Misbehaving Capacitor Controllers Spell Trouble

DFA Technology Corrects Problem, Prevents Damage

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On August 9, 2004, Pickwick Electric Cooperative performed annual maintenance on some of its capacitor banks. This included testing the banks and replacing their controllers. At 13:21 that afternoon, one bank began cycling ON and OFF repetitively. By the end of the day, it had cycled 22 times.

As a customer of TVA, Pickwick participates in the Distribution Fault Anticipation (DFA) project that EPRI sponsors at Texas A&M University. Shortly after the capacitor began cycling, the DFA Prototype at the substation that feeds this feeder indicated the problem, and Pickwick dispatched a crew to the offending bank. The crew made a simple change to the bank's controller settings, thereby correcting the problem less than 24 hours after it began.

Without the DFA, the bank would have continued to cycle excessively for an indefinite period of time, probably until the next annual cycle or until it caused a problem. It is difficult to know what the effects of prolonged misbehavior would have been if the condition had been allowed to persist. Therefore, it also is difficult to quantify the benefits derived by finding and fixing the problem early. In this case, however, another utility's DFA-related efforts provided this important information.

TXU Electric Delivery also participates in the DFA project and has a DFA Prototype installed at one of its substations. One of TXU's primary objectives in the DFA project is to document the consequences of faults and other anomalous behavior, which will enable them and others to quantify the benefits of anticipating and preventing these problems. This is creating a valuable body of information that does not exist today. TXU allows their DFA-monitored feeders to operate as they normally would if the DFA were not present. They use the DFA to monitor and document the progression and consequences of various problems and failures. Some of this information is directly applicable to the case at hand. The following paragraphs illustrate what happened when a malfunction of a TXU capacitor controller, identical to the malfunction at Pickwick, occurred and ran its natural course.

In January 2004, a capacitor bank on one of TXU's feeders began to misbehave. During early January, it cycled ON and OFF an average of 28 times per day, a figure remarkably similar to the 22 times Pickwick experienced the afternoon their problem began.

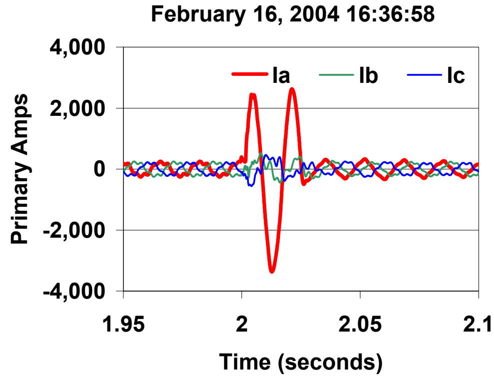

Figure 1. After 3,000 switching operations in a few weeks, the phase-A capacitor finally gave up.

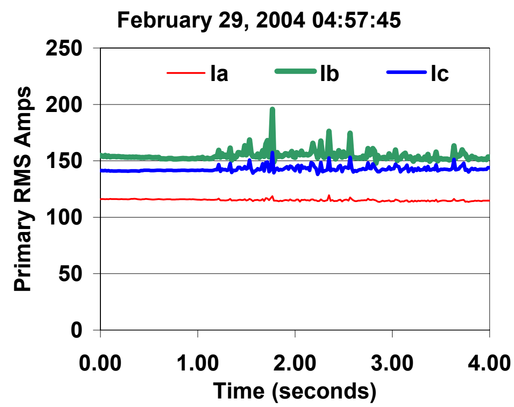

Figure 2. Weeks of excessive operations wore out the switch.

Over time, the problem worsened. By mid February, the bank had logged more than 3,000 switching cycles in a period of less than two months.

On February 16, the bank's phase-A capacitor finally gave up, resulting in the overcurrent fault of Figure 1 and the loss of the capacitor on that phase. After this, the frequent cycling continued and the average number of daily cycles increased further. The worst single day was February 18, when the bank cycled more than 185 times in a single day!

