Entergy's Mayflower EHV Substation Tornado Restoration

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Abstract- On April 27th, 2014, five tornadoes packing winds up to 200 miles per hour ripped through central Arkansas. Entergy's Mayflower EHV substation sustained a direct hit from one of the tornadoes registered as an EF4. Nearly 70% of the substation was destroyed. With summer load fast approaching, it was essential to return the substation to service as quickly as possible. This paper discusses a unique two phased approach to restoring this substation to normal. The first phase was a temporary solution that returned the substation to service by June 3rd, 2014; exactly 37 days after being destroyed. The second phase was the permanent solution that converted the existing 500KV ring bus to a breaker and a half arrangement. This construction occurred while the temporary solution was energized.

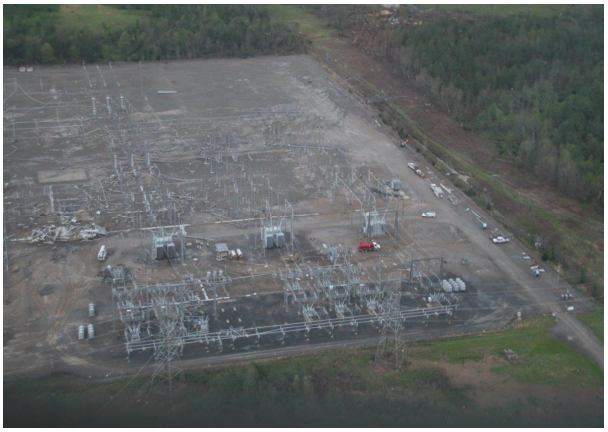
Introduction

Entergy is a large investor owned utility serving a four state area through operating companies in Arkansas, Louisiana, Mississippi, Texas, and New Orleans.

Mayflower is a critical substation within the Arkansas 500KV system, providing power into the 115KV grid via three auto-transformers. On April 27, 2014, five tornadoes ripped through central Arkansas packing winds up to 200 miles per hour. Entergy's Mayflower EHV substation sustained a direct hit from one of the tornadoes registered as an EF4. Nearly 70% of the substation was destroyed. Twenty five 500KV transmission line structures and seventy six 115/161KV structures were destroyed. With summer load fast approaching, returning the substation to service as quickly as possible was essential.

This paper will focus on the technical challenges Entergy faced during the substation restoration effort including safety, environmental, procurement, and protection and control issues. The discussion will cover a unique restoration approach featuring a temporary and permanent solution.

Before



After

Safety and Environmental

The first responders to set foot inside the remains of the substation were witness to countless

scenes of destruction, such a bucket truck lying on top of what used to be the relay control house, steel structures twisted beyond recognition, and several inches of crushed rock simply vanished from the substation floor.

The batteries within the control house continued to leak acid into the cable trough system, which had to be quarantined to prevent exposure. Once the bucket truck was removed from the control house and the structure was deemed safe enough to enter, the environmental personnel were able to contain and remove the battery set.

The substation includes three 500/115KV auto transformers holding roughly 24,500 gallons of oil each. With all of the projectiles, radiators on two of the three auto transformers were damaged and leaking oil. The oil containment in place was only as good as the environmental standards from when it was constructed in the 1970's. Several internal, state, and federal environmental experts assisted with the clean-up of the spills. The bigger challenge was choreographing the operation and restoration functions without impeding the environmental mitigation and restoration process while remaining safety oriented.

The demolition process included removal of a large number of twisted structures in the substation and transmission line right of ways. The structures could not simply be unbolted and taken apart; with the twisting of the steel, every structure had to be approached with a safety conscious mindset. There was at least one safety coordinator present onsite everyday during the temporary restoration. Each morning began with a group safety moment before work started followed by individual group tailboards.

