSL4 Suite. Each of these doors provide an airtight seal to the rooms/spaces in which they are located. The two types of doors are mechanically operated APR doors which are completely manually operated and pneumatic bladder APR doors which utilize an inflatable silicon gasket to create an air tight seal. All but six barrier doors are of the mechanical type the remainder are pneumatic bladder type. The six barrier pneumatic bladder type doors separate the chemical showers from the suit rooms.

The operation of the doors is through the security system and the BAS has no influence on the operation of the door locks or seals. The chemical shower APR doors do have two way communication, via relays, between the BAS and the public safety Programmable Logic Controllers (PLCs). When a chemical shower APR door closes, the PLC sends a signal to the BAS to start the chemical shower cycle (start compressors, inject disinfectant, inject water, and modulate airflow).

When the chemical shower cycle completes, the BAS sends a signal to the PLC to allow exit from and access to the chemical shower.

Per the trends, several APR Doors indicated on the BAS that the magnetic locking mechanisms engaged/disengaged, door seals(where applicable) were inflated/deflated and door proximity sensors indicated that the doors had been opened and closed. During the event, several of the APR doors trended that they cycled through open and closed states several times. It is physically impossible for the mechanical type doors to open automatically since manual operation is required. With respect to the bladder type doors, Merrick reviewed security video footage of rooms 244 and 245. Room 244 footage, (Monday, 4:01 PM through Tuesday 05:30 AM). During this duration, the APR door lights changed from red to yellow and back to red, but the doors did not open. Reviewing Room 245 footage (Monday05:28 through Tuesday 02:24) the APR door lights did not cycle, the red light remained red the entire duration of the video and no doors were opened.

The APR doors associated within a common BSL4 suite are monitored by the same BAS control panel. Further review of the trended door open/close scenarios, showed that the doors experienced cycling of the locking mechanisms, door seals(where applicable) were inflated/deflated and door proximity sensors indicated that the doors had been opened and closed at nearly the same time. Since a lag of several seconds is required after a door is unlocked before it can be opened, it would indicate that the control panels were not operating normally due to the effects of the Broadcast Storm.

Siemens supports this conclusion, stating that one of the effects of the Broadcast Storm is their control panels can malfunction in a way that the panels will cycle the control inputs and outputs on and off as opposed to actually receiving signals from the security system. This cycling appeared to have occurred as the trends show different doors simultaneously opening and closing at nearly the exact same time. Additionally the videos indicate, the doors did not open.

See Appendix A for APR door trends that show 3 separate doors trending opening and closing events at virtually the same time indicating that the BAS panels may have been experiencing operational issues.

Pneumatic (bladder-type) APR door operation:

The sequence of operation for the pneumatic (bladder type) APR doors is as follows:

- Door closed, door mounted LED is red
- When entry button is depressed, the LED on that door changes to yellow
- Signal is sent to door control cabinet to activate vacuum pump to deflate bladder.
- Once bladder is deflated, mag lock is released and door light changes to green.
- Security system transmits bladder deflated and mag lock off status to the BAS.

- Once door is shut, bladder re-inflates, security system sees the door shut and the light goes to green.

BSL3 Areas – Air Handling Units

The supply air systems serving the BSL3 suites consist of three Air Handling Units (AHU-BSL3-1 thru AHU-BSL3-3) and 3 exhaust fans (EFBSL3-1 thru EFBSL3-3). All three AHUs and exhaust fans (each designed for 50% of the load) are designed to operate continuously 24 hours per day/ 365 days per year.

Per the trends, all three supply AHUs were last shown operating normally at 19:45 on Monday. AHU trends are setup to record data every 15 minutes and were recording data correctly up until that time. The chart below shows operation of the AHU's during the event:

Time Stamp	BSL3 AHU-1	BSL3 AHU-2	BSL3 AHU-3
Mon 19:45	operating normally	operating normally	operating normally
Mon 20:00	showing normal voltage (5.86 v)	No data showing	No data showing
Mon 20:10	Showing voltage readings	Showing voltage readings	Showing voltage readings
Mon 20:15	Showing voltage readings	No voltage showing	No voltage showing
Mon 20:18	No data registered	Failed execution status (not executing commands)	Failed execution status (not executing commands)
Mon 20:30		No data registering	No data registering
Mon 20:45		No data registering	No data registering
Mon 20:52	No data registering	Failed execution status (not executing commands)	Failed execution status (not executing commands)
Mon 21:00		Failed execution status (not executing commands)	Failed execution status (not executing commands)
Mon 21:16 thru Tues 0:30	Showing voltage readings	No voltage showing	No voltage showing
Tues 0:45 thru Tues 1:45	No voltage showing	No data registering	No data registering
Tues 0:45	No voltage showing	No voltage showing	No voltage showing
Tues 2:15	Showing voltage readings	Showing voltage readings	No voltage showing

Tues 3:15	Operating normally	Operating normally	Operating normally

See Appendix A for trend data for AHU-BSL3 units.

<u>BSL3 Areas – Exhaust Fans</u>

The exhaust fans were also trended at 15 minute intervals and were last trended operating normally up until 20:10. The last time the units were operating under normal conditions was 19:45, and this was before the Notification Errors were indicated on the network switches. The BAS switches indicated Notification Errors at 19:59, and this was just before the status was reading "Failed" and these events line up in the timeline.

The following chart indicates operation of the exhaust fans during the event.

Time Stamp	BSL 3 Exhaust Fans
Mon 20:10	Operating normally
Mon 20:15	No data recorded
Mon 20:18	All 3 fans show failed execution status
Mon 20:18 thru 20:52	No data recorded
Mon 20:52	Voltage indicated to all 3 fans; but failure status is also shown
Mon 21:00	Voltage indicated to all 3 fans; but failure status is also shown
Mon 21:00 thru Tues 1:45	No data recorded
Tues 1:45	All fans indicate "on", but only two fans show voltage
Tues 2:00	All fans indicate normal and are approaching normal operating voltage
Tues 2:30	All fans operating normally at 8 volts

See Appendix A for trend data for EF-BSL3 units.

Summarizing, the BSL3 suites experienced sustained reversal of airflow starting at approximately 20:00, when the notification errors occurred on the BAS switches. These suites were affected by the air systems, exhaust system failing to operate while the supply system remaining “on” during the Broadcast Storm. Normally, the system is configured for the supply to track the exhaust with room lockout modes that are network based. The lockout modes are described as follows:

Stage 1 Lockout Mode

When an individual BSL3 suite enters a Stage 1 lockout mode, two conditions must be met; the door is closed and room pressure is above set point (-0.01”adj) or below set point (-0.10”adj) for 30 secs (adj). When both of these conditions are met, all supply and exhaust valves should close. TheBSL3 lab exhaust valve is set to a position that will keep all pressure monitors within the suite below -0.01” (adj) and not create a hyper negative condition.

Stage 2 Lockout Mode

When an individual BSL3 suite enters a Stage 2 lockout mode, the room differential pressure at the corridor/ante room pressure monitors (both differential pressure monitors) cannot maintain -0.01” wc. The Stage 2 lockout mode transmits a shutdown signal to both the BSL3 air handlers and all but one of the BSL3 exhaust fans. The Stage 2 lockout mode will also command the supply and exhaust air closed with the exception of the lab exhaust terminal which remains open to maintain directional airflow during the Stage 2 lockout.

The pressure sensors for these BSL3 suites are located in panels that must communicate across the network to perform these lockout sequences. When the Broadcast Storm occurred, the lockout sequences could not be executed. The exhaust system was not operational and the room controls continued to try to maintain directional airflow by opening the exhaust control air valves and closing the supply air control valves (not shutoff/bubble tight type). With no exhaust air fans in operation and with the supply air system remaining in operation, the system was unable to maintain negative pressure and the rooms experienced a sustained reversal of airflow.

The BSL3 Lockout Modes were unable to execute during the Broadcast Storm and some suites experienced a sustained reversals of airflow. Upon the network communications being restored at 01:44, the Stage 2 lockouts were executed, the Air Handling Units were commanded off and suites were brought to a neutral state.

ABSL3 Areas – Air Handling Units

Similar to the BSL3 Areas, the air systems serving the ABSL3 consist of three AHUs (AHU-BSL3A-1 thru AHU-BSL3A-3) and 3 exhaust fans (EFBSL3A-1 thru EFBSL3A-3). All three AHUs and exhaust fans (each designed for 50% of the load) are designed to operate continuously 24 hours per day and 365 days per year. The following chart indicates operation of the AHU's during the event.

Time Stamp	ABSL3 AHU-1	ABSL3 AHU-2	ABSL3 AHU-3
Mon 19:45	operating normally	operating normally	operating normally
Mon 20:00	showing normal voltage (6.37 v)	No data showing	No data showing
Mon 20:10	Showing voltage readings	Showing voltage readings	Showing voltage readings
Mon 20:15	Showing voltage readings	No voltage showing	No voltage showing
Mon 20:18	No data registered	Failed execution status (not executing commands)	Failed execution status (not executing commands)
Mon 20:30		No data registering	No data registering
Mon 20:45		No data registering	No data registering
Mon 20:52	No data registering	Indicated "off"	Indicated "off"
Mon 21:00		Indicated "off"	Indicated "off"
Mon 21:16 thru Tues 0:30	Showing voltage readings	No voltage showing	No voltage showing
Tues 1:45 thru Tues 2:15	No voltage showing	No data registering	No data registering
Tues 2:30 thru 2:45	Data registering, an slight voltage showing	Data registering, but showing 0 voltage	Data registering, but showing 0 voltage
Tues 3:00	Showing voltage readings	Showing voltage readings	Showing voltage readings
Tues 3:30	Operating normally	Operating normally	Operating normally

See Appendix A for trend data for AHU-BSL3A units.

ABSL3 Areas – Exhaust Fans

The last time the units were operating under normal conditions was 19:45, and this was before the Notification Errors were indicated on the network switches. The network switches indicated Notification Errors at 19:59, this was just before the Status was reading off. These events line up in the timeline.

The following chart indicates operation of the Exhaust Fans during the event:

Time Stamp	ABSL 3 Exhaust Fans
Mon 19:45	All fans operating normally
Mon 20:00	7 data points recorded for ABSL3 EF-1; no data recorded on the other two fans
Mon 20:12	All 3 fans show failed execution status
Mon 20:18	All 3 fans show failed execution status
Mon 20:52	Voltage indicated to all 3 fans; but failure status is also shown
Mon 21:00	Voltage indicated to all 3 fans; but failure status is also shown
Mon 21:26 thru Tues 1:45	No data recorded
Tues 1:45	All fans indicate "normal", but only two fans show voltage
Tues 2:00	All fans indicate normal and are approaching normal operating voltage
Tues 2:30	All fans operating normally at 8 volts

ABSL3 suites (623, 624, 626, 628, 629, and 630) experienced sustained reversals of airflow. These suites were affected by the air systems, exhaust system being off and the supply system remaining on during the Broadcast Storm. These rooms are configured for the supply to track the exhaust with room lockout modes that are network based. The ABSL3 suites are configured with lockout modes, controlled by the BAS system, to prevent reversal of pressure. Lockout strategies are as defined above for the BSL3 Suites. At 21:09 Stage 1 Lockouts for suite 623, 624, 626, 628, 629, (630 was at

20:01) were registered and believed to be when the last operational exhaust fan failed. No Stage 2 lockouts registered.

The ABSL3 Lockout Modes were unable to execute due to the Broadcast Storm and the suites experienced a sustained reversals of airflow. Upon the network communications being restored at 01:44, the Stage 2 lockouts were executed and the air handlers were commanded off and the suites brought to a neutral state.

Recommendations:

Response of the system during the Broadcast Storm event brought to light the critical need for a stable communication between the BAS field panels. The stability of the network and the predictability of the failures are critical to ensuring the Building Automation System can adequately respond to events. To this end, we have grouped recommendations into two categories: Network Related and Controls Related.

Recommendations for the Network are directed towards monitoring and rules. The inherent redundancies in the system should continue to be leveraged to direct network traffic in the event of failures. However management of the network in both monitoring and establishing protocols within the network to respond to anomalies should be implemented. If safeguards are in place to reduce the impact of a Broadcast Storm and detect one earlier in the future, the current logic within the BAS should provide the proper safeguards to eliminate sustained airflow reversals.

With respect to Controls, we are recommending that changes be made to the BAS in trending, monitoring, alarming and response. When network communications were lost, the BAS system was not utilized to its potential to warn of the event escalating or even that the event was occurring. We suggest that alarms be generated at the server level which if in place, could have eliminated the delay in the identification of the network failure.

We also recommend that a permissive interlock be implemented that would require the exhaust system to be operational in order for the supply air handlers to operate – and this should be independent of the BAS network. Finally, data used to review the incident was not universal in format nor in pre-established collection groupings. As a result much manipulation of raw data was required. A standard set of trends for equipment types and spaces to more easily evaluate system performance and status is recommended. All recommended changes shall be tested and verified upon implementation. Specifically, we recommend the following:

BAS Network:

1. Increase the urgency status of NEIDL network switch monitoring. These should be at the highest level of urgency on par with life safety systems. Alarm will page and send text messages to all network personnel. This is defined as a critical alarm.

2. Change how reports of outages are handled for the network. Network failures should escalate directly to the Network Engineering staff 24/7 through an on call notification system. This will bypass the BUMC help desk and provide direct contact to the on call network engineer for any issues relating to the BAS and network.

3. Apply Unidirectional Link Detection protocol to all the uplinks on the VLAN switches to reduce the impact of a Broadcast Storm. Unidirectional Link Detection (UDLD) is a data link layer protocol from Cisco Systems to monitor the physical configuration of the cables and detect unidirectional links. UDLD complements the Spanning Tree Protocol which is used to eliminate switching loops.
4. Upgrade the distribution router code to the latest safe harbor standards. Safe harbor is the most stable and latest version of operating code for the router. Performing periodic review of code is part of normal operational sustainment.

5. Increase monitoring on ports for up/down events and high network traffic. Monitor the network to establish baseline bandwidth prior to establishing thresholds. Currently the uplinks and switches are monitored; this will be increased to include all ports on the switch. This will alert if one of the panels "goes down" on a loss of feed.

6. Implement Broadcast Storm Control according to best practice. This will limit the amount of broadcast traffic that can be seen on a port and will automatically shut the port down. The threshold for this is currently being evaluated.

7. Implement Spanning Tree Root Guard (STP) enhancement according to best practice. The main purpose of STP is to ensure that you do not create loops when you have redundant paths in your network.

