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Controlled Switching for Circuit Breakers with Pre-insertion Resistors Energizing Shunt Capacitor Banks

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SUMMARY

A circuit breaker equipped with a controlled switching system can energize a shunt capacitor bank at a relatively low voltage, reducing the inrush current to improve network stability and reduce equipment wear. An alternative solution to shunt capacitor inrush current is pre-insertion resistors, which reduce the inrush current during the most severe portion of the close operation.

The economics and electrical parameters of EHV and UHV systems often lead to the use of all available mitigation techniques rather than a single technique as is commonly used for lower voltages. However, interaction between different technologies must be evaluated to ensure that the optimal strategy is employed. When controlled switching and pre-insertion resistor are combined, special care must be given to match the controlled switching setting to this application.

Field data of a 550kV circuit breaker with both controlled switching and pre-insertion resistors were obtained. The controlled switching system was originally set to minimize initial inrush current through the resistor. This strategy proved to be insufficient for minimizing circuit breaker wear over a large number of operations. Analysis of the circuit breaker timing, system parameters, and resistor rating showed that a different closing target would decrease wear on the circuit breaker.

The principle of using a controlled switching system to energize a shunt capacitor bank using a circuit breaker equipped with a pre-insertion resistor is discussed in this paper. Performance data from before and after the change in controlled switching strategy is analyzed, showing that the change reduced the inrush current duty experienced by the circuit breaker interrupter.

KEYWORDS

Controlled switching system – Point on wave controller – Capacitor bank switching – Closing resistor – Installation and commissioning – Switchgear – Field testing experience

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1. Introduction

Both controlled switching and closing resistors can be applied on a circuit breaker to minimize inrush current while energizing a shunt capacitor bank by targeting a point where the voltage across the closing resistor is at a minimum when the resistor is bypassed.

A circuit breaker equipped with controlled switching can energize a shunt capacitor bank at a relatively low voltage, reducing the inrush current to improve network stability and reducing equipment wear. Typical controlled switching systems (CSS) continuously monitor bus voltage and send close signals to each phase with staggered timing so that the interrupters close shortly after the voltage zero for their respective phase. Pre-strike will always occur on EHV and UHV systems because interrupters cannot close instantaneously. The CSS must minimize the magnitude and duration of that pre-striking to limit wear on the interrupter, particularly the nozzle. The pre-strike with a capacitive load is especially damaging for the circuit breaker due to its high amplitude and frequency combined with a high number of operations [1]. On the other hand, when both controlled switching and closing resistors are applied together, it is necessary to consider that the voltage across the resistor influences the magnitude of the inrush current after the resistor is bypassed.

This paper shows the switching strategy, the reduction effect on inrush current, and the field application in a case where both controlled switching and closing resistors are applied together to the circuit breaker.

2. Analysis of Controlled Switching

The capacitor bank circuit inside a 500kV substation is shown in Figure 1 below. A single break dead tank circuit breaker is applied to switch a single 343.2 MVAr capacitor bank. The EMTP-RV analysis shown in Figure 2 is of the representative worst case close operation of this circuit breaker if it did not have either controlled switching or closing resistors.

Figure 3 shows the EMTP-RV analysis of this case with only controlled switching utilized to mitigate inrush current. It is confirmed that the inrush current can be reduced by controlled switching in comparison with no controlled switching as shown in Figure 2.

