

Lessons Learned Quick Reference Guide

Lessons learned are a resource enabling industry to identify problems, find what works, document the process, and share with industry. The creation of a lessons learned document is a collaborative effort between NERC, the Regional Entities, and the registered entities. A successful lessons learned document clearly identifies the lessons, contains sufficient information to understand the issues, visibly identifies the difference between the actual outcome and the desired outcome, and includes an accurate sequence of events, when it provides clarity. This document provides a brief summary of the lessons learned published since 2015 and will be regularly updated as more are published. All lessons learned published since 2010 are currently available on the [Event Analysis](#) web page.

2025 Lessons Learned

Date	LL #	Category	Title	Summary
6/25/2025	LL20250601	Communications	Loss of Monitoring and Control due to a Communication Failure between Control Centers	A communication failure between control centers caused several entities to experience loss of monitoring and control.
3/12/2025	LL20250301	Communications	Loss of SCADA/EMS Monitoring and Control – GPS Clock Failure	Manual intervention stemming from the replacement of a failed Global Positioning System (GPS) clock led to a loss of supervisory control and data acquisition (SCADA) and energy management system (EMS) monitoring and control due to an incorrect configuration of the network time protocol (NTP).

2024 Lessons Learned

Date	LL #	Category	Title	Summary
12/30/2025	LL20241201	General Processes	Root Cause Analysis Tools - Events and Causal Factors Charting	Note: This is a topical Lesson Learned. In this case, the objective is to provide information on a root-cause methodology more than to discuss a specific event. This is the third in a series of U.S. Department of Energy (DOE) root-cause analysis methodologies provided in NERC Lessons Learned that are simple in concept and powerful in use. Events and causal factors charting (ECFC) incorporates a sequence of events with the outputs of change analysis and barrier analysis in an easily understood format that can

2024 Lessons Learned

Date	LL #	Category	Title	Summary
				be used in management presentations. Like the prior LL20210201 RCA Tools – Change Analysis, and LL20210201 RCA Tools – Barrier Analysis, this Lesson Learned includes a case study with an example chart and a user’s “how-to” guide.
5/23/2024	LL20240501	Generation Facilities, Bulk Power System Operations	Incorrect IBR Primary Frequency Response Logic Caused Negative ACE	A supervisory control and data acquisition (SCADA) provider’s primary frequency response (PFR) was incorrectly applied in response to a grid frequency event as evidenced by the independent system operator’s (ISO) root cause analysis (RCA). Energy storage resources (ESR) that do not have controller logic set in a manner that applies the PFR droop offset as “additive” to the dispatch setpoint may produce anomalous responses.
3/4/2024	LL20240301	Relaying and Protection Systems	Protective Relay Solid-State Output Contact Voltage Leakage	An entity experienced unnecessary breaker failure initiation signals due to solid-state output contact voltage leaks which can operate downstream devices with optically coupled isolator (OCI) inputs or air gap inputs. A traditional corrective action was used that is now considered a less than optimal work-around by the vendor.

2023 Lessons Learned

Date	LL #	Category	Title	Summary
11/30/2023	LL20231102	Generation Facilities	540 MW of Wind Turbine Generation Loss due to Unexpected and Insufficient Ride-through Performance	Insufficient ride-through performance for wind turbine generators continues to cause repeated events due to incorrect protection settings, insufficiently maintained uninterruptible power supply (UPS) systems, and the previous tripping causes remaining unidentified. This lesson learned discusses a recent wind farm event to serve as an example of the type of event occurring frequently across the bulk power system (BPS).
11/30/2023	LL20231101	Communications	Loss of Communication to Transmission Substations	A TO experienced an unplanned interruption on its “Path A” (fiber optic) that impacted several communication circuits due to previously rerouted circuits during an ongoing planned outage on “Path B” (microwave). As a result, select relay communications were affected in addition to the monitoring and control to several

2023 Lessons Learned				
Date	LL #	Category	Title	Summary
				remote substations. As a result of this break, both analog communications and digital SCADA communications were interrupted for 11 hours and 30 minutes.
9/28/2023	LL20230901	Communications	Abnormal Area Control Error due to a Model Translation Error	After a scheduled quarterly model update, the entity experienced an abnormal area control error (ACE) deviation from expected ranges. It was identified that the automatic generation control (AGC) application sent invalid setpoint instructions to the generation fleet due to a model translation error.
8/10/2023	LL20230801	Communications	Loss of Monitoring due to a “Half Failed” High Availability Switch Pair	Due to an incomplete failover between firewalls, an entity experienced intermittent inter-control center communications protocol (ICCP) data failures and data quality issues in the energy management system (EMS) and plant information (PI) applications. As a result, the entity lost monitoring capability for more than 30 minutes until the system was switched to a Backup Control Center.
7/5/2023	LL20230701	Facilities Design, Commission, and Maintenance, Planning and Modeling, Generation Facilities, Transmission Facilities, Bulk-Power System Operations, Emergency Response	Weathering the Storm: System Hardening	The electric system requires additional system hardening in coastal areas to reduce the cost of impact from hurricanes. This is necessary because population growth and infrastructure concentration along the coast has greatly increased the cost of damage from extreme weather events in North America over the last 20 years. Some system hardening has already occurred in Florida and has reduced restoration times there.
4/19/2023	LL20230401	Generation Facilities	Combustion Turbine Anti-Icing Control Strategy	Unexpected icing due to intermittent interference from outside sources may present operating challenges.