BAS Controls:

1. Implement Siemens panel monitoring and alarming protocols.

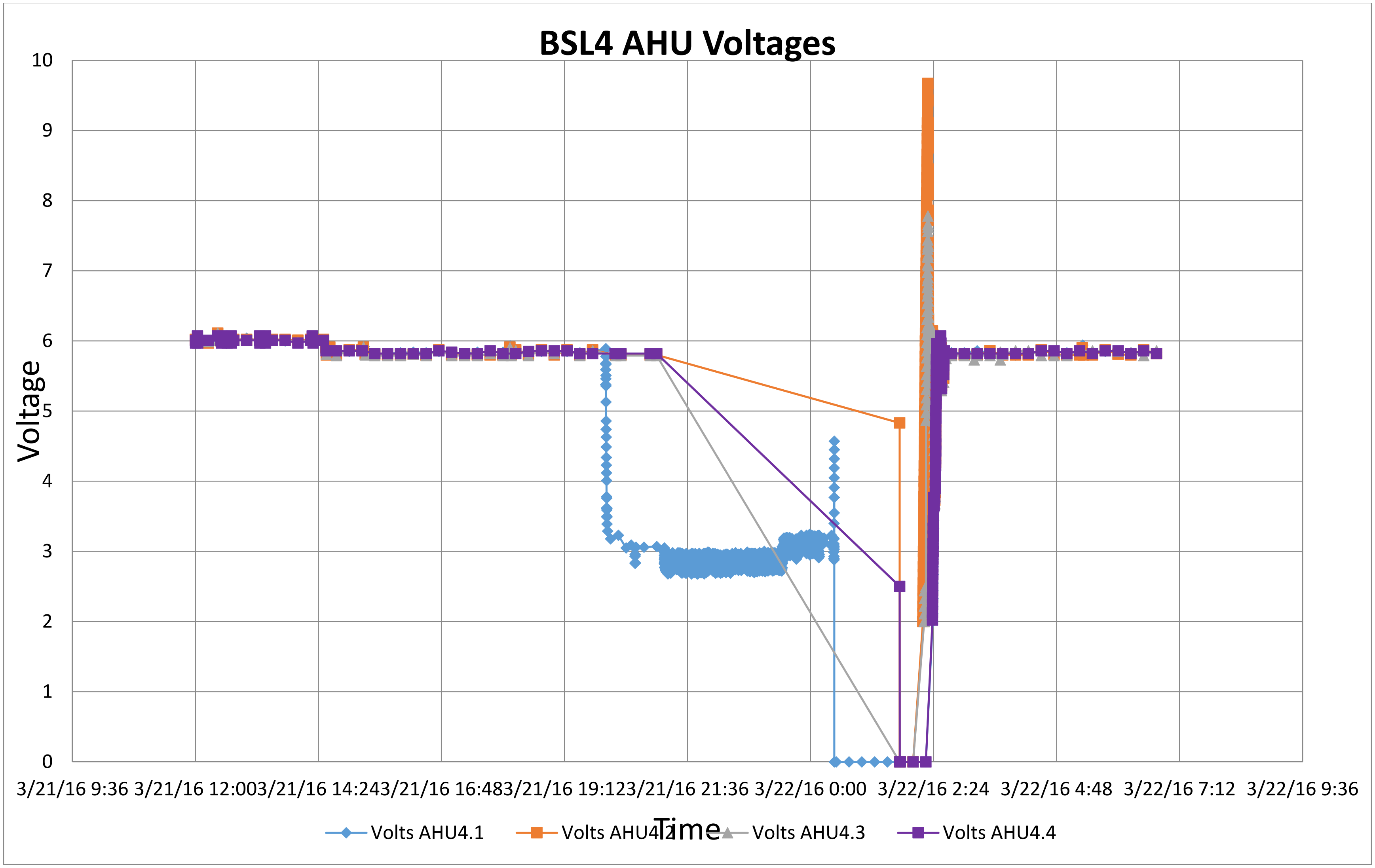
2. Revise BAS data trending parameters to assure data set completeness.

3. Explore the use of hardwire interlocks between exhaust and supply fans.

4. Explore the need for security trending of door conditions in addition to permissive actions.

5. Explore modifications to the current trending strategies to capture additional information that would assist in operational needs of the system.

Appendix A: Trends



BSL4 AHU Voltages
Voltage
Time
10
9
8
7
6
5
4
3
2
1
0
3/21/16 9:36
3/21/16 12:00
3/21/16 14:24
3/21/16 16:48
3/21/16 19:12
3/21/16 21:36
3/22/16 0:00
3/22/16 2:24
3/22/16 4:48
3/22/16 7:12
3/22/16 9:36
Volts AHU4.1
Volts AHU4.2
Volts AHU4.3
Volts AHU4.4

Time	Volts AHU4.1	Volts AHU4.2	Volts AHU4.3	Volts AHU4.4	Status
3/21/16 19:45	5.86				-N-
3/21/16 19:45		5.87			-N-
3/21/16 19:45			5.86		-N-
3/21/16 19:45				5.82	-N-
3/21/16 20:00	5.88				-N-
3/21/16 20:00	5.68				-N-
3/21/16 20:00	5.38				-N-
3/21/16 20:00	5.59				-N-
3/21/16 20:00	5.46				-N-
3/21/16 20:00	5.67				-N-
3/21/16 20:00	5.78				-N-
3/21/16 20:00	5.89				-N-
3/21/16 20:00	5.78				-N-
3/21/16 20:00	5.67				-N-
3/21/16 20:00	5.51				-N-
3/21/16 20:00	5.36				-N-
3/21/16 20:00	5.13				-N-
3/21/16 20:00	4.86				-N-
3/21/16 20:00	4.74				-N-
3/21/16 20:00	4.63				-N-
3/21/16 20:00	4.49				-N-
3/21/16 20:00	4.34				-N-
3/21/16 20:01	4.23				-N-
3/21/16 20:01	4.12				-N-
3/21/16 20:01	4.01				-N-
3/21/16 20:01	3.78				-N-
3/21/16 20:01	3.62				-N-
3/21/16 20:01	3.76				-N-
3/21/16 20:01	3.59				-N-
3/21/16 20:01	3.76				-N-
3/21/16 20:01	3.62				-N-
3/21/16 20:01	3.5				-N-
3/21/16 20:01	3.61				-N-
3/21/16 20:01	3.49				-N-
3/21/16 20:01	3.39				-N-
3/21/16 20:02	3.29				-N-
3/21/16 20:05	3.18				-N-
3/21/16 20:11				5.82	-N-
3/21/16 20:11		5.8			-N-
3/21/16 20:12			5.79		*F*
3/21/16 20:12		5.8			*F*
3/21/16 20:13				5.82	*F*

3/21/16 20:15	3.23				-N-
3/21/16 20:17				5.82	*F*
3/21/16 20:18			5.79		*F*
3/21/16 20:18		5.8			*F*
3/21/16 20:24	3.05				-N-
3/21/16 20:30	3.09				-N-
3/21/16 20:34	2.93				-N-
3/21/16 20:34	2.83				-N-
3/21/16 20:34	2.96				-N-
3/21/16 20:34	2.84				-N-
3/21/16 20:34	2.95				-N-
3/21/16 20:35	3.06				-N-
3/21/16 20:45	3.06				-N-
3/21/16 20:52				5.82	*F*
3/21/16 20:52			5.79		*F*
3/21/16 20:52		5.8			*F*
3/21/16 21:00	3.07				-N-
3/21/16 21:00		5.8			*F*
3/21/16 21:00			5.79		*F*
3/21/16 21:00				5.82	*F*
3/21/16 21:08	2.89				-N-
3/21/16 21:08	3.05				-N-
3/21/16 21:08	2.94				-N-
3/21/16 21:22	2.78				-N-
3/22/16 0:27	4.57				-N-
3/22/16 0:27	0				-N-
3/22/16 0:30	0				-N-
3/22/16 0:45	0				-N-
3/22/16 1:00	0				-N-
3/22/16 1:15	0				-N-
3/22/16 1:30	0				-N-
3/22/16 1:44		4.83			-N-
3/22/16 1:44		0			-N-
3/22/16 1:44			0		-N-
3/22/16 1:44				2.5	-N-
3/22/16 1:44				0	-N-
3/22/16 1:45	0				-N-
3/22/16 1:45		0			-N-
3/22/16 1:45			0		-N-
3/22/16 1:45				0	-N-
3/22/16 2:00	0				-N-
3/22/16 2:00		0			-N-
3/22/16 2:00			0		-N-

3/22/16 2:00				0	-N-
3/22/16 2:11		2			-N-
3/22/16 2:11		2.11			-N-
3/22/16 2:11		2.22			-N-
3/22/16 2:11		2.33			-N-
3/22/16 2:11		2.44			-N-
3/22/16 2:12		2.55			-N-
3/22/16 2:12		2.67			-N-
3/22/16 2:12		2.78			-N-
3/22/16 2:12		2.89			-N-
3/22/16 2:12		3			-N-
3/22/16 2:12		3.11			-N-
3/22/16 2:12		3.22			-N-
3/22/16 2:12		3.33			-N-
3/22/16 2:12		3.44			-N-
3/22/16 2:12		3.56			-N-
3/22/16 2:12		3.67			-N-
3/22/16 2:12		3.78			-N-
3/22/16 2:13		3.89			-N-
3/22/16 2:13			2		-N-
3/22/16 2:13		4			-N-
3/22/16 2:13		4.1			-N-
3/22/16 2:13			2.11		-N-
3/22/16 2:13			2.22		-N-
3/22/16 2:13		4.22			-N-
3/22/16 2:13			2.33		-N-
3/22/16 2:13		4.33			-N-
3/22/16 2:13		4.44			-N-
3/22/16 2:13			2.44		-N-
3/22/16 2:13		4.56			-N-
3/22/16 2:13		4.67			-N-
3/22/16 2:13		4.77			-N-
3/22/16 2:13		4.89			-N-
3/22/16 2:13		5			-N-
3/22/16 2:13		5.11			-N-
3/22/16 2:14		5.22			-N-
3/22/16 2:14		5.33			-N-
3/22/16 2:14		5.44			-N-
3/22/16 2:14		5.56			-N-
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3/22/16 2:14		5.78			-N-
3/22/16 2:14		5.89			-N-
3/22/16 2:14		6			-N-

3/22/16 2:14		6.11			-N-
3/22/16 2:14		6.22			-N-
3/22/16 2:14		6.33			-N-
3/22/16 2:14		6.44			-N-
3/22/16 2:15	0				-N-
3/22/16 2:15		6.47			-N-
3/22/16 2:15				0	-N-
3/22/16 2:15		6.56			-N-
3/22/16 2:15			2.5		-N-
3/22/16 2:15		6.67			-N-
3/22/16 2:15		6.78			-N-
3/22/16 2:15			4.87		-N-
3/22/16 2:15		6.89			-N-
3/22/16 2:15			4.98		-N-
3/22/16 2:15		6.99			-N-
3/22/16 2:15			5.09		-N-
3/22/16 2:15		7.11			-N-
3/22/16 2:15			5.19		-N-
3/22/16 2:15		7.22			-N-
3/22/16 2:15			5.31		-N-
3/22/16 2:15		7.32			-N-
3/22/16 2:15			5.42		-N-
3/22/16 2:15		7.44			-N-
3/22/16 2:15			5.52		-N-
3/22/16 2:15		7.56			-N-
3/22/16 2:15			5.64		-N-
3/22/16 2:15		7.66			-N-
3/22/16 2:15			5.76		-N-
3/22/16 2:15		7.78			-N-
3/22/16 2:16			5.86		-N-
3/22/16 2:16		7.89			-N-
3/22/16 2:16			5.98		-N-
3/22/16 2:16		7.99			-N-
3/22/16 2:16			6.09		-N-
3/22/16 2:16		8.11			-N-
3/22/16 2:16			6.19		-N-
3/22/16 2:16		8.22			-N-
3/22/16 2:16			6.31		-N-
3/22/16 2:16		8.33			-N-
3/22/16 2:16			6.42		-N-
3/22/16 2:16		8.44			-N-
3/22/16 2:16			6.53		-N-
3/22/16 2:16		8.56			-N-

3/22/16 2:16			6.64		-N-
3/22/16 2:16		8.66			-N-
3/22/16 2:16			6.76		-N-
3/22/16 2:16		8.78			-N-
3/22/16 2:16			6.86		-N-
3/22/16 2:16		8.89			-N-
3/22/16 2:16			6.98		-N-
3/22/16 2:16		9			-N-
3/22/16 2:16			7.09		-N-
3/22/16 2:16		9.11			-N-
3/22/16 2:17			7.2		-N-
3/22/16 2:17		9.22			-N-
3/22/16 2:17			7.31		-N-
3/22/16 2:17		9.33			-N-
3/22/16 2:17			7.44		-N-
3/22/16 2:17		9.44			-N-
3/22/16 2:17			7.56		-N-
3/22/16 2:17		9.56			-N-
3/22/16 2:17			7.66		-N-
3/22/16 2:17		9.67			-N-
3/22/16 2:17		9.42			-N-
3/22/16 2:17			7.78		-N-
3/22/16 2:17		9.11			-N-
3/22/16 2:17		8.98			-N-
3/22/16 2:17			7.62		-N-
3/22/16 2:17			7.37		-N-
3/22/16 2:17		8.88			-N-
3/22/16 2:17			7.19		-N-
3/22/16 2:17		8.75			-N-
3/22/16 2:17		8.45			-N-
3/22/16 2:17		8.32			-N-
3/22/16 2:17			7.35		-N-
3/22/16 2:17			7.23		-N-
3/22/16 2:17		8.2			-N-
3/22/16 2:17		8.09			-N-
3/22/16 2:17			7.07		-N-
3/22/16 2:17			6.9		-N-
3/22/16 2:17		7.86			-N-
3/22/16 2:17		7.72			-N-
3/22/16 2:17		7.42			-N-
3/22/16 2:17		7.23			-N-
3/22/16 2:17			6.8		-N-
3/22/16 2:17		7.12			-N-

3/22/16 2:17		7.41			-N-
3/22/16 2:17		7.28			-N-
3/22/16 2:17		7.11			-N-
3/22/16 2:17		6.99			-N-
3/22/16 2:17		6.87			-N-
3/22/16 2:17			6.7		-N-
3/22/16 2:17		6.76			-N-
3/22/16 2:17			6.57		-N-
3/22/16 2:17			6.45		-N-
3/22/16 2:17			6.35		-N-
3/22/16 2:17		6.65			-N-
3/22/16 2:17		6.53			-N-
3/22/16 2:17			6.45		-N-
3/22/16 2:17		6.43			-N-
3/22/16 2:17			6.34		-N-
3/22/16 2:17		6.53			-N-
3/22/16 2:17			6.24		-N-
3/22/16 2:17			6.14		-N-
3/22/16 2:17		6.43			-N-
3/22/16 2:17		6.33			-N-
3/22/16 2:17			6.24		-N-
3/22/16 2:18		6.21			-N-
3/22/16 2:18			6.14		-N-
3/22/16 2:18		6.31			-N-
3/22/16 2:18			6.03		-N-
3/22/16 2:18		6.16			-N-
3/22/16 2:18		6.05			-N-
3/22/16 2:18			6.17		-N-
3/22/16 2:18		6.15			-N-
3/22/16 2:18			6.03		-N-
3/22/16 2:18			5.92		-N-
3/22/16 2:18			6.03		-N-
3/22/16 2:18		6.05			-N-
3/22/16 2:18		5.94			-N-
3/22/16 2:18		6.06			-N-
3/22/16 2:18			5.92		-N-
3/22/16 2:18			6.08		-N-
3/22/16 2:18		5.93			-N-
3/22/16 2:18			5.97		-N-
3/22/16 2:18		6.11			-N-
3/22/16 2:18		6			-N-
3/22/16 2:18			5.86		-N-
3/22/16 2:18		5.89			-N-