Material Requirements

With such a large quantity of damaged material the procurement group was an integral part of the core restoration team. Entergy's operating companies have a database with a limited quantity of spare EHV substation and relaying equipment, which created a huge challenge considering the limited amount of restoration time available. The core team compiled a list of available spare material along with material that was scheduled for delivery for other projects across the Entergy jurisdictions. With this list, and leaning on some preferred suppliers, a temporary solution was developed.

Temporary Solution

The challenge was to develop a temporary solution with the limited amount of physical and relay material available. The goal was to restore at least two auto-transformers and reconnect

them to the two 500 KV transmission lines leaving the substation. Before the core design team was able to visit what was left of the substation, word was received that one 500KV breaker remained in what appeared to be usable condition, two of the three auto-transformers could be repaired, and one 115KV bus could be easily restored. On paper a couple of options were sketched using the one remaining breaker as to what was thought of as an achievable plan in the time frame given.

After the core team was able to set foot onsite they quickly discovered that the initial ideas would have to be reconsidered, and a more creative solution would be needed. What previously looked good on paper wasn't practical as all of the 500KV bus work leading to the remaining breaker was on the ground and twisted. Material needed to reconstruct the 500KV bus was not available in the timeframe needed. The idea of using string bus to create a temporary bypass was tossed around and after several discussions was determined to be the best option. Triple bundle transmission line would connect to the existing dead-end structure and run across the yard, passing in front of the auto-transformers and eventually connecting to the dead-end structure for the other transmission line. Wooden poles would support this string bus high above the substation to allow for future bus work to be constructed at a normal EHV height without having to take the by-pass out of service. In order to provide high side separation between the two auto-transformers a breaker and motor operated switch were placed between them. Figure 1 shows the temporary bypass arrangement as described above and figure 2 shows the portion of the 115KV that was energized during the temporary phase.

Entergy had one available spare 500KV breaker that was used here. As a contingency plan Entergy purchased a 500KV breaker from another utility company that would serve as a spare. None of the existing auto-transformers were in a usable condition; each transformer either had radiator damage, control cabinet damage, damage to the gauges or bushings. With the long lead time for some of these parts and the fact that two of the transformers were identical, parts were salvaged from one to restore the other. Entergy was able to find the parts needed to repair the third auto-transformer. This would give Entergy two fully restored auto-transformers.

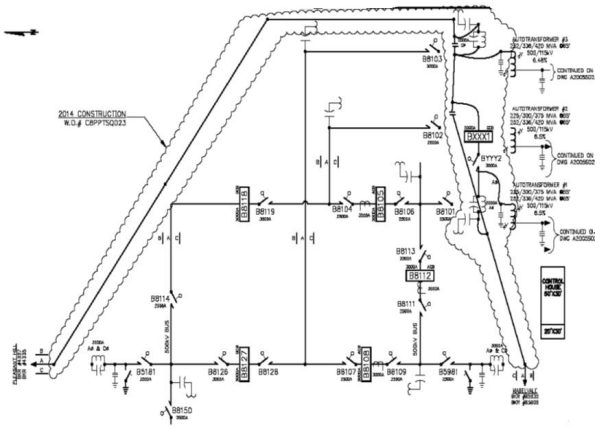


Figure 1.

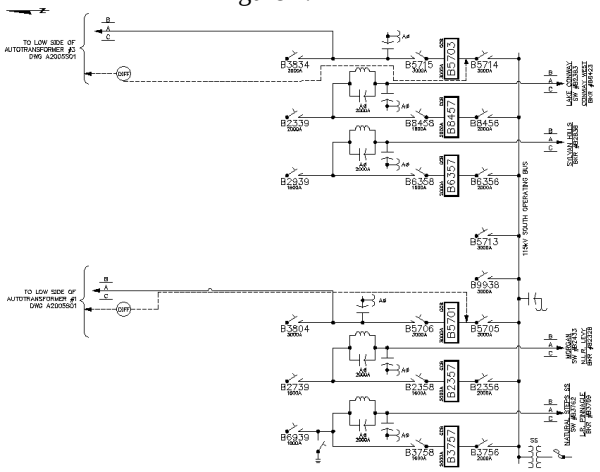


Figure 2.