2022 Lessons Learned				
Date	LL #	Category	Title	Summary
12/15/2022	LL20221201	Transmission Facilities	Air Breaker Cold Weather Operations	Cold weather temperatures can drastically challenge the reliability of the Bulk Electric System (BES). This lesson learned focuses on a

2022 Lessons Learned				
Date	LL #	Category	Title	Summary
				specific issue for sectionalizing elements in substations. Extreme cold can impede the ability to perform local actions and quick switching of network topology. Restriction of operating maneuvers caused by cold weather also limits scenarios that system operators can perform to overcome emergencies.
11/16/2022	LL20221101	Relaying and Protection Systems	Preventing Unwanted Operations during Relay Diagnostic Restarts	Protection relays may experience restarts for various reasons; these can range from diagnostic restarts to settings revisions to setting group changes depending on the type of relay. This lesson learned contains some suggested practices to help prevent unwanted operations during these restarts.
9/28/2022	LL20220901	Communications	Loss of Energy Management System Functionality due to Server Resource Deadlock	An antivirus software engine installed on energy management system (EMS) production servers had a flaw that caused affected servers to deadlock server resources and become unresponsive, effectively making the EMS unavailable to operators. This flaw was latent in the engine and activated by certain malware signatures applied to the EMS production environment. The flaw was not recognized in test environments due to the difference in input/output (I/O) workload on test servers versus those seen on production servers. Deadlocks only appeared on live production servers that have extremely high file I/O, causing the server deadlock flaw to manifest more quickly. The high file I/O on these servers is due to routine EMS processes and file backup services that resulted in more opportunity for the antivirus engine to deadlock on files.
8/22/2022	LL20220801	Communications	EMS Pausing During Database Deployment	Several entities have experienced energy management system (EMS) outages during EMS database deployment. All of the cases had the same EMS vendor.
7/20/2022	LL20220702	Bulk-Power System Operations, Transmission Facilities	Tower Climber Incident	On an August day, a climber was reported to be on the top of a tower shared by three circuits (a 500 kV circuit, a 230 kV circuit, and a 115 kV circuit). As a result, the three circuits were required to be manually removed from service to protect the safety of the

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				climber while taking into account system limitations that may be caused by their removal from service. They were later returned to service after the climber was reported to be safely down from the tower.
7/20/2022	LL20220701	Bulk-Power System Operations, Transmission Facilities, Generation Facilities	Forecasted High Winds	High-speed wind days can pose challenges to transmission, distribution, and wind-generation availability. ¹ This lesson learned focuses on the implementation of coping strategies by a specific utility developed from prior experience; it is largely a success story.
4/13/2022	LL20220406	Communications	Intermittent Network Connection Causes EMS Disruption	Intermittent disruptions of the primary network path connectivity at the backup control center (BCC) resulted in loss of access to the energy management system (EMS) and voice over internet protocol (VoIP) for 25 minutes.
4/13/2022	LL20220405	Transmission Facilities	Unintended Consequences of Altering Protection System Wiring to Accommodate Failing Equipment	Following standard entity practice on discovering a failing capacitor coupled voltage transformer (CCVT), the voltage sensing for the equipment protecting the CCVT line position was jumpered to a CCVT on a nearby line position, but the failing CCVT was left connected to the Bulk Electric System. The applied jumper provided a false indication of good sync voltage across the open breaker, causing the sync-check relays in the reclosing system to close the breakers into a permanent fault multiple times in rapid succession. This in turn caused relay operations at three non-faulted line terminals that were determined to be misoperations.
4/13/2022	LL20220404	Transmission Facilities	Substation Flooding Events Highlight Potential Design Deficiencies	Heavy rainfall of 5.7 inches of rain and hail over a 2.5 hour period led to the flooding of a basement relay room in the control building at a 230 kV transformer station. This led to unexpected equipment and protection operations during the event that resulted in two

¹ This Lesson Learned is about near-term (1–5 day forecast) damaging wind warnings and actions to take. There is another lesson learned under development on system hardening that is about longer term work to improve the system’s resistance to damage.

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Date	LL #	Category	Title	Summary
				230 kV circuits and six generating units (representing a total of 495 MW) being removed from service over a period of 1 hour and 7 minutes.
4/13/2022	LL20220403	Communications	Model Data Error Impacts SE and RTCA	State estimator (SE) and real-time contingency analysis (RTCA) systems experienced a software issue post network model deployment that resulted in a questionable solution. The solution quality issue was the result of a software problem that allowed the SE to continue to solve with telemetered MW/MVAR data that had stopped updating.
4/13/2022	LL20220402	Bulk Power System Operations, Generation Facilities	Islanding and Insufficient Primary Frequency Response Resulted in Unintended UFLS	An entity separated from the Interconnection and experienced an under frequency event. Upon reviewing the islanded system's response to the under frequency event (see Figure 1), the entity discovered that the generator response was not as expected in a number of instances along with other contributing factors, such as low system inertia and inadequate pre-arranged load shedding. This entity worked with GOs to identify shortcomings in unit frequency response and make improvements.
4/13/2022	LL20220401	Bulk Power System Operations, Transmission Facilities, Generation Facilities	DER Performance During a Disturbance	A three-phase-to-ground fault resulted in two 500 kV circuits being removed from service. This led to a net loss of approximately 1,300 MW of voltage-sensitive loads as well as at least 300 MW of supply from distributed energy resources (DER) also occurred.
3/9/2022	LL20220301	Bulk Power System Operations	Managing UFLS Obligations and Service to Critical Loads during an Energy Emergency	Due to the amount of load shed during Winter Storm Uri, entities found it difficult to rotate customer outages while maintaining service to critical loads and underfrequency load shed (UFLS) feeders. Simultaneously, the percent of system load connected to UFLS feeders created a risk of frequency overshoot and instability in the event of UFLS activation.