3/22/16 2:19			5.96		-N-
3/22/16 2:19			5.86		-N-
3/22/16 2:19			5.76		-N-
3/22/16 2:19		5.77			-N-
3/22/16 2:19			5.86		-N-
3/22/16 2:19		5.88			-N-
3/22/16 2:19			5.76		-N-
3/22/16 2:19		5.78			-N-
3/22/16 2:19			5.86		-N-
3/22/16 2:19			5.76		-N-
3/22/16 2:19			5.86		-N-
3/22/16 2:19			5.74		-N-
3/22/16 2:19			5.64		-N-
3/22/16 2:19			5.76		-N-
3/22/16 2:19		5.67			-N-
3/22/16 2:19			5.86		-N-
3/22/16 2:19		5.78			-N-
3/22/16 2:19			5.73		-N-
3/22/16 2:19		5.67			-N-
3/22/16 2:19			5.84		-N-
3/22/16 2:19			5.73		-N-
3/22/16 2:20		5.78			-N-
3/22/16 2:20			5.62		-N-
3/22/16 2:20		5.67			-N-
3/22/16 2:20			5.72		-N-
3/22/16 2:20		5.78			-N-
3/22/16 2:20			5.59		-N-
3/22/16 2:20		5.67			-N-
3/22/16 2:20			5.71		-N-
3/22/16 2:20			5.61		-N-
3/22/16 2:20			5.71		-N-
3/22/16 2:20			5.82		-N-
3/22/16 2:20		5.78			-N-
3/22/16 2:20			5.71		-N-
3/22/16 2:20			5.84		-N-
3/22/16 2:20		5.88			-N-
3/22/16 2:20			5.94		-N-
3/22/16 2:20			6.05		-N-
3/22/16 2:20		5.98			-N-
3/22/16 2:20		6.08			-N-
3/22/16 2:20			5.95		-N-
3/22/16 2:20			5.84		-N-
3/22/16 2:20		5.96			-N-

3/22/16 2:20			5.95		-N-
3/22/16 2:20		5.86			-N-
3/22/16 2:21			6.06		-N-
3/22/16 2:21		5.99			-N-
3/22/16 2:21			5.95		-N-
3/22/16 2:21		5.88			-N-
3/22/16 2:21			6.06		-N-
3/22/16 2:21		5.98			-N-
3/22/16 2:21			5.95		-N-
3/22/16 2:21		6.08			-N-
3/22/16 2:21		5.97			-N-
3/22/16 2:21			6.07		-N-
3/22/16 2:21			5.97		-N-
3/22/16 2:21		6.07			-N-
3/22/16 2:22			6.07		-N-
3/22/16 2:22		5.96			-N-
3/22/16 2:22			5.95		-N-
3/22/16 2:22		6.06			-N-
3/22/16 2:22		5.94			-N-
3/22/16 2:22			6.06		-N-
3/22/16 2:22		6.05			-N-
3/22/16 2:22			5.95		-N-
3/22/16 2:22			6.07		-N-
3/22/16 2:22		5.93			-N-
3/22/16 2:22		6.04			-N-
3/22/16 2:22			5.95		-N-
3/22/16 2:22		5.93			-N-
3/22/16 2:22			6.05		-N-
3/22/16 2:22			6.15		-N-
3/22/16 2:22				2.02	-N-
3/22/16 2:22			5.95		-N-
3/22/16 2:22		6.04			-N-
3/22/16 2:22			5.82		-N-
3/22/16 2:22		6.14			-N-
3/22/16 2:22				2.13	-N-
3/22/16 2:22		5.97			-N-
3/22/16 2:22			5.93		-N-
3/22/16 2:22		5.86			-N-
3/22/16 2:22				2.24	-N-
3/22/16 2:22		5.98			-N-
3/22/16 2:22				2.34	-N-
3/22/16 2:22				2.44	-N-
3/22/16 2:23	2				-N-

3/22/16 2:23				2.55	-N-
3/22/16 2:23	2.11				-N-
3/22/16 2:23				2.67	-N-
3/22/16 2:23	2.22				-N-
3/22/16 2:23				2.78	-N-
3/22/16 2:23			6.03		-N-
3/22/16 2:23	2.33				-N-
3/22/16 2:23				2.89	-N-
3/22/16 2:23	2.44				-N-
3/22/16 2:23		6.08			-N-
3/22/16 2:23				3	-N-
3/22/16 2:23	2.55				-N-
3/22/16 2:23				3.11	-N-
3/22/16 2:23	2.67				-N-
3/22/16 2:23				3.22	-N-
3/22/16 2:23	2.78				-N-
3/22/16 2:23		5.98			-N-
3/22/16 2:23			5.93		-N-
3/22/16 2:23				3.33	-N-
3/22/16 2:23	2.89				-N-
3/22/16 2:23			5.81		-N-
3/22/16 2:23				3.44	-N-
3/22/16 2:23		5.88			-N-
3/22/16 2:23	3				-N-
3/22/16 2:23			5.71		-N-
3/22/16 2:23		5.77			-N-
3/22/16 2:23	3.11				-N-
3/22/16 2:23			5.61		-N-
3/22/16 2:23				3.55	-N-
3/22/16 2:23			5.5		-N-
3/22/16 2:23		5.67			-N-
3/22/16 2:23	3.22				-N-
3/22/16 2:23		5.56			-N-
3/22/16 2:24			5.4		-N-
3/22/16 2:24	3.33				-N-
3/22/16 2:24		5.46			-N-
3/22/16 2:24				3.65	-N-
3/22/16 2:24			5.28		-N-
3/22/16 2:24	3.44				-N-
3/22/16 2:24		5.35			-N-
3/22/16 2:24			5.17		-N-
3/22/16 2:24	3.56				-N-
3/22/16 2:24		5.25			-N-

3/22/16 2:24			5.06		-N-
3/22/16 2:24	3.67				-N-
3/22/16 2:24		5.15			-N-
3/22/16 2:24			4.96		-N-
3/22/16 2:24				3.77	-N-
3/22/16 2:24			4.86		-N-
3/22/16 2:24		5.01			-N-
3/22/16 2:24	3.78				-N-
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3/22/16 2:24			4.76		-N-
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3/22/16 4:15		5.8			-N-

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3/22/16 5:00			5.79		-N-
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3/22/16 5:30	5.81				-N-
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3/22/16 6:00	5.85				-N-
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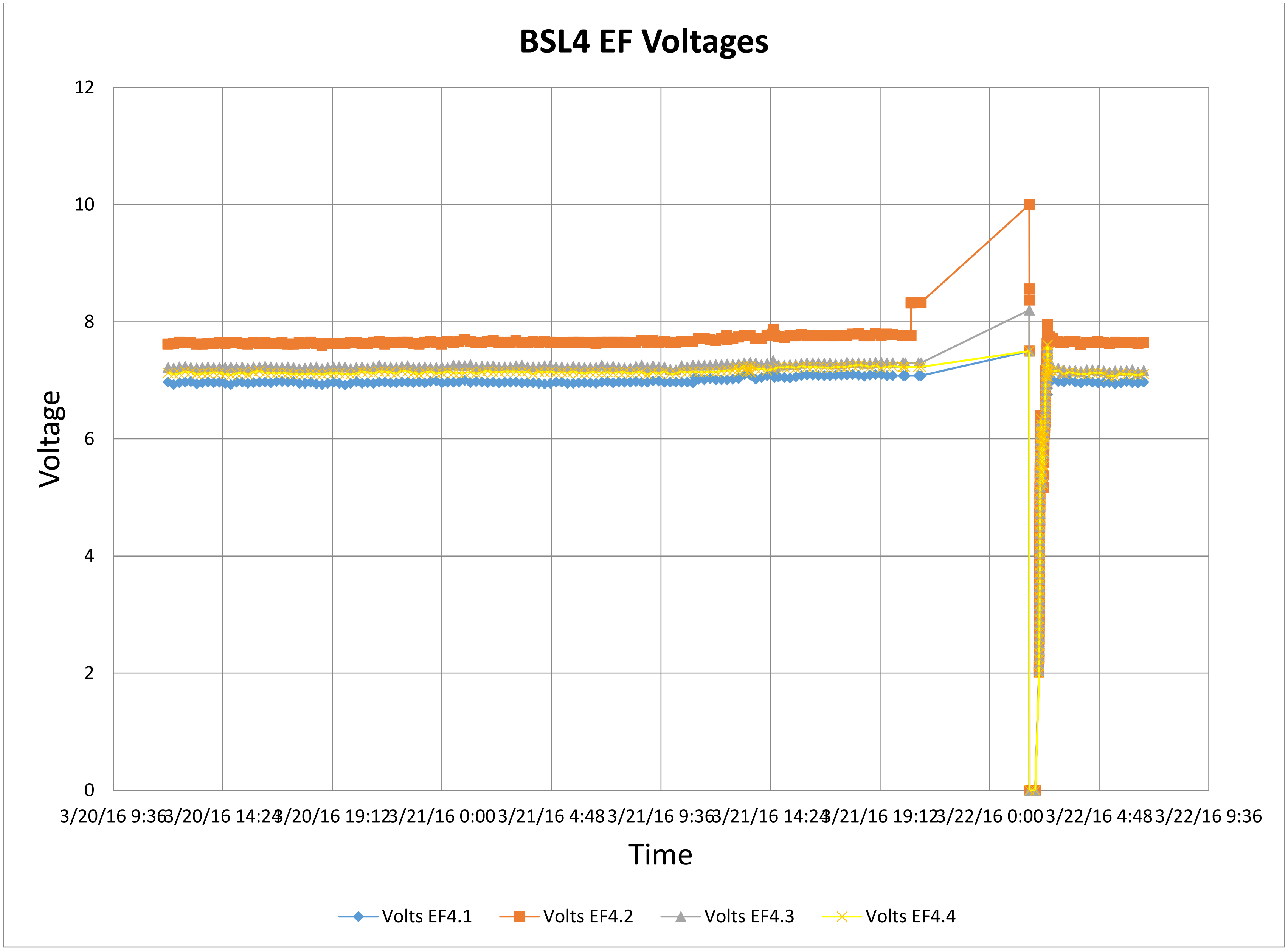
3/22/16 6:00				5.86	-N-



BSL4 EF Voltages
Voltage
12
10
8
6
4
2
0
3/20/16 9:36
3/20/16 14:24
3/20/16 19:12
3/21/16 0:00
3/21/16 4:48
3/21/16 9:36
3/21/16 14:24
3/21/16 19:12
3/22/16 0:00
3/22/16 4:48
3/22/16 9:36
Time
Volts EF4.1
Volts EF4.2
Volts EF4.3
Volts EF4.4

Time	Volts EF4.1	Volts EF4.2	Volts EF4.3	Volts EF4.4	Status
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3/21/16 19:45			7.3		-N-
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3/21/16 20:11			7.3		-N-
3/21/16 20:11		7.77			-N-
3/21/16 20:12				7.23	*F*
3/21/16 20:12	7.08				-N-
3/21/16 20:13			7.3		*F*
3/21/16 20:13		7.77			*F*
3/21/16 20:13	7.08				*F*
3/21/16 20:18		7.77			*F*
3/21/16 20:18				7.23	*F*
3/21/16 20:18			7.3		*F*
3/21/16 20:18	7.08				*F*
3/21/16 20:33		7.77			*F*
3/21/16 20:33		8.32			*F*
3/21/16 20:33		8.33			-N-
3/21/16 20:52				7.23	*F*
3/21/16 20:52			7.3		*F*
3/21/16 20:53	7.08				*F*
3/21/16 20:54		8.33			*F*
3/21/16 21:00	7.08				*F*
3/21/16 21:00			7.3		*F*
3/21/16 21:00				7.23	*F*
3/21/16 21:00		8.33			*F*
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3/22/16 2:11			3.48		-N-
3/22/16 2:11		3.81			-N-
3/22/16 2:11				3.18	-N-
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3/22/16 2:11		4.6			-N-
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3/22/16 2:12	5.52				-N-
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3/22/16 2:12				4.76	-N-
3/22/16 2:12		5.42			-N-
3/22/16 2:12	5.64				-N-
3/22/16 2:12			5.18		-N-
3/22/16 2:12		5.52			-N-
3/22/16 2:12				4.88	-N-
3/22/16 2:12	5.76				-N-
3/22/16 2:12			5.3		-N-
3/22/16 2:12				4.98	-N-
3/22/16 2:12		5.64			-N-

3/22/16 2:12	5.88				-N-
3/22/16 2:12			5.42		-N-
3/22/16 2:12				5.1	-N-
3/22/16 2:12		5.76			-N-
3/22/16 2:12	5.98				-N-
3/22/16 2:12			5.52		-N-
3/22/16 2:13				5.22	-N-
3/22/16 2:13		5.88			-N-
3/22/16 2:13			5.64		-N-
3/22/16 2:13		5.98			-N-
3/22/16 2:13				5.34	-N-
3/22/16 2:13	6.09				-N-
3/22/16 2:13			5.76		-N-
3/22/16 2:13				5.44	-N-
3/22/16 2:13	5.95				-N-
3/22/16 2:13	6.12				-N-
3/22/16 2:13			5.88		-N-
3/22/16 2:13		6.09			-N-
3/22/16 2:13				5.56	-N-
3/22/16 2:13			5.98		-N-
3/22/16 2:13				5.68	-N-
3/22/16 2:13	6.24				-N-
3/22/16 2:13		6.19			-N-
3/22/16 2:13				5.8	-N-
3/22/16 2:13			6.09		-N-
3/22/16 2:13				5.9	-N-
3/22/16 2:13				6.01	-N-
3/22/16 2:13	6.13				-N-
3/22/16 2:13		6.08			-N-
3/22/16 2:14				6.11	-N-
3/22/16 2:14	6.24				-N-
3/22/16 2:14		6.19			-N-
3/22/16 2:14	6.34				-N-
3/22/16 2:14	6.2				-N-
3/22/16 2:14	6.08				-N-
3/22/16 2:14		6.3			-N-
3/22/16 2:14			6.19		-N-
3/22/16 2:15		6.4			-N-
3/22/16 2:15		6.4			-N-
3/22/16 2:15	6.07				-N-
3/22/16 2:15		6.25			-N-
3/22/16 2:15			6.24		-N-
3/22/16 2:15		6.05			-N-