Since Mayflower restoration was given the highest priority among existing projects any relay material deemed necessary was borrowed from previously scheduled projects, even those that were currently in construction. For the 500KV section the following material was borrowed: four CCVTs, two traps/tuners, one line panel, one line/breaker control panel both with carrier capability, and two transformer differential panels were borrowed. This would allow for single phase carrier communications between Mayflower and the two remote 500KV substations. The two transformer differential panels didn't meet Entergy's typical level of auto-transformer protection standards; however they provided the minimal amount of protection needed. Since there was no high side interrupting device to disconnect the transformers from each transmission line, the protection scheme was setup to trip the 500KV tie breaker and key a transfer trip to either remote end in the event of a transformer differential operation.

The 115KV portion of the substation sustained less damage from the tornado. The south bus remained standing with a couple of breakers sustaining minor damage. The entire 115KV north bus was lying on the ground and the breakers connected to it were destroyed. It is amazing how a distance of approximately 25' south was enough to save the south bus from the ravages of the tornado. To protect the 115KV section, 6 relay panels were borrowed from multiple projects: one bus differential panel, four line/breaker control panels, and one dual breaker control panel. The dual breaker control panel was used for the two autotransformer low side breakers.

The next challenge was deciding where to place the protection panels since the existing control house was destroyed. A control house is another long lead item but the core team was fortunate to find a vendor that had one that could be delivered in time. The available control house had only enough room to accommodate the required panels, which meant no space remained for a battery set. Finding a battery set and a place to put it wasn't as difficult as initially thought. Entergy decided to use a temporary battery trailer from the maintenance department. The battery trailer was positioned adjacent to the temporary control house with cables connecting it to the disconnect switch in the house.

The challenge of providing relay protection wasn't over yet. Load flow studies indicated thermal overloads for first contingency loss of one auto transformer. To mitigate this concern, a unique tripping scheme was put in place to companion trip the North Little Rock Levy line's breaker any time one of the autos tripped and the remaining auto transformer overloaded. With the simplistic single 500KV breaker arrangement; there was concern among the core group about the possibility of the 115KV back feeding the 500KV. Should the 500KV breaker that tied the two 500KV lines together trip without either low side breaker tripping, the concern was that power would flow from one 500KV line through the 115KV bus and back onto the other 500KV line. Reverse power elements are not typically implemented in Entergy's breaker control relays, but to insure that the previously mentioned situation wouldn't happen the 32 element in the relays were used to trip under a set MW flow in the reverse direction. These were the only two major challenges presented during design of the temporary protection scheme for the 115KV bus.

Permanent Solution

Determining what the ultimate arrangement of the substation would be was the simple part; constructing the permanent arrangement with the temporary solution energized posed the challenge. The original substation was a five breaker ring with two 500KV lines and three auto-transformers. The substation was originally laid out to allow for expansion into a breaker and a half arrangement; during scoping of the permanent solution the decision was made to reconstruct the substation into this configuration. Figure 3 shows the permanent solution arrangement. By placing one auto-transformer per bay, the electrical separation was increased, preventing any breaker failure from tripping two auto-transformers at the same time. This also allows for future expansion to be performed easily. Bus work for the ultimate arrangement started once the temporary solution was energized, and since the strung bus was above the clearance zone, the majority of the work could be done with the exception of the cut-ins.

From a protection stand point, switching the 500KV section from the temporary arrangement to the final arrangement presented a challenge but the physical aspect of the transfer was straight forward. A brief outage would be needed to add jumpers to connect the respective substation components into the final arrangement. Attention was necessary to ensure there were no gaps in protection during the transfer.

