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The BLeading Edge...

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Monitoring Capacitor Banks for Health & Performance

Introduction

Capacitor bank controls typically monitor neutral current to provide an indication of the health of the capacitors, fuses, and switches. Typically, with all three phases open, neutral current is not present. However, large amounts of neutral current will be present if the control commands the bank open, and two phases open but one phase malfunctions and remains closed. When the control commands the bank to close and a partial failure exists in one of the capacitors, a smaller but significant amount of neutral current will be present there as well. Finally, neutral current is detectable if a load imbalance exists between the three phases.

A popular way to monitor the status of the capacitor bank is to have SCADA send a command to operate the bank and then compare the VAr change at the feeder or bus. If one or more phases do not change by the expected value, the control can generate an alarm to alert system operators to inspect the bank.

This can be difficult to apply for smaller capacitors, especially when the metering at the substation is on the bus and not individual feeders as the change seen at the source may not be enough to determine the bank's health properly. Using this system, even when the bank is correctly flagged as failed, the capacitor can remain in the partially closed state until crews are dispatched. This can cause voltage disparities as well as increased neutral current.

> *With the advent of IVVC (Integrated Volt VAr Control) or CVR (Conservation Voltage Reduction), capacitors are playing an increasingly important role in the distribution grid. Unfortunately, capacitor banks are prone to partial failures due to lighting strikes and other issues. Most utilities estimate that over 40 percent of their capacitor banks are out of service at any given time. Without the capacitor banks, utilities can be penalized for low power factor and have increased reactive losses on their system. The loss of the capacitor banks makes it impossible for utilities to see the full benefits of IVVC or CVR because down line voltage will be too low to allow further reduction at the head end. For these reasons, it is vital for utilities to know the health of their banks in real-time.*

This article addresses the benefits derived from monitoring the capacitor bank for neutral current, considering the low cost involved to improve system reliability, power factor, and decreased energy losses, which is typically in the range of $200 per site for the additional equipment required.

Benefits of Monitoring the Neutral Current

Intelligent capacitor controls not only monitor the neutral current, but also allow for automatic operations on detection of abnormally high amounts of neutral current. If the neutral current was not present prior to an attempted operation (either an automatic operation or a remotely commanded operation), the capacitor control can assume that the cause of the neutral current is due to a partial operation.

The control can then initiate several retries in an attempt to get the phase that did not fully operate to complete the operation and finish in the same state as the other phases. If successful, this eliminates the neutral current and the capacitor bank can remain in service. If the neutral current is still present, the capacitor control can attempt to reverse the operation to remove the neutral current and have all three phases return to similar voltages and VAr flows. This is the preferred state as opposed to having an imbalance. The capacitor control can then lockout the bank and generate an alarm to SCADA to initiate a maintenance alert for the bank.

If the capacitor control detects neutral current without an operation being attempted, it can automatically trip the bank to remove the neutral current, as this is typically an indication of a permanent failure such as a blown fuse or failed capacitor. The control can then lockout the bank and assert a SCADA alarm.
This second scenario can cause the lockout of a healthy capacitor due to the misoperation of a single-phase recloser. For this reason, the capacitor control should allow for a time-delay before tripping the bank to allow lockout by the recloser timer. If the lockout is a three-phase lockout, this will eliminate the neutral current detected due to the single-phase tripping and reclosing, and the capacitor can remain in service. However, if a single-phase lockout is a possibility then the capacitor control can still lockout out a healthy capacitor bank.

In this case, the capacitor control should permit the user to program a lockout time followed by the bank returning to service. If the neutral current is still present during the next operation, the capacitor control will trip again and lockout the bank for the same period. If the operation is successful with no neutral current present, the capacitor bank can be returned to service. The utility should set the lockout time slightly longer than the average restoration time of a faulted line.

Figure 1 shows the oscilligraph from a closed capacitor bank with a blown fuse on one phase. The neutral current present is approximately 60 amps.