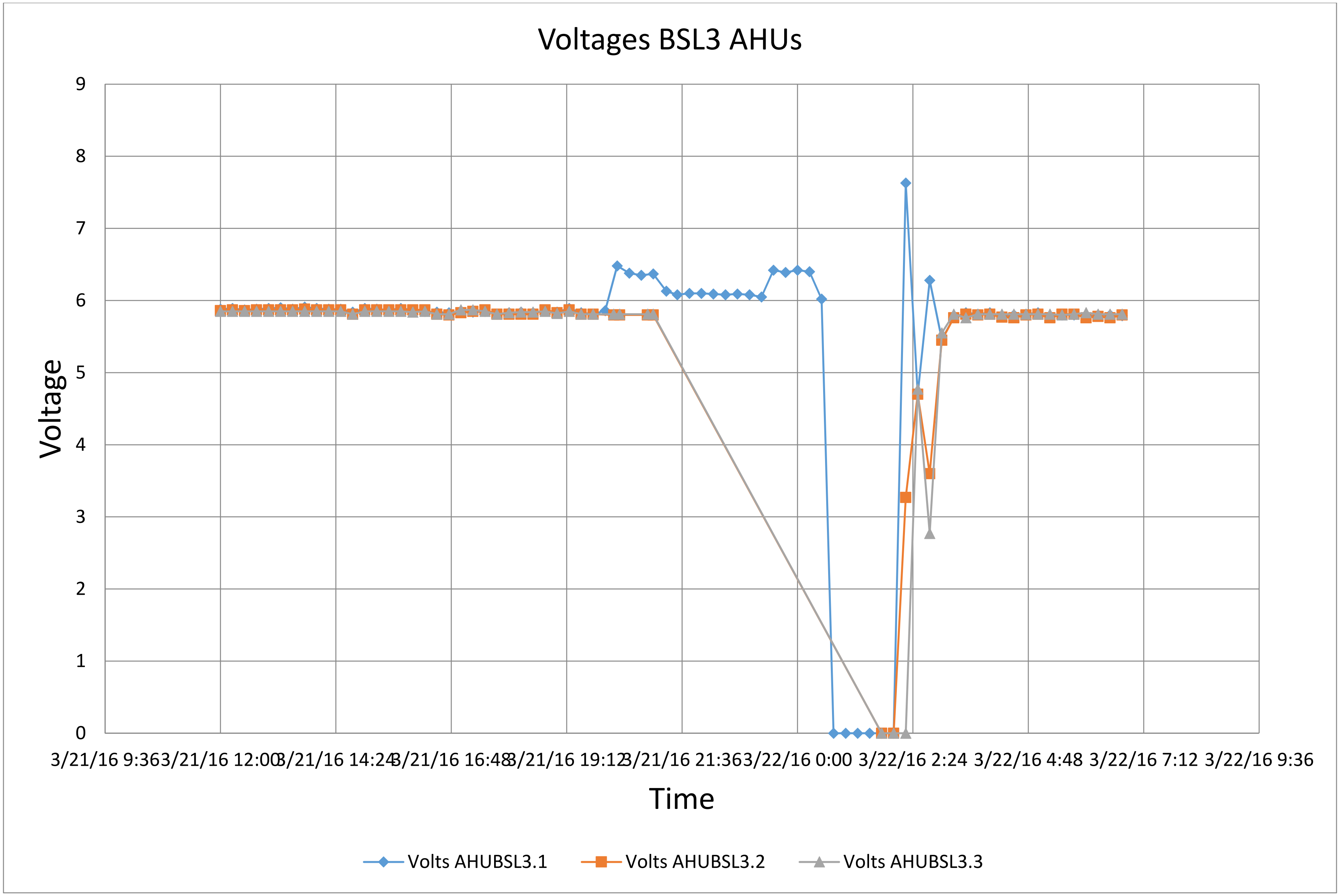
3/22/16 2:15				6.07	-N-
3/22/16 2:15			6.3		-N-
3/22/16 2:15			6.02		-N-
3/22/16 2:15				6.24	-N-
3/22/16 2:15				6.34	-N-
3/22/16 2:15			6.12		-N-
3/22/16 2:15				6.12	-N-
3/22/16 2:15		6.16			-N-
3/22/16 2:15	6.18				-N-
3/22/16 2:15			6.22		-N-
3/22/16 2:15				6.24	-N-
3/22/16 2:16		6.26			-N-
3/22/16 2:16			6.11		-N-
3/22/16 2:16				6.14	-N-
3/22/16 2:16		6.14			-N-
3/22/16 2:17			6.21		-N-
3/22/16 2:17		6.24			-N-
3/22/16 2:17				6.24	-N-
3/22/16 2:17			6.11		-N-
3/22/16 2:17		6.14			-N-
3/22/16 2:17				6.14	-N-
3/22/16 2:17			6		-N-
3/22/16 2:17	5.98				-N-
3/22/16 2:17		6.03			-N-
3/22/16 2:17				6.01	-N-
3/22/16 2:17		5.92			-N-
3/22/16 2:17				5.9	-N-
3/22/16 2:17			5.89		-N-
3/22/16 2:17	5.87				-N-
3/22/16 2:17		5.82			-N-
3/22/16 2:17			5.79		-N-
3/22/16 2:17			5.67		-N-
3/22/16 2:17	5.71				-N-
3/22/16 2:17		5.71			-N-
3/22/16 2:17				5.75	-N-
3/22/16 2:17				5.65	-N-
3/22/16 2:17	5.61				-N-
3/22/16 2:17			5.57		-N-
3/22/16 2:17		5.6			-N-
3/22/16 2:17				5.55	-N-
3/22/16 2:17		5.48			-N-
3/22/16 2:17	5.5				-N-
3/22/16 2:18			5.46		-N-

3/22/16 2:18				5.44	-N-
3/22/16 2:18	5.4				-N-
3/22/16 2:18		5.38			-N-
3/22/16 2:18			5.36		-N-
3/22/16 2:18				5.34	-N-
3/22/16 2:19		5.27			-N-
3/22/16 2:19	5.29				-N-
3/22/16 2:20			5.25		-N-
3/22/16 2:20				5.23	-N-
3/22/16 2:22		5.17			-N-
3/22/16 2:22			5.76		-N-
3/22/16 2:22			5.91		-N-
3/22/16 2:22	5.8				-N-
3/22/16 2:22		5.38			-N-
3/22/16 2:22		5.6			-N-
3/22/16 2:22		5.73			-N-
3/22/16 2:22			6.03		-N-
3/22/16 2:22				5.54	-N-
3/22/16 2:22				5.78	-N-
3/22/16 2:22	6.01				-N-
3/22/16 2:22		5.88			-N-
3/22/16 2:22				5.93	-N-
3/22/16 2:22		6.02			-N-
3/22/16 2:22			5.92		-N-
3/22/16 2:22				6.04	-N-
3/22/16 2:22	5.89				-N-
3/22/16 2:22		5.88			-N-
3/22/16 2:22				5.91	-N-
3/22/16 2:22			6.03		-N-
3/22/16 2:22	6.01				-N-
3/22/16 2:22		5.98			-N-
3/22/16 2:22				6.03	-N-
3/22/16 2:23	6.11				-N-
3/22/16 2:23		6.09			-N-
3/22/16 2:23			6.17		-N-
3/22/16 2:23				6.13	-N-
3/22/16 2:23		6.19			-N-
3/22/16 2:24			6.07		-N-
3/22/16 2:24		6.08			-N-
3/22/16 2:25			6.17		-N-
3/22/16 2:25		6.19			-N-
3/22/16 2:25	6.22				-N-
3/22/16 2:25				6.24	-N-

3/22/16 2:26			6.28		-N-
3/22/16 2:26	6.32				-N-
3/22/16 2:26		6.3			-N-
3/22/16 2:26			6.38		-N-
3/22/16 2:26				6.34	-N-
3/22/16 2:26		6.4			-N-
3/22/16 2:26	6.45				-N-
3/22/16 2:26			6.49		-N-
3/22/16 2:26				6.45	-N-
3/22/16 2:26		6.5			-N-
3/22/16 2:26	6.57				-N-
3/22/16 2:26			6.59		-N-
3/22/16 2:26				6.55	-N-
3/22/16 2:26		6.61			-N-
3/22/16 2:26				6.65	-N-
3/22/16 2:26	6.67				-N-
3/22/16 2:26			6.69		-N-
3/22/16 2:26		6.73			-N-
3/22/16 2:26				6.76	-N-
3/22/16 2:26	6.78				-N-
3/22/16 2:26			6.8		-N-
3/22/16 2:26		6.84			-N-
3/22/16 2:26				6.86	-N-
3/22/16 2:27	6.88				-N-
3/22/16 2:27			6.91		-N-
3/22/16 2:27	6.99				-N-
3/22/16 2:27		6.95			-N-
3/22/16 2:27			7.01		-N-
3/22/16 2:27				6.97	-N-
3/22/16 2:27		7.06			-N-
3/22/16 2:27				7.07	-N-
3/22/16 2:27			7.11		-N-
3/22/16 2:27	7.09				-N-
3/22/16 2:27		7.16			-N-
3/22/16 2:27	7.2				-N-
3/22/16 2:27			7.21		-N-
3/22/16 2:27				7.18	-N-
3/22/16 2:30	7.14				-N-
3/22/16 2:30		7.12			-N-
3/22/16 2:30			7.12		-N-
3/22/16 2:30				7.12	-N-

Point Name:NEIDL.APRD.227A				Point Name:NEIDL.APRD.227B				Point Name:NEIDL.APRD.227C			
Trend Every:	COV			Trend Every:	COV			Trend Every:	COV		
Report Timings:	All Hours			Report Timings:	All Hours			Report Timings:	All Hours		
3/21/2016 20:29:13	OPEN	-N-	NONE	3/21/2016 20:29:13	OPEN	-N-	NONE	3/21/2016 20:29:14	OPEN	-N-	NONE
3/21/2016 20:29:14	CLOSED	-N-	NONE	3/21/2016 20:29:14	CLOSED	-N-	NONE	3/21/2016 20:29:14	CLOSED	-N-	NONE
3/21/2016 20:31:01	OPEN	-N-	NONE	3/21/2016 20:31:01	OPEN	-N-	NONE	3/21/2016 20:31:01	OPEN	-N-	NONE
3/21/2016 20:31:02	CLOSED	-N-	NONE	3/21/2016 20:31:02	CLOSED	-N-	NONE	3/21/2016 20:31:02	CLOSED	-N-	NONE
3/21/2016 20:33:01	OPEN	-N-	NONE	3/21/2016 20:33:01	OPEN	-N-	NONE	3/21/2016 20:33:02	OPEN	-N-	NONE
3/21/2016 20:33:02	CLOSED	-N-	NONE	3/21/2016 20:33:02	CLOSED	-N-	NONE	3/21/2016 20:33:02	CLOSED	-N-	NONE
3/21/2016 21:09:10	OPEN	-N-	NONE	3/21/2016 21:09:10	OPEN	-N-	NONE	3/21/2016 21:09:12	OPEN	-N-	NONE
3/21/2016 21:09:13	CLOSED	-N-	NONE	3/21/2016 21:09:13	CLOSED	-N-	NONE	3/21/2016 21:09:13	CLOSED	-N-	NONE
3/21/2016 21:19:39	OPEN	-N-	NONE	3/21/2016 21:19:39	OPEN	-N-	NONE	3/21/2016 21:19:38	OPEN	-N-	NONE
3/21/2016 21:19:39	CLOSED	-N-	NONE	3/21/2016 21:19:39	CLOSED	-N-	NONE	3/21/2016 21:19:39	CLOSED	-N-	NONE
3/21/2016 21:24:19	OPEN	-N-	NONE	3/21/2016 21:24:19	OPEN	-N-	NONE	3/21/2016 21:24:20	OPEN	-N-	NONE
3/21/2016 21:24:21	CLOSED	-N-	NONE	3/21/2016 21:24:21	CLOSED	-N-	NONE	3/21/2016 21:24:21	CLOSED	-N-	NONE
3/21/2016 21:28:26	OPEN	-N-	NONE	3/21/2016 21:28:26	OPEN	-N-	NONE	3/21/2016 21:28:26	OPEN	-N-	NONE
3/21/2016 21:28:27	CLOSED	-N-	NONE	3/21/2016 21:28:27	CLOSED	-N-	NONE	3/21/2016 21:28:27	CLOSED	-N-	NONE
3/21/2016 21:46:35	OPEN	-N-	NONE	3/21/2016 21:46:35	OPEN	-N-	NONE	3/21/2016 21:46:34	OPEN	-N-	NONE
3/21/2016 21:46:35	CLOSED	-N-	NONE	3/21/2016 21:46:35	CLOSED	-N-	NONE	3/21/2016 21:46:35	CLOSED	-N-	NONE
3/21/2016 21:54:34	OPEN	-N-	NONE	3/21/2016 21:54:34	OPEN	-N-	NONE	3/21/2016 21:54:34	OPEN	-N-	NONE
3/21/2016 21:54:35	CLOSED	-N-	NONE	3/21/2016 21:54:35	CLOSED	-N-	NONE	3/21/2016 21:54:35	CLOSED	-N-	NONE
3/21/2016 22:23:20	OPEN	-N-	NONE	3/21/2016 22:23:20	OPEN	-N-	NONE	3/21/2016 22:24:05	OPEN	-N-	NONE
3/21/2016 22:24:06	CLOSED	-N-	NONE	3/21/2016 22:24:06	CLOSED	-N-	NONE	3/21/2016 22:24:06	CLOSED	-N-	NONE
3/21/2016 23:29:09	OPEN	-N-	NONE	3/21/2016 23:29:09	OPEN	-N-	NONE	3/21/2016 23:29:10	OPEN	-N-	NONE
3/21/2016 23:29:11	CLOSED	-N-	NONE	3/21/2016 23:29:11	CLOSED	-N-	NONE	3/21/2016 23:29:11	CLOSED	-N-	NONE
3/21/2016 23:30:58	OPEN	-N-	NONE	3/21/2016 23:30:58	OPEN	-N-	NONE	3/21/2016 23:30:59	OPEN	-N-	NONE
3/21/2016 23:31:00	CLOSED	-N-	NONE	3/21/2016 23:31:00	CLOSED	-N-	NONE	3/21/2016 23:31:00	CLOSED	-N-	NONE
3/21/2016 23:32:46	OPEN	-N-	NONE	3/21/2016 23:32:46	OPEN	-N-	NONE	3/21/2016 23:32:47	OPEN	-N-	NONE