2021 Lessons Learned				
Date	LL #	Category	Title	Summary
10/25/2021	LL20211001	General Processes	Pandemic Response	By the early 2000's, most entities had created business continuity plans (BCP) for various disaster scenarios, including a major pandemic, and had periodic scenario drills to practice these plans. The COVID-19 pandemic resulted in actual use of these plans early in 2020. The first time a plan is executed with a real-life situation, it can be expected that adjustments will need to be made, and lessons will be learned to improve the effectiveness of future pandemic response plans and possibly improve response to other scenarios contained within the BCP.
8/6/2021	LL20210803	Communications	Loss of Monitoring or Control Capability due to a Software Version Mismatch	A couple of entities have experienced energy management system (EMS) outages due to a software version mismatch between the product development system (PDS), quality assurance system (QAS), and production system (production).
8/6/2021	LL20210802	Relaying and Protection Systems	Multiple Faults in Rapid Succession Contribute to Relay Misoperations Leading to Loss of Load	Four separate faults occurred in rapid succession in a bulk power substation as a result of weather-induced salt contamination. Relay misoperations in the presence of the faults resulted in loss of load.
8/6/2021	LL20210801	Transmission Facilities	Insulator Flashovers Due to Combination of Salt Spray Deposits Followed by Light Rainfall Initiating Loss of Load	Multiple parallel insulators in a bulk power substation that had been exposed to salt spray during a tropical storm flashed over two and a half days later when light rain began to fall. The flash overs were attributable to dry band arcing. Relay misoperations in the presence of the flashover faults resulted in loss of load.
5/4/2021	LL20210501	Bulk Power System Operations, Generation Facilities	Interconnection Oscillation Disturbances	An Interconnection-wide oscillation of approximately 0.25 Hz frequency propagated through the entire Eastern Interconnection
4/13/2021	LL20210401	Generation Facilities, Transmission Facilities, Bulk Power System Operations	Controlled Islanding due to Wildfire Event	A registered entity experienced a wildfire in a transmission right of way (ROW) on a critical transmission corridor. To enable the firefighters to use aerial suppression agents on the fire, the entity was requested to de-energize all the transmission lines in the corridor, forming an electrical island. The registered entity was able

2021 Lessons Learned				
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				to successfully separate a part of the system in a controlled manner and was able to assist firefighters in controlling the fire effectively.
3/29/2021	LL20210302	Transmission Facilities	Catastrophic Failure of 345 kV Oil Filled Metering Current Transformer in a Transmission Substation	A 345 kV substation line current transformer C-phase experienced a catastrophic failure and caused the current transformer (CT) to explode, sending a significant amount of bushing glass shrapnel throughout the switchyard and creating a fire in the switchyard.
3/29/2021	LL20210301	Transmission Facilities	Battery Energy Storage System Cascading Thermal Runaway	A fire started in a Battery Energy Storage System (BESS), resulting remote alarm triggering at approximately 16:55 PST. The utility, the maintenance provider, and fire fighters responded to the site. At approximately 20:04 PST, an explosion occurred that injured several firefighters and significantly damaged the BESS. A comprehensive investigation of the event was performed that identified the cause of the fire as being a cascading thermal runaway event that was initiated by an internal cell failure within one battery cell in the BESS.
2/25/2021	LL20210204	Relaying and Protection Systems	Transient Induced Misoperation: Approach II (Loss of Protection during Severe Lightning Event)	System 1 and System 2 protection groups shut down as a result of a lightning-strike-induced fault at one terminal of a 345 kV transmission line. Neither System 1 nor System 2 local relay protection cleared the fault. The fault continued for over 1.5 seconds until protection at the remote terminals tripped as designed via time-delayed elements.
2/25/2021	LL20210203	Relaying and Protection Systems	Transient Induced Misoperation: Approach I (Control Circuit Transient Misoperation of Microprocessor Relay)	Voltage transients were found to initiate protective relay digital inputs during close-in faults to a hydroelectric dam. The false inputs resulted in multiple powerhouse line protection misoperations and the unnecessarily tripping of hundreds of megawatts of generation. Due to the vintage of the equipment and a failure of the relay to properly log events, little data was initially available for troubleshooting. The powerhouse line relays at both the substation and powerhouse were owned and operated by the TOP but were connected to and powered by the GOP's control circuits and battery at the powerhouse.

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Date	LL #	Category	Title	Summary
2/10/2021	LL20210202	General Processes	Root Cause Analysis Tools – Barrier Analysis	<p>The entity was adding a source of backup power to their primary system operating center (PSOC). Considerable movement of people and materials in and out of critical infrastructure protection (CIP) controlled areas occurred as contract workers had to install equipment and route cable. The contract construction workers had background checks and had been trained on the access procedure. After several access violations had been noted, a work stand-down was declared, and security expertise from one of the entity's nuclear stations was contacted for consultation.</p> <p>The security consultant used Barrier Analysis to determine the effectiveness of access control and logging at the PSOC. The consultant found that shortcuts bypassing the expected path had been used to move material from an outside laydown area and that barriers that should have prevented this were ineffective. There were access procedure weaknesses identified as well.</p>
2/10/2021	LL20210201	General Processes	Root Cause Analysis Tools – Change Analysis	<p>A transformer catastrophically failed after approximately 20 years of service. It was one of two nearly identical transformers operating in parallel to feed a large community. Protective relays responded appropriately, opening the station's 138 kV and 13.8 kV breakers (one each) to isolate the fault.</p> <p>Because there were two 138/13.8 kV transformers, one that failed and one that did not fail, the entity used Change Analysis to find the root cause of the failure.</p>

2020 Lessons Learned				
Date	LL #	Category	Title	Summary
11/12/2020	LL20201102	Communications	Loss of State Estimator due to Contradicting Information from Dual ICCP Clusters	The entity encountered an operational problem, causing the state estimator (SE) to become nonconvergent. An evaluation indicated