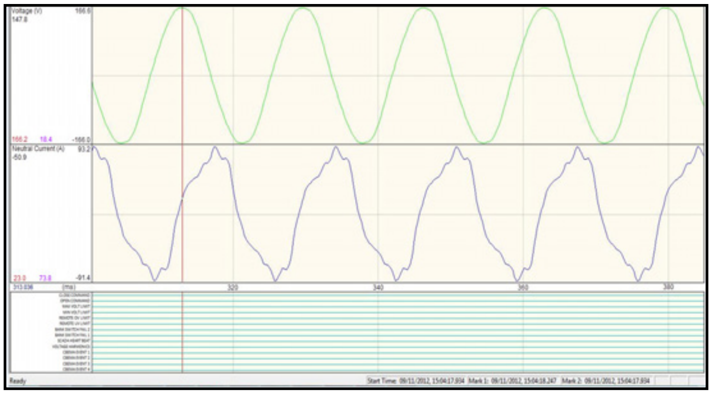

Figure 1: Capacitor with Neutral current due to blown fuse

Figure 2 shows the datalog retrieved from the same capacitor bank. As can be seen, the neutral current was very low prior to the blown fuse.

Figure 2: Datalog showing increased neutral current when fuse failed

An additional benefit of monitoring neutral current is its use as an aid in identifying sites that may be causing noise in communications equipment when the bank operates. By looking at the harmonics present in the neutral current one can predict when the closing of a capacitor bank may have an adverse effect on customers that are nearby.

Figure 3 shows an oscillograph captured by a capacitor bank controller. Notice that no neutral current is present prior to the capacitor closing, but when closed; the neutral current is present and settles into a third harmonic current; the same frequency used by many communications systems. Also, notice that the harmonics generated have an impact on the voltage in the circuit. By monitoring the actual neutral current, the utility was able to detect the problem and relocate the bank several spans from the original location, thus providing enough impedance change to eliminate the problem.

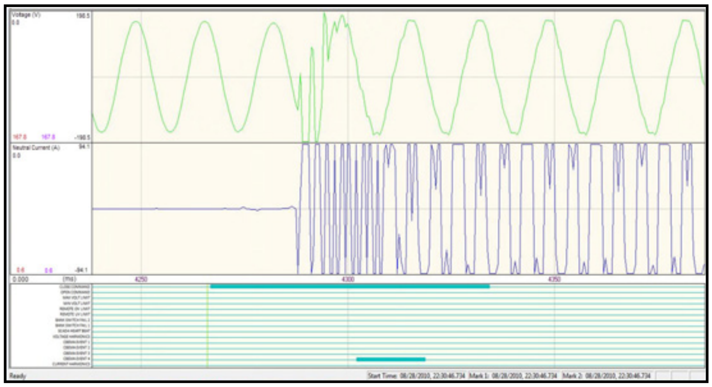

Figure 3: Closing of a capacitor bank with neutral current

Figure 4 further illustrates the clean voltage prior to operation and the harmonics on the voltage after operation.

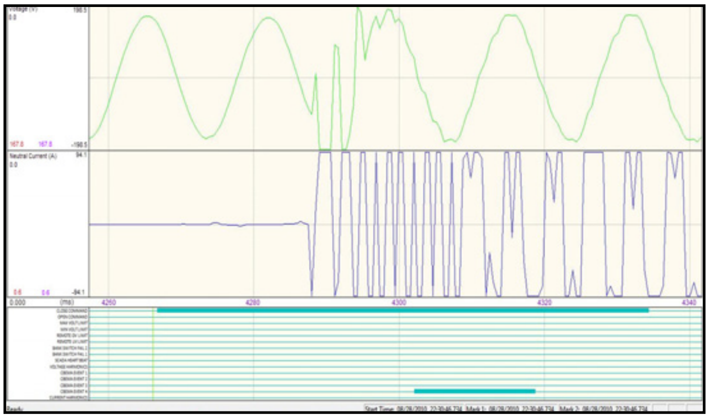

Figure 4: Harmonics caused by the closing of the capacitor bank

The recommended method of obtaining this harmonic information is by installing a CT on the neutral conductor. Avoid using line post sensors because the CT provides a more accurate signal. For safety reasons the recommendation is for a 0 - 200 mA CT as opposed to a 0 - 5 amp CT. **Figure 5** shows the addition of a 0 - 200 mA neutral CT to an existing switched capacitor bank neutral conductor.

