Texas Reliability Entity
Event Analysis

Event:
March 19, 2012 Event
Category 1a(i) Event

Texas Reliability Entity
September 21, 2012

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Executive Summary

On March 19, 2012, a Transmission Operator experienced multiple element outages at a major 345/138 kV substation. Reliability Coordinator (RC) and Balancing Authority (BA) personnel and systems operated effectively to restore system frequency by deploying reserves, and then afterwards restored those reserves. This report provides: (1) an overview of the event; (2) background on system conditions just prior to the event; (3) the detailed sequence of events; (4) an analysis of the causal and contributing factors for concerns that arose in this event; and (5) recommendations for follow-up action.

I. Event Overview

At 16:58:08 on March 19, 2012, a Transmission Operator (TOP) experienced multiple element outages at a major 345/138 kV substation.

The initiating event was a 138 kV capacitor bank circuit breaker failure. The resulting relay actions cleared the 138 kV bus. At the same time, the 345/138 kV autotransformer experienced an internal failure, which resulted in clearing the 345 kV bus. This also resulted in tripping 422 MW of radially connected generation and opening one end of the six 345 kV transmission lines which terminated on the 345 kV bus. The automatic reclosing scheme for the 345 kV bus failed to operate correctly. During the event, a 138/13 kV distribution transformer connected to the 138 kV bus also experienced an extended outage with the loss of load to customers.

System frequency measured at the RC's control center dropped from 60.016 Hz to 59.900 Hz, based on 4-second scans, because of the loss of generation. The drop was arrested by governor action of ERCOT region generators, aided by automatic deployment of 380 MW of regulation. These actions led to system frequency recovery within 3 minutes and 15 seconds to the pre-disturbance value of 60 Hz.

The TOP conducted a thorough cause analysis on the key components of the outage, including a detailed cause analysis of the failed 138 kV capacitor breaker, the failed 345/138 kV autotransformer, and the slow operations of a 138 kV circuit breaker. The TOP also examined the 345 kV bus reclosing issue and reviewed the station service configuration for possible enhancements.

The event met the criteria of a Category 1a(i) event under NERC's Event Analysis procedure.

II. Initial System Conditions Prior to Event

Conditions on March 19, 2012 at 16:58:00:

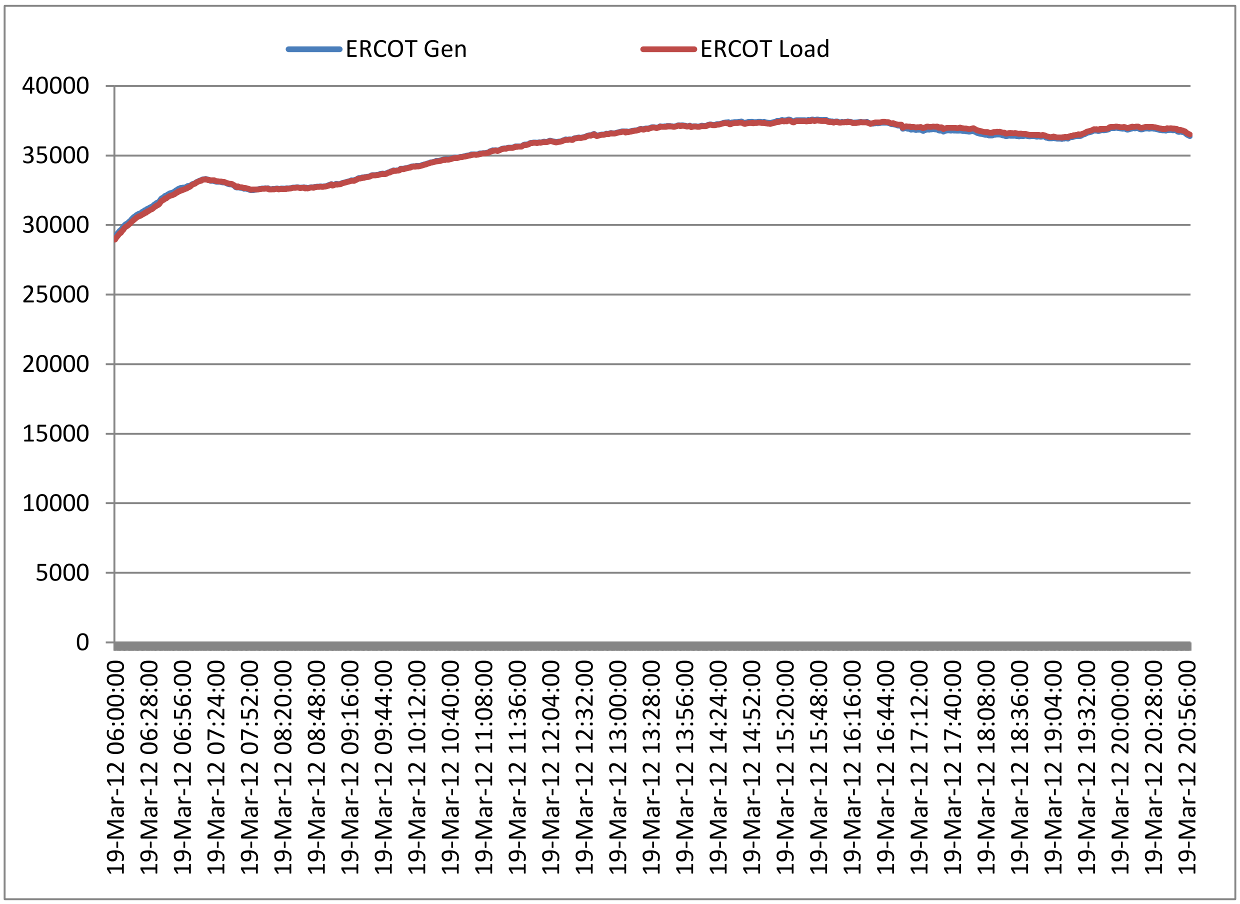
Forecasted Pk HR Demand:	37,384 MW
Actual Demand:	37,226 MW
Generation for Pk HR Demand	42,999 MW
System Frequency:	60.018 Hz
Area Control Error (Total):	~ 125 MW @ 16:58
Physical Responsive Capability:	~3215 MW @ 16:58