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				that SE was failing upon opposing device status sent from independent dual ICCP clusters.
11/12/2020	LL20201101	Transmission Facilities, Bulk Power System Operations	Cold Weather Operation of SF₆ Circuit Breakers	When a SF ₆ circuit breaker (CB) hits its critical low pressure, its fault interrupting capability can be compromised. Most TOs protect against this by either auto-opening the CB prior to reaching the critical low-pressure level or by blocking the CB from tripping (when it reaches the critical low-pressure level) and relying on adjacent CBs to open in the event of a fault (breaker failure mode). If this occurs across multiple locations, it can place the Bulk Electric System (BES) at additional risk since it weakens the overall topology of the system and can result in more facilities being removed from service to clear a fault. It also means that the contingencies modeled and studied in real-time contingency analysis (RTCA) studies may no longer be accurate, thereby potentially putting the BES in a less secure or unknown state. That condition occurred during the severe cold weather event that hit the upper Midwest region of North America on January 29–30, 2019.
10/6/2020	LL20201001	Transmission Facilities	Single Phase Fault Precipitates Loss of Generation and Load	A single phase to ground fault on a 400 kV transmission line in Southern England precipitated the loss of 1,878 MW of generation. This led to a frequency decline that resulted in a loss of 931 MW of load. This European event has lessons applicable in North America.
7/30/2020	LL20200703	Relaying and Protection Systems	Lockout Relay Component Failure Causes Misoperation and Reportable Event	Unnecessary trips for nonfault conditions are problematic for any protective relay and can be particularly problematic for lockout relays. Lockout relays are typically used to isolate and hold BES electrical equipment out of service for extended periods of time to allow for visual inspection and typically result in the operation of multiple interrupting devices. Many lockout relay types require manual reset, meaning that field personnel must travel to the relay location, inspect, and perform switching to restore systems to service. The resulting extended abnormal operating condition of the system may put the reliability of the BES at risk.

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Date	LL #	Category	Title	Summary
7/30/2020	LL20200702	Relaying and Protection Systems	Verification of AC Quantities during Protection System Design and Commissioning	<p>Failure to employ effective commissioning testing practices or effective quality checks of protection system designs when installing or modifying protection systems can lead to protection system misoperations. These can occur with all components of protection systems, but issues with voltage and current instrument transformer wiring regularly surface when protection system misoperations occur. Protection system misoperations have an immediate negative impact on the reliability of the bulk power system and may cause a significant increase in the magnitude and scope of a disturbance.</p> <p>It should be noted that this lessons learned document is an expanded version of the NERC lesson learned document titled “Verification of AC Quantities during Protection System Commissioning” that was issued on March 11, 2014. The document has been expanded to provide additional guidance based on events noted since 2014.</p>
7/10/2020	LL20200701	Relaying and Protection Systems	Mixing Relay Technologies in DCB Schemes	<p>Multiple composite protection system misoperations have occurred on the Bulk Electric System (BES) as a result of mixing protective relay technologies at the remote terminals of directional comparison blocking (DCB) schemes. One of the most challenging mix of technologies is utilizing a relay system based on newer microprocessors (μP) at one terminal and an older electromechanical (EM) relay system at the opposite terminal (examples shown in the figures below). Utilizing different models of μP based relays at each terminal can also be problematic. Often, only one terminal of a DCB system is upgraded to μP based relays due to various reasons, including different ownership of terminals, budget constraints, and emergency replacements. Relay timing and directional coordination is critical in DCB schemes that may be overlooked when relay technology or relay models vary between terminals.</p>

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Date	LL #	Category	Title	Summary
6/11/2020	LL20200602	Bulk Power System Operations	Preventing Energy Emergency Alerts	As several energy emergency alerts (EEAs) were issued over the course of several months, key items were identified that could have prevented the EEAs from being issued and, in some cases, prevented the BAs from unnecessarily shedding firm load to maintain system reliability.
6/11/2020	LL20200601	Bulk Power System Operations	Unanticipated Wind Generation Cutoffs during a Cold Weather Event	A registered entity experienced extreme cold weather January 29–31, 2019. Unplanned wind generation outages contributed to a maximum generation event, resulting in the entity calling on load management resources (including demand response, behind-the-meter generation, and voluntary reductions) to avoid using emergency power purchases.
4/14/2020	LL20200403	Communications	Loss of Automatic Generation Control During Routine Update	During a weekly automatic generation control (AGC) software update, a critical AGC task aborted at one of two fully redundant control centers, and the same critical task aborted at the other control center four minutes later. As a result, generation schedules could not be set, and area control error (ACE) could not be automatically calculated until the issue was resolved. The cause was a modified line of code.
4/14/2020	LL20200402	Transmission Facilities, Relaying and Protection Systems	Protected Fault in a Transmission Substation	Electronic communications equipment utilized to transmit and receive information from the remote terminals of a transmission line automatically shut down within milliseconds when a bus fault occurred at one terminal of the line. Neither the primary nor the back-up relay protection cleared the fault. The fault continued for over four minutes.
4/14/2020	LL20200401	Transmission Facilities, Relaying and Protection Systems	Misoperation of 87N Transformer Ground Differential Relays Causing Loss of Load	Gaps in implementing a modification and subsequent commissioning processes led to the omission of neutral connections for three separate transformer neutral differential relays, ultimately causing three simultaneous misoperations and a subsequent loss of load.