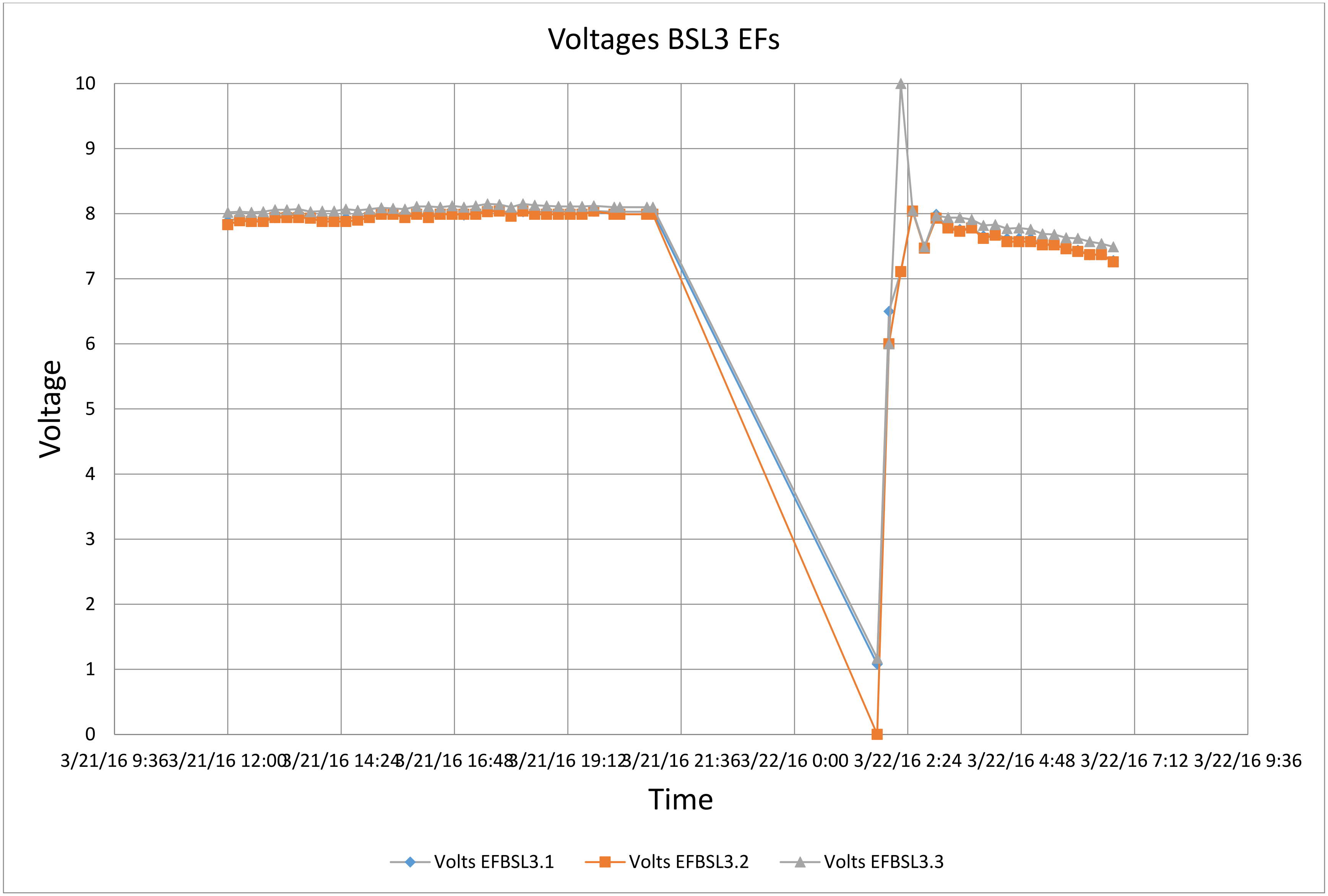
Partial APR Door Trends



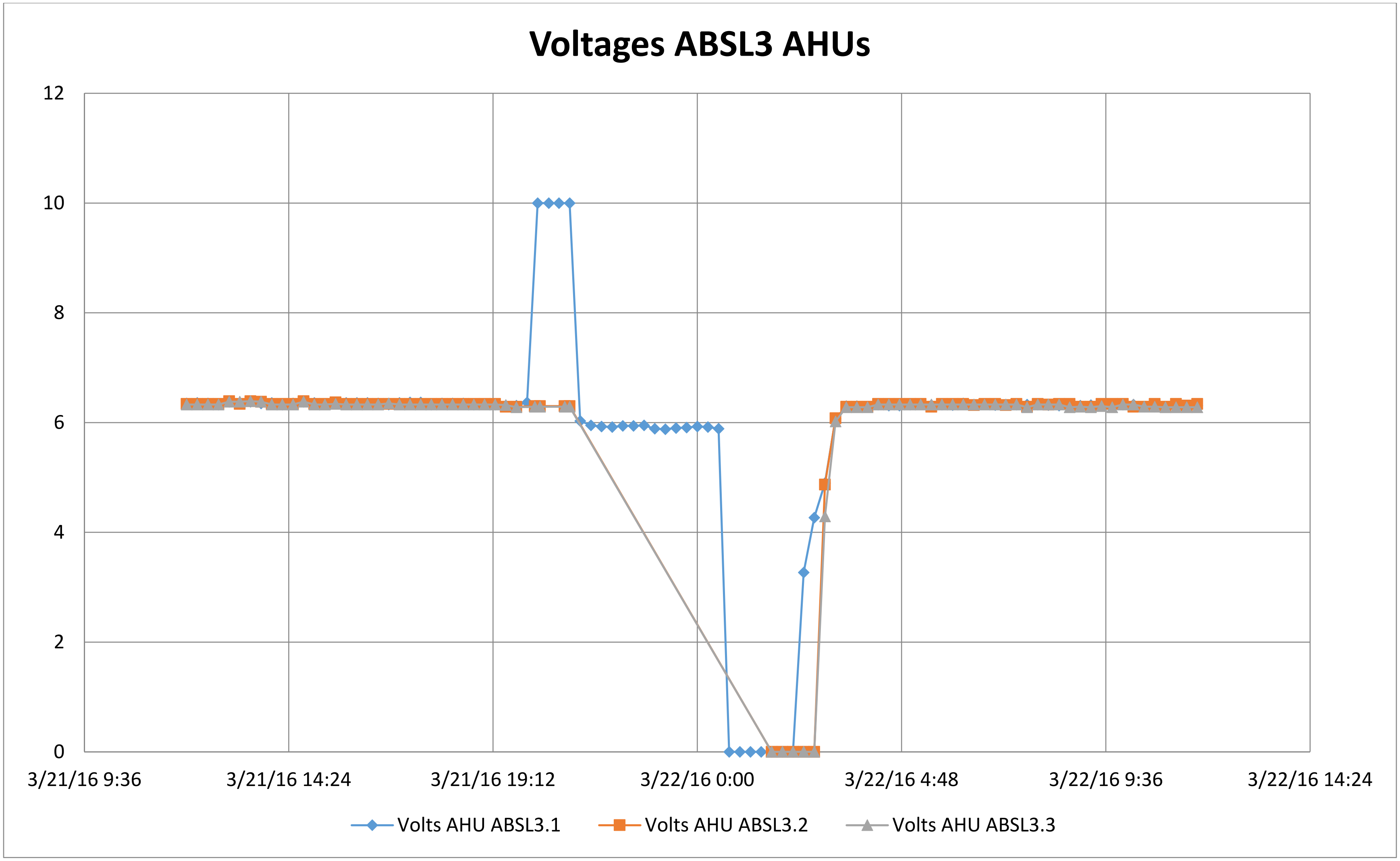
Voltages BSL3 AHUs
9
8
7
6
5
4
3
2
1
0
Voltage
3/21/16 9:36
3/21/16 12:00
3/21/16 14:24
3/21/16 16:48
3/21/16 19:12
3/21/16 21:36
3/22/16 0:00
3/22/16 2:24
3/22/16 4:48
3/22/16 7:12
3/22/16 9:36
Time
Volts AHUBSL3.1
Volts AHUBSL3.2
Volts AHUBSL3.3

Time	Volts AHUBSL3.1	Volts AHUBSL3.2	Volts AHUBSL3.3	Status
3/21/16 19:45	5.81			-N-
3/21/16 19:45		5.81		-N-
3/21/16 19:45			5.81	-N-
3/21/16 20:00	5.86			-N-
3/21/16 20:10			5.81	-N-
3/21/16 20:10		5.8		-N-
3/21/16 20:15	6.48			-N-
3/21/16 20:18			5.81	*F*
3/21/16 20:18		5.8		*F*
3/21/16 20:30	6.38			-N-
3/21/16 20:45	6.35			-N-
3/21/16 20:52		5.8		*F*
3/21/16 20:52			5.81	*F*
3/21/16 21:00	6.37			-N-
3/21/16 21:00		5.8		*F*
3/21/16 21:00			5.81	*F*
3/21/16 21:16	6.13			-N-
3/22/16 0:30	6.02			-N-
3/22/16 0:45	0			-N-
3/22/16 1:00	0			-N-
3/22/16 1:15	0			-N-
3/22/16 1:30	0			-N-
3/22/16 1:45	0			-N-
3/22/16 1:45		0		-N-
3/22/16 1:45			0	-N-
3/22/16 2:00	0			-N-
3/22/16 2:00		0		-N-
3/22/16 2:00			0	-N-
3/22/16 2:15	7.63			-N-
3/22/16 2:15		3.27		-N-
3/22/16 2:15			0	-N-
3/22/16 2:30	4.7			-N-
3/22/16 2:30		4.7		-N-
3/22/16 2:30			4.77	-N-
3/22/16 2:45	6.28			-N-
3/22/16 2:45		3.6		-N-
3/22/16 2:45			2.77	-N-
3/22/16 3:00	5.46			-N-
3/22/16 3:00		5.45		-N-
3/22/16 3:00			5.55	-N-
3/22/16 3:15	5.76			-N-
3/22/16 3:15		5.76		-N-

3/22/16 3:15			5.81	-N-


Voltages BSL3 EFs
10
9
8
7
6
5
4
3
2
1
0
Voltage
3/21/16 9:36
3/21/16 12:00
3/21/16 14:24
3/21/16 16:48
3/21/16 19:12
3/21/16 21:36
3/22/16 0:00
3/22/16 2:24
3/22/16 4:48
3/22/16 7:12
3/22/16 9:36
Time
Volts EFBSL3.1
Volts EFBSL3.2
Volts EFBSL3.3

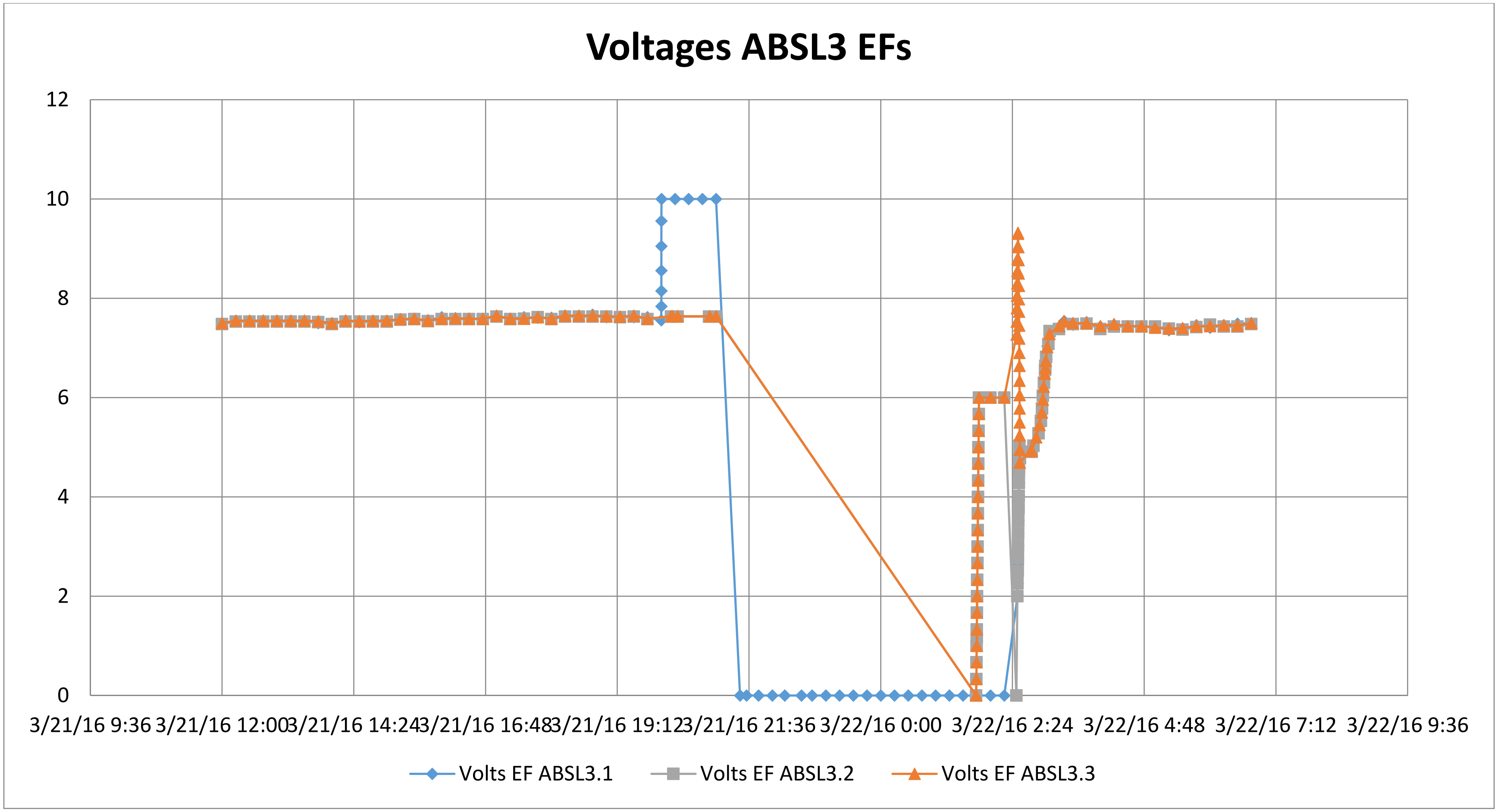
Time	Volts EFBSL3.1	Volts EFBSL3.2	Volts EFBSL3.3	Status
3/21/16 19:45	8.04			-N-
3/21/16 19:45		8.04		-N-
3/21/16 19:45			8.12	-N-
3/21/16 20:10	8.03			-N-
3/21/16 20:10		7.99		-N-
3/21/16 20:10			8.1	-N-
3/21/16 20:18		7.99		*F*
3/21/16 20:18			8.1	*F*
3/21/16 20:18	8.03			*F*
3/21/16 20:52	8.03			*F*
3/21/16 20:52		7.99		*F*
3/21/16 20:52			8.1	*F*
3/21/16 21:00	8.03			*F*
3/21/16 21:00		7.99		*F*
3/21/16 21:00			8.1	*F*
3/22/16 1:45	1.08			-N-
3/22/16 1:45		0		-N-
3/22/16 1:45			1.17	-N-
3/22/16 2:00	6.5			-N-
3/22/16 2:00		6		-N-
3/22/16 2:00			6	-N-
3/22/16 2:15	7.11			-N-
3/22/16 2:15		7.11		-N-
3/22/16 2:15			10	-N-
3/22/16 2:30	8.05			-N-
3/22/16 2:30		8.04		-N-
3/22/16 2:30			8.05	-N-
3/22/16 2:45	7.48			-N-
3/22/16 2:45		7.47		-N-
3/22/16 2:45			7.49	-N-
3/22/16 3:00	7.99			-N-
3/22/16 3:00		7.93		-N-
3/22/16 3:00			7.97	-N-
3/22/16 3:15	7.79			-N-
3/22/16 3:15		7.78		-N-
3/22/16 3:15			7.94	-N-



Voltages ABSL3 AHUs
12
10
8
6
4
2
0
3/21/16 9:36
3/21/16 14:24
3/21/16 19:12
3/22/16 0:00
3/22/16 4:48
3/22/16 9:36
3/22/16 14:24
Volts AHU ABSL3.1
Volts AHU ABSL3.2
Volts AHU ABSL3.3

Time	Volts AHU ABSL3.1	Volts AHU ABSL3.2	Volts AHU ABSL3.3	Status	Alarms
3/21/16 19:45	6.31			-N-	
3/21/16 19:45		6.29		-N-	
3/21/16 19:45			6.28	-N-	
3/21/16 20:00	6.37			-N-	
3/21/16 20:10			6.29	-N-	
3/21/16 20:10		6.3		-N-	
3/21/16 20:15	10			-N-	
3/21/16 20:18		6.3		*F*	
3/21/16 20:18			6.29	*F*	
3/21/16 20:30	10			-N-	
3/21/16 20:45	10			-N-	
3/21/16 20:52		6.3		*F*	
3/21/16 20:53			6.29	*F*	
3/21/16 21:00	10			-N-	
3/21/16 21:00		6.3		*F*	
3/21/16 21:00			6.29	*F*	
3/21/16 21:15	6.03			-N-	
3/21/16 21:30	5.95			-N-	
3/21/16 21:45	5.93			-N-	
3/21/16 22:00	5.92			-N-	
3/21/16 22:15	5.94			-N-	
3/21/16 22:30	5.94			-N-	
3/21/16 22:45	5.95			-N-	
3/21/16 23:00	5.89			-N-	
3/21/16 23:15	5.88			-N-	
3/21/16 23:30	5.9			-N-	
3/21/16 23:45	5.91			-N-	
3/22/16 0:00	5.93			-N-	
3/22/16 0:15	5.92			-N-	
3/22/16 0:30	5.89			-N-	
3/22/16 0:45	0			-N-	
3/22/16 1:00	0			-N-	
3/22/16 1:15	0			-N-	
3/22/16 1:30	0			-N-	
3/22/16 1:45	0			-N-	
3/22/16 1:45		0		-N-	
3/22/16 1:45			0	-N-	
3/22/16 2:00	0			-N-	
3/22/16 2:00		0		-N-	
3/22/16 2:00			0	-N-	
3/22/16 2:15	0			-N-	
3/22/16 2:15		0		-N-	

3/22/16 2:15			0	-N-	
3/22/16 2:30	3.27			-N-	
3/22/16 2:30		0		-N-	
3/22/16 2:30			0	-N-	
3/22/16 2:45	4.27			-N-	
3/22/16 2:45		0		-N-	
3/22/16 2:45			0	-N-	
3/22/16 3:00	4.9			-N-	
3/22/16 3:00		4.87		-N-	
3/22/16 3:00			4.29	-N-	
3/22/16 3:15	6.07			-N-	
3/22/16 3:15		6.08		-N-	
3/22/16 3:15			6.02	-N-	
3/22/16 3:30	6.3			-N-	
3/22/16 3:30		6.29		-N-	
3/22/16 3:30			6.28	-N-	