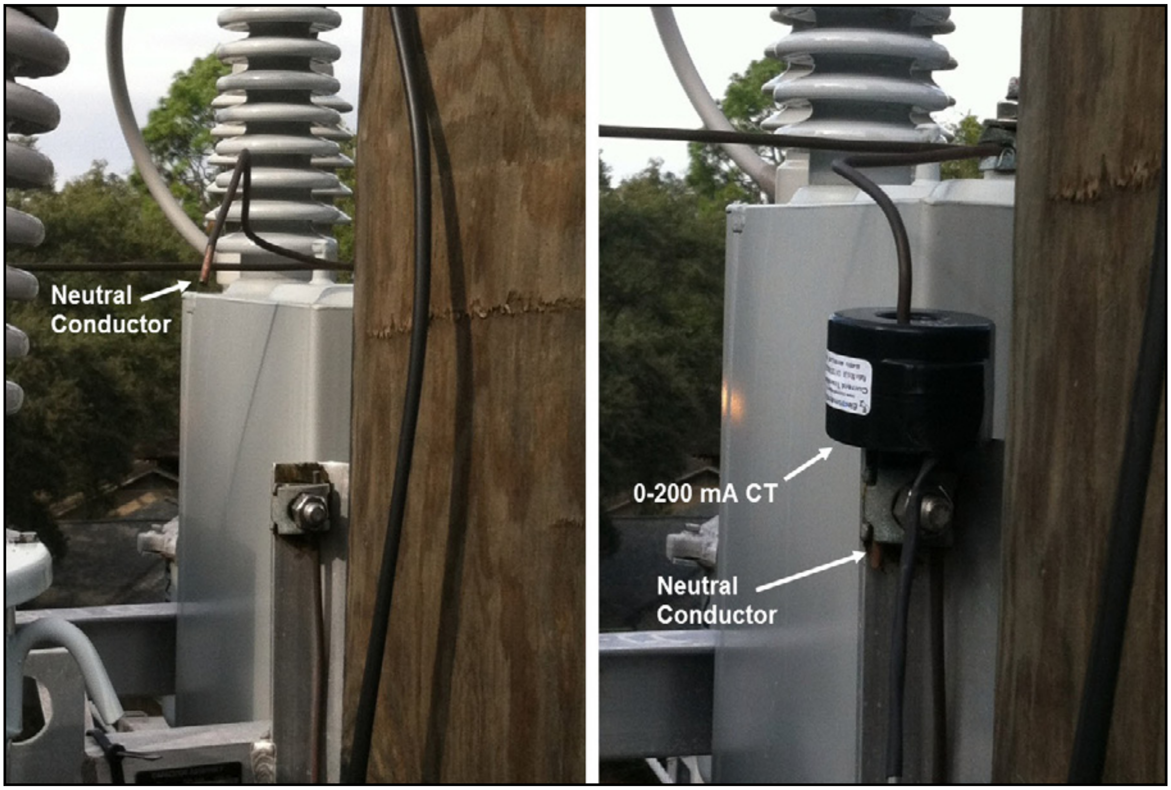

Figure 5: Neutral Current CT Installation

Installation of the Neutral CT

The most common error that occurs with neutral current monitoring is the incorrect installation of the neutral CT. Many utilities will tie the neutral of each capacitor can together and then either connect the common return to the pole ground or to the neutral conductor on the overhead circuit, or both. In the case where the common return of the capacitors is tied to both pole ground and the overhead neutral, it is important to locate the neutral CT close to the common return of the capacitors before it splits between going up the pole to the overhead neutral or going down the pole to the pole ground.