2019 Lessons Learned				
Date	LL #	Category	Title	Summary
12/17/2019	LL20191201	Generation Facilities, Transmission Facilities	Moisture Intrusion in Hermetically Sealed Metering Current Transformers	Three hermetically sealed oil-filled metering current transformers (CTs) were placed in service after being in open storage for several years. One failed after five weeks of service; another failed after 10 weeks.
9/5/2019	LL20190901	Communications	Risks Posed by Firewall Firmware Vulnerabilities	A vulnerability in the web interface of a vendor's firewall was exploited, allowing an unauthenticated attacker to cause unexpected reboots of the devices. This resulted in a denial of service (DoS) condition at a low-impact control center and multiple remote low-impact generation sites. These unexpected reboots resulted in brief communications outages (i.e., less than five minutes) between field devices at sites and between the sites and the control center.
08/13/19	LL20190804	Transmission Facilities	Breaker Failure due to Multiple Reclose Attempts	During a 115 kV permanent line fault, a line breaker malfunctioned and reclosed into the fault eight times before failing internally, resulting in a bus differential lockout clearing all breakers on the 115 kV bus. After working with the manufacturer, it was determined that the issue was caused by maintenance being done on the breaker incorrectly.
08/01/19	LL20190803	Transmission Facilities	Inadvertent CVT Fuse Removal on a Live Circuit	During planned maintenance work on a 230 kV circuit (Circuit A), CVT fuses for a parallel circuit (Circuit B) were inadvertently removed during isolation. The inadvertent removal of the fuses resulted in the subsequent removal of Circuit B from service by line protection operation and a load loss of approximately 382 MW.
08/01/19	LL20190802	Transmission Facilities	RAS Unexpected Operation	An unexpected remedial action scheme (RAS) operation was triggered by an external physical action that initiated a large amount of generation rejection and automatic load shedding as programmed according to the RAS settings.
08/01/19	LL20190801	Communications	Loss of Monitoring or Control Capability due to Power Supply Failure	Several entities have experienced energy management system (EMS) outages due to power supply failure.

2019 Lessons Learned

Date	LL #	Category	Title	Summary
05/22/19	LL20190503	Communications	Telecom Provider Failure Induced Loss of ICCP from Regional Neighbors	A registered RC experienced a temporary loss of inter-control center communications protocol (ICCP) data feeds from their regional neighbors. This loss of connectivity was due to third-party telecommunications vendor equipment that experienced a malfunction. For the next nine hours, these data links were intermittently unavailable. There was no adverse effect on the Bulk Electric System.
05/22/19	LL20190502	Communications	Enhanced Alarming Can Help Detect State Estimator and Real-Time Contingency Analysis Issue	Several entities in the ReliabilityFirst (RF) Region have experienced state estimator (SE) or real-time contingency analysis (RTCA) outages that could have been mitigated more quickly with better alarming.
05/22/19	LL20190501	Transmission Facilities	Automatic Capacitor Operations along Radial Feed Result in Load Shed	An unplanned 138 kV bus outage created a radial load pocket without voltage or thermal violations. Shortly after, automatic switching involving two capacitor banks resulted in low voltages below emergency levels. The RC directed the TOP to shed approximately 30 megawatts (MW) of load to restore voltages to acceptable levels.
02/28/19	LL20190202	Generation Facilities Transmission Facilities	Substation Fires: Working with First Responders	Two substation fire events occurred that highlight the importance of having an incident response procedure and command structure. In the first case, a fire occurred due to an arc flash on a 12 kV feeder circuit breaker within an enclosed substation. Although the fire department was dispatched to extinguish the fire, the ability to respond to the substation fire was delayed. In the second case, a 160 MVA, 230 kV/35 kV Transformer high-side bushing failed in an outdoor substation resulting in multiple operations removing the transformer, a 230 kV bus, and three transmission circuits in a large metropolitan city. An incident command post was established across the street promptly on the arrival of utility and fire department personnel.
02/28/19	LL20190201	Generation Facilities Transmission Facilities	Current Drone Usage	Some entities have begun using unmanned aerial vehicles (UAVs), commonly called “drones,” for various purposes, such as major

2019 Lessons Learned

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				storm damage survey, line repair, substation/switching station and line inspections, power plant inspections, wind farm, gas pipeline inspections, and security. Many transmission tasks currently done with helicopters can be completed by or supplemented with drones, resulting in reduced cost, increased safety, and more schedule flexibility. Additional uses and benefits are likely to develop through utilizing this emerging technology.

2018 Lessons Learned

Date	LL #	Category	Title	Summary
10/17/18	LL20181002	Transmission Facilities	Incorrect Field Modification and RAS Operation Lead to Partial System Collapse	During an outage to isolate a 500 kV line disconnect switch and install a temporary bypass to facilitate its replacement, the position of an auxiliary contact multiplier relay was incorrectly modified by field staff. This incorrect multiplier position enabled line stub bus protection, which misoperated due to the increase in flow despite there being no actual line fault. This incorrect multiplier position also prevented the remedial action scheme (RAS) from operating as designed for the loss of the respective 500 kV circuit. The actuations resulted in separation of a large portion of the entity's system, load losses, generator trips, and islanding of a small pocket sustained by local generation.
10/02/18	LL20181001	Communications	Networking Packet Broadcast Storms	When a second network cable was connected from a voice over internet protocol (VOIP) phone to a network switch lacking proper settings, a packet broadcast storm prevented network communications from functioning, and supervisory control and data acquisition (SCADA) was lost for several hours. Broadcast storm events have also arisen from substation local area network (LAN) issues.
08/07/18	LL20180802	Transmission Facilities	Firewall Failure After Time Limit Exceeded	Due to a firmware error, a firewall stopped processing network traffic without proper failover after an internal run-time limit was