Voltages ABSL3 EFs
12
10
8
6
4
2
0
3/21/16 9:36
3/21/16 12:00
3/21/16 14:24
3/21/16 16:48
3/21/16 19:12
3/21/16 21:36
3/22/16 0:00
3/22/16 2:24
3/22/16 4:48
3/22/16 7:12
3/22/16 9:36
Volts EF ABSL3.1
Volts EF ABSL3.2
Volts EF ABSL3.3

Time	Volts EF ABSL3.1	Volts EF ABSL3.2	Volts EF ABSL3.3	Status
3/21/16 19:45	7.62			-N-
3/21/16 19:45		7.58		-N-
3/21/16 19:45			7.59	-N-
3/21/16 20:00	7.56			-N-
3/21/16 20:00	7.84			-N-
3/21/16 20:00	8.15			-N-
3/21/16 20:00	8.56			-N-
3/21/16 20:00	9.05			-N-
3/21/16 20:00	9.56			-N-
3/21/16 20:00	10			-N-
3/21/16 20:10			7.64	-N-
3/21/16 20:10		7.63		-N-
3/21/16 20:12			7.64	*F*
3/21/16 20:12		7.63		*F*
3/21/16 20:15	10			-N-
3/21/16 20:18		7.63		*F*
3/21/16 20:18			7.64	*F*
3/21/16 20:30	10			-N-
3/21/16 20:45	10			-N-
3/21/16 20:52		7.63		*F*
3/21/16 20:53			7.64	*F*
3/21/16 21:00	10			-N-
3/21/16 21:00		7.63		*F*
3/21/16 21:00			7.64	*F*
3/21/16 21:26	0			-N-
3/21/16 21:33	0			-N-
3/21/16 21:46	0			-N-
3/21/16 22:01	0			-N-
3/21/16 22:15	0			-N-
3/21/16 22:33	0			-N-
3/21/16 22:45	0			-N-
3/21/16 23:00	0			-N-
3/21/16 23:15	0			-N-
3/21/16 23:30	0			-N-
3/21/16 23:45	0			-N-
3/22/16 0:00	0			-N-
3/22/16 0:15	0			-N-
3/22/16 0:30	0			-N-
3/22/16 0:45	0			-N-
3/22/16 1:00	0			-N-
3/22/16 1:15	0			-N-
3/22/16 1:30	0			-N-

3/22/16 1:44		0		-N-
3/22/16 1:44			0	-N-
3/22/16 1:44		0.33		-N-
3/22/16 1:44			0.33	-N-
3/22/16 1:44		0.67		-N-
3/22/16 1:44			0.67	-N-
3/22/16 1:44		1		-N-
3/22/16 1:44			1	-N-
3/22/16 1:45	0			-N-
3/22/16 1:45		1.17		-N-
3/22/16 1:45			1	-N-
3/22/16 1:45		1.33		-N-
3/22/16 1:45			1.33	-N-
3/22/16 1:45		1.67		-N-
3/22/16 1:45			1.67	-N-
3/22/16 1:45		2		-N-
3/22/16 1:45			2	-N-
3/22/16 1:45		2.33		-N-
3/22/16 1:45			2.33	-N-
3/22/16 1:45		2.67		-N-
3/22/16 1:45			2.67	-N-
3/22/16 1:45		3		-N-
3/22/16 1:45			3	-N-
3/22/16 1:46		3.33		-N-
3/22/16 1:46			3.33	-N-
3/22/16 1:46		3.67		-N-
3/22/16 1:46			3.67	-N-
3/22/16 1:46		4		-N-
3/22/16 1:46			4	-N-
3/22/16 1:46		4.33		-N-
3/22/16 1:46			4.33	-N-
3/22/16 1:46		4.67		-N-
3/22/16 1:46			4.67	-N-
3/22/16 1:46		5		-N-
3/22/16 1:46			5	-N-
3/22/16 1:47		5.33		-N-
3/22/16 1:47			5.33	-N-
3/22/16 1:47		5.67		-N-
3/22/16 1:47			5.67	-N-
3/22/16 1:47		6		-N-
3/22/16 1:47			6	-N-
3/22/16 2:00	0			-N-
3/22/16 2:00		6		-N-

3/22/16 2:00			6	-N-
3/22/16 2:15	0			-N-
3/22/16 2:15		6		-N-
3/22/16 2:15			6	-N-
3/22/16 2:28		0		-N-
3/22/16 2:28			7.27	-N-
3/22/16 2:28			7.53	-N-
3/22/16 2:28			7.8	-N-
3/22/16 2:29			8.05	-N-
3/22/16 2:29			8.3	-N-
3/22/16 2:29			8.55	-N-
3/22/16 2:29		2		-N-
3/22/16 2:29	2			-N-
3/22/16 2:29		2.26		-N-
3/22/16 2:29			8.8	-N-
3/22/16 2:29			8.55	-N-
3/22/16 2:29	2.26			-N-
3/22/16 2:29		2.51		-N-
3/22/16 2:29			8.8	-N-
3/22/16 2:29			9.05	-N-
3/22/16 2:29	2.51			-N-
3/22/16 2:29		2.77		-N-
3/22/16 2:29			9.3	-N-
3/22/16 2:30	2.64			-N-
3/22/16 2:30		2.8		-N-
3/22/16 2:30			9.32	-N-
3/22/16 2:30	2.77			-N-
3/22/16 2:30		3.02		-N-
3/22/16 2:30	3.02			-N-
3/22/16 2:30		3.27		-N-
3/22/16 2:30			9.03	-N-
3/22/16 2:30	3.27			-N-
3/22/16 2:30		3.52		-N-
3/22/16 2:30			8.77	-N-
3/22/16 2:30	3.52			-N-
3/22/16 2:30		3.77		-N-
3/22/16 2:30			8.5	-N-
3/22/16 2:30	3.77			-N-
3/22/16 2:30		4.02		-N-
3/22/16 2:30			8.25	-N-
3/22/16 2:31	4.02			-N-
3/22/16 2:31		4.28		-N-
3/22/16 2:31			7.98	-N-

3/22/16 2:31	4.28			-N-
3/22/16 2:31			7.73	-N-
3/22/16 2:31		4.53		-N-
3/22/16 2:31			7.45	-N-
3/22/16 2:31	4.53			-N-
3/22/16 2:31			7.19	-N-
3/22/16 2:31		4.78		-N-
3/22/16 2:31			6.9	-N-
3/22/16 2:31	4.78			-N-
3/22/16 2:31			6.64	-N-
3/22/16 2:31		5.03		-N-
3/22/16 2:31			6.34	-N-
3/22/16 2:31			6.05	-N-
3/22/16 2:31	5.03			-N-
3/22/16 2:31			5.78	-N-
3/22/16 2:31			5.5	-N-
3/22/16 2:31			5.24	-N-
3/22/16 2:31			4.95	-N-
3/22/16 2:31	4.74			-N-
3/22/16 2:31			4.69	-N-
3/22/16 2:32		4.78		-N-
3/22/16 2:44			4.95	-N-
3/22/16 2:45	4.92			-N-
3/22/16 2:45		4.91		-N-
3/22/16 2:45			4.92	-N-
3/22/16 2:45	4.99			-N-
3/22/16 2:47		5.03		-N-
3/22/16 2:49			5.2	-N-
3/22/16 2:52	5.24			-N-
3/22/16 2:52		5.28		-N-
3/22/16 2:53			5.45	-N-
3/22/16 2:55	5.49			-N-
3/22/16 2:55		5.53		-N-
3/22/16 2:56			5.7	-N-
3/22/16 2:56	5.75			-N-
3/22/16 2:56		5.78		-N-
3/22/16 2:57			5.96	-N-
3/22/16 2:57	6.01			-N-
3/22/16 2:57		6.04		-N-
3/22/16 2:58			6.22	-N-
3/22/16 2:58	6.26			-N-
3/22/16 2:58		6.3		-N-
3/22/16 2:59			6.48	-N-

3/22/16 2:59	6.52			-N-
3/22/16 2:59		6.56		-N-
3/22/16 3:00	6.62			-N-
3/22/16 3:00		6.64		-N-
3/22/16 3:00			6.6	-N-
3/22/16 3:00			6.74	-N-
3/22/16 3:00	6.78			-N-
3/22/16 3:00		6.82		-N-
3/22/16 3:01			7.02	-N-
3/22/16 3:02	7.04			-N-
3/22/16 3:03		7.08		-N-
3/22/16 3:04			7.28	-N-
3/22/16 3:04	7.29			-N-
3/22/16 3:04		7.34		-N-
3/22/16 3:15	7.42			-N-
3/22/16 3:15		7.38		-N-
3/22/16 3:15			7.44	-N-
3/22/16 3:20			7.54	-N-
3/22/16 3:20	7.54			-N-
3/22/16 3:30	7.47			-N-
3/22/16 3:30		7.48		-N-
3/22/16 3:30			7.5	-N-
3/22/16 3:45	7.52			-N-
3/22/16 3:45		7.49		-N-
3/22/16 3:45			7.5	-N-

Appendix B: NEIDL BAS Network Outage

BU IS&T

Report on NEIDL Incident of 3/21/2016

At 17:01 on March 21, 2016 a small form factor pluggable (SFP) module began having uplink failures on a BAS network switch on the sixth floor of the NEIDL. This was not a complete failure as the module turned on and off every five minutes for about the next 3 hours. This on/off failure is often described as "flapping". At 19:59, all switches on the BAS network started receiving "flapping errors". Shortly thereafter, the SFP module entered an unanticipated error state and precipitated a flood of network traffic. This flood overwhelmed the network and is referred to as a "broadcast storm".

The SFP module in question is standard on all switch architectures. It looks like the picture below and is roughly the size of a pinky finger. This failed optic is the root cause of the network failure in question.

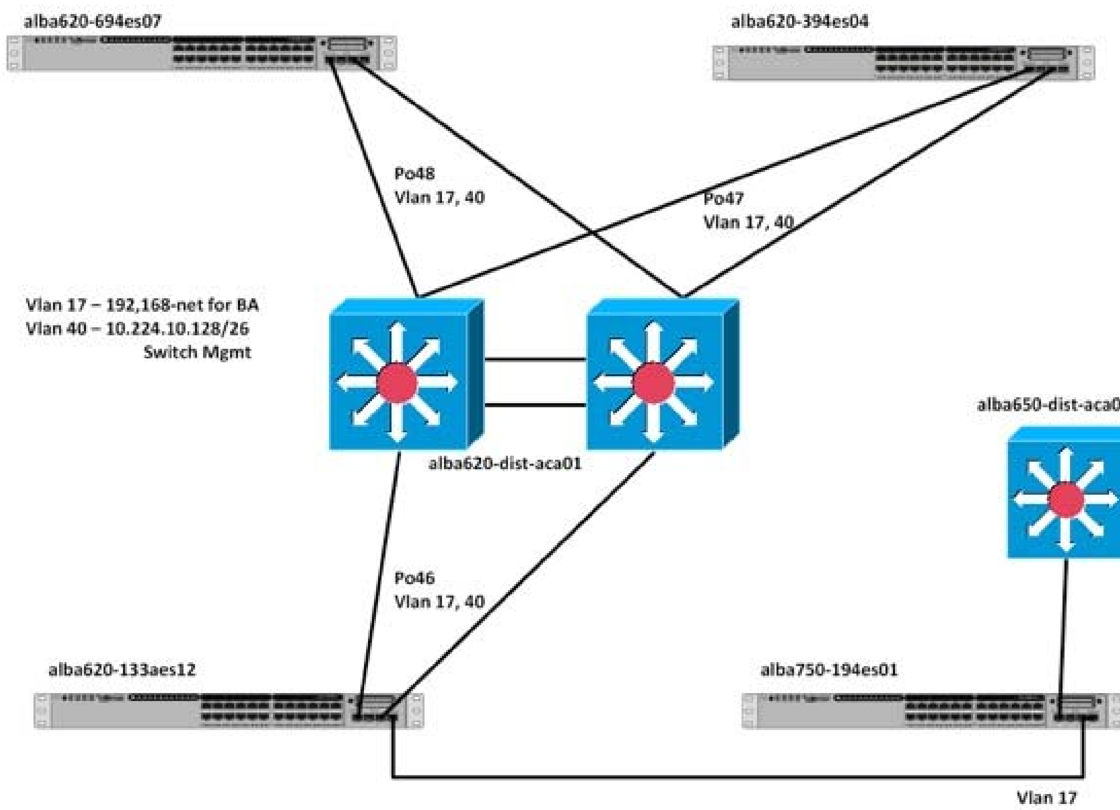
However, the optic did not fail in a "normal" way. In conversations with network professionals from Cisco (with more than 20 years of experience) about flapping induced spanning tree protocol instability in general, they shared that they had only personally seen this type of failure in this way only once 8 years ago. They hadn't personally seen this type of failure before or since. Had the SFP module failed normally, the network traffic would have switched over to the redundant links and the network would have continued correctly. Instead, the unusual nature of the SFP module failure precipitated a broadcast storm which disabled the network with a massive amount of traffic.

Cisco is unable to provide any diagnostics on the SFP module as it has completely stopped working. It is completely dead. Cisco is working on providing statistics for the failure rate of these kinds of SFP modules but that may not have much value. Again, a typical failure is anticipated and planned for through redundancy. This type of failure is very rare as referenced by the one other similar failure to Cisco's knowledge in 8 years.

There has been some discussion about the network changes that BU IS&T made to the BAS network configuration and whether introducing redundancy aggravated the broadcast storm or prevented the network from failing quickly and allowing the Siemens panels to "fail safe". The following will address these questions.

The original network topology (design) of the NEIDL BAS was a Line topology. All the switches were daisy chained together and configured as a “flat” network. A flat network means there is no routing or segmentation within the network; it is all viewed as one big network. The original network used Netgear Model FS750T2 switches. The design would have looked something like this …

This network configuration is not considered best practice and is highly susceptible to failure. Each link on this non-redundant, flat network is a single point of failure. Any single malfunction has the potential to bring down the whole network. In addition, the Netgear switches were old and lacked much of the modern technology that makes modern networks more fault tolerant. Thus a decision was made to update the switches to modern, BU standard Cisco switches and the re-architect the network to introduce redundancy.



This network configuration introduced two distribution routers (as shown in the two blue squares in the center) which were connected to the three switches on the BAS network. The switches are were no longer connected to each other but had two connections each to the two central distribution routers (one to each router). A fourth switch was added to allow monitoring of the network from the power plant for off-hour support. That switch is shown on the bottom right and is connected to the BU network. Security is maintained across this network using logical VLANs. The fourth switch has access to the switches themselves for monitoring and direction but does not have access to the BAS network.

This redundant network was (and is) still designed as a flat network. The redundancy eliminates the single point of failure scenario but does not segment the network. The network is still seen as a single big loop with everything connected to everything else. The distribution routers are not configured to route network traffic and are simply serving as a pass through.

In the scenario that occurred on March 21, 2016 the redundancy worked as it was designed. Every time the SFP module "flapped" off, the network failed over to the other link and continued normally. When the SFP module flapped back on, network traffic resumed normally. Both routers performed normally throughout the entire event and evidenced no failures of any kind. They simply passed network traffic back and forth. Very shortly after 19:59 on the 21st, the SFP module entered into an unanticipated error state a precipitated a broadcast storm. There was no failure of the network itself or the routers. They simply became overwhelmed with network traffic.

