SWITCH BEARING ISSUES AND SOLUTIONS

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ABSTRACT

Brazos Electric Power Cooperative began experiencing operational failures of 138 kV switches in 2017 that continued for the next several years. An investigation into the operational failures determined that the bearing assemblies on the rotating insulators were at fault. The bearing assemblies had suffered moisture ingress, which caused them to rust and to seize. Temporary and long-term solutions were researched and implemented in order to address existing switches, and the purchase specifications were updated to prevent bearing issues on new switches.

INTRODUCTION

Brazos Electric Power Cooperative (Brazos) experienced a switching failure on October 19, 2017, when the Itasca M30 switch failed to close. The 138 kV motor-operated horizontal mount vertical break (HMVB) switch was only able to close about 20 degrees of the 95 degrees (blade angle) required to travel from open to close. The operating arm that connects the drive rod to the rotating insulator of the driven phase broke at the rotating insulator. A mobile substation was installed in order to isolate the switch and the switch was replaced. Brazos then experienced two similar switching failures, in which the switches failed to open, on October 26, 2018, at two stations that are sequential on the same line. All three switches were 138 kV, 2,000 A, Southern States EV-2 switches manufactured in 2006, and all three switches were horizontally mounted.

IDENTIFYING THE PROBLEM

Starting with the first switch, the rotating insulators were found to be locked up and unable to rotate. The live parts could move freely when disconnected from the rotating insulators, and the rotating insulators could not rotate even when disconnected from all drive hardware. This meant that the bearing assemblies were at fault. The bearing assemblies from the first switch were disassembled in order to determine the root issue. Figures 1 through 4 depict the investigation into the bearing assemblies. First, the castle nut was removed from the bottom of the shaft, then the shaft was pressed out of the housing and the grease removed from the shaft. Then the upper and lower bearings were pressed out of the housing (or pulled from the shaft if they stuck to the shaft), and finally the bearings were dissected.

Bearing Assembly
Figure 1

Shaft Removed from Housing
Figure 2

Bearing Removed from Housing
Figure 3

Bearing After Removing Outer Race
Figure 4

In every instance, a significant amount of rust was found in both the upper and lower ball bearings. It was also reported at Itasca that water was pushed out of the bearing assembly when grease was pumped into the housing in an attempt to free the bearings. Moisture intrusion was clearly causing some of the steel in the bearings to rust, but our specifications for 138 kV and above gang operated switches require stainless steel bearings. While stainless steel can rust, the amount of rust found in the bearings was far more than expected for switches not installed in a corrosive environment.

Due to the amount of rust on what we believed was stainless steel, Brazos had a third party perform material testing on the bearings to determine the types of steel used for their construction. The inner and outer races were found to be SAE 52100 steel, and the balls were found to be 400 series stainless steel. While 52100 is a common steel for bearings, it is not a stainless steel and is quite susceptible to corrosion. [1]

Our investigation found that water was collecting on top of the top bearings whenever the switches were exposed to rain. Eventually the water migrated under the seal and into the bearing. The water eventually migrated past the lower seal of the top bearing to the lower bearing. Since 2019, we have had multiple EV-2 bearing failures each year. All of the EV-2 bearing failures have been on switches that are horizontally mounted. None of the EV-2 switches on our system that are vertically mounted have experienced bearing failure. This is likely due to the fact that rainwater does not pool on the bearing seals since the seals are perpendicular to the ground when the switches are mounted vertically.

SOLUTIONS

The Power Maintenance group was tasked with researching and implementing solutions that would allow for repairing seized switches in the field. Due to the physical clearances available on the affected EV-2 switches, it is possible to replace the bearing assembly in the field without removing the rotating insulator or any of the live parts. Therefore, the chosen solution was to find a suitable replacement bearing and/or bearing assembly.

It was noted that Brazos had no record of bearing failures of the older EV model switches, which have been in service on the Brazos system since 1974. The EV bearing assembly has similar mounting dimensions to the EV-2 bearing assembly, but the EV bearing assembly utilized stainless balls and races in an aluminum housing. Brazos requested that Southern States resume manufacturing of the EV bearing assembly for field replacement of seized bearings and to use on future switches.