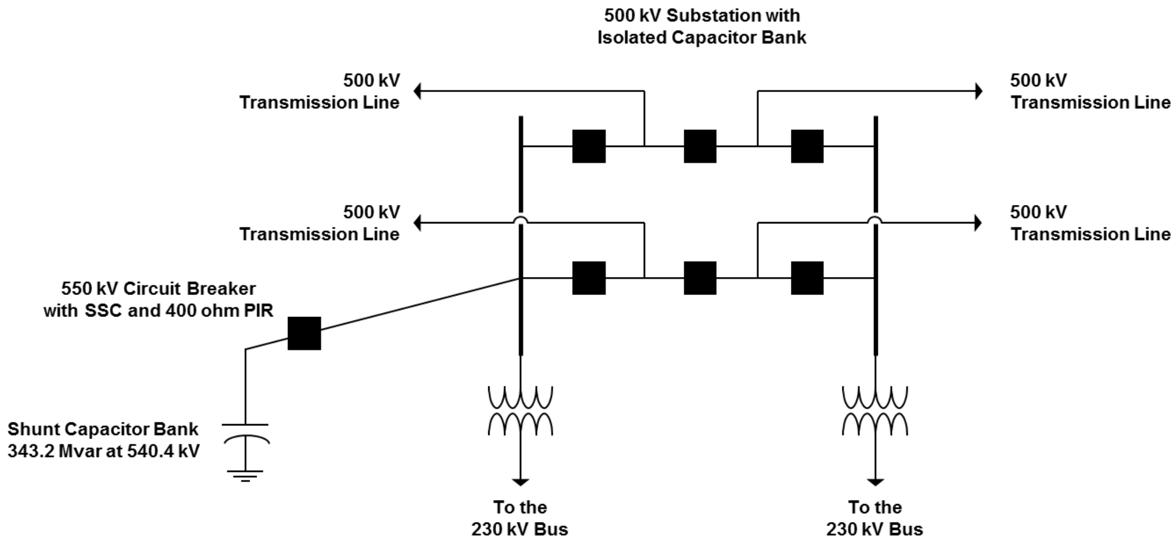

Figure 1 – One-line diagram

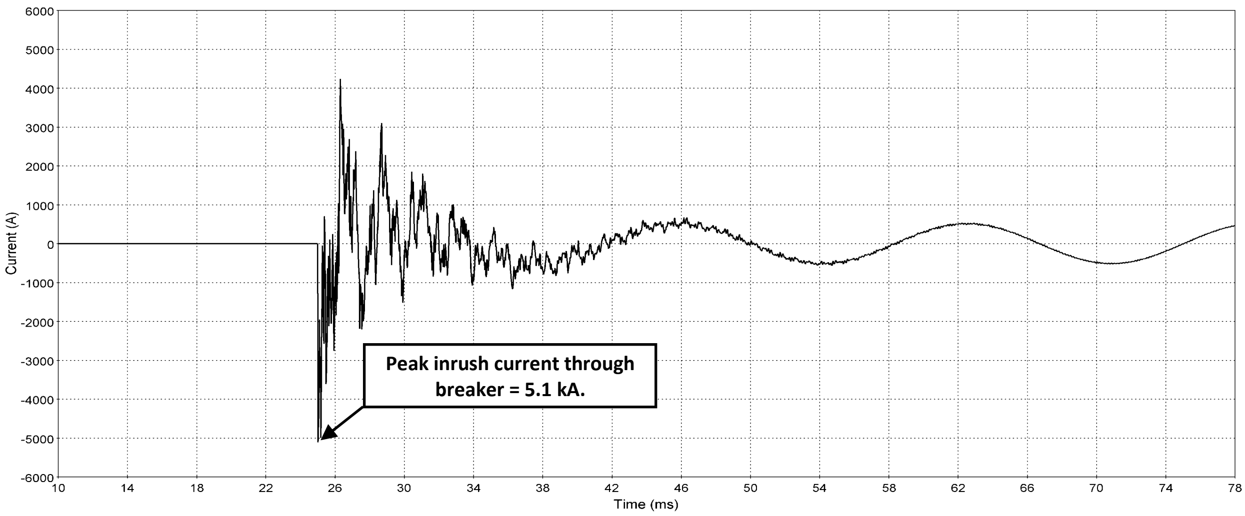

Figure 2 – Analysis of a close operation without controlled switching and closing resistors