If placed in a location after the split, the neutral CT will not see all the neutral current and will be reading less than the total amount. Calculations performed based on the size of the bank and the voltage level of the feeder circuit will provide an estimated value. When commissioning the bank, close the bank temporarily with one phase open to verify that the neutral current monitored by the neutral CT is within the expected range of the estimated value.

Coordination Settings with the Neutral CT

The neutral current setting should be provided with a time-delay. The time-delay should be determined with two factors in mind. First, the setting should be longer than the operate time of the slowest switch. If the switches on the three phases have different operate times, neutral current will be present for a short duration for every switch operation. As an example, if the switch time on two of the phases is five seconds (motor driven switches) and the operate time on the third phase is 50 milliseconds (a solenoid driven switch) then neutral current will exist for almost 5 seconds on every switch operation.

In order to eliminate false alarms, the time-delay on the neutral current pickup should be set to at least seven seconds.

The second coordination issue for the pickup time-delay is due to single-phase recloser operations. If a fault is on one of the phases not providing power to the capacitor control, as the single-phase recloser trips that phase, the capacitor will see neutral current. The pick-up should therefore be set to a time longer than the setting of the lockout timer. This way, if the feeder holds in in one of the closing attempts prior to lockout, the control will not generate false alarms.

Conclusion

While capacitor bank failures can be detected at times by having SCADA monitor VAr flow after an operation this method has its drawbacks. First, it requires communications to be operational, second it requires SCADA to know when an operation should have occurred (i.e. the capacitor controls cannot be in local-automatic mode) and third, failures can be difficult to detect when the capacitor banks are small or the SCADA is monitoring a bus, and not a feeder.

Monitoring neutral current provides 100 percent coverage but also includes several other benefits. Once the control detects neutral current, it can automatically attempt a fix by retrying the operation, which can be successful in some cases. If the neutral current is still present, the capacitor control can attempt to return the bank to a state that will remove the current or remove it by tripping the bank off. Finally, the capacitor control can provide waveforms of the neutral current that can be used to detect negative effects that the capacitor bank may be causing with local customers.

Finally, the capacitor control can provide waveforms of the neutral current that is useful in detecting negative effects that the capacitor bank may be causing with local customers. Finally, the detection and attempted removal of the neutral current can be performed without the need for communications. In addition, those sites without communications can have an external LED connected to the capacitor control that serves as a visual alarm for drive by inspections when a neutral current condition is present. With the cost of the neutral current CTs being in the range of $200 per site, it is easy to justify the addition of the neutral current monitoring feature to all capacitors, even at fixed bank locations. uhQ

Author Profiles

Bob McFetridge is a Technical Applications Solution Architect for Beckwith Electric and has more than 20 years of experience in the electric utility industry. McFetridge worked as an application engineer with Virginia Power and Georgia Power. He also worked for several other well known industry suppliers with specialization in automation, protection and control. During his career, McFetridge has served as a project manager, field engineer, head of training/customer support and product testing/design engineer.

McFetridge holds a Bachelor of Science degree in Electrical Engineering from West Virginia University. He is the author of numerous papers on substation automation, many of which he presented at conferences such as Texas A&M and the Marquette University Substation Automation Seminars.

Barry Stephens is a Principal Engineer for Georgia Power in Distribution Reliability, Automation and SCADA. Stephens has more than 32 years of experience with Georgia Power, including 15 years of field engineering and operations in transmission substations and 12 years of field engineering, design, and operations in distribution reliability, automation and SCADA. Stephens is the technical advisor to the Southern Company Recloser & Switch Committee, and Chair of the Georgia Power Automation Development & Deployment Committee. He has a Bachelor of Science degree in Mechanical Engineering from the Georgia Institute of Technology and is a Licensed Professional Engineer in the state of Georgia as well as an IEEE member.