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				exceeded. This resulted in persistent remote terminal unit (RTU) communication issues.
08/07/18	LL20180801	Communications	Loss of Substation Data Circuits to SCADA	While initiating a transfer of SCADA (Supervisory Control And Data Acquisition) from the company's alternate control center (ACC) to primary control center (PCC), an interruption of vendor-provided substation data circuits occurred that resulted in a temporary and partial loss of SCADA operating and monitoring capability for more than 30 minutes..
07/24/18	LL20180702	Transmission Facilities	Preparing Circuit Breakers for Operation in Cold Weather	After two sequential line faults, an entire substation and a 1,150 MW nuclear plant tripped off-line due to consecutive breaker failures during cold weather (4°F).
07/24/18	LL20180701	Transmission Facilities	Risk of Internet Accessible Cyber Assets	An electronic access point connected to the internet from a low-impact facility for remotely accessing a capacitor bank was compromised by unauthorized internet users for seven months prior to discovery
06/05/18	LL20180603	Communications	Back Office EMS Support Tools Impact Real-Time Situational Awareness	Upon receiving a call from its RC about a particular contingency, a registered entity identified that half of the contingency lists in the energy management system (EMS) list were disabled. This was due to a back-office study where the contingency list control display was opened and modified, inadvertently impacting the contingencies being displayed in the real-time environment.
06/05/18	LL20180602	Communications	External Model Data Causing State Estimator to Not Converge	Several entities in the ReliabilityFirst (RF) Region have experienced state estimator (SE) outages due to Inter-Control Center Communications Protocol (ICCP) data received from neighboring entities. Upon investigation, the topology of the neighboring system had changed but the receiving entities had not updated their representation so the ICCP data no longer matched with the older model. The SE was unable to converge (or solve).
06/05/18	LL20180601	Transmission Facilities	Loss of Communication to Multiple SCADA RTUs at a Switching Center	Grid operations lost communication with multiple substation remote terminal units (RTUs) when conditions allowed a pre-existing configuration error to express itself. The event that

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				transpired had wide reaching impacts to both control center operations and field personnel.
03/06/18	LL20180302	Transmission Facilities	Breaker Failure Due to Trip Coil Polarity	A temporary phase-phase-ground fault occurred on a 115 kV line. A 115 kV line breaker at one end of the line was slow to operate. Breaker failure protection operated, which caused the remaining two 115 kV breakers of a three-breaker switching station to open. This left the switching station de-energized. The breaker that failed to operate utilized two trip coils. Onsite investigation indicated that both trip coils had been damaged when they were energized to trip the breaker.
03/06/18	LL20180301	Communications	State Estimator Outages Requiring Tuning/Calibrating EMS Settings	Several registered entities have experienced short SE outages due to the software solutions not converging. The entities began troubleshooting techniques to locate and remove possible erroneous data point inputs into the energy management system (EMS) to help the SE to solve. After these techniques failed, each of the entities reached out to their EMS vendor for assistance.
01/03/18	LL20180101	Communications	Inadequate Battery Configuration Management Damaged a Generating Station and Tripped an HVDC Conversion Station	Progressive voltage drops occurred on three-phase transmission lines between a multiunit generating station and an AC-DC conversion station for a major intertie. At the same time, all units at the generating station were without monitoring and half of the units were running without control and protection due to the loss of DC supply.

2017 Lessons Learned				
Date	LL #	Category	Title	Summary
08/24/17	LL20170801	Transmission Facilities	Auxiliary Power Loss to STATCOM Leads to UVLS Operation	A voltage disturbance on the transmission system led to the loss of redundant auxiliary cooling system power sources for a static synchronous compensator (STATCOM), causing the STATCOM to trip. Both auxiliary cooling power supplies were fed from the same high-voltage substation. The loss of the STATCOM exacerbated a low-voltage condition on the transmission system. Undervoltage

2017 Lessons Learned				
Date	LL #	Category	Title	Summary
				load shed (UVLS) relays on distribution feeders in the area tripped as a result of the low voltage, shedding 92 MW of firm load.
07/11/17	LL20170701	Generation Facilities	Loss of Wind Turbines Due to Transient Voltage Disturbances on the Bulk Transmission System	Voltage disturbance events on the transmission system in Australia and Texas have highlighted concerns with voltage ride through and in some wind turbine control system parameters.
06/20/17	LL20170601	Generation Facilities	Generator Trip While Performing Frequency Response	Two generating units were responding to a large frequency excursion when they tripped off-line on low boiler furnace pressure.
05/16/17	LL20170503	Communications	Loss of SCADA Operating and Monitoring Ability	A registered entity's system control center and their commercial operations center experienced a temporary loss of SCADA operating and monitoring capability. As a result, the entity's state estimator and contingency analysis were rendered inoperable for a 50-minute time period. Loss of SCADA connectivity (e.g., monitoring and control) was also experienced with the entity's HVD/LVD substations and the RC. The incident was a result of telecommunication equipment for the SCADA system being inadvertently powered down while non-routine scheduled maintenance was being performed.
05/16/17	LL20170502	Communications	Line Frequency Excursion Causes UPS Shutdown and Control Center Evacuation	A control center was evacuated due to automatic shutdown of transmission switching and generation dispatcher SCADA workstations and system operation center servers. This shutdown was caused by a frequency excursion on the primary source transmission line that was feeding the control center.
05/16/17	LL20170501	Communications	Loss of Monitoring Due to Authentication Software Update	During a scheduled test of updated SCADA/EMS authentication software on the backup control center, the entity experienced loss of remote monitoring and control that lasted for 51 minutes before full system recovery. During this time, RTU polling ceased, and the ICCP datalink to its neighboring TOP and RC was not operational.

2017 Lessons Learned

Date	LL #	Category	Title	Summary
04/12/17	LL20170401	Generation Facilities	Dispatched Reduction in Generation Output Causes Frequency Deviation	A process conflict occurred during a normal data transfer process that resulted in undesirable unit commitment outputs from a Balancing Authority's security-constrained economic dispatch unit commitment software. System operators intervened by identifying and blocking the undesirable dispatches; however, some of the instructions could not be blocked or overridden. This caused the Balancing Authority to experience a reduction in generation output that caused its area control error (ACE) and system frequency to deviate for almost 20 minutes.
03/14/17	LL20170302	Communications	Loss of State Estimator Due to Propagated Database Values With Invalid Data	The entity encountered an operational problem, causing the state estimator (SE) to become nonconvergent. As a result, the Real Time Contingency Analysis (RTCA) application stopped running. An evaluation indicated that the SE application had encountered invalid data referred to as NaN (not a number, or invalid number, resulting typically from a divide by zero). This created invalid results that were propagated through many of the SE calculations, causing the SE to fail. The NaN values were generated by the application. These values were manually overridden to temporarily correct the issue.
03/14/17	LL20170301	Facilities Design, Commission, and Maintenance	Slow Circuit Breaker Operation Due to Lubrication Issues	In 2015 and 2016, a total of 19 circuit breaker fail-to-trip operations were reported through the event analysis process. Twelve of those events were slow-to-trip circuit breakers.