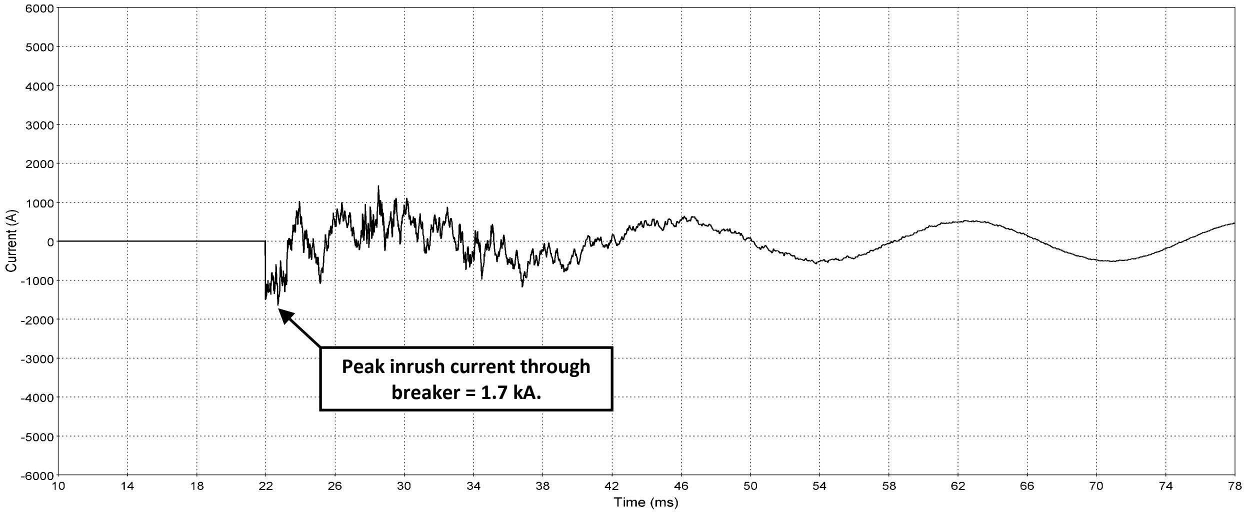

Figure 3 – Analysis of a close operation with only controlled switching

Furthermore it is necessary to use the closing resistor with controlled switching together to reduce the inrush current more effectively than only controlled switching. During the close operation, the pre-insertion resistor makes electrical contact first, several milliseconds before being bypassed by the normal current path of the interrupter. Pre-insertion resistors are typically sized to be able to withstand fault current through multiple operations in a short period [2], so they have no difficulty with the significantly lower current of a shunt capacitor bank load. After the pre-insertion resistor absorbs the initial most severe portion of the inrush current, it is bypassed by the interrupter's arcing contacts. The arcing contacts of the interrupter experience pre-strike even with the use of pre-insertion resistors due to the voltage established across the pre-insertion resistor.

The original point on wave setting for electrical make for this circuit breaker was 14° after a voltage zero based on the applied voltage, mechanical scatter, and the closing resistor's rate of decrease of dielectric strength (RDDS). This point minimizes the voltage at the point when current initiates through the closing resistor. The calculated result of this strategy is shown in Figure 4.

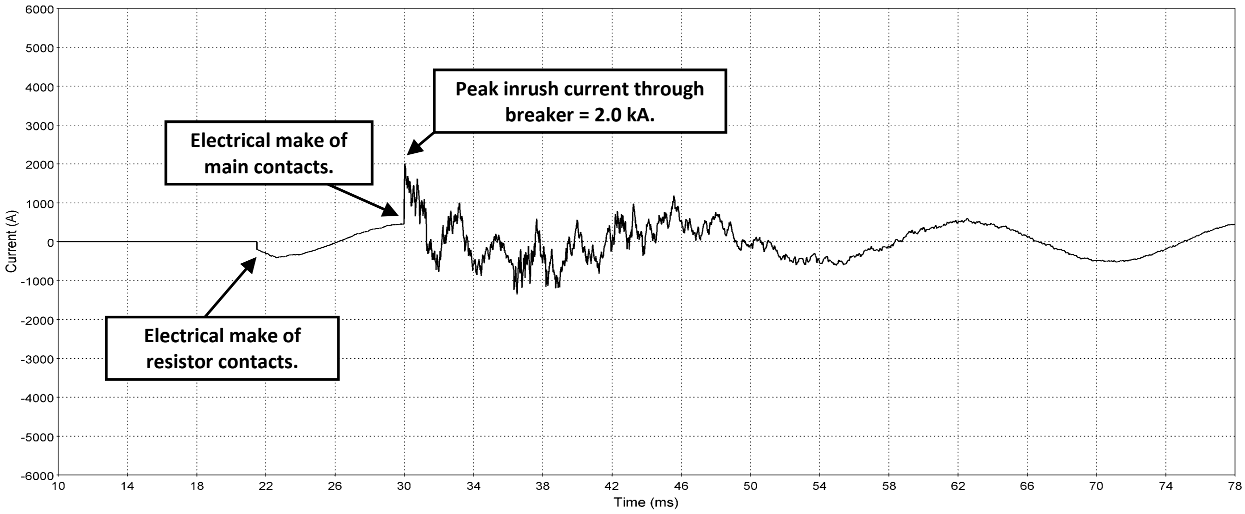

Figure 4 – Analysis of a close operation with the original controlled switching target