The problem escalated further on February 29. Figure 2 shows the RMS feeder currents measured

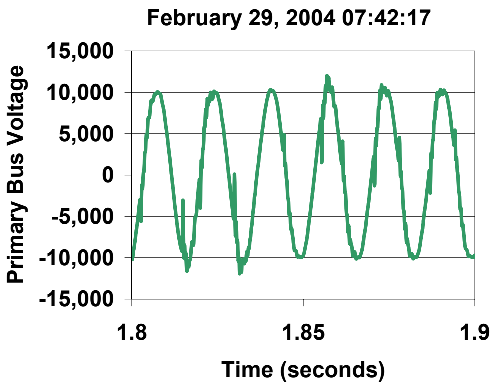

Figure 3. Failing switch produced severe voltage transients at bus for four days.

at the substation shortly after the bank switched ON that morning. When the bank switched ON, the internal contacts of its phase-B oil switch failed to make a good connection, presumably because of the excessive wear and tear they had accumulated during the past two months. This kind of poor connection results in contact arcing, which is electrically similar to the contacts making and breaking connection many times per second. Switching a capacitor ON a single time generally causes a significant voltage transient on the feeder, on the bus, and even on other feeders connected to that bus. This in turn causes a significant current transient. When capacitor switch contacts arc, their repetitive making and breaking causes countless instances of these voltage and current transients in close succession, as the waveforms of Figure 2 illustrate.

Figure 3 shows the repetitive voltage transients that a failing capacitor switch causes. In this case, these transients were measured at the bus, so they were seen by all customers connected to that bus, although it should be noted that TXU received no reports of customer problems during this period.

Contrary to intuition, this arcing problem did not burn the switch up rapidly, which might have cleared the problem from the system. Rather, for the next four days, the controller continued to cycle the bank ON and OFF many times. Whenever the bank was in the ON position, the switch arced internally and caused the repetitive transients on all feeders connected to the affected bus. After four days, the phase-B capacitor finally failed in an open-circuit condition, opening the electrical path and effectively removing the problem from the system.

Field Findings

After the entire sequence of events was over, a crew patrolled the feeder. They found numerous components with failures that had resulted from the excessive operations and the subsequent prolonged switch failure. The bank with the faulty controller had two failed phase "cans." The controller's counter confirmed that it had cycled the bank more than 4,000 times since the utility maintained that bank the previous summer. The phase-B oil switch had failed. The phase-A and phase-C switches had not failed, but they had experienced the excessive operations, making their continued service questionable as well.

In addition to the damage to the bank with the faulty controller, the nearly continuous series of transients caused two other capacitor banks to experience failures as well. One of the other banks was on the same feeder as the bank with the faulty controller, and the other was on another feeder connected to the same bus. Each involved failure of a single-phase capacitor can. Including the two failed cans on the bank with the faulty controller, there were a total of four failed phase capacitors.

One usually does not consider the possibility of a problem with one capacitor causing failure of others, particularly those on other feeders. However, basic circuit theory explains, and even predicts, this kind of interaction. Subjecting a capacitor to the kind of transients shown in Figure 3, time and time again over a period of days, causes repetitive surges of current through the capacitor, weakening it and eventually causing it to fail.

Conclusions

TXU Electric Delivery has used and continues to use the DFA project to build an important body of knowledge about "real world" failure processes. Relevant to the present case, they have documented the consequences of a misbehaving capacitor controller, a problem that one otherwise might assume to be relatively innocuous. Without this knowledge, few would have considered the extent to which this misbehavior affects not only the bank with the bad controller, but also other banks, even those on other feeders.

In addition to the technical knowledge that this project is producing, it also is providing the basis for quantifying benefits that can be achieved by using DFA technology to warn of incipient failures and other problems in their early stages of development. For Pickwick Electric, this meant the ability to solve a problem quickly, before it escalated, thereby avoiding significant voltage disturbances and the potential costs associated with labor and materials to repair or replace multiple capacitors, switches, and related apparatus.