Until the old-style EV bearing assemblies could be procured, we needed to be able to rebuild the EV-2 bearing assemblies with stainless bearings that would not corrode and seize due to rain. The bearings used in the EV-2 bearing assemblies are 6209-2RS single row deep groove sealed ball bearings. Since stainless bearings have reduced strength compared to bearings made with 52100 steel, we had to ensure that whichever replacement bearing we selected would be able to sustain the mechanical loading of the switch. We sought a bearing that had the most corrosion resistance while still being able to handle the mechanical loading. The available options that we found were bearings constructed with 316 stainless steel and 440 stainless steel. The 400 series stainless steels can be hardened, so bearings made with it retain 80% of the load carrying capacity, compared to the equivalent 52100 bearings, while maintaining good corrosion resistance. The 300 series stainless steels cannot be hardened with heat treatment, so bearings made with it can only operate under low loads and speeds; however, they maintain excellent corrosion resistance. [1]

Since we have not seen failed EV-2 bearings on vertically mounted switches, we focused our efforts on loads seen by horizontally mounted switches. Bearings are typically designed for continuous, or at least routine, movement. However, switch bearings see very infrequent movement, and typically only rotate 190 degrees or less at very low speeds. Therefore, static loading was our primary focus. [2]

As a general rule, Brazos typically installs switches with minimal outside loading of the live parts. This is normally accomplished by either using flexible conductor with negligible tension or rigid bus with expansion joints that are supported without the switch. As such, there is minimal radial loading on the bearings. Most of the load seen by the bearings comes from the drive rod for radial and the weight of the rotating TR 288 insulator for axial, which was considered to be 150 lbf. [3] The weight of the live parts is carried by two insulators, but the loading depends on whether the switch is open or closed. To conservatively account for this, we used 2x the weight of the insulator for axial thrust in our calculations.

We needed to calculate the equivalent radial load for our loading situation in order to evaluate the different bearing options. In a previous switch research project, Brazos found that most 138 kV switches require 150 ft-lbs of torque or less to open. This was measured with a calibrated torque wrench and a jig to connect the torque wrench to the rotating insulator. Since the moment arm acting on the rotating insulator is approximately 14 inches, we used 12 inches as the moment arm to be conservative. This gives us a radial load of 150 lbf per phase, but the driven phase can see the combined force for all three phases combined, so we conservatively used 450 lbf for the radial load.

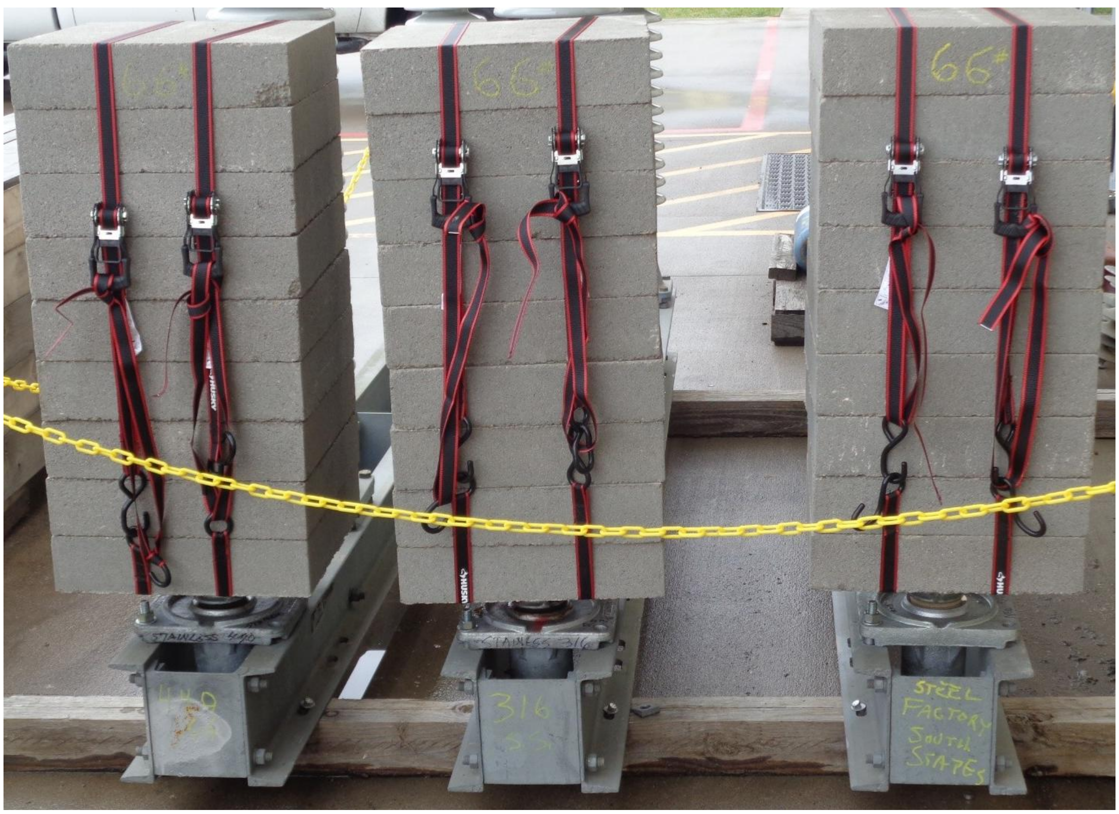
Equation 1 is given on page 571 of [1]. F_e is the equivalent radial load, F_a is the axial thrust, F_r is the radial load, V is a rotation factor (1 is used since the inner ring rotates), and X, Y, and *e* are found on Table 11-1 on page 572 of [1]. C_0 is the basic static load rating for a given bearing. C_0 for the 316 bearing is 1825 lbf and for the 440 bearing is 4108 lbf. [4]