The TOP had 64 planned outages scheduled and 8 forced outages prior to the event.

Substation Conditions:

345 kV Bus Voltage:	348.5 kV
138kv Bus Voltage:	140.8 kV
345/138 kV Autotransformer load:	184.75 MVA

All lines, breakers, autotransformers, and distribution transformers were normal prior to the event. There were no alarms or loading issues present prior to the event.



III. Sequence of Events on 3/19/2012

- 16:58:00 ERCOT region frequency prior to disturbance was 60.001 Hz.

- 16:58:08 138 kV capacitor breaker fails internally on "C" phase.

  - At 3 cycles, 345/138 kV autotransformer fails on "C" phase
  - At 4.1 cycles, 345/138 kV autotransformer differential relay protection issues trip signals to the 345 kV bus breakers and the autotransformer 138 kV circuit breaker
  - At 5.8 to 6.7 cycles, the 345 kV bus circuit breakers trip. This causes the loss of 422 MW of radially connected generation
  - At 5.8 cycles, the 138 kV bus breakers receive trip signals from the 138 kV bus differential protection
  - At 8.8 to 9.1 cycles, the 138 kV bus circuit breakers trip (except for one breaker which was slow to trip). This isolates the failed 345/138 kV autotransformer from the system.
  - At 18.4 cycles, the last 138 kV bus circuit breaker trips. This isolates the failed 138 kV capacitor circuit breaker from the system.

- 16:58:36 ERCOT region frequency drops to approximately 59.900 Hz

- 17:01:24 ERCOT region frequency recovers to 60 Hz.

- 17:57 to 17:59 System Operator begins to close circuit breakers on the 345 kV bus to restore the bus to service

- 19:19 All customer load restored

IV. Analysis of the Event

A. 138 kV Capacitor Bank Circuit Breaker Failure

This 138 kV, 3200 amp special purpose circuit breaker was connected to the 138 kV bus and functioning as the protection device for the 138 kV, 110 MVAR capacitor bank and used for switching on and off the first stage (36.8 MVAR) of the capacitor bank.

Investigation of the failed circuit breaker consisted of the following:

- On-site inspection post-failure
- Teardown of failed components
- Comparative measurements performed with an identical model breaker
- Lab analysis of failed components
- Manufacturer causal analysis investigation

Investigation of the breaker revealed that the C-phase linkage had failed to function properly due to the snap ring dislodging from the connecting pin on the H-Link that connects the operator crank shaft to the interrupter shaft. With the snap ring missing, the connecting pin disengaged from the circuit breaker interrupting shaft, causing the interrupter to operate improperly.

Root cause analysis concluded that the snap ring coming off the connecting pin was due to improper installation of the ring at the factory. This caused the snap ring to become dislodged over time due to force and/or loss of grip due to incorrect orientation. Both the connecting pin and snap ring were found on the floor of the breaker cabinet during inspection. The wear pattern on the ring showed on both sides, indicating that it could have been removed and re-installed at the factory.

When the pin fell out during a trip operation (by SCADA control to remove the capacitor bank), Pole C operating linkage disconnected at the sliding interrupter shaft which slowed the opening slightly as determined in the review of DFR records. Pole 3 interrupter was open, and held open by the gas pressure within the interrupter. At this point, the connecting pin was out of the H-link that normally couples the operator crank lever to the sliding interrupter shaft resulting in all three phase interrupters in the open position. No indication of abnormal conditions existed at this point since the breaker tripped successfully with all three phases clearing.

When the breaker was called upon by SCADA to perform a close operation placing the capacitor bank on-line, the crank lever on the operator shaft on Pole 3 contacted the sliding interrupter shaft and forced the interrupter toward the closed position. This resulted in Pole 3 being forced into a partially closed position for a period of time due to friction at the main and arcing contacts as the H-link was no longer in place to drive the interrupter contacts into the fully closed position.

The gas pressure within the interrupter forced the interrupter into a partially open position until the sliding interrupter shaft contacted the operating crank lever on the operator shaft. As the contacts parted, arcing initiated between the arcing contacts within the interrupter due to the slow contact part and no SF6 gas puff generated. The heating of the elements involved in the arc started with the phase partially closed and under the current of the capacitor bank. This eroded the arcing contacts and eventually melted the arcing nozzle. The nozzle and copper tungsten tip of the arcing contact separated and fell to the tank floor initiating a phase to ground fault within the interrupter tank. Upon inspection, the tip of the stationary arcing contact was found at the bottom of the tank.

The circuit breaker tripped 2.9 cycles after initiation of the ground fault. Since the fault was internal to the breaker, the 138 kV bus differential protection scheme operated to isolate the fault. However, because another bus circuit breaker was slow in opening, the ground fault continued until cleared by the remote end.

The breaker manufacturer participated in the root cause analysis at the manufacturer's circuit breaker plant, and will provide a complete manufacturer failure analysis report on this circuit breaker.

B. 345/138 kV Autotransformer Failure

The autotransformer was a 448 MVA, 345/138 kV shell form designed unit that was manufactured in 1979 (33 years of age). It was connected to the 345 kV bus through a 345 kV, 1,600 amp switch and to the 138 kV bus through one 138 kV Oil Circuit Breaker (OCB).

The following details the steps taken to perform a full root cause analysis and assessment of the modes of failure and damage for the autotransformer at the station. The assessment includes both electrical tests and physical inspections.

The autotransformer experienced a close-in 138kV through-fault resulting in failure of C-phase 345 kV winding as a result of the failure of the 138 kV capacitor bank circuit breaker. The ground fault was evidenced by a 345 kV C-phase voltage collapse to zero. The autotransformer differential operated on B and C phase. The sudden pressure relay operated. The mechanical relief device operated with oil release.

Visual inspection of the autotransformer after the failure showed that all three extra high voltage (EHV) bushings had porcelain movement at the mounting flange and exhibited oil leakage. The main tank walls were bulged and a burn mark was evident on H0/X0 bus bar where it was attached to the case.

Diagnostic testing was performed following appropriate testing procedures. A full suite of electrical tests was performed to give a complete condition of the autotransformer.

The autotransformer tests yielded the following results:

- Dissolved Gas Analysis (DGA) indicated electrical and thermal fault gasses with 830 ppm of Acetylene. The Total Combustible Gas (TCG) test showed the total combustible gases were greater than 3.0%.

- The DC Insulation test (also called Megger test) is used to determine integrity of autotransformer insulation. The test indicated a dead short between the high and low sides to the tertiary grounded. Half of the main core was shorted to ground.

- The overall power factor tests tripped the test set indicating a winding or lead shorted to ground.

- During the excitation current test, it was found that the H1 winding would not accept any voltage.

- The autotransformer turn-to-turn ratio (TTR) test is an electrical test to diagnose potential winding issues and to confirm if the autotransformer has the right ratio corresponding to its rated voltage in primary and secondary. In this case, the H1/X1 winding would not ratio.

- The sweep frequency response analysis (SFRA) test is a measurement to detect core or winding movement along with electrical short circuits within the transformer. During the SFRA Test, the H1 winding indicated extreme deviation from the H2 & H3 windings.

An internal inspection was performed to assess damage and locate potential failure causes. The inspection revealed extensive damage within the autotransformer main tank. The H1/X1 winding package was displaced with insulation and barrier boards blown out. The wooden lead structure adjacent to H1/X1 winding was sheared and displaced. The H1/X1 de-energized tap changer (DETC) was completely pulled off its mounting support. There were also extensive carbon deposits littered throughout main tank.

C. 345 kV Bus Reclosing Scheme Failure

During the trip of the 345 kV autotransformer, design of the system allows for the reclosing of the 345 kV Bus after the high side switch of the autotransformer trips. This did not occur on March 19, 2012. The condition was initially discovered on October 12, 2011 during relay maintenance when the electric reset portion of the 345kV bus differential lockout relay test failed during testing on the 345/138 kV Autotransformer.

During relay testing of the Autotransformer DC control scheme, the 345 kV bus did not reclose after the 345kV Motor-Operated Air Break (MOAB) switch opened because the electric reset function of the 345 kV bus lockout relay was defective. The TOP determined repair would require a bus clearance in order to replace the lockout relay. Such a clearance would have to be coordinated with the RC, a generator owner/operator, and a 345 kV customer. The TOP decided to coordinate the outage for the spring of 2012, and the relay technician let system operator know that, in the interim, the bus would not reclose for a 345/138 kV Autotransformer fault. This information was communicated to the on-duty system operator, placed into the system operator log on October 12th and carried over on the carry-over log until January 29, 2012.

On January 28, 2012, the on duty system operator added an Information Tag to the autotransformer stating, “If Autotransformer trips the 345 kV bus relay needs to be manually reset . . . New relay panel will be installed later this year.”

The on duty system operator removed the item from the carry-over log on January 29, 2012.

When the outage occurred, there was confusion as to the loss of the 345 kV Bus, the autotransformer and the 138 kV bus. It appeared to fall outside of known parameters of normal relay operation. The Information Tag went unnoticed during the event.

An interview was conducted with the system operator whose login was used to place the Information Tag. The system operator could not remember placing the Information Tag, nor could he recall removing the information from the carry-over log.

D. 138 kV Circuit Breaker Delayed Clearing Time

This circuit breaker functions as the line protection for a 138 kV line to another transmission owner. This breaker was the last breaker to open at the substation during the event and the remote line breaker cleared the fault before this circuit breaker opened**.** This circuit breaker reached its open state 4 cycles after the remote breaker cleared the fault or 12.3 cycles after it received its trip signal.

An investigation was performed on the 138 kV circuit breaker after it exhibited delayed clearing time during the failure event. During the sequence of events, the circuit breaker failed to open until 18.4 cycles after the start of the fault, a few cycles after the remote circuit breaker cleared the fault.

Internal inspection of the breaker found assembly components that needed replacement. Upon removing the bell crank cover, bearings in the bell crank showed to be slightly seized. Further investigation after removing the trip latch assembly revealed a bolt being used in place of a pin. The pawl was found to be bent on the smaller end. With the pawl being bent, it could not release off the pressure plate that it rests on.

Neither a manual nor an electrical operation could move the pressure plate enough to release the pawl.

The corrective actions that have been taken include 1) replacing the entire trip latch assembly including the trip coil, 2) replacing all bearings in the operator as well as two bearings in the bell crank, 3) adding a connecting pin in place of the bolt, and 4) replacing the roller bearing.

V. Response Analysis

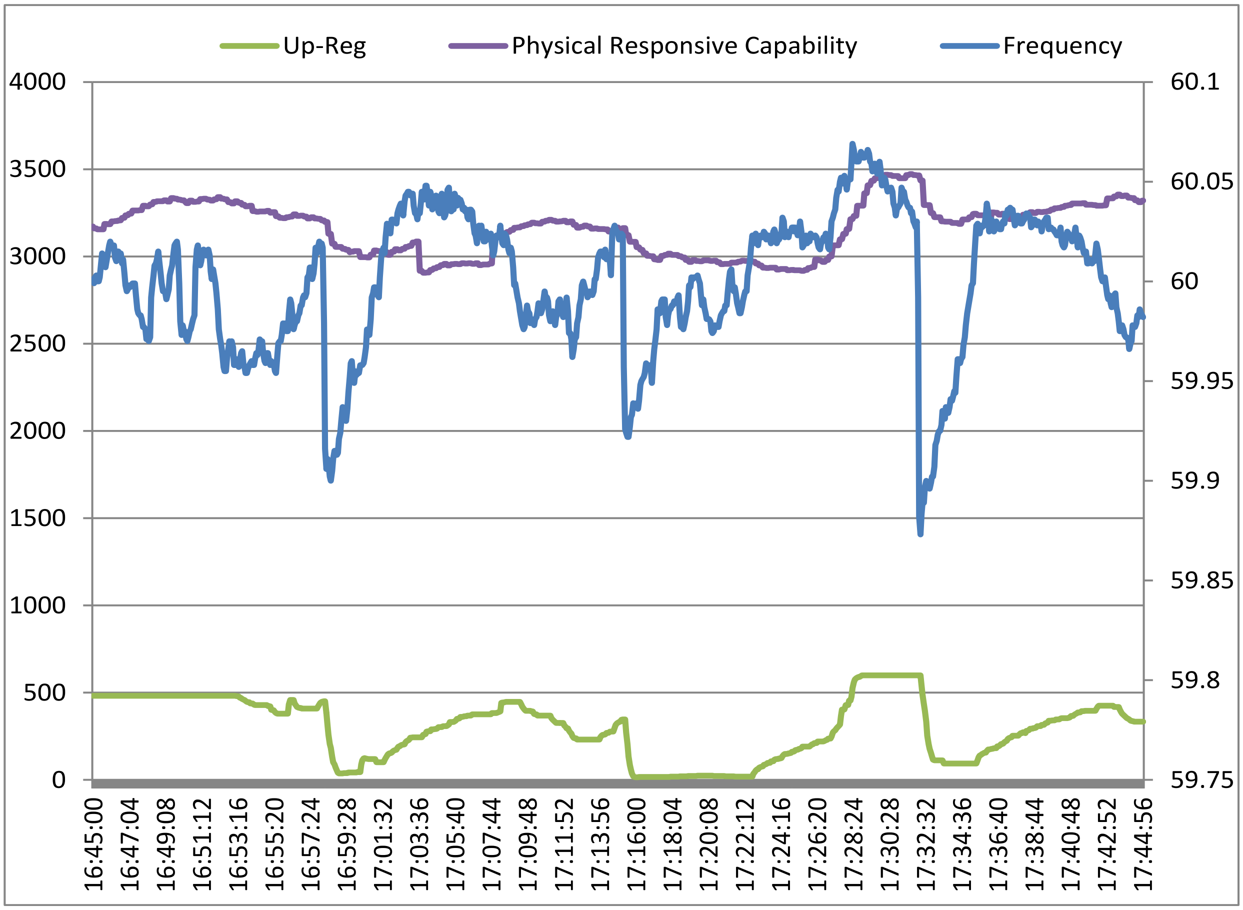
A. Initial Response

The loss of generation in the ERCOT Region during the afternoon of March 19, 2012 constituted a minor disturbance to grid. The BA used the Region's resources and reserves to balance resources and demand and return system frequency to pre-disturbance frequency well within the 15 minute target set by the BAL-002 Disturbance Control Performance Reliability Standard.

ERCOT region frequency was at 60.018 Hz prior to the disturbance. Immediately after the disturbance, system frequency dropped to 59.900 Hz, based on 4-second scans. The following are among the actions that registered entities initially took to stabilize the system:

- The BA's control center computer made a step deployment of 380 MW of generation regulation, within 10 seconds of the frequency bottom, modifying the setpoint sent to QSEs to accomplish this deployment. Texas RE did not identify any problems with this automatic deployment by ERCOT's system or the response from QSEs to ramp their generators output up within 10 minutes as required.
- As a result of these actions, system frequency returned to its pre-disturbance value of 60 Hz within 3 minutes and 15 seconds.

The loss of the multiple transmission elements (6-345 kV transmission lines, 345/138 kV autotransformer, and 138 kV bus) also created a minor disturbance to the grid. Due to the system conditions and low loads, the loss of the elements did not create any element overload conditions.



B. Reserves

The Physical Responsive Capability remained above 2900 MW for the duration of the event.

VI. Conclusions

Steps taken in the recovery from this event achieved the desired results. The TOP's System Operators effectively followed appropriate guidelines and protocols.