It is our opinion that redundancy did not contribute to the broadcast storm. In conversations with professionals from Cisco they shared their opinion that based on the IS&T account of the events and the support case notes from the troubleshooting performed during this incident it did not appear the network topology (design) had any kind of adverse effect on the network during this incident. A broadcast storm was possible in the old network configuration as it was in the new. It has been suggested that the SFP module failure in the old network would have caused it to fail more quickly. It is true that had the SFP module failed in a normal manner then the network would have failed in the old design. But the SFP module did not have a normal or anticipated failure. The SFP module didn't just stop working. It precipitated a flood of broadcast traffic that neither network topology was designed to handle and is not routinely tested for in normal business practice.

The timeline of the human response to the incident and how the BAS network recovered is detailed very well in the BU IS&T report dated April 6th.

There has also been a question as to whether the failure of the BAS network could have contributed to the lockout issues listed on page 9 and 10 of the Merrick report. The confusion in our original denial of this possibility stemmed from a communication problem. The question was put to us if there was a possibility the broadcast storm from the BAS network spilled over onto the "security network". Assuming the "security network" in question meant the network that maintains building security including IRIS ID and badge scanning, we correctly said no. The two networks are not connected and there is no possibility of the broadcast storm "spilling over". However, there does appear to be a system connected to the BAS network that monitors or controls (we are unsure which or both) the lockout mechanism. This system uses the BAS network to communicate and would have been unable to communicate correctly during the broadcast storm. We were not aware of this lockout system and its connection to the BAS at the time of the incident. This may also explain the questions around showers and vacuum pumps but we are unsure. These are building operation issues in which we do not have a full view. What we can state is that any system or panels connected to the BAS network during the incident would not have been able to communicate across the BAS network. What these systems or panels control is a question for Siemens and NEIDL operations.

Finally, we have instituted several corrective actions that will help mitigate the potential for a future broadcast storm and we would like to work with Siemens to institute any other suggested changes to this end. Our corrective actions are as follows ….

1) We increased the urgency of NEIDL network switch monitoring. These now are at our highest level of urgency on par with life threatening systems like 911.
2) We changed how reports of outages are handled for the network. Before, a call went into our service desk that was correctly routed to our network team. Now any network failures escalate directly to the Network Engineering staff 24/7 through our on call notification system.
3) We applied a UDLD protocol to all the uplinks on the switches to reduce that chance of a broadcast storm. This will shut down any uplink that demonstrates flapping behavior or any of a series of anomalous events. This will cause a hard fail to the uplink hopefully preventing a similar incident from happening again. The redundant network should pick up the slack and run normally.
4) We upgraded the distribution router code to the latest safe harbor standard. This was on the roadmap prior to the incident as part of our Network refresh project. This simply make sure all the routers have the most current software and patches to handle network issues.
5) We increased monitoring on ports for up/down events and high network traffic. We are currently monitoring the network to establish a baseline for these events and traffic before we set alarm thresholds. These alarms will be used to notify Network Engineering of any anomalous traffic spike or on/off events.
6) We reviewed our network topology with Cisco. Cisco verified that our current network design was stable and standard for this type of implementation. They also recommended the following changes ….
    a. Implement UDLD according to best practice found here. This has already been implemented and was part of our Network refresh project.
       - http://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst6500/ios/12-2SX/best/practices/recommendations.html#wp1050563
    b. Implement Storm Control according to best practice found here – Needs to be reviewed with Siemens -Storm Control
       - http://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst6500/ios/12-2SX/best/practices/recommendations.html#wp1044029
    c. Implement Root guard according to best practice found here - Needs to be reviewed with Siemens - Root-Guard
       - http://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst6500/ios/12-2SX/best/practices/recommendations.html#wp1052377
7) We will work with Siemens to see if the two changes recommended by Cisco follow their best practices and also potentially implement a segmented, "non-flat" network design based on their recommendations.

It should be noted that there is no way to completely prevent a broadcast storm or in general any single network failure. The redundancy of our current network design and the changes mentioned above will significantly increase the fault tolerance of the BAS network in the future.

Appendix C: Siemens BMS Assessment Report

SIEMENS

Building Management System
ASSESSMENT & RECOMMENDATIONS REPORT

PREPARED FOR:

BU NEIDL
620 Albany Street
Boston, MA 02118

PREPARED BY:

Siemens Industry, Inc.
Building Technologies Division
85 John Rd
Canton, MA 02021

May 4, 2016

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Executive Summary

Purpose and Scope

Siemens Industry, Inc. Building Technologies Division (Siemens) was engaged by BU NEIDL to assess the Building Management System (BMS) system performance in the NEIDL Building against the specified design and performance during an event that occurred on the afternoon of 3/21/16 and continued through the morning of 3/22/16. It was identified by BU NEIDL staff that the BSL-3 space observed a positive pressure event during a window of time between 3/21/16 and 3/22/16.

The primary goal of this report is to:

- Provide a summary of what is understood to have happened during a window of time starting at approximately 3pm on 3/21/16 and continued up until approximately 6am on 3/22/16
- Provide Root Cause Specific and Best Practice Recommendations

The recommendations provided within this report are based on information outlined in this report, further discussions with the BU NEIDL team, and discussions with BU NEIDL's consultant, Merrick & Company. The recommendations will be categorized by improvements that specifically address the root cause of this event, and any other best practice recommendations that should be taken into consideration for future operations.

This report addresses the BMS for Critical Components in NEIDL Building only and includes: Siemens control panels, controlled equipment, monitored equipment, alarms, and known BU IT network systems supporting the Siemens BMS.

Assessment Participants

BU:

- Joe Barbercheck, BU EHS
- Joe Corbett, BU Facilities
- William Gibbons, Public Safety
- Tom Daley, FM&P
- Scott Rusk, NEIDL
- Bryan Bettencourt, BUMC IT
- John McCall, NEIDL IT
- Matt Rarick, NEIDL Facilities
- David Flynn, Facilities NEIDL
- Joe Kajunski, BU

Merrick & Company:

- Bill Clark

SIEMENS:

- Brycen Spencer
- Dennis Olszewski

Summarized Root Cause Assessment

Siemens utilized information from the BMS and what was learned during the 2 day (4/13/16 & 4/14/16) meeting with the BU NEIDL team and Merrick & Company to interpret what happened with the BMS during the event in question.

After review of the BMS data and other available information, it is believed that the root cause was the failure of a fiber module at the Cisco Ethernet switch that caused heavy network traffic on the network that the Siemens BMS resides on. This network traffic has been referred to as a ‘broadcast storm’. The volume of data being passed on the network, and through the Siemens BMS panels well surpassed the design specifications of the Siemens BMS control panels prohibiting some panels from performing properly.

The BAS trend data shows that the programmed sequence of operations executed as designed, but the commands sent to controlled exhaust fans failed. To elaborate on this, Siemens program was sending an ‘ON’ command to the Exhaust Fans, but the point status returned from this command in the trended BAS data shows that the point failed to execute at 20:18 on 3/21/16. An extracted trend file from the Exhaust Fan data can be seen in the below table:

Trend Data Detail Report (Temporary Report)
Point System Name: NEIDL.EF.BSL3.1.EAFSS
Trend Every: 15 minutes
Date Range: 3/21/2016 00:00:00 - 3/22/2016 23:59:59
Date Time Value Status Priority
3/21/2016 19:00:00 ON -N- NONE
3/21/2016 19:15:00 ON -N- NONE
3/21/2016 19:30:00 ON -N- NONE
3/21/2016 19:45:00 ON -N- NONE
3/21/2016 20:10:46 ON -N- NONE
3/21/2016 20:18:09 ON *F* NONE
3/21/2016 20:52:34 ON *F* NONE
3/21/2016 21:00:00 ON *F* NONE

It is believed that the positive pressure event in the BSL-3 suite was caused by the failed ‘ON’ command to the exhaust fans while the supply air fan serving the BSL3 continued to run.

The original design of the network was a stand-alone flat Ethernet network that utilized Netgear switches. This configuration was commissioned and tested for network communication failure, and designed to maintain the integrity of the design in this failure mode. The network layout was changed approximately one year ago by BU IT to managed Cisco switches through redundant routers that met the campus standard. A broadcast storm was not a failure mode that the system was designed or tested for during commissioning. This level of communication traffic is not recommended. Since the event, we understand that BU IT has reconfigured the switches so that they can be monitored and ports can be isolated should network traffic begin to escalate as it did on 3/21/16. Further discussions are needed with BU NEIDL, BU IT, and Merrick and Company before finalizing on a recommended network configuration other than that which was originally installed and commissioned.

BSL-3 Suite Control Sequence

The below text is an excerpt from the sequence of operations for the BSL3 Suites to describe how the system was designed to operate:

1 GENERAL DESCRIPTION – BSL3 SUITES

A. This control sequence applies to the BSL3 Lab Suites. Each suite is a restricted area with entry and exit controlled by Security. Each BSL3 suite can consist of an Ante Room, BSL3 Lab, Equipment Room, and Shower.

B. The Ante Room, BSL3 Lab, and Equipment Room are equipped with airflow valves on the supply and exhaust ducts. The exhaust ducts from a suite are ganged to one common single HEPA exhaust filter. Manual bioseal (bubble tight) dampers will be an integral part of the HEPA filter housing. The Shower Room has only a supply valve

C. Room pressure monitors are located at each door of the suite and will reference the differential pressure across the door. The room pressure monitors have both audible and visual alarms and display locally and report back to the BMS.

D. Directional airflow for the suite will be from the clean corridor through to the BSL3 Lab. Room airflow volume will be balanced to achieve a target value of 0.05" w.c. across boundary doors.

E. All setpoints shall be adjustable. Alarm setpoints and timer functions shall be adjusted during preliminary testing and the commissioning process to ensure proper operation.

F. BSL3 spaces will be maintained as follows:

2 STEADY STATE OPERATION – NORMAL

A. BSL3 Lab control:

1) Steady state operational mode is designed to be approximately (10-12) air changes per hour as set through the balance of the exhaust air valve controller, and is constant volume. The general exhaust airflow valve will modulate to maintain the total exhaust air volume for the space at set point.

2) The supply air is through one supply air valve. The set point for the supply air flow for this room will be established by tracking the general exhaust air volume from this space and applying an offset/ratio (adj). An offset reset shall reset the supply volume to maintain room pressure differential on the Lab room pressure monitor associated with the suite. Upon the differential pressure falling below setpoint (-0.065" adj) on the Lab room pressure monitor associated with the suite, transmit an Offset Maintenance Alarm and incrementally (25 CFM) decrease the offset to maintain differential pressure setpont on all associated pressure monitors. Upon the differential pressure rising above setpoint(-0.035" adj) on the Lab room pressure monitors associated with the suite,transmit an Offset Maintenance Alarm and incrementally (25 CFM) increase the offset to maintain differential pressure setpoint on all associated pressure monitors. Maximum offset reset shall be 75 CFM in either direction.

3) Upon receiving a signal that the door is open, the supply air valve shall control to its current offset CFM. The pressure reset offset shall be disabled whenever a door is opened. An open door alarm shall be sent (both at the BAS and the individual space) whenever a door is open for more than 1 minute (adj).

4) All pressure alarms shall be disabled for One minute (adj) when any door entering space is indicated "open". Control loops shall be configured to restore airflow settings as quickly as required to avoid nuisance alarms.

5) The supply air reheat coil valve will modulate to maintain space temperature. Space temperature sensor is located in the exhaust duct.

B. Ante room control:

1) Steady state operational mode is designed to be approximately (8-10) air changes per hour as set through the balance of the exhaust air valve controller, and is constant volume. The general exhaust airflow valve will modulate to maintain the total exhaust air volume for the space at set point.

2) The supply air is through one supply air valve. The set point for the supply air volume for this room will be established by tracking the general exhaust air volume from this space and applying an offset/ratio (adj).

3) The supply air reheat coil valve will modulate to maintain space temperature. Space temperature sensor is located in the exhaust duct.

4) The Ante room to corridor differential pressure is monitored by two differential pressure sensors; a differential pressure sensor that is associated with the magnehelic gauge and the *room pressure monitor at the ante room entry door.*

C. *Equipment room control:*
   1) *Steady state operational mode is designed to be approximately (8-10) air changes per hour as set through the balance of the exhaust air valve controller, and is constant volume. The general exhaust airflow valve will modulate to maintain the total exhaust air volume for the space at set point.*
   2) *The supply air is through one supply air valve. The set point for the supply air volume for this room will be established by tracking the general exhaust air volume from this space and applying an offset/ratio (adj).*
   3) *The supply air reheat coil valve will modulate to maintain space temperature. Space temperature sensor is located in the exhaust duct.*

D. *Shower room control:*
   1) *Steady state operational mode is designed to be approximately (8-10) air changes per hour as set through the supply air valve controller, and is constant volume. The supply airflow valve will modulate to maintain the total supply air volume for the space at set point.*
   2) *The supply air reheat coil valve will modulate to maintain space temperature. Space temperature sensor is located in the exhaust duct.*

E. *Entry/Exit sequence:*
   1) *Entry doors to the BSL3 Suite from the clean corridors are secured through a card access system and are interlocked so only one door can be opened at a time.*
   2) *Under normal conditions directional airflow is from the clean corridor through to the BSL3 Lab. Under failure conditions the space in the Suite shall not be permitted to go positive to the central corridor.*

3 *SETBACK MODE*
   A. *N/A*

4 *PLANNED STARTUP & SHUTDOWN OPERATION*
   A. *Startup:*
      1) *Automatic startup of the room will follow its associated supply air system and exhaust air system startup. When both the supply and exhaust air systems are proven operational, trigger signals shall be sequentially transmitted to the suite panels for the staged startup of the BSL3 suites. Upon a BSL3 Suite receiving the trigger signal the suite shall be allowed to startup.*
      2) *Disable all alarms for five minutes (adj) and enable alarms after that time period.*
      3) *Ramp up the exhaust airflow valve first then supply airflow valves to simultaneously maintain a directional airflow and achieve Steady State operation.*
   B. *Shutdown:*
      1) *Automatic shutdown of the room will follow its associated supply air system and exhaust air system shutdown. When either the supply or exhaust air systems are proven non-operational, a trigger signal shall be received by the BSL3 Suite panels for shutdown.*
      2) *Disable alarms on shutdown of the suite.*
      3) *Close airflow valves and reheat control valve.*
   C. *The suite or individual rooms can be manually started or shutdown by an operator via the BAS, as required for operational and maintenance needs.*
   D. *Automatic startup of the suite will be timed with facility wide power restart strategy based on load distribution and containment.*

5 *SMOKE/ FIRE ALARM MODE*
   A. *The fire signal associated with this suite is an alert signal only and does not have any effect on its operation. Occupants are to follow Facility protocols and procedures.*
   B. *If it is decided by the room occupants to evacuate the suite then the exit is through normal entry/exit sequences. Room shutdown can be achieved through a command to the BAS at an OWS.*

6 *POWER INTERRUPTION MODE*
   A. *N/A*

7 *EMERGENCY MODE*
   A. *On a DDC panel malfunction, a critical alarm will be sent to the BAS for notification. Airflow valves and reheat valves will fail in position (FIP); humidifier will be disabled.*
   B. *Room Pressure Excursion: 2-Stage Lockout Mode*

1) *Stage 1: An Individual BSL3 lab Suite shall enter Stage 1 lockout mode when any room pressure monitor in the suite reports an alarm condition. Two (2) conditions must occur to generate a room pressure alarm. One condition is when the door is closed and the room pressure is above -0.03 (adj.) in wc or below -0.07 (adj.) in wc for 30 seconds (adj.). Upon either of these conditions, all supply valves and exhaust valves except the BSL3 Lab exhaust valve shall close. The BSL3 Lab exhaust valve shall be set to an exhaust volume or position (25% FA) that will keep all pressure monitors associated with the suite below -.01 wc and not create a hyper negative condition in any of the spaces in the suite.*
2) *Stage 2: An Individual BSL3 Suite shall enter Stage 2 Lockout Mode immediately whenever the room differential pressure at the Corridor/Ante room pressure monitors (both differential pressure sensors) cannot maintain -.01 in wc (adj). Stage 2 Lockout Mode shall transmit shutdown signal to both the AH-BSL3 air handling systems and the EF-BSL3 systems. (See Air Handler and Exhaust Fan Sequences for responses required for those systems during BSL3 Lockout Stage 2 Mode) The lockout will require an operator reset in order for the controller to be released to steady state operation.*
3) *The Stage 2 lockout mode will command the supply and exhaust air terminals closed except for the Lab terminal, it shall be set to a fixed position to maintain directional airflow during a Stage 2 Lockout*
4) *For all emergency conditions, staff is to follow appropriate Facility protocols and procedures.*

8 BIOHAZARD ALARM MODE

A. N/A

9 DECON / MAINTENANCE MODES

A. Follow Facility protocols and procedures in decontaminating the lab suite.

B. Software buttons shall be provided on the graphics to place the Suite into either a decon or maintenance mode. Shut down (complete close) all valves in a manner that maintains directional airflow during the shutdown Disable alarms and indicate on graphic that suite is in either a decon or maintenance mode

C. Valves can be manually positioned to maintain slight negative

10 ALARMS AND LIMITS

A. *Refer to points list in contract documents for alarm points. Alarm points and appropriate message to be segregated and classified to complement facility protocols and procedures. The intent is to minimize nuisance alarms so as to reduce the amount of network traffic on the BAS and the amount of information generated at the OWS and printers.*

Key Findings

Network

A fiber module failed on one of the redundant connections between the switch and the router. This failure caused a cascading broadcast storm that affected the BU IT network switches that support the Siemens BMS panels.