2016 Lessons Learned

Date	LL #	Category	Title	Summary
12/06/16	LL20161202	Communications	SCADA System Software Design Flaw Prevented Processing of Alarms and Events	A SCADA system encountered an operational problem when a software design flaw prevented the application from processing alarms and events due to a character limit within the SCADA database.

2016 Lessons Learned				
Date	LL #	Category	Title	Summary
12/06/16	LL20161201	Communications	Loss of ICCP – Local Control Center Notifications	The loss of ICCP connectivity at one entity's (Entity A) control center resulted in a loss of the state estimator at another entity's (Entity B) control center.
11/01/16	LL20161103	Communications	Loss of ICCP due to Database Sizing Issue	During a network model update, a problem was caused by a combination of the number of points being requested by the state estimator (STE) and the number of points available in ICCP. This problem initiated a failure of ICCP, which resulted in the inability to obtain reliable results from the STE and contingency analysis applications.
11/01/16	LL20161102	Communications	Failover Configuration Leads to Loss of EMS	Configuration settings of an entity's EMS applications and tasks caused unintended automatic failovers to backup EMS servers multiple times in a row. This set up a failover loop, hindering recovery efforts.
11/01/16	LL20161101	Communications	Redundant Systems May Not Cold-Start Unless Fully Intact to Prevent Dual Primary Operation	A system failure occurred during routine maintenance of critical IP network infrastructure. Due to redundancy present in the system, no significant service interruption was expected.
10/04/16	LL20161001	Relaying and Protection Systems	DC Grounds and AC Tied to DC Cause Multiple Relay Misoperations	A dc ground coupled with an ac voltage tied to the 125 VDC battery system caused false breaker status indications on a line relay. This resulted in a relay misoperation. Also, a high-speed auxiliary relay misoperated momentarily to introduce 125 VDC due to the extremely small air gap in the normally open contacts.
08/30/16	LL20160801	Relaying and Protection Systems	Tie Line Relay Coordination	A loss of three 345 kV transmission lines occurred when a phase A to ground fault on one line resulted in a misoperation that tripped a second line. As a result of these two lines tripping, the third line was open-ended due to the station bus configuration. The misoperation was the result of not coordinating relay communications equipment outages due to equipment failure between the different organizations.
07/05/16	LL20160701	Communications	Unavailability of the Transmission Stability	The transmission stability limits calculation application became unavailable twice during a five-hour period. The first interruption

2016 Lessons Learned				
Date	LL #	Category	Title	Summary
			Limits Calculation Application	was for a period of two hours and the second for 30 minutes. During the time that the application was unavailable, the transmission stability limits were not updated, but thermal real-time limits and post-contingency limits were still available during that time.
06/14/16	LL20160604	Communications	ICCP Communication Failure Due to Firewall Patch Update	During a regularly scheduled firewall patch installation, a Transmission Owner experienced multiple inter-control center communications protocol communication failures with external entities.
06/14/16	LL20160603	Communications	Loss of Monitoring Capabilities Due to FEP Hardware Malfunction	An entity experienced a loss of monitoring capabilities at the primary control center and backup control center due to a front end processor (FEP) hardware malfunction.
06/14/16	LL20160602	Communications	SCADA Failover Event	While initiating a failover process between the entity's primary and secondary data source, supervisory control and data acquisition caused the system to come up in a paused state. This paused state created a temporary loss of generating management system functionality.
06/07/16	LL20160601	Relaying and Protection Systems	Transmission Relaying - Relay Setting Issue	A line relay protecting a 230 kV line misoperated for a fault on a 115 kV line. The relay misoperation occurred due to the entity utilizing a manufacturer's automatic setting method based on line parameters. The relay misoperation resulted in the tripping of the two associated 115 kV low-side transformer breakers and the transfer tripping of the two remote terminal breakers of the 230 kV line. The line relaying on the faulted 115 kV line operated correctly.
05/24/16	LL20160501	Communications	Control Center Loss of SCADA Control and Monitoring Capability	An energy management system supervisory control and data acquisition group-control command was initiated to disable instantaneous relay trip settings for approximately 300 distribution feeder circuit breakers. This caused the application to abort and not restart, rendering SCADA unavailable for 67 minutes.

2015 Lessons Learned				
Date	LL #	Category	Title	Summary
12/29/15	LL20151203	Generation Facilities	Human Error Leads to Evacuation of Primary Control Room	A utility had to evacuate its primary control center due to smoke from a nearby fire that was caused by maintenance worker failing to follow proper hot work procedures.
12/29/15	LL20151202	Communications	Control Network Communication Path	Following a failover exercise being conducted pursuant to EOP-008-1, the TOP's router bandwidth for network traffic between control centers saturated and led to a flat-line condition, preventing communication between the active control center and the active data center. The active data center serves the active control center's monitoring and controlling capability by housing the active supervisory control and data acquisition servers and associated equipment. As a result of the bandwidth saturation, the active control center lost the ability to monitor and control its portion of the Bulk Electric System for approximately 39 minutes.
12/29/15	LL20151201	Bulk Power System Operations	SOL and IROL Monitoring Tool Leads to Unnecessary Manual Load Shedding	A breaker fault on a shunt reactor of a high-voltage transmission line caused the line to trip. This event led to the exceedance of two interconnection reliability operating limits. Immediate actions were taken to clear those exceedances within the required 30 minutes. However, the involved interfaces have both a system operating limit and an interconnection reliability operating limit. This caused the transmission system operator to misinterpret the information by not noticing that the flows were still above the system operating limits while the interconnection reliability operating limit exceedances were being addressed. Since the transmission system operator confused the two limits, the operator proceeded to manually shed load in an attempt to return the flows back to within what was believed to be interconnection reliability operating limit values but were really system operating limits. This occurred 28 minutes after the start of the event.
10/20/15	LL20151001	Communications	Loss of EMS Due to RTU LAN and UPS Failure	A temporary rack-mounted uninterruptible power supply failed, resulting in the loss of the remote terminal unit local area network,