3. Switching Strategy

When controlled switching and closing resistors are both applied to a circuit breaker to mitigate inrush currents, the optimal target should be examined sufficiently. Figure 5 shows an illustration of the concept applied for the original controlled switching strategy where the purpose is to minimize the current through the closing resistor by targeting a point where the voltage is near zero across the contacts of the closing resistor. Using this strategy the current through the closing resistor can be minimized successfully. However, when the main current path closes to bypass the resistor, the voltage across the resistor is at a maximum which would result in high current through the interrupter. Because the interrupter and the contacts for the closing resistor are mechanically linked, the target points for each set of contacts cannot be controlled independently. Therefore, it is not possible to achieve an optimal target for both the contacts for the resistor and the main contacts without a redesign of the circuit breaker.

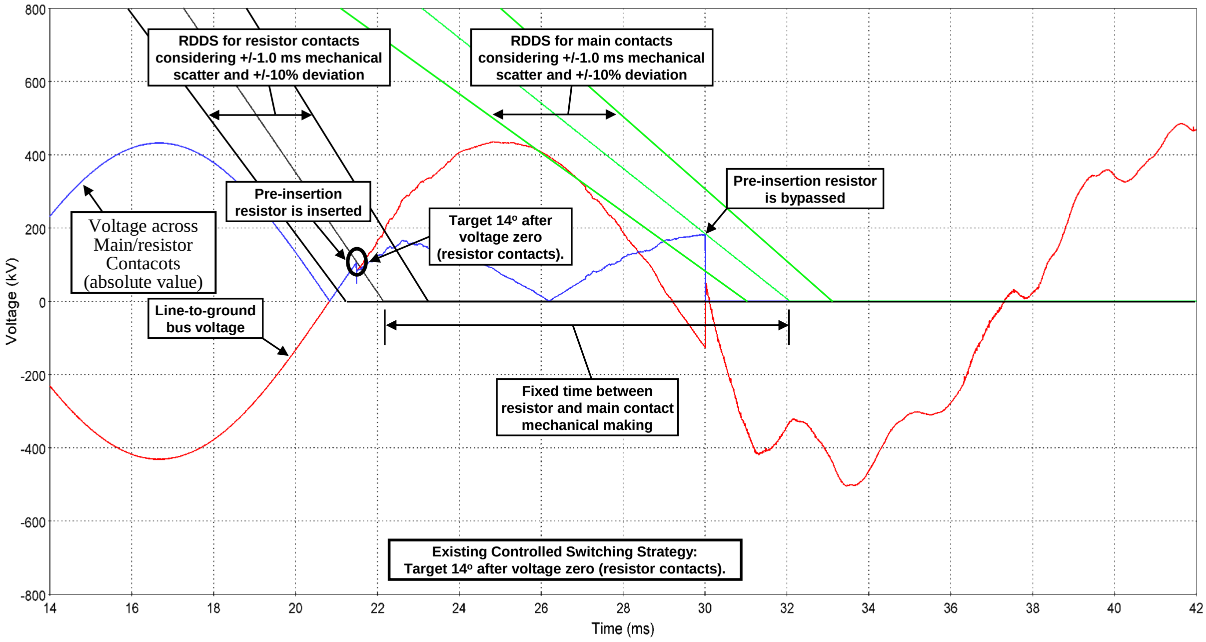

Figure 5 – Illustration of existing controlled switching strategy

Figure 6 shows a proposed controlled switching strategy where the purpose is to minimize the current through the interrupter by targeting a point where the voltage across the main contacts is at a minimum when the resistor is bypassed. The target point for the closing resistor contacts using the proposed strategy is 56° after a voltage zero which is near a voltage peak point on wave. Although this would result in nearly the highest inrush current through the closing resistor, this current is still very low because of the large resistance introduced into the circuit by the closing resistor. Figure 7 is an analysis the inrush current with a target energization point of 56° after a voltage zero.