$$\frac{F_e}{VF_r} = X + Y\frac{F_a}{VF_r} \qquad \text{when } \frac{F_a}{VF_r} > e \tag{1}$$

This gives us an equivalent radial load of 645 lbf for the 316 bearing and 741 lbf for the 440 bearing. These are both well below the static load ratings of both the 316 and the 440 bearings, especially when we consider that there are two bearings in each bearing assembly. We, therefore, selected the 316 stainless bearing from Lily Bearing for our bearing assembly rebuilding project.

Testing

Some of the management at Brazos was concerned with utilizing a non-OEM bearing in the rebuilt bearings, so they directed us to set up a simple test. We decided to rebuild one phase's bearing assembly with 316 bearings, rebuild another phase's bearing assembly with 440 bearings, and leave one phase's bearing assembly with the OEM 52100 bearings. We would then overload the bearing assemblies with four times the weight of a TR 288 insulator. We took a switch from inventory, removed the rotating insulators, rebuilt the bearing assemblies as described, and stacked 600 lbs of concrete blocks on top of each of the bearing assemblies. Figure 5 shows the test setup. The test switch was set up for 1 year, and each bearing assembly was rotated weekly for 2 months to verify that the bearings were still functional, and then the bearings did not move for the final 10 months.



Simple Overloading Setup
Figure 5

At the end of the year, all three bearing assemblies rotated freely with minimal input force.