2015 Lessons Learned				
Date	LL #	Category	Title	Summary
				the loss of system visibility, and the failure of the inter-control center communications protocol link for 50 minutes.
09/15/15	LL20150902	Relaying and Protection Systems	Relay Design and Testing Practices to Prevent Scheme Failures	A single-phase-to-ground fault occurred on a 230 kV three-terminal feeder. All associated circuit breakers initially tripped. The line automatically reclosed at one end, re-establishing the fault. Although the protection schemes were fully redundant, because of the occurrence of two protection equipment failures, which were unrelated to each other, no tripping occurred after the automatic reclose. The fault evolved to a multi-phase-ground fault and persisted for a total of 58 seconds eventually clearing by backup ground protection on two 500 kV lines. Breaker failure protection was not initiated during this event.
09/15/15	LL20150901	Communications	Loss of EMS Communications Due to Lack of Validation on EMS Database RTU Configuration Parameter	An energy management system lost communication with some remote terminal units.
06/25/15	LL20150604	Communications	EMS Recovery Strategy	An energy management system auto-recovery process was configured such that all nodes (e.g., servers, workstations) in the system were prompted to reboot for a particular condition. This complete system restart sequence took 47 minutes to complete. Consequently, there was a complete loss of control and monitoring functionality until each critical server and workstation reported its status as normal and fully functional.
06/25/15	LL20150603	Bulk Power System Operations	Pre-Contingent Load Shed Event	During the planning process of an outage to remove a 345-kV circuit breaker from service for retrofit and maintenance, a cascading outage was identified and analyzed for conditions affecting generation and loading in the outage area. The Reliability Coordinator utilized the real-time contingency analysis tool to identify an overload on an adjacent system transformer that indicated a loss of a 345 kV line, which could cause the loss of any

2015 Lessons Learned				
Date	LL #	Category	Title	Summary
				remaining 345 kV due to the bus configuration with the breaker out of service and could subsequently eliminate all 345 kV support in the substation.
06/09/15	LL20150602	Generation Facilities	Generator Distributed Control System Impact on Automatic Voltage Regulators	The Reliability Coordinator and Transmission Operator within an RC footprint observed unusual generator reactive output following the switching of a shunt reactor near all of the generators' points of interconnection.
06/09/15	LL20150601	Communications	Real-Time Contingency Analysis Failure due to a Modeling Error	A Real-Time Contingency Analysis process failed to converge for 46 minutes.
04/21/15	LL20150402	Transmission Facilities	Severe Flooding Damages Transformer Substations	Record rainfall within a metropolitan area caused severe localized flooding at two large transmission substations, quickly rendering the stations and all terminating circuits unavailable and damaging telecommunication, protection, and station service equipment.
04/21/15	LL20150401	Relaying and Protection Systems	Detailed Installation and Commissioning Testing to Identify Wiring or Design Errors	During a recent event, problems were encountered regarding redundant relays associated with a remedial action scheme, where two redundant remedial action scheme input/output (I/O) devices failed due to a firmware RAM/ROM processor error. The device failure alarms went undetected because of an error on the wiring diagram that prevented the positive dc from being connected properly, thus disabling the signaling of the I/O device's alarm status. While the schematic (or elementary diagram) correctly showed the proper I/O device alarm circuit design and connections, the wiring diagram of the RAS panel did not match the schematic.
03/03/15	LL20150302	Communications	Importance of State Estimator Save Cases and Troubleshooting Guide	A state estimator failed to solve for 37 minutes, resulting in real-time contingency analysis also being unavailable.
03/03/15	LL20150301	Communications	Importance of Backup EMS Failover Testing After	There was a loss of energy management system supervisory control and data acquisition functionality for 49 minutes during a

2015 Lessons Learned				
Date	LL #	Category	Title	Summary
			Network Device Reconfiguration	scheduled transfer of the EMS from the alternate control center to the primary control center.
02/10/15	LL20150202	Relaying and Protection Systems	Consideration of the Effects of Mutual Coupling when Setting Ground Instantaneous Overcurrent Elements	An event occurred that caused the unintended trip of a transmission line connected to a large generation facility. The transmission system and generation response to the loss of this line resulted in an unintended total loss of transmission connection to the generating facility. An investigation revealed that the unintended trip of the transmission line was due to an incorrect setting on a numerical relay directional ground instantaneous overcurrent element. This setting caused it to misoperate in response to a fault on a mutually coupled adjacent line. Failure to consider the effects of mutual coupling between adjacent lines led to the improper derivation of the ground instantaneous overcurrent element settings, and this resulted in a protection system misoperation.
02/10/15	LL20150201	Relaying and Protection Systems	Digital Inputs to Protection Systems May Need to be Desensitized to Prevent False Tripping Due to Transient Signals	A converter station was lost due to the erroneous initiation of a top-oil temperature trip signal from a transformer protection system. The operating entity investigated the connections in the transformer cabinet at the time and visually inspected the transformer and temperature gauges. Both the transformer's current temperature and the drag hand for the high-temperature indication were well below the alarm and trip levels. There was no evidence found to indicate any loose or corroded connections in the transformer cabinet. Multiple events initiated by this type of erroneous input signal have been observed in the event analysis process.