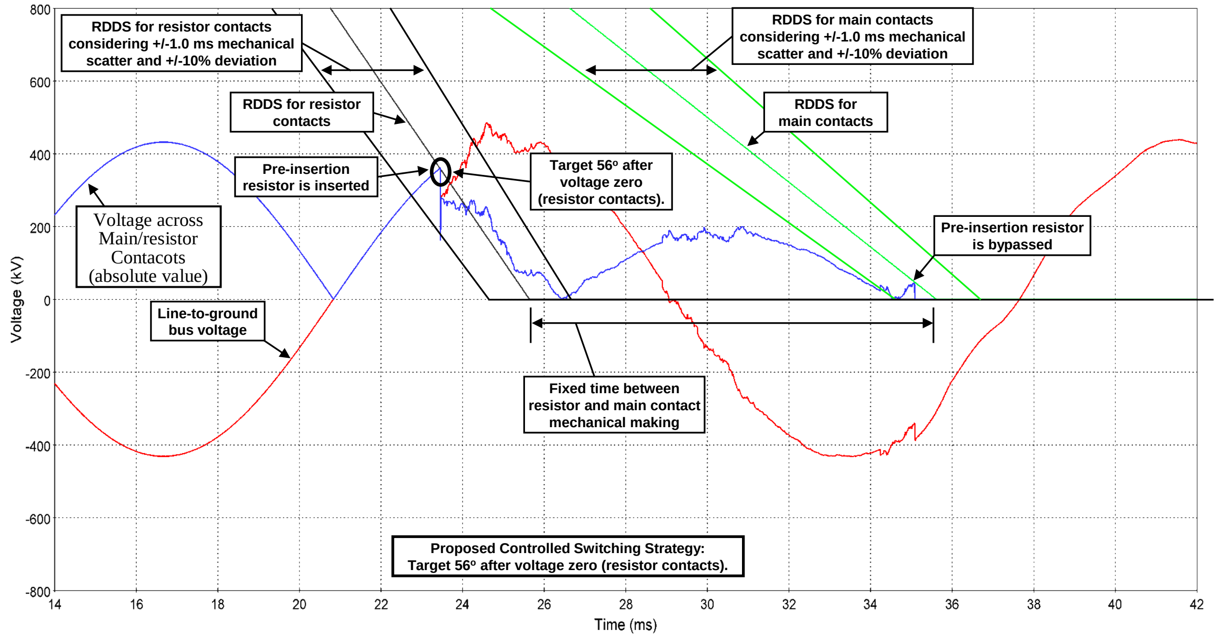

Figure 6 – Illustration of proposed controlled switching strategy

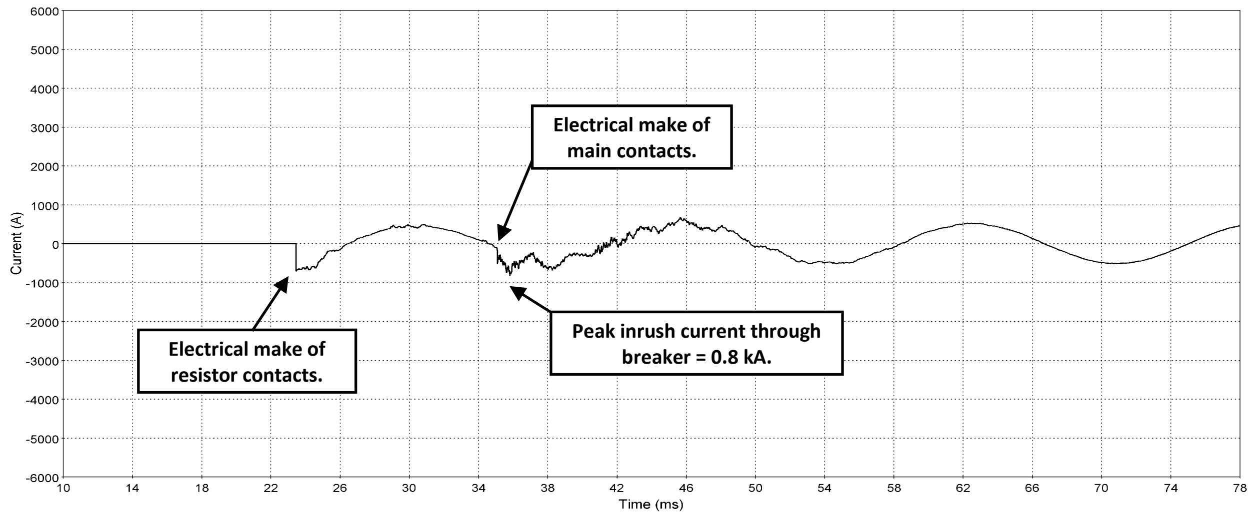

Figure 7 – Analysis of the proposed controlled switching strategy

4. Field Application

The actual performance of the circuit breaker under this switching strategy appeared satisfactory based on recordings of the switching operations. The controlled switching device records the current and voltage of close operations, but filtering on these inputs means that they don't accurately reflect the