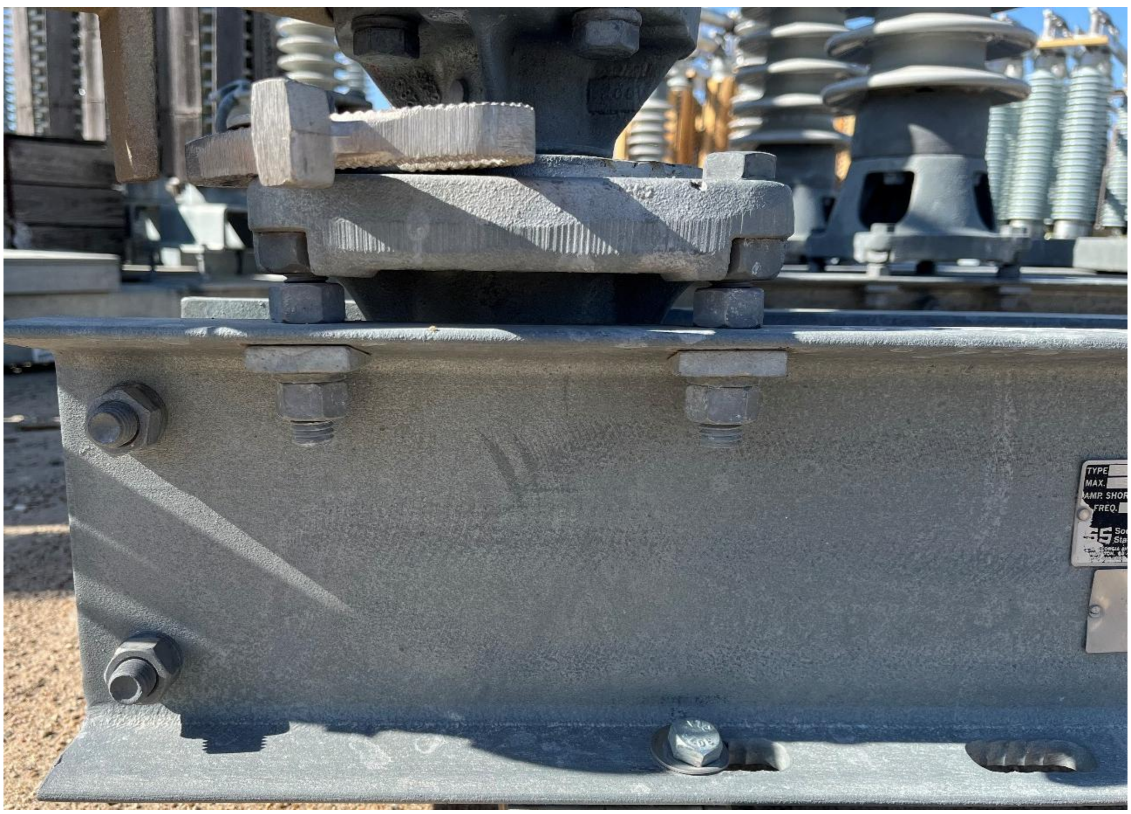
MAINTENANCE/REPAIR STRATEGIES

One of the main focuses for Power Maintenance was to advocate for more frequent operation of these switches. More frequent operation will help to prevent full bearing failure as well as allow us to find already-failed bearings during scheduled maintenance.

As noted previously, the design of the EV-2 switch allows for the field replacement of the bearing assembly without removing the rotating insulator. Once the switch is deenergized and grounded, the bearing assembly can be changed with the following procedure:

- Remove the lower bolts from the rotating insulator
- Remove the linkage arm from between the insulator and the bearing assembly
- Mark the threads on the jacking bolts and nuts with match-marks where the bearing assembly sits
- Remove the jacking bolts and note each one's location on the switch
- Lower the bearing assembly down to the switch base
- Slide the bearing assembly toward the stationary insulators
- Lift the bearing assembly out of the switch base
- Reverse the above steps to install the new or rebuilt bearing assembly, making sure to set the jacking nuts and bolts in their original locations and line up the match marks

Figure 6 shows a close view of the bearing assembly and how it is mounted to the switch base. By working carefully and intentionally, it is possible to replace the bearing assembly without compromising the switch's adjustment or alignment.



Bearing Assembly Mounted on Switch Base
Figure 6

NEW SWITCHES

In order to prevent future bearing failures, Brazos has updated our general specifications for all 138 kV and above gang-operated switches to require all of the metal components of bearings to be made of stainless steel, including the balls, cage, inner race, and outer race. Southern States now offers their EV style bearing assembly on EV-2 switches, which is the option that Brazos selects. The bearing assembly is available with or without seals, and Brazos selects the option without seals to allow water to flow through the bearing assembly.

CONCLUSIONS

We have installed 96 rebuilt bearing assemblies with 316 grade stainless steel bearings on 32 total switches since we first started rebuilding them in 2019, and none of the rebuilt bearing assemblies have failed. Additionally, none of the EV-2 switches that were purchased with fully stainless bearings have experienced a bearing failure.

Proactive switching programs can help to prevent bearing seizure and allow for existing switch issues to be discovered during scheduled maintenance. It is also important to have an adequate inventory of spare parts in order to make field repairs possible and timely.

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BIOGRAPHY

Thomas Wittner is the Power Maintenance Superintendent at Brazos Electric Power Cooperative in Waco, Texas, a role he has held since 2021. Previously, he served as the Power Maintenance Engineer from 2015. He holds a Bachelor of Science in Mechanical Engineering from Baylor University. His team oversees testing and maintenance of substation equipment, including transformers, circuit breakers, disconnect switches, capacitors, reactors, arresters, and batteries.