Siemens BMS Panels

At roughly 4:24 PM on the 21st we started seeing panel failures and returns from failure. This happened throughout the evening up until a complete network failure and disconnect at 8:00 PM. At the same time we started seeing panels come and go, a trend collection was occurring, and the chemical shower system skid started producing alarms and performing erratically. In addition, the panel failures started to slow communications to the server. Therefore, the panels didn't report failure until approximately 9:26 PM.

At roughly 1:44 AM on the 22nd, the BMS network communications were restored. At this time, the panels slowly started to connect and some Siemens BMS panels disconnected and reconnected a few times. Panel communication stabilized around 6:30 am on the 22nd.

Additionally, some sequences of operations require communication across the network in order to provide status to controlled equipment like displays in labs and alert lights. These points are not visible in a network failure and could be compromised in a broadcast storm like the one that resulted on 3/21/16.

The Siemens BMS panels in the BU NEIDL are retired legacy products no longer manufactured by Siemens. The Siemens Service Team is still able to maintain the panels, but there are no longer manufactured spare parts or firmware revisions available for the equipment. Siemens has previously provided panel upgrade proposals, and will continue to work with BU NEIDL to develop a comprehensive and phased technology upgrade roadmap for BU NEIDL that aligns with Siemens best practices, the priorities of each controlled space, and the needs of BU NEIDL. It should be noted that the panel hardware and firmware is not believed to be a root cause of this event, nor does Siemens believe that the latest Siemens BMS panels would have been able to sustain the level of network traffic seen during this broadcast storm.

Controlled Equipment

The network traffic compromised the Siemens BMS panel's ability to successfully execute commanded equipment. It is difficult to determine all of the effected equipment due to the fact that not all equipment was trended for analysis after an event like this. It was determined that the exhaust fans digital outputs were not able to successfully execute the intended 'ON' command.

Controlled displays and alert strobe lights are controlled with logic based on information shared across the network. For example, each strobe in the suites are controlled by the following triggers:

Red Strobe – Breathing air failure
Fire alarm

Amber Strobe – Liquid Decon alarm
Mechanical failure
Lab Alert button has been activated
Bio-waste leak
Chemical shower alarm
Fire advisory
Low chemical shower reserve
Backup breathing air warning
Manual message on graphic monitors
Low chemical shower rinse
Fire alarm east side
Fire alarm west side
Decon abort
Apr Door alarm
Room pressure advisory alarm
Room pressure alarm
Equipment alarm

During the 2 day meeting it was discussed that door lights to the BSL4 labs were observed to flash between red and amber a number of times according to video evidence. The security system controls the function of these lights. Siemens' only interaction with the security system for these doors is to receive a signal from the security system to enable showers. Once a signal is received, Siemens controls valves that turn the showers on. Once the shower cycle is complete the Siemens BMS sends a signal to the security system to indicate that the shower cycle is complete. The security system then runs through its logic. Further understanding of the security systems logic will need to be investigated with the manufacturer of the security system controls.

Root Cause Specific Recommendations

1. **Network Configuration and Impact to Siemens BMS**

Siemens recommends that BU NEIDL consult with an IT network engineer to implement a network configuration that will eliminate, or limit as much as possible, the possibility of broadcast storms on the BMS network. There will be a level of Siemens technical support required for various IT network configurations put in place by BU IT. There has been discussion between Siemens and BU IT regarding separating the network, and maintaining the current redundant pathway configuration in order to limit the impact of any future broadcast storm should one reoccur. Siemens would need to, at a minimum, support BU IT in breaking up the network by re-addressing the IP addresses of the panels if this is the selected plan. Other implications may exist, so it's strongly recommended that Siemens and BU IT meet before a final network design is chosen and implemented.

As mentioned in the "Trend Data Detail Report" Siemens panels were not able to fully execute a commanded digital output (DO) point leading to the exhaust fans to stop running. This issue was caused by the large amount of data that was generated by the broadcast storm and the panels rapidly disconnecting and reconnecting to the network.

Siemens Technical Support confirmed that when the BMS panels rapidly disconnect and reconnect to the network, the BMS panels generate and share database backups (referred to as 'tombstone databases'). When the database becomes larger (500 entries or more), it starts affecting network communication. Since the tombstone database is sent from one panel to another, this large amount of data starts depleting the memory at the field panel such that when the Field Panel runs out of memory, it initiates a coldstart. In field panels such as PXC Modulars, MBC's, and MECs the amount of network traffic generated by the tombstone data being sent from one panel to another, causes the field panel to spend a lot of time processing this traffic instead of performing other tasks. While processing this network traffic, if the field panel is unable to scan the mBus within four seconds, the DO points are forced to cycle causing equipment to turn off/on.

a. **Resolution**: BU NEIDL should consult with an IT network engineer to implement a network configuration that will eliminate, or limit as much as possible, the possibility of broadcast storms on the BMS network. Siemens will have to evaluate the level of Siemens support needed and any technical implications that should be considered based on the selected design.

b. **Resolution**: Siemens can manually edit the database sharing settings to limit the sharing of the tombstone database between panels. This would be a mitigation technique for this type of failure mode should a broadcast storm repeat. Please note that this will not eliminate the issue, but rather extend ability of the panels to continue processing commands during a broadcast storm. Siemens does not have a recommended or tested upper limit of network traffic that can be provided as a cut off threshold.

c. **Resolution**: BU may also consider designing mechanically redundant fail safes if broadcast storms can't be eliminated completely so that there is always a mechanical back up during this type of failure mode.

2. **Hardwire Critical Points**

The supply and exhaust BMS panels currently share data across the network to perform the specified sequence of operations. To prevent complications in the future BU NEIDL should work with its engineer to consider hardwiring critical data points such as the supply and exhaust systems to enable continuous visibility of critical points in a network outage, broadcast storm, or other network related malfunction.

a. Resolution: Siemens can work with BU NEIDL and its consultant to determine what points are critical based on original design, operating procedure, and BMS configuration.

3. **Exhaust Fan Fail Safe Design**

The exhaust fans, in this scenario failed to continue to run due to a failed digital output command from the panel during the broadcast storm. If it is BU NEIDL's intention to ensure that there is always an exhaust air available regardless of BMS or network function, then it is recommended that this solution be engineered and tested.

a. **Resolution:** An engineer should work with BU NEIDL and Siemens to design a system that mechanically ensures there is always a minimum amount of exhaust air regardless of BMS and network functionality.

Best Practice Recommendations

1. **BMS Technology Upgrade Roadmap**

The BMS system in the BU NEIDL has reached the end of life. The hardware and firmware is no longer manufactured by Siemens. Siemens can still maintain and service the installed equipment, firmware, and software for ongoing operations, and it will likely last many years with limited failure. Siemens technology development model is built for forward/backward compatibility allowing for a phased upgrade of the technology while the new technology still works seamlessly with the legacy products. A technology upgrade program should be developed to get the facility operating on the latest platform.

a. **Resolution:** Siemens should meet with BU NEIDL staff to prioritize mission critical BMS panels that should be upgraded first to ensure maximum reliability. Parts remaining from legacy upgraded panels can be used for spare parts inventory for the remaining legacy controllers. It is Siemens recommendation to prioritize critical spaces first that require minimal downtime during daily operations.

2. **Maintenance Program for Uptime**

A collaborative analysis of the maintenance needs should be done with the BU NEIDL team to ensure that all best practice maintenance is covered by in house staff, by Siemens, or by another entity. Currently our maintenance plan is built around panel maintenance. There are various controlled systems that should be evaluated and predictive reporting that can be implemented to ensure the site is maintained to the highest standard. Three categories of maintenance should be considered; Predictive, Preventative, and Reactive.

a. **Resolution:** Siemens will plan to meet with BU NEIDL to evaluate best practice maintenance recommendations and better understand what, if any, gaps exist in the existing plan. It would also be beneficial to understand how maintenance needs might change as the facility becomes more active.

3. **Compliance Support Option (CSO) for Insight**

The BU NEIDL BMS system currently has the Compliance Support Option for Insight, but it is not being used at this time to its full potential. The CSO provides functionality for detailed tracking of modifications and deletions of supervised objects. With this option, you can track which property of an object was changed, its value before and after the change, who made the change, why the change was made, who authorized the change, and from where the change was made.

a. **Resolution:** If this is a recommendation that is approved BU NEIDL and Siemens would need to meet and review which systems and system points should be enabled.

4. Alarm Issue Management (AIM) for Insight

BU NEIDL currently has the Alarm Issue Management Option for Insight, but it is not being used to its fullest potential. AIM allows you to manage the life cycle of an alarm issue through all stages, from initiation to resolution. By configuring a point for Alarm Issue Management, an ordered procedure is imposed for each point in alarm: Acknowledge, Assign (to a contact), Answer, Resolve, and Clear. Each step is logged through the Alarm Issue Management application, which provides you with the full history of that alarm issue. AIM is a best practice technology module that many of our Siemens life science customers use to ensure systems alarms are handled according to procedure.

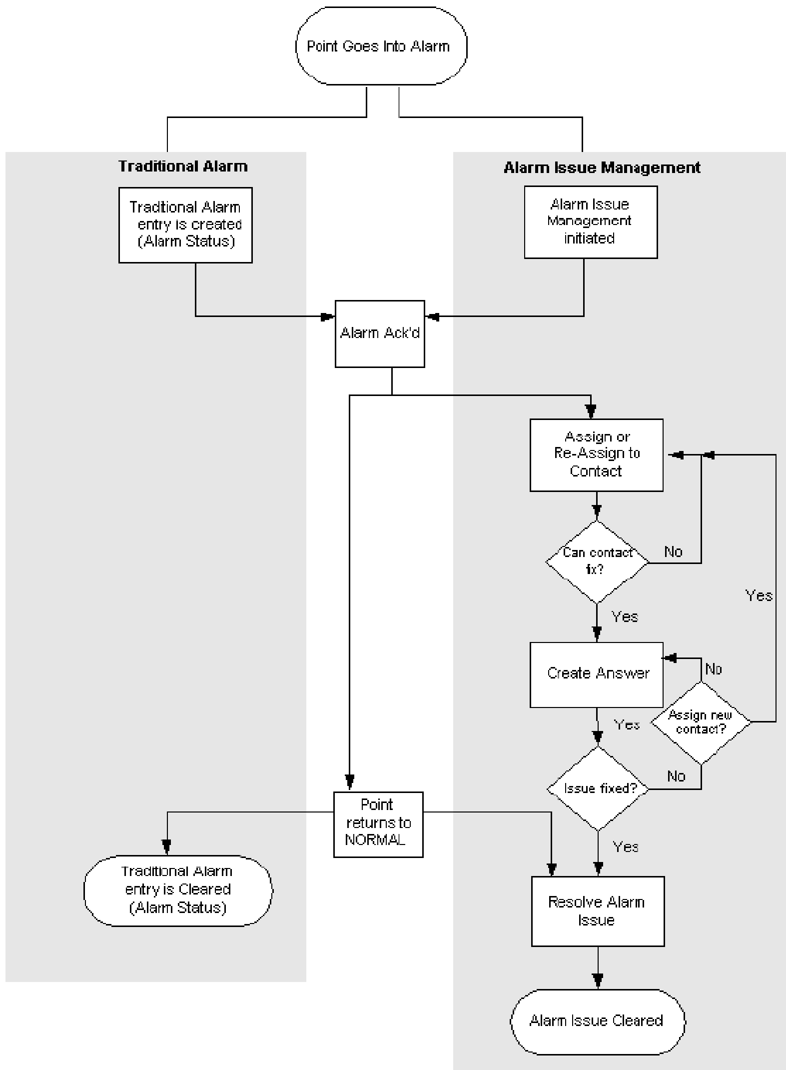

Figure 4. Traditional vs. Alarm Issue Management Lifecycle Illustration.

a. **Resolution:** Implement full features of AIM and assign points of contact for process flow.

5. Trending and Trend Collection Strategies

During the evaluation of the trends from 3/21/16 through 3/22/16 it was noticed that a more standard set of trends would be helpful for future evaluation of the system performance.

a. **Resolution:** Implement a standard set of trends for equipment types and spaces that are aligned throughout the facility to better evaluate system performance.

6. SOP (Standard Operation Procedures) links in BMS

In critical situations when assessing the building performance it is helpful to have any standard operating procedures or policies available as links on the BMS graphical screen for easy reference.

a. **Resolution:** BU NEIDL determine what SOP's or policies would be essential and working with Siemens to provide links to those documents on appropriate graphics in Insight workstation.

7. User Access Rights and Management

The Siemens BMS user interface is called Insight. The Insight application resides on a server behind the protection of BU's network security. It is critical that BU IT manage user access to its network and the access to the Insight application. Access the Insight application is controlled by a username and password. Each user is capable of having an individual username, password, and set of user rights. Using individualized username and password combinations allows the BMS Activity Log to track the changes made by each user. It is critical to review the user access to the Siemens BMS and ensure that the rights of each user is correct based on facility requirements.

a. **Resolution:** BU IT to ensure user access to the network meets needs of facility. BU NEIDL to ensure that current user list is accurate, and ensure that each user is logging in with their credentials.

Implementation Considerations and Timeline

Siemens is committed to providing the local and national resources and recommendations that BU NEIDL needs in order to resume normal operations and proceed with day-to-day business and research as soon as possible. At this juncture we would propose a follow up meeting to review all parties' findings and recommendations and discuss implementation, timeline, and implications for BU NEIDL.