magnitudes and frequencies of the inrush current. A separate event recorder accurately captured the capacitor energization operations, as shown in Figure 8.

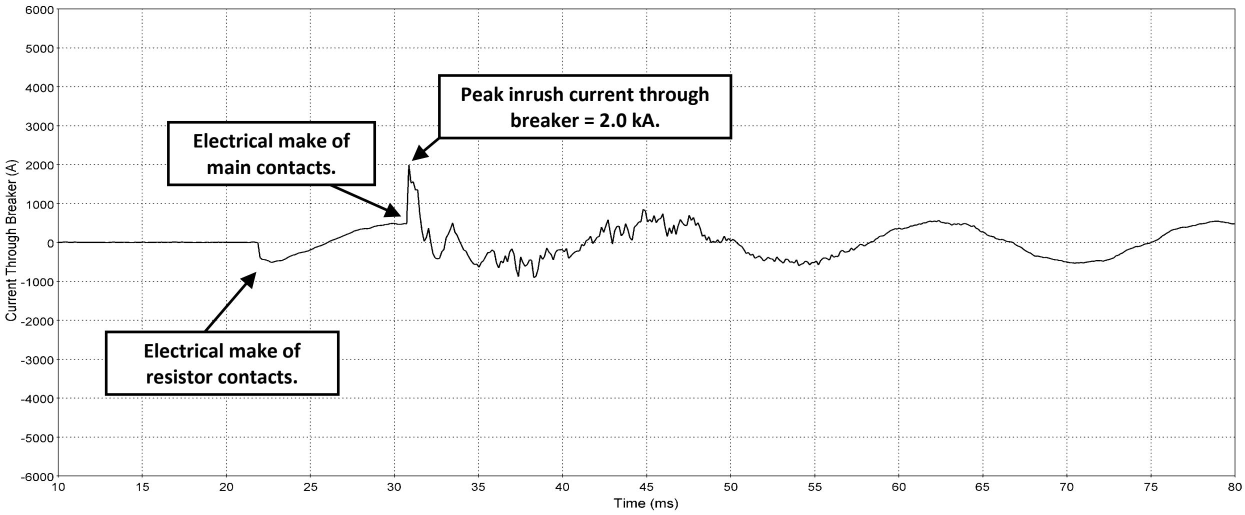

Figure 8 – Measured closing operation with original controlled switching target

Figure 9 shows one of the measured close operations after the target point was changed to the proposed 56°. The current through the closing resistor is moderately increased and the inrush current that occurs when the resistor is bypassed is substantially lower.