At this point, auto-transformer #2 was connected to the permanent solution since it was never connected to the temporary bus work. Prior to the cutover, the relaying for the 115KV north bus was tested and commissioned along with auto-transformer #2 and the new 500KV arrangement. The safest process with the least amount of outage time was approached as follows. First, take an outage on one of the 500KV lines while simultaneously taking an auto-transformer out so that they could both be transferred to the ultimate arrangement. The next step was transferring the low side of both auto transformers and associated loads to the north bus so that they would be protected with the permanent relaying. Once this was complete, the third autotransformer and second 500kv line

were moved to the permanent relay protection scheme, followed by the 115kv south bus, and finally the remaining 115kv relaying.
The 500KV breaker that was purchased as a contingency plan was used in the permanent solution, although some work was required to install the necessary alarm devices to meet Entergy standards. The permanent solution took approximately 1 year to complete. Figure 3 below is the permanent 500KV arrangement and figure 4 is the 115KV restored arrangement.

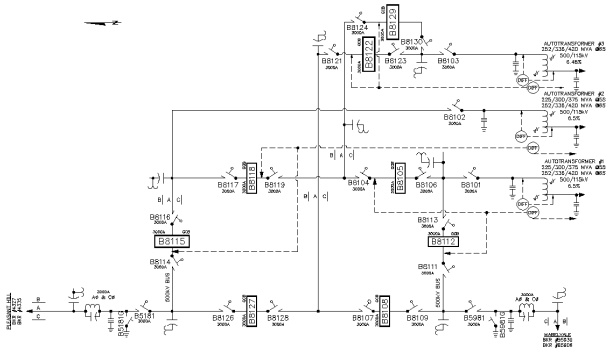


Figure 3.

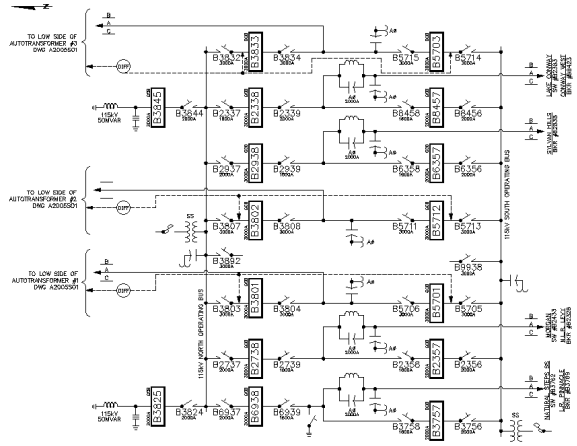


Figure 4.

Conclusion

The EF4 tornado that damaged the Mayflower substation brought many challenges to Entergy and its employees. A core team was selected to determine what the obstacles were and how they could be overcome in the short window that was given due to the fast approaching summer load. If the timeline given was not met, it was envisioned that a potential rolling brown out could have occur. The only way this project was achievable was with everyone working together with perfect coordination and communications. Materials borrowed for the temporary restoration effort included:

6 Transmission Line Panels
2 Transformer Differential Panels
1 Bus Differential Panels
1 Dual Breaker Control Panel
1 SCADA RTU
1 HV Circuit Breaker
1 Battery Trailer
1 Battery Charger
Additional minor material was needed.

Materials needed for the Permanent solution:

New control house
60 - Relay panels
4 – 500kV Line traps
4 – 115kV Line traps
16 – 500kV CCVTs
13 – 115kV CCVTs
800,620 feet of control cable
15 – 500kV switches
5 – 500kV breakers
2 – RTUs

David Daigle, P.E. BSEE-1984 Graduate of the University of New Orleans. Member of IEEE. David joined Entergy in 1984 as a telecommunications engineer. He later moved into substation maintenance and became relay maintenance supervisor in 1994. He moved to his present position as relay design supervisor in 2000. David is a registered professional engineer.

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Michael Milton, PMP Graduate of the University of Central Arkansas. Michael joined Entergy in 2008 as project manager in operations information technology. In 2011 he joined the transmission project management and construction group working as a project manager. Prior to this he worked in a management role in the financial sector for more than eight years, with experience ranging from Federal Reserve to small business banking. Michael is a certified Project Management Professional (PMP).