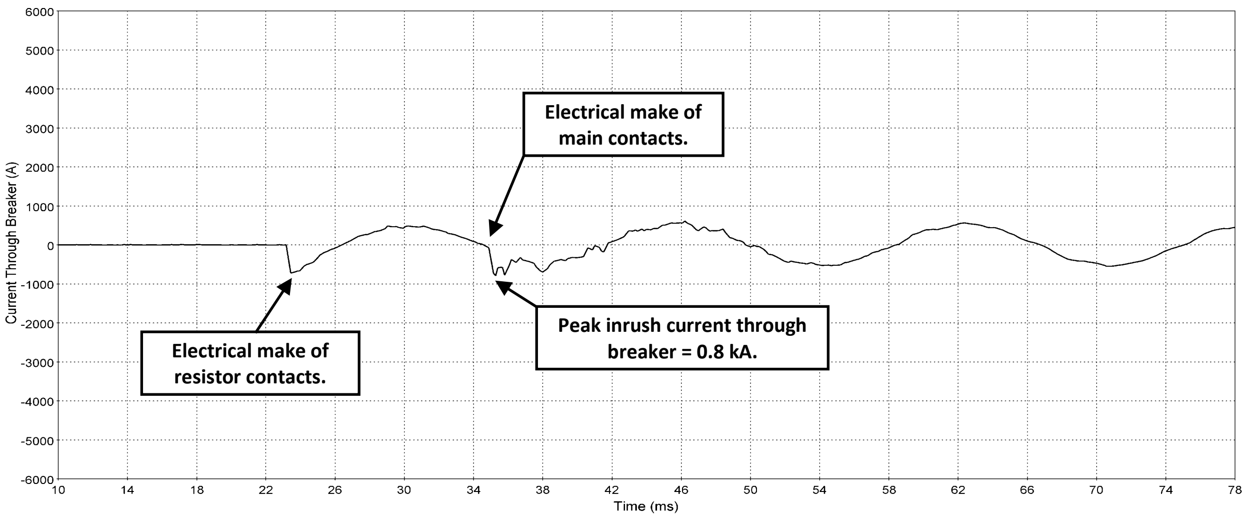

Figure 9 – Measured close operation with new controlled switching target

The change in measured inrush current was significant. A summary of 5 operations before the change in closing targets and after is in Table 1. The data from after the setting change was downloaded several months after the change had been in effect. The event recorder showed that the peak inrush current was reduced from an average of 1921 Amps to an average of 742 Amps. The pre-strike duration decreased from an average of 2.1 milliseconds to 0.5 milliseconds. The pre-strike duration is calculated from the voltage at the moment of current initiation and the RDDS of this circuit breaker's arcing contacts.

Table 1 – Inrush current magnitude and pre-strike duration before and after change to controlled switching settings

Date	PEAK INRUSH CURRENT (A)			PRE-STRIKE DURATION (ms)		
	Phase A	Phase B	Phase C	Phase A	Phase B	Phase C
Original Target Points						
2-Feb-15	1809	1925	2042	2.1	2.1	2.1
5-Feb-15	2161	1858	1987	2.2	2.1	2.1
9-Feb-15	1907	1889	1894	2.2	2.2	2.1
10-Feb-15	1853	1842	1842	2.2	2.1	2.1
12-Feb-15	1962	2026	1819	2.1	2.2	2.2
Average =	1921			2.1		
New Target Points						
11-Jan-16	792	647	652	0.5	0.4	0.4
11-Jan-16	846	644	745	0.6	0.3	0.6
13-Jan-16	727	631	603	0.6	0.3	0.4
14-Jan-16	914	678	683	0.7	0.5	0.5
14-Jan-16	918	818	826	0.7	0.4	0.7
Average =	742			0.5		

5. Conclusion

With controlled switching, the inrush currents associated with energizing a shunt capacitor bank can be reduced. Reduced inrush currents improve network stability and reduce equipment wear, particularly for the capacitor bank and the switching circuit breaker's interrupter. Although pre-insertion resistors can also reduce inrush currents, their use in conjunction with controlled switching changes the optimal point on wave to energize the capacitor bank.

The inrush currents calculated and measured in this paper show that properly accounting for the influence of the pre-insertion resistor can greatly improve the effectiveness of controlled switching. The optimal point calculated in this paper can be used for the same circuit breaker in other substations and similar applications, but is unique to this circuit breaker design. For other circuit breakers, the manufacturer must calculate their own optimal point that includes the parameters of their circuit breaker, the resistance of their pre-insertion resistor, and the system voltage.

BIBLIOGRAPHY

[1] CIGRE Working Group A3.07 (2004) "Controlled Switching of HVAC Circuit Breakers – Part 1: Benefits and Economic Aspects", CIGRE Technical Brochure 262

[2] IEC 62271-100: 2006, High-voltage alternating-